MODULE II

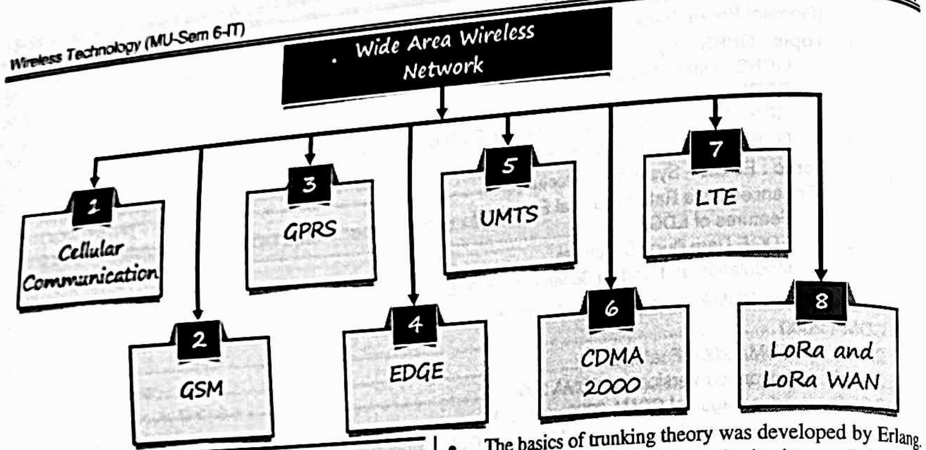
CHAPTER 2

Wide Area Wireless Network

University Prescribed Syllabus w.e.f Academic Year 2021-2022

Principle of Cellular Communication – Frequency Reuse concept, cluster size and system capacity, cochannel interference and signal quality; GSM – System Architecture, GSM Radio Subsystem, Frame Structure; GPRS and EDGE – System Architecture; UMTS – Network Architecture; CDMA 2000 – Network Architecture; LTE – Network Architecture; Overview of LoRa & LoRaWAN.

Self-learning Topics : IS-95.



2.1 INTRODUCTION TO TELECOMMUNICATION TRAFFIC

- Teletraffic theory is defined as the application of probability theory to the solution of problems consisting of planning, performance, evaluation, operation and maintenance of telecommunication systems.
- The term telecommunication traffic covers all types of data communication traffic and telecommunication traffic.

GQ. Define Trunking.

- **Definition of Trunking :** In telecommunication traffic theory, the term trunk refers to any entity that will carry one call. And the arrangement of trunks and switches in telecommunication system is known as the trunking. The number of trunks depend on the amount of traffic to be handled of the day.
  - **Busy hour :** It is one hour period of the day that corresponds to the peak traffic load.
  - In analysis of trunking theory, busy hour traffic consideration is very important.
  - The main aim of the telecommunication traffic theory is to design cost effective systems with predefined grade of service. It also specifies controlling methods to maintain actual grade of service and suggests necessary actions in case of congestion in the network.

2.1.1 Trunking Theory

GQ. Explain the concept of trunking.

- *Trunking allows large number of people to use small number of channels. this is done by providing access as per demand from a pool of available channels. once the call is terminated the channel is returned to the pool.*
- The basics of trunking theory was developed by Erlang. Hence the unit of traffic intensity is given as Erlangs.
- The amount of traffic intensity that is carried by one channel is expressed as **one Erlang**. e.g. a radio channel that is occupied for 45 minutes during an hour caries 0.75 Erlangs of traffic.

GQ. Explain two types of trunked system.

- There are two types of trunking systems :
  1. Blocked calls cleared system
  2. Blocked calls delayed system

1. Blocked calls cleared system

- It does not support queuing of the call requests.
- When the call request is raised from the user, he is given immediate access if the channel is available.
- If the channel is not available then the call is blocked without access and the user is free to try again later. This system is known as blocked calls cleared system.
- It is assumed that the calls are arriving as determined by Poisson's distribution.
- In this there are few assumptions made :
  (a) There are memoryless arrivals of requests, implying that all users including blocked users may request a channel at any time.
  (b) The probability of the user occupying a channel is exponentially distributed, so that longer calls are likely to occur as described by an exponential distribution
  (c) There are finite number of channels available in the trunking pool. This is known as M/ M/m/m queue.

- This type of queues addresses the Erlang B formula which is also known as blocked calls cleared system. This formula assumes that the calls are getting blocked.
- The formula is as given below :

$$P_r\,[\text{blocking}] = \frac{\dfrac{A^C}{C!}}{\sum\limits_{k=0}^{C} \dfrac{A^k}{k!}} = \text{GOS}$$

2. Blocked calls delayed system

- In this system, the queue is provided to hold the calls which are blocked.
- If the call request arises and channel is not available, the request is delayed until, the channel becomes available. this type of system is known as Blocked calls delayed system. This leads to Erlang C formula.

$$P_r\,[\text{delay} > 0] = \frac{A^C}{A^C + C!\left(1-\frac{A}{C}\right)\sum\limits_{k=0}^{C-1} \frac{A^k}{k!}}$$

- The GOS of the trunked radio system where blocked calls are delayed is given by

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

$=$

$P_r\,[\text{delay} > 0]\,\exp\,(-(C-A)\,t/H)$

The average delay D for all calls in a queued system is given by

$$D = P_r\,[\text{delay} > 0]\;\frac{H}{C-A}$$

where the average delay for those calls which are queued is given by $H/(C-A)$.

2.2 THE UNIT OF TRAFFIC

GQ. Define and explain :
(i) Grade of service (ii) Traffic intensity

(1) Traffic intensity

- **Definition :** It is defined as the average number of calls in progress. It is the measure of channel time utilization. It is dimensionless quantity but unit is named as 'erlang' after the scientist A.K. Erlang. It is denoted by 'A'.

(2) Holding time : It is defined as the duration of call.

(3) Setup time : The time required to allocate the trunked radio channel to the requesting subscriber is called as setup time.

(4) Blocked calls / lost calls : The calls which cannot be completed at the time of request due to congestion are called as blocked or lost calls.

(5) Load : It is the traffic intensity across the entire trunked radio system measured in Erlangs.

(6) Grade of service (GOS) : This is the measure of congestion which is specified as the probability of a call being blocked or call being delayed beyond certain amount of time.

(7) Request rate : It is the average number of call requests per unit time. Denoted by λ/sec.

- The traffic intensity 'A' is given as,

$A = U\,A_u$

where U = No. of users

A_u = traffic intensity per user

and $A_u = \lambda H$

$\therefore\; A = \dfrac{CH}{T}$ [C = avg. no. of calls arriving during T]

where λ = average no. of call request per unit time

H = Holding time

T = Time

- From these equations, number of channels in the trunked system can be determined and traffic intensity per channel can be calculated as

$$A_c = \frac{U\,A_u}{C}$$

- Sometimes traffic is expressed in terms of hundreds of call seconds per hour (CCS)

1 erlang = 36 CCS

2.3 CONGESTION / GRADE OF SERVICE

- When all the trunks in trunked system are busy and it cannot accept any call request, the situation is called as congestion.
- In message switching systems, in the case of congestions messages wait in queue rather than getting lost. Such systems are called as delay systems or queuing systems.
- In circuit switched system, all request during congestion is denied. Such systems are called as lost call systems.
- Hence in lost call system,

Traffic carried = traffic offered – traffic lost

- Grade of service is a measure of congestion.
- For lost call system, GOS is given as,

$$B = \frac{\text{Number of calls lost}}{\text{Number of calls offered}}$$

Module 2

$$B = \frac{\text{traffic lost}}{\text{offered traffic}}$$

- Larger the grade of service, poorer is the system.
- GOS is generally specified for busy hour traffic.

2.3.1 Traffic Tables

- These tables show relationships of offered traffic 'A', blocking probability i.e. GOS B and number of trunks N.
- Procedure to read traffic table :
  - (i) Select appropriate (or given) value of B.
  - (ii) Select specified / given / calculated number of trunks N.
  - (iii) Intersection of row showing N and column showing B will be offered traffic A.

  e.g. if B = 0.005 and N = 18 then A = 9.6 Erlangs [Refer Table 2.3.1]

Table 2.3.1 : Traffic table for full availability group

Number of trunks	1 lost call in 50 (0.02)	100 (0.01)	200 (0.005)	1000 (0.001)	Number of trunks	1 lost call in 50 (0.02)	100 (0.01)	200 (0.005)	1000 (0.001)
	E	E	E	E		E	E	E	E
1	0.020	0.010	0.005	0.001	51	41.2	38.8	36.8	33.4
2	0.22	0.15	0.105	0.046	52	42.1	39.7	37.6	34.2
3	0.60	0.45	0.35	0.19	53	43.1	40.6	38.5	35.0
4	1.1	0.9	0.7	0.44	54	44.0	41.5	39.4	35.8
5	1.7	1.4	1.1	0.8	55	45.0	42.4	40.3	36.7
6	2.3	1.9	1.6	1.1	56	45.9	43.3	41.2	37.5
7	2.9	2.5	2.2	1.6	57	46.9	44.2	42.1	38.3
8	3.6	3.2	2.7	2.1	58	47.8	45.1	43.0	39.1
9	4.3	3.8	3.3	2.6	59	48.7	46.0	43.9	40.0
10	5.1	4.5	4.0	3.1	60	49.7	46.9	44.7	40.8
11	5.8	5.2	4.6	3.6	61	50.6	47.9	45.6	41.6
12	6.6	5.9	5.3	4.2	62	51.6	48.8	46.5	42.5
13	7.4	6.6	6.0	4.8	63	52.5	49.7	47.4	43.4
14	8.2	7.4	6.6	5.4	64	53.4	50.6	48.3	44.1
15	9.0	8.1	7.4	6.1	65	54.4	51.5	49.2	45.0
16	9.8	8.9	8.1	6.7	66	55.3	52.4	50.1	45.8
17	10.7	9.6	8.8	7.4	67	56.3	53.3	51.0	46.6
18	11.5	10.4	9.6	8.0	68	57.2	54.2	51.9	47.5
19	12.3	11.2	10.3	8.7	69	58.2	55.1	52.8	48.3
20	13.2	12.0	11.1	9.4	70	59.1	56.0	53.7	49.2
21	14.0	12.8	11.9	10.1	71	60.1	57.0	54.6	50.1
22	14.9	13.7	12.6	10.8	72	61.0	58.0	55.5	50.9
23	15.7	14.5	13.4	11.5	73	62.0	58.9	56.4	51.8
24	16.6	15.3	14.2	12.2	74	62.9	59.8	57.3	52.6
25	17.5	16.1	15.0	13.0	75	63.9	60.7	58.2	53.5
26	18.4	16.9	15.8	13.7	76	64.8	61.7	59.1	54.3
27	19.3	17.7	16.6	14.4	77	65.8	62.6	60.0	55.2
28	20.2	18.6	17.4	15.2	78	66.7	63.6	60.9	56.1
29	21.1	19.5	18.2	15.9	79	67.7	64.5	61.8	56.9
30	22.0	20.4	19.0	16.7	80	68.6	64.4	62.7	58.7
31	22.9	21.2	19.8	17.4	81	69.6	66.3	63.6	58.7
32	23.8	22.1	20.6	18.2	82	70.5	67.2	64.5	59.5

Number of trunks	1 lost call in 50 (0.02)	100 (0.01)	200 (0.005)	1000 (0.001)	Number of trunks	1 lost call in 50 (0.02)	100 (0.01)	200 (0.005)	1000 (0.001)
	E	E	E	E		E	E	E	E
33	24.7	23.0	21.4	18.9	83	71.5	68.1	65.4	60.4
34	25.6	23.8	22.3	19.7	84	72.4	69.1	66.3	61.3
35	26.5	24.6	23.1	20.5	85	73.4	70.1	67.2	62.1
36	27.4	25.5	23.9	21.3	86	74.4	71.0	68.1	63.0
37	28.3	26.4	24.8	22.1	87	75.4	71.9	69.0	63.9
38	29.3	27.3	25.6	22.9	88	76.3	72.8	69.9	64.8
39	30.1	28.2	26.5	23.7	89	77.2	73.7	70.8	65.6
40	31.0	29.0	27.3	24.5	90	78.2	74.7	71.8	66.6
41	32.0	29.9	28.2	25.3	91	79.2	75.6	72.7	67.4
42	32.9	30.8	29.0	26.1	92	80.1	76.6	73.6	68.3
43	33.8	31.7	29.9	26.9	93	81.0	77.5	74.3	69.1
44	34.7	32.6	30.8	27.7	94	81.9	78.4	75.4	70.0
45	35.6	33.4	31.6	28.5	95	82.9	79.3	76.3	70.9
46	36.6	34.3	32.5	29.3	96	83.8	80.3	77.2	71.8
47	37.5	35.2	33.3	30.1	97	84.8	81.2	78.2	72.6
48	38.4	36.1	34.2	30.9	98	85.7	82.2	79.1	73.5
49	39.4	37.0	35.9	31.7	99	86.7	83.2	80.0	74.4
50	40.3	37.9	35.9	32.5	100	87.6	84.0	80.9	75.3

2.3.2 Solved Examples

List of Important Formulae

(1) $A = U A_u$

where U = No. of users

A_u = traffic intensity per user

(2) $A_u = \lambda H$

(3) $A = \frac{CH}{T}$ [C = avg. no. of calls arriving during T]

where λ = average no. of call request per unit time

H = Holding time

T = Time

Ex. 2.3.1 : During busy hour 1000 calls were offered to a group of trunks and 5 calls were lost. The average call duration was 2 minutes

(i) Find traffic offered (ii) Traffic carried
(iii) Traffic lost (iv) Grade of service
(v) Total duration of periods of congestion

Soln. :

Given : H = 2 minutes; C = 1000 calls ; lost calls = 5

(i) Traffic offered

$$A = \frac{CH}{T}$$ ...[Standard Formula]

$$= \frac{1000 \times 2}{60} = 33.33$$

A = 33 Erlangs

(ii) Traffic carried = $A = \frac{CH}{T}$

but C = Total calls – lost calls = 1000 – 5 = 995

$$\therefore A = \frac{995 \times 2}{60} = \mathbf{33.166\ Erlangs}$$

(iii) C = 5 lost calls

$\therefore$ Lost traffic $A_c = \frac{CH}{T}$ ...[Standard Formula]

$$= \frac{5 \times 2}{60} = \mathbf{0.166\ E}$$

(iv) $GOS = B = \frac{\text{Traffic lost}}{\text{Traffic offered}} = \frac{0.166\ E}{33.33\ E} = \mathbf{0.005}$

(v) Total duration of period of congestion GOS × 3600 = 0.005 × 3600 = **18 seconds**

Ex. 2.3.2 : During busy hour, 1200 calls were offered to a group of trunks and six were lost. The average call duration was 3 minutes. Find.

(i) Traffic offered (ii) Traffic carried
(iii) Traffic lost (iv) Grade of service
(v) Total duration of periods of congestion

☑ **Soln. : Given :** C=1200 ; lost calls = 6; H = 3 minutes

(i) Traffic offered

$$A = \frac{CH}{T} \quad \text{...[Standard Formula]}$$

$$= \frac{1200 \times 3}{60}$$

$$\therefore A = 60E$$

(ii) Traffic carried $A_c = \frac{CH}{T}$

but C = Total calls – lost calls = 1200 – 6 = 1194

$$\therefore A_c = \frac{1194 \times 3}{60} = 59.7\ E$$

(iii) Lost calls = 6

$$\therefore \text{Traffic lost} = \frac{CH}{T} = \frac{6 \times 3}{60} = 0.3E$$

(iv) Grade of service = B = $\frac{\text{Traffic lost}}{\text{Traffic offered}} = \frac{0.3E}{60\ E}$

B = 0.005

(v) Total duration of periods of Congestion = GOS × 3600 = 0.005 × 3600 = 18 seconds

Ex. 2.3.3 : A group of 20 servers carry a traffic of 10 E. If average duration of calls is 3 minutes, calculate the number of calls put through by a single server and a group as a whole in 1 hr period.

☑ **Soln. :**

Given : A = 10 E; H = 3 minutes ; No. of servers = 20

(i) Traffic per server = $\frac{10}{20}$ = 0.5 E

This means that, the server is busy for 30 min in one hour

(ii) Number of calls put through by one server = $\frac{30}{3}$ = 10 calls

(iii) Total no. of calls put through by the group = 10 × 20 = 200 calls

Ex. 2.3.4 : Over a 20 minutes observation interval 40 subscribers initiates a call. Total duration of calls is 4800 sec. Calculate load offered to network by the subscribers and average subscriber traffic ?

☑ **Soln. :**

Given :

(1) Number of subscribers = 40

(i) Mean call arrival rate C = $\frac{\text{Number of subscribers}}{\text{observation interval}}$

$$= \frac{40}{20} = 2 \text{ calls/min}$$

(ii) Mean holding time = $\frac{\text{Total duration of calls}}{\text{Number of subscribers}}$

$$= \frac{4800/60}{40} = \frac{4800}{60 \times 40}$$

$$= 2 \text{ minutes / calls}$$

(iii) Offered traffic = A × C = 2 × 2 = 4E

(iv) Average subscriber traffic = $\frac{4}{40} = \frac{A}{N}$ = 0.1 E

2.4 INTRODUCTION TO CELLULAR TELEPHONE SYSTEM

- In earlier days, a single high powered transmitter with an antenna mounted on a tall tower was used to cover a large service area as shown in Fig. 2.4.1.

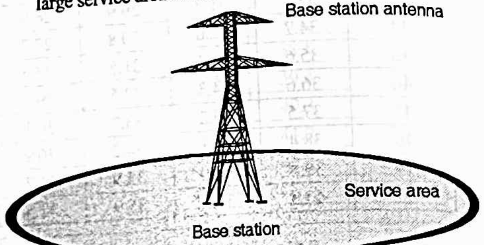


Fig. 2.4.1 : Single base station covering the complete service area

- Spectral congestion and user capacity was a major problem. The service providers could not make spectrum allocations in proportion to the increasing demand for the mobile services. The radio telephone system was reconstructed to obtain high capacity with limited radio spectrum while at the same time covering large areas.
- The cellular concept was a major breakthrough is solving the problem of user capacity and spectral congestion. It offers a very high capacity in limited spectrum.
- In the cellular concept, the single high power transmitter is replaced with many low power transmitters each providing coverage to only a small part of service area as shown in Fig. 2.4.2. Each base station is allocated a portion of the total number of channels and nearby base stations are assigned different group of channels.
- The neighbouring base stations are assigned different groups of channels so that the interference between the base stations is minimized.

- If these base stations and their channel groups are systematically placed throughout a market then the available channels are distributed throughout the service area. They can be reused as many time as possible or as many times as essential.
- The co-channel interference is kept below the acceptance level.
- As the demand for the service increase, the number of base stations can be increased to supply an additional radio capacity with no additional increase in the radio spectrum.
- This is the principle of all modem wireless communication systems as it allows a fixed number of channels to service a large number of subscribers by reusing the channels throughout the service area.
- The cellular concept allows each cell phone to be manufactured with the same set of channels, so that any mobile can be used anywhere in the service region.

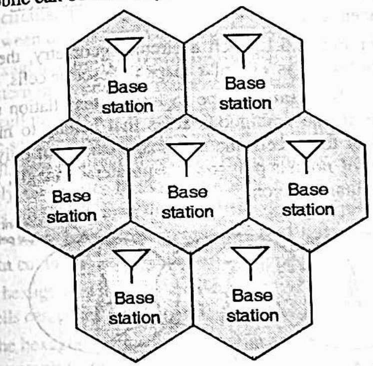


Fig. 2.4.2 : Cellular concept

2.4.1 Terminologies Associated with Mobile Communication

GQ. Define the following terms regarding wireless communication :

1. Page
2. Mobile Switching Center
3. Control channel
4. Base station
5. Forward channel

GQ. Define following terms :

(1) Forward Channel (2) Reverse Channel
(3) Control Channel (4) Paging System
(5) Hand-off (6) Base Station

Table 2.4.1 : Wireless communication system definitions

Sr. No.	Term	Definition
1	Base station	It is a fixed station in mobile communication system used for radio communication with mobile stations located in the centre of at the edge of the cell site.
2	Mobile station	They are the handheld personal mobile units or units installed in moving cars used by the subscribers.
3	Mobile switching centre	It is the coordinating system in mobile radio architecture for large service area.
4	Forward channel	Channel used for transmission from base station to mobile station.
5	Reverse channel	Channel used for transmission from mobile station to base station.
6	Control channel	Radio channel used for transmission of call setup, call request, call initiation and other control signalling purpose.
7	Handoff	The process by which mobile station is transferred from one base station or from one channel to another is handoff mechanism or handover.
8	Page	It is a message which is broadcasted over the entire service area.

2.5 BASIC CELLULAR SYSTEM

A basic cellular system comprises of three units : a mobile unit, a cell site and a Mobile Telephone Switching Office (MTSO) as shown in Fig. 2.5.1.

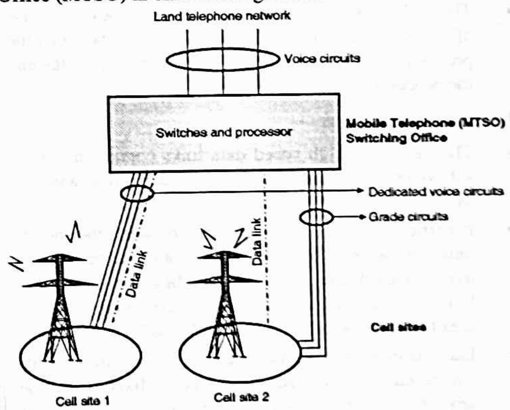


Fig. 2.5.1 : A cellular system

Module 2

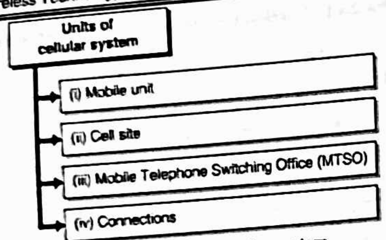


Fig. 2.5.2 : Units of cellular system

(i) Mobile unit

It comprises a control unit, a transceiver and an antenna system.

(ii) Cell site

Its **function** is to provide interface between the mobile units and MTSO. It comprises of a control unit, radio cabinets, antennas, a power plant and data terminals.

(iii) Mobile Telephone Switching Office (MTSO)

- It is the central co-ordinating unit for all cell sites. It comprises of the cellular processor and the cellular switch.
- It interfaces the telephone company zone offices. The MTSO is responsible for controlling the call processing operations and handling the billing activities of the subscriber.
- The MTSO is the heart of the cellular system. Its processor provides central co-ordination and cellular administration.
- The cellular switch can be analog or digital in nature.
- It connects the mobile subscribers to other mobile subscribers and to the nationwide telephone network.
- The cellular switches use voice trunks. They comprise of data links that provide supervision links between the processor and the switch and between the cell sites and the processor.

(iv) Connections

- The radio and high speed data links connect the three subsystems i.e. the mobile unit, cell sites and the MTSO.
- It carries the voice and signalling between the mobile unit and the cell site. These links cannot be transmitted over standard telephone trunks. They use microwave links or T carriers (wire lines) that carry both voice and data between the cell site and the MTSO.
- Each mobile unit can use one channel at a time for its communication. But the channel is not fixed. It can be any channel in that service area. Each cell site has multichannel capabilities that can connect to different mobile units simultaneously.

2.6 CELL GEOMETRY

What is a Cell ?

- The signal strength degrades as it travels away from the antenna's coverage area that is base station area. The region over which the signal strength lies above the threshold value x dB is known as the coverage area of a BS.
- It must be a circular region, assuming BS as an isotropic radiator.
- A group of radio channels is allocated a separate circular base station to be used within a small geographic area called **cell**. The actual radio coverage of a cell is called as a **footprint**. The footprint can be found out from the field measurements or the propagation prediction models.
- It might so happen that either there may be an overlap between any two such side by side circles or there might be a gap between the coverage areas of two adjacent circles.
- Refer Fig. 2.6.1. Such a circular geometry, therefore, cannot serve as a regular shape to describe cells.
- For cells of 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 of only three types of regular polygons : equilateral triangle, square or regular hexagon.

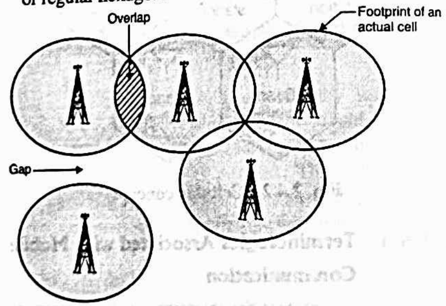


Fig. 2.6.1 : Footprint of cells showing the overlaps and gaps

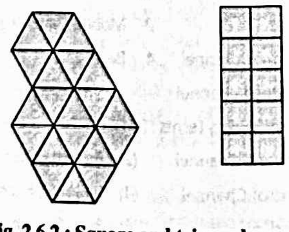


Fig. 2.6.2 : Square and triangular cells

- A hexagonal cell is the closest approximation of a circle. It is being typically used for the system.

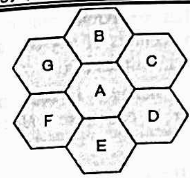


Fig. 2.6.3 : Arrangement of hexagonal cells to provide greater coverage without creating ambiguous returns

GQ. Why hexagonal cell shape is preferred in cellular architecture ?

- The **reasons** for selecting the hexagonal shape over square or triangular cell shape **are summarized** as **follows :**

(i) Hexagon allows easy and manageable analysis of a cellular system.

(ii) In circular pattern, adjacent circles can have gaps in between or can create overlapping regions.

(iii) Hexagon closely approximates the circular radiation pattern in an omni-directional base station antenna.

(iv) A cell must be designed to serve the weakest mobiles in the service area and they are located at the edge of the cell. For a given distance between the center of a polygon and its farthest perimeter points, the hexagon has the largest area than the triangle and square. **Thus, by using hexagonal geometry, less number of cells can cover the entire market.**

- If hexagonal geometry is used then only few number of cells can cover a geographic region.
- The hexagon is close to a circular radiation pattern that can result from an omni directional base station antenna and if there is free space propagation.
- But in Practice the sectored directional antennas are used in corner excited cell and the omni-directional antennas are used in centre excited cells.
- However, the practical considerations do not support the base stations to be placed exactly as they are seen in the hexagonal layout.

Syllabus Topic : Principle of Cellular Communication - Frequency Reuse concept

2.7 CONCEPT OF FREQUENCY REUSE

GQ. Explain the concept of Frequency Reuse.

GQ. With figure explain Frequency Reuse concept in detail. Define cluster size and write the equation for system capacity.

- The base stations in adjacent cells are assigned channel groups that contain completely different channels than the neighbouring cells. The antennas located on base station are designed to obtain the required coverage for a specific cell.
- If the coverage area is limited to within boundaries of the cell then the same group of channels can cover different cells that are separated from each other by large distances. The design method of selecting and allocating channel groups for all cellular base stations within a system is called as frequency reuse or frequency planning.
- Fig. 2.7.1 shows the concept of cellular frequency reuse, where cells labelled with the same letter use the same group of channels.
- In order to understand the concept of frequency reuse we will consider a cellular system having S duplex channels.
- Then, if each cell is allocated a group if n channels (n < S) and if S channels are divided among N cells into unique and disjoint channel groups with each having the same number of channels, then the total number of available radio channels is,

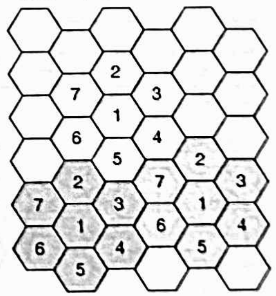
$$S = nN \quad ...(2.7.1)$$

2.7.1 Cluster

GQ. Define Cluster.

- The N cells will collectively use the complete set of available frequencies. It is termed as a **cluster.**
- A **cluster** is defined as a group of cells that use different frequencies in each cell or the repeating pattern of cells is also called as a **cluster.**
- Now if this cluster is repeated m times within the system, then the total number of duplex channels C can be used to measure capacity. It is expressed as,

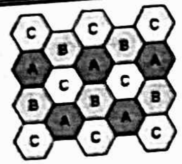
$$C = mnN = mS \quad ...(2.7.2)$$



(a) 7-cell reuse pattern

Fig. 2.7.1 : Frequency reuse

Module 2



(b) 3-cell reuse pattern

Fig. 2.7.1 : Frequency reuse

Syllabus Topic : Principle of Cellular Communication - cluster size

2.7.2 Channel Capacity and Selection of Cluster Size

- The **channel capacity** is defined as the maximum number of channels that can be provided for a particular fixed frequency band.
- Thus, **the capacity of a cellular system is directly proportional to the number of times a cluster is repeated in a fixed service area.** The factor N is called as the cluster size and is typically 4, 7 or 12.
- If the cluster size N is small, clusters can be repeated in large numbers and hence more capacity is obtained.
- A large cluster size decreases the ratio between the cell radius and the distance between co-channel leading to weaker co-channel interference. But, a smaller cluster size indicates that the co channel cells are located much closer together and result in more interference.
- The value of N is a function of the amount of interference a mobile or base station can tolerate while maintaining a good quality of communication.
- For maximum capacity, the smallest possible value of N is desired. $\frac{1}{N}$ is called as the **frequency reuse factor** as each cell within the cluster is only assigned $\frac{1}{N}$ times of the total available channels.

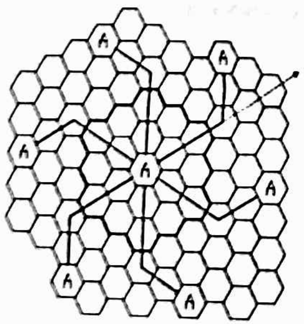


Fig. 2.7.2 : Example of locating co-channel cells in cellular system where N = 19 (i = 3, j = 2)

- The hexagon has six equidistant neighbours and the lines joining the centers of any cell and its neighbours are separated by multiples of 60°.
- The geometry of hexagon is such that the number of cells per cluster N can have values that satisfy the equation,

$$N = i^2 + ij + j^2 \quad \text{...(2.7.3)}$$

where i and j are non-negative integers.

- In order to find the nearest co-channel cells of a particular cell one must do the following:
  (i) Move i number of cells in any direction.
  (ii) Turn 60 degrees in counter clockwise direction and move j number of cells.
- Table 2.7.1 lists possible cluster sizes.

Table 2.7.1 : Possible cluster size

i	j	N
1	1	3
2	0	4
2	1	7
3	0	9
2	2	12
3	1	13
4	0	16
3	2	19
4	1	21

2.7.3 Solved Examples on Concept of Frequency Reuse

List of Important Formula

- Total number of channels available per cell $= \frac{\text{Total number of Channels}}{\text{Number of cell}}$

Ex. 2.7.1 : A particular FDD cellular system uses two 25 kHz simplex channels to provide full duplex voice and control channels. The total band allocated for the system is 40 MHz. Compute the number of channels available per cell if the system uses (a) 3-cell reuse (b) four-cell reuse (c) 12 cell reuse. If 2 MHz of the allocated spectrum is dedicated to control channels, determine the distribution of voice and control channels in each cell and in each of the three systems.

Soln. : Given :

Total bandwidth = 40 MHz

Channel bandwidth = 25 kHz × 2 simplex channels = 50 kHz/duplex channel

$\therefore$ Total available channels $= \frac{40 \times 10^6}{50 \times 10^3} = 800$ channels

(a) **For 3-cell reuse i.e. N = 3**

Total number of channels available per cell

$= \frac{800}{3} = $ **267 channels** ...Ans.

(b) **For 4-cell reuse i.e. N = 4**

Total number of channels available per cell

$= \frac{800}{4} = $ **200 channels** ...Ans.

(c) **For 12-cell reuse i.e. N = 12**

Total number of channels available per cell $= \frac{800}{12}$

$=$ **67 channels** ...Ans.

A 2 MHz spectrum for control channel implies that there are $\frac{2 \times 10^6}{50 \times 10^3} = 40$ control channels out of the 800 channels available. To evenly distribute the control and voice channel, simply allocate the same number of voice channels in each cell wherever possible.

Here, the 800 channels must be evenly distributed to each cell within the cluster. Practically only 760 voice channels will be allocated as control channels are allocated as 1 per cell.

(a) For **three-cell reuse**, we can have $\left(\frac{40}{3} \approx 13\right)$ 13 control channels and (267 – 13 = 254) 254 voice channels per cell. In practice however each cell only needs a single control channel. Thus, one **control channel** and **254 voice channels will** be assigned to each cell.

(b) For **four-cell reuse** we can have $\left(\frac{40}{4} = 10\right)$ **10 control channels** and (200 – 10 = 190) **190 voice channels per cell.**

(c) **For 12 cell reuse,** we can have eight cells with five control channels and 62 voice channels and four cells **with three control channels and 64 voice channels.**

Ex. 2.7.2 : If a total of 33 MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses two 25 kHz simplex channels to provide full duplex voice and control channels. Compute the number of channels available per cell if a system uses (a) four-cell reuse (b) seven-cell reuse (c) 12-cell reuse. If 1 MHz of the allocated spectrum is dedicated to control channels, determine an equitable distribution of control channels and voice channels in each of the three systems.

Soln. :

Given : Total bandwidth = 33 MHz,

Channel bandwidth = 25 kHz × 2 simplex channels = 50 kHz/duplex channel

$\therefore$ Total available channels $= \frac{33 \times 10^6}{50 \times 10^3} = 660$ channels

(a) **Four-cell reuse**

Total number of channels available per cell

$= \frac{660}{4} \approx$ **165 channels**

(b) **Seven cell reuse**

Total number and channels available per cell

$= \frac{660}{7} \approx$ **95 channels**

(c) **12 cell reuse**

Total number of channels available per cell

$= \frac{660}{12} = $ **55 channels**

A 1 MHz spectrum for control channel implies that there are $\frac{1000 \times 10^3}{50 \times 10^3} = 20$ control channels out of the 660 channels available. The 660 channels must be evenly distributed to each cell within the cluster. Practically only the 640 voice channels will be allocated as control channels are allocated as 1 per cell.

(a) For **four-cell reuse** we can have five control channels and 160 voice channels per cell. Practically, each cell needs a single control channel. Thus, **one control channel and 160 voice channels** will be assigned to each cell.

(b) For **seven-cell reuse**, four cells with three control channels and 92 voice channels and two cells with three control channels and 90 voice channels and one cell with two control channels and 92 voice channels will be allocated. Practically, each cell will have a control channel, four cells will have **91 voice channels and three cells will have 92 voice channels.**

(c) For **12 cell reuse**, we can have eight cells with two control channels and 53 voice channels and four cells with one control channel and 54 voice channels each. Practically each cell will have **one control channel, eight cells will have 53 voice channels and four cells will have 54 voice channels.**

2.8 CHANNEL ASSIGNMENT STRATEGIES

GQ. Briefly explain different channel assignment strategies.

- The radio spectrum needs to be efficiently used. For achieving this we need a frequency reuse method that has consistency in increasing the capacity and minimum interference. To achieve these objectives different channel assignment strategies have been developed.
- The channel assignment strategies are classified as **fixed, dynamic and hybrid** depending on the system performance in managing calls when a mobile user is handed off from one cell to another.

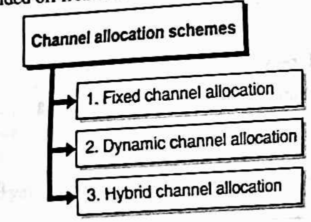


Fig. 2.8.1 : Channel Assignment Strategies

2.8.1 Fixed Channel Assignment

GQ. Explain Static channel assignment strategy.

- In the fixed channel assignment method each cell is assigned a predetermined set of voice channels.
- Any effort that is done to call a number within the cell can be serviced by the unused channels in that particular cell.
- In case if all the channels in that cell are used, then the call is **blocked**. In such a situation the subscriber does not get service.
- There are different modifications in the fixed channel assignment strategy.

Channel borrowing

- Channel borrowing involves borrowing channels from other cells or same cell. The main advantage of channel borrowing is that prevents cell splitting that is costly.
- In one method a cell is allowed to borrow channels from an adjacent cell if all of its channels are occupied. This method is called as **borrowing strategy**.
- The borrowing procedure is supervised by the Mobile Switching Centre (MSC). The MSC also ensures that the channel borrowing does not disturb or interfere any calls that are in progress in the donor cell.

2.8.2 Dynamic Channel Assignment

GQ. Explain Dynamic channel assignment strategy.

- In dynamic channel assignment strategy there is no permanent allocation of channels. Every time a call request is done, the base station requests a channel from the Mobile Switching Centre (MSC).
- The MSC only allocates the channel after verifying that the channel is not currently in use in the cell or any other cells that comes within the minimum restricted distance of frequency reuse to avoid co-channel interference.
- Dynamic channel assignment strategy reduces the probability of blocking and increases the trunking capacity of the system.
- These strategies need the MSC to collect real-time data i.e. traffic distribution, channel occupancy etc. It increases load on the MSC but provides the advantage on increased channel utilization and reduced probability of blocked call.

2.8.3 Comparison of Fixed Channel Assignment and Dynamic Channel Assignment

Table 2.8.1 : Comparison of fixed channel assignment and dynamic channel assignment

Sr. No.	Fixed channel assignment	Dynamic channel assignment
1	Specific channels are allocated to specific cells.	There is no relationship between channels and cells.
2	The allocation of channels is permanent.	The allocation of channels is not permanent.
3	No need to check for channel availability.	The algorithms used for checking the availability of channels introduces complexity.
4	It is suitable for uniform and heavy traffic systems.	It is suitable for non-uniform and moderate to light traffic systems.
5	Sensitive to time and spatial changes.	Not sensitive to time and spatial changes.
6	Unstable grade of service per cell in an interference cell group.	Stable grade of service per cell in an interference cell group.

2.8.4 Hybrid Channel Allocations

- It is the combination of fixed and dynamic channel allocation schemes.
- A fixed number of channels are allocated to cell sites on long term basis and when they all are occupied a request for dynamic channel is raised.

- The ratio of number of fixed channels and dynamic channels is based on the traffic conditions or it may vary according to estimated values of instantaneous load distributions.
- It is observed that Hybrid schemes perform better for traffic load up to 50%, beyond that FCA gives better results.

Syllabus Topic : Principle of Cellular Communication – system capacity, cochannel interference and signal quality

2.9 INTERFERENCE AND SYSTEM CAPACITY

GQ. What is interference ?

- The performance of cellular systems is highly affected by **interference**.
- The different sources of interference include another mobile in the same cell, a call that is in progress in the adjacent cell, other base stations operating in the same frequency band or any non-cellular system that leaks energy into the cellular frequency band.
- On voice channels, interference produces cross talk because of undesired transmission.
- There can be missed and blocked calls in the control channels as a result of interference. The interference is more severe in urban areas because of greater RF noise floor and large number of mobiles and base stations.
- Interference is main problem in increasing capacity. It results in dropped calls.

2.9.1 Types of Cellular Interferences

GQ. Define Co-channel cells.

- **There are two types of cellular interferences :**
  1. Co-channel interference
  2. Adjacent channel interference.
- In the frequency reuse method, several cells use the same set of frequencies in the given service area. The cells using the same set of channels are called as **co-channel cells**. The interference between signals from these cells is called as **co-channel interference**.
- The interference resulting from the channels that are adjacent in frequency to the desired channel is called as adjacent channel interference.
- It is difficult to control the interfering signals, although they are generated within the cellular system. The interference because of out-of-band users is even more difficult to control. It is a result of the front end overload of the subscriber equipment or intermittent intermodulation products.

2.9.1(A) Co-channel Interference Reduction Factor and Frequency Reuse Distance Relationship

GQ. Define co-channel interference.
GQ. Explain Co-channel interference in cellular system.

- In the frequency reuse method, several cells use the same set of frequencies in the given service area. The cells using the same set of channels are called as **co-channel** cells. The interference between signals from these cells is called as **co-channel interference**.
- In order to reduce the co-channel interference, the co-channels cells are physically separated by a minimum distance to provide isolation.
- This minimum distance that allows the same frequency to be reused depends on factors like number of co-channel cells nearby the centre cell, the type of geographic terrain contour, antenna height and power transmitted at each cell site.
- The frequency reuse distance D is

$$D = \sqrt{3N}\,R \qquad \ldots(2.9.1)$$

where N is the frequency reuse pattern or cluster size.

R is the radius of the cell.

As $N = i^2 + ij + j^2$ the smallest value of N = 3 by setting i = 1, j = 1.

Table 2.9.1 gives different values of D for given values of N.

Table 2.9.1

i	j	N	Q = D/R
1	1	3	3.00
2	0	4	3.46
2	1	7	4.58
3	0	9	5.20
2	2	12	6.0
3	1	13	6.24
4	0	16	6.93
3	2	19	7.55
4	1	21	7.94

- If all the cell sites transmit the same power, then N increases and the frequency reuse distance D increases. This increased D reduces the probability that co-channel interference can occur.
- Practically a large N is desired. However, the total number of channels that are allocated is fixed. If N is too large the number of channels assigned to each of N cells become small.

Module 2

- If the total number of channels in N cells is divided as N increases, then it results in trunking inefficiency. Hence, we need to select the minimum frequency reuse distance with a view to reduce co-channel interference.
- In order to final the co-channel interference reduction factor we assume that all the cells are of same size and the base stations transmit same power, the co-channel interference ratio is independent of the transmitted power. It becomes a function of the radius of the cell R and the distance between the nearest co-channel cells D. The ratio $\frac{D}{R}$ is called as the **co-channels reuse ratio** or **co-channel interference reduction factor**. It is expressed as,

$$Q = \frac{D}{R} \quad ...(2.9.2)$$

- The co-channel interference reduction factor is related to the cluster size N as,

$$Q = \frac{D}{R} = \sqrt{3N} \quad ...(2.9.3)$$

- A small value of Q provides large capacity as the cluster size N is small. A large Q i.e. a large value of $\frac{D}{R}$ indicates that the spatial separation between the co-channel cells relative to the coverage distance of a cell is increased. Thus, the cochannel interference is reduced. But the transmission quality is improved. In actual design a trade-off must be done between both.

2.9.2 $\frac{S}{I}$ Ratio Consideration and Calculation for Minimum Channel Interference

GQ. Derive equation for signal to interference ratio.

- **The signal to interference ratio** $\left(\frac{S}{I}\right)$ for a mobile receiver that observes a forward channel can be expressed as,

$$\frac{S}{I} = \frac{S}{\sum_{i=0}^{i_0} I_i} \quad ...(2.9.4)$$

Where, i_0 : number of interfering co-channel cells

S : desired signal power from desired base station

I_i : Interference power from i^{th} interfering co-channel cell base station.

- If we know the signal levels of the co-channel cells, then the $\frac{S}{I}$ ratio for the forward link can be found.

- If propagation measurements are done in a mobile radio channel then the average received power at any point decreases as a power law of distance of separation between the transmitter and the receiver. The average received power P_r is,

$$P_r = P_0\left(\frac{d}{d_0}\right)^{-n} \quad ...(2.9.5)$$

or $$P_r(\text{dBm}) = P_0(\text{dBm}) - 10\, n \log\left(\frac{d}{d_0}\right) \quad ...(2.9.6)$$

Where, d : distance from the transmitting antenna.

P_0 : power received at a close-in reference point in the far field region of the antenna at small distance do from the transmitting antenna.

n : path loss component.

- Consider a forward link where the desired signal is offering service to the base station and interference is because of co-channel base stations.
- If D_i is the distance of the i^{th} interferer from the mobile, then the power received at a given mobile because of the i^{th} interfering cell is proportional to $(D_i)^{-n}$.
- When the path loss exponent is same throughout the coverage area and the transmit power of each base station is equal then the $\frac{S}{I}$ for a mobile is,

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}} \quad ...(2.9.7)$$

- If the first layer of interfering cells is considered and if the interfering base stations are placed at an equal distance D between the cell centres the Equation (2.9.7) simplifies to

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0} \quad ...(2.9.8)$$

- Equation (2.9.8) relates $\frac{S}{I}$ to the cluster size N and determines the overall capacity of the system.

2.9.3 Adjacent Channel Interference

GQ. Define adjacent channel interference.

- **Definition** : The interference that results from the signals that are adjacent in frequency to required signal is called as **adjacent channel interference.**
- It is a result of the imperfect receiver filters that permit the nearby frequencies into the pass band of the desired channel.

- If the user that is using an adjacent channel and is transmitting in close range to subscriber's receiver then while the receives tries to receive a base station on the desired channel the problem can be critical.
- It is called as **near-far effect** i.e. a nearby transmitter captures the receiver of the subscriber. If comes into picture when a mobile that is close to a base station transmits on channel near that is used by a weak mobile. The base station can face problems in discriminating the mobile user from **"bleed over"** caused by close adjacent channel mobile.
- By proper filter and channel assignments the adjacent channel interference can be minimized. As each cell is given only a part of the available channels, a cell needs assigned channels that are adjacent in frequency.
- If in a given cell the frequency separation between the cells is made large then the adjacent channel interference can be considerably reduced.
- By sequentially assigning the successive channels in frequency band to different cells many allocation methods are available to separate adjacent channels in a cell by N channel bandwidths, where N is the cluster size.
- Fig. 2.9.1 shows the sequential assignment of successive channels in the frequency band to different cells in one cluster.

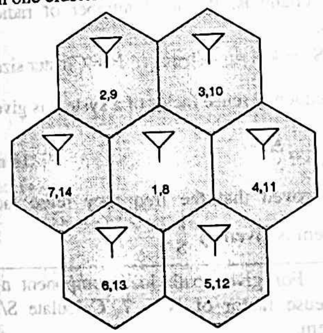


Fig. 2.9.1 : Channel assignments to reduce adjacent channel interference

- Another cause for adjacent channel interference is **"frequency reuse"** when the frequency reuse is high there are more chances for interferences because of neighbouring channels and because of separation concept.
- Also the power control needs to properly done at the base station to reduce interference at the subscriber's mobile unit.

2.9.4 Solved Examples on Interference

List of Important Formulae

(1) Co-channel interference reduction factor

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

where D = Frequency reuse distance

R = Radius, N = Size of cluster

(2) Signal to interference ratio $\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} = \frac{(D/R)^n}{i_0}$

Where, i_0 : number of interfering co-channel cells

S : desired signal power from desired base station

I_i : Interference power from i^{th} interfering co-channel cell base station.

Ex. 2.9.1 : Prove that the co-channel reuse ratio is given by $Q = \sqrt{3N}$ where $N = i^2 + ij + j^2$ (use cosine law and hexagonal geometry).

Soln. : The geometry of an array of regular hexagonal cells is shown in Fig. P. 2.9.1 where R is the radius of the hexagonal cell (from its centre to the vertex). A hexagon has six equidistant neighbouring hexagons corresponding to six sides of the hexagon.

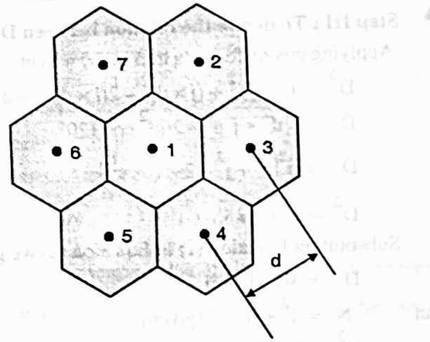


Fig. P. 2.9.1 : Distance between two adjacent cells, d

- **Step I : Relation between d and R.**

Let the distance between the centres of two adjacent hexagonal cells be d.

Then, $d = \sqrt{3}\,R$ (using trigonometric identities) ...(1)

- **Step II : Procedure of locating a co-channel cell.**

The nearest co-channel hexagonal cell to the cell under consideration can be located using the shift parameters i, j of cluster size N in regular hexagonal geometry.

Fig. P. 2.9.1(a) shows regular hexagonal geometry of one co-channel cell, corresponding to any one side of the hexagon as follows :

(i) Firstly move i number of cells along the i axis from the centre of hexagonal cell under consideration (say point X to point Y) along one side of hexagon.

(ii) Secondly, turn 60 degrees counterclockwise.

(iii) Then move j number of cells along j axis (point Y to point Z) to locate the centre of nearest co-channel cell. Let D be distance from the centre of the cell under consideration to the centre of nearest co-channel cell (i.e. XZ).

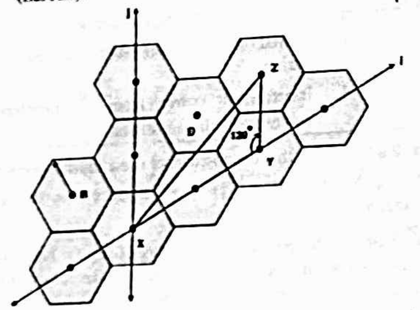


Fig. P. 2.9.1(a) : Co-channel cell in a regular hexagonal geometry

▸ **Step III : To derive the relation between D, d and ij.**

Applying cosine formula to Δ XYZ we get,

$$D^2 = (i \times d)^2 + (j \times d)^2 - 2(i \times d)(j \times d)\cos 120°$$

$$D^2 = i^2 d^2 + j^2 d^2 - 2ijd^2 \cos 120°$$

$$D^2 = d^2\left(i^2 + j^2 - 2 \times ij \times \frac{-1}{2}\right)$$

$$D^2 = d^2 (i^2 + ij + j^2) \quad ...(2)$$

Substituting Equation (1) in Equation (2) we get,

$$D^2 = 3R^2 (i^2 + ij - j^2)$$

But $N = i^2 + ij - j^2$ (given)

$$D^2 = 3R^2 N \quad ...(3)$$

▸ **Step IV : To establish relation between Q and N.**

$$D^2 = 3R^2 N$$

$$\therefore \frac{D^2}{R^2} = 3N$$

Taking square root of both the sides,

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

But by definition $Q = \frac{D}{R}$

$$\therefore Q = \sqrt{3N} \quad ...\text{Hence proved}$$

Thus, the frequency reuse ratio Q can be determined from the cluster size N.

Ex. 2.9.2 : If a 20 MHz of total spectrum is allocated for a duplex wireless cellular system each simplex channel has 25 KHz RF bandwidth, find (a) the number of duplex channels and (b) the total number of channels per cell site if N = 4 cell reuse is used.

☑ **Soln. :**

(a) To find the number of duplex channels

$$\text{Number of duplex channels} = \frac{20 \times 10^6}{25 \times 10^3 \times 2} = 400 \quad ...\text{Ans.}$$

(b) If N = 4 find the number of channels per cell

$$\text{Number of channels per cell} = \frac{400}{4} = 100 \quad ...\text{Ans.}$$

Ex. 2.9.3 : Show that the frequency reuse factor for a cellular system is given by $\frac{k}{S}$, where k is the average number of channels per cell and S is the total number of channels available to the cellular service provider.

☑ **Soln. :**

If each cell is allocated a group of k channels (k < S) and if the S channels are divided among N cells into unique and disjoint channel groups with each having the same number of channels, the total number of radio channels available is,

$$S = kN \quad \text{Where,} \quad N = \text{Cluster size}$$

The frequency reuse factor of a system is given by $\frac{1}{N}$

$$\therefore \frac{1}{N} = \frac{k}{S} \quad ...\text{Hence proved}$$

Thus, proved that the frequency reuse factor for a cellular system is given by $\frac{k}{S}$.

Ex. 2.9.4 : For given path loss component n = 4 and frequency reuse factor of N = 7. Calculate S/I ratio in cellular system.

☑ **Soln. :**

Given : n = 4 , N = 7

$$\frac{D}{R} = \sqrt{3N} = \sqrt{3 \times 7} = 4.582$$

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} = \frac{(D/R)^n}{i_0} = \frac{1}{6} \times (4.582)^4 = 73.46$$

$$\frac{S}{I} = 10 \log (73.46) = 10 \times 1.8660$$

$$= 18.66 \text{ dB} \quad ...\text{Ans.}$$

Ex. 2.9.5 : If a signal to interference ratio of 15 dB is required for satisfactory forward channel performance of a cellular system, what is the frequency reuse factor and cluster size that should be used for maximum capacity if the path loss exponent is (1) n = 4 (2) n = 3 ? Assume that there are six co channel cells in the first tier and all of them are at the same distance from the mobile. Use suitable approximations.

☑ **Soln. :**

(a) n = 4

Consider a seven cell reuse pattern,

$$\frac{D}{R} = \sqrt{3N} = \sqrt{3 \times 7} = 4.582$$

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} = \frac{(D/R)^n}{i_0} = \frac{1}{6} \times (4.582)^4 = 73.46$$

$$\frac{S}{I} = 73.46$$

$$\frac{S}{I} = 10 \log (73.46) = 10 \times 1.8660 = 18.66 \text{ dB}$$

As $\left(\frac{S}{I}\right)$ is > 18 dB, N = 7 can be used.

(b) n = 3

Consider a seven cell reuse pattern,

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(4.582)^n}{6} = 16.03$$

$$\frac{S}{I} = 10 \log (10.03) = 12.05 \text{ dB}$$

As $\left(\frac{S}{I}\right)$ is < 18 dB, i.e. minimum required $\left(\frac{S}{I}\right)$ we need to use large N.

Consider N = 12

$$\therefore \frac{D}{R} = \sqrt{3N} = \sqrt{3 \times 12} = 6$$

$$\therefore \frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(6)^3}{6} = 36$$

$$\frac{S}{I} = 10 \log (36) = 15.56 \text{ dB}$$

For N = 12
$$\left(\frac{S}{I}\right)_{min} = \frac{1}{2(Q-1)^{-3} + 2(Q+1)^{-3} + 2Q^{-3}}$$

$$= \frac{1}{2(6-1)^{-3} + 2(6+1)^{-3} + 2(6)^{-3}}$$

$$\left(\frac{S}{I}\right)_{min} = \frac{1}{0.016 + 5.83 \times 10^{-3} + 9.25 \times 10^{-3}}$$

$$\left(\frac{S}{I}\right)_{min} = 32.165 = 10 \log (32.165) = 15.07 \text{ dB}$$

As $\frac{S}{I}$ > 15 dB i.e. minimum required $\left(\frac{S}{I}\right)$, N = 12 can be used.

(c) Now consider the interference from the first and the second layers.

$$\frac{S}{I} = \frac{1}{6(Q_1^{-4} + Q_2^{-4})}$$

$$Q_1 = \frac{D_1}{R} = 4.587 \text{ (for N = 7)}$$

$$Q_2 = \frac{2D_1}{R} = 9.165$$

$$\therefore \frac{S}{I} = \frac{1}{6(4.587^{-4} + 9.165^{-4})}$$

$$= \frac{1}{6(2.258 \times 10^{-3} + 1.417 \times 10^{-4})}$$

$$\frac{S}{I} = 69.452$$

$$\frac{S}{I} = \mathbf{10 \log (69.452) = 18.4 \text{ dB}}$$

But the $\left(\frac{S}{I}\right)$ value considering first layer interference only is 18.66 dB. The drop in $\left(\frac{S}{I}\right)$ is 18.66 – 18.4 = 0.26 dB when the second layer interference is included. Hence, the second and higher layer interferences can be neglected as compared with the interference from the first layer.

Ex. 2.9.6 : A celluar system has a cluster size 7 and path loss exponent n = 4. Determine the S/I for the system. Now, if each cell is sectored in 120° sectors, what will be the improvement in S/I compared to non-sectored system in dB?

☑ **Soln. : Given :** Path loss exponent n = 4

For a seven cell reuse pattern,

$$\frac{D}{R} = \sqrt{3N} = \sqrt{3 \times 7} = \sqrt{21} = 4.582$$

The $\frac{S}{I}$ ratio assuming that there are six-co-channel cells (i_0 = 6) in the first tier and all of them are at the same distance from the mobile is,

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} = \frac{(4.582)^4}{6} \quad (n = 4 \text{ given})$$

$$\therefore \frac{S}{I} = 73.46$$

$$\therefore \frac{S}{I} = 10 \log (73.46) = 10 \times 1.8660$$

$$\therefore \frac{S}{I} = \mathbf{18.66 \text{ dB}}$$

If the same system is sectored in 120 sectors i.e. **there are 3 sectors per cell** then the number of interferes in the first tier is reduced from six to two i.e. i_0= 2 it is because only two of the six co-channel cells will receive interference with a particular sectored group. The resulting $\frac{S}{I}$ can be found as,

$$\frac{S}{I} = \frac{(\sqrt{3N})^4}{i_0} = \frac{(\sqrt{3 \times 7})^4}{2}$$

$$\frac{S}{I} = \frac{441}{2} = 220.5$$

$$\frac{S}{I} = 10 \log (220.5) = 23.43 \text{ dB}$$

This, 120° sectoring improves the $\frac{S}{I}$ ratio by around 5 dB (23.43 – 18.66 ≈ 5 dB)

There is an improvement over the non-sectored case. If a mobile is 20 times as close to the base station as another mobile and has energy spill out of its passband, the signal to interference ratio at the base station is

$$\frac{S}{I} = (20)^{-n}$$

For n = 4, $\frac{S}{I}$ = – 52 dB

If the (IF) Intermediate Frequency filter of the base station has a slope of 20 dB/ octave, then an adjacent channel interferer must be displaced by at least six times the passband bandwidth from the center of the receiver frequency passband to obtain 52 dB attenuation.

A separation of approximately six channel bandwidths is needed for typical filters in order to provide 0 dB S/I ratio from a close-in adjacent channel user. It indicates that six channel separations are needed to bring the adjacent channel interference to an acceptable level.

Ex. 2.9.7 : A cellular system has 32 cells; each cell has 1.6 km radius and the system reuse factor of 7. The system is to support 336 traffic channels in total. Determine the total geographical area covered, the number of traffic channels per cell and total number of simultaneous calls supported by this system.

☑ **Soln. :**

▸ **Step I :** To calculate the total geographical area covered. Considering N = 7 reuse cellular pattern with hexagon cells arranged inside. For a cell radius of 1.4 km, the full area is assumed to be an approximate square outline with hexagon cells.

The area of hexagon cells= $\frac{3\sqrt{3}r^2}{2} = 1.5r^2\sqrt{3}$ of radius r is

$$\text{Area (A)} = 1.5\,(1.6)^2\sqrt{3} \qquad (r = 1.6 \text{ km})$$

$$A = \mathbf{6.6510 \text{ km}^2}$$

Total geographical area covered (A_T) = (Area) (number of cells) = (6.6510) × (32)

Total geographical area covered = 212.83 km²

▸ **Step II :** To find the number of traffic channels per cell

For N = 7 Frequency reuse pattern, the number of channels per cell is

$$\frac{\text{Number of traffic channels}}{7} = \frac{336}{7} = \mathbf{48 \text{ channels/cell}}$$

$$\text{Total capacity } (C_T) = \left(\begin{matrix}\text{Total number}\\ \text{of channels}\end{matrix}\right) (\text{Number of cells})$$

$$= 48 \text{ channels/cell} \times 32 \text{ cells}$$

$$C_T = \mathbf{1536 \text{ channels}}$$

Ex. 2.9.8 : Consider two different cellular systems that share the following characteristics. The frequency bands are 825-845 MHz for uplink and 870-890 MHz for the downlink. Aduplex circuit consists of one 30 kHz channel in each direction. The systems are distinguished by the reuse factor, which are 4 and 19 respectively. For these systems, (i) Find the maximum number of simultaneous conversations that can be supported by a single cell in each system. (ii) Suppose that in each systems the cluster of cells (4, 19) is duplicated 16 times, find the number of simultaneous conversations that can be supported by each system. Assume 8 TDMA slots/frame for each system.

☑ **Soln. : Given :**

(i) uplink frequency link = 825 – 845 MHz = 20 MHz

(ii) downlink frequency link = 870 – 890 MHz = 20 MHz

(iii) Frequency reuse factor = 4 and 19

(i) Each duplex channel = 30 × 2 = 60 KHz

$\therefore$ Number of channels = $\frac{40 \text{ MHz}}{60 \text{ KHz}} = 667$

(a) For 4 cell reuse

Total number of channels available per cell

$= \frac{667}{4} = 167$ channels /cell

(b) For 19 cell reuse

Total number of channels available per cell

$= \frac{667}{19} = 35$ channels/cell

(I) Maximum number of simultaneous conversations that can be supported by each cell in 4 cell reuse system assuming 8 TDMA slots/frame for each system

= (167 channels/cell) × 9 (time slots) = 1336

(II) For 19 cell reuse system = 35 × 8 = 280 conversations

(III) Cluster is duplicated 16 times

(i) For 4 cell reuse system

Total number of cells in system = 4 × 16 = 64

Number of channels / cell = 167

$\therefore$ Maximum conversations = 64 × 167 = 10688

(ii) For 19 cell reuse system

Maximum conversations = 19 × 16 × 35 = 10640

Ex. 2.9.9 : A total of 24 MHz of bandwidth is allocated to a particular FDD cellular system that uses two 30 KHz simplex channels to provide full duplex voice and control channels. Assume each cell phone user generates 0.1 Erlangs of traffic. (i) Find the number of channels in each cell for a four-cell reuses system. (ii) If each cell is to offer capacity that is 90% of perfect scheduling, find the maximum number of users that can be supported per cell.

☑ **Soln. : Given :**

1. Allocated bandwidth = 24 MHz
2. Simplex channel width = 30 KHz

$\therefore$ Duplex channel bandwith = 2 × 30 KHz = 60 KHz

3. A_u = 0.1 Erlangs

(i) Number of channels available = $\frac{24 \text{ MHz}}{60 \text{ KHz}} = 400$

(ii) Number of channels per cell in 4 cell reuse system

$= \frac{400}{4} = 100$ channels / cell

(iii) Now, each cell offers 90% of perfect scheduling

Hence, 90% of 100 Erlangs = 90 Erlangs

But A = UA_u = 90 = Traffic intensity

$\therefore U = \frac{90}{A_u} = \frac{90}{0.1}$ = **900 users**

2.9.5 Difference between Co-channel Interference and Adjacent Channel Interference

GQ. Explain the difference between co-channel interference and adjacent channel interference.

Sr. No.	Co-channel interference	Adjacent channel interference
1.	The interference between the signals from co-channel cells is called as co-channel interference.	The interference that results from the signals that are adjacent in frequency to the required signal is called as adjacent channel interference.
2.	To reduce co-channel interference co-channel cells are physically separated by a minimum distance to provide sufficient isolation.	By proper filter and channel assignments the adjacent channel interference can be minimized.
3.	A large co-channel reuse ratio improves the transmission quality because of smaller level of co-channel interference.	Another cause for adjacent channel interference is "frequency reuse" when the frequency reuse is high there are more chances for interferences because of separation.

2.10 HANDOFF STRATEGIES

GQ. Briefly describe hand-off strategies in cellular system.

GQ. Define Hand off.

GQ. What is meant by Hand off and explain different Hand off strategies? How handoff operation is performed while mobile moves into a different cell while a conversation is in progress. Discuss the cases for proper and improper handoff situations.

GQ. Define Handover. List and explain the types of handover.

❑ **Definition of handoff** or **handover** : The process of transferring a mobile station from one channel or base station to another is called as **handoff** or **handover.**

- When a mobile moves into a different cell while a conversation is in progress the mobile switching centre automatically transfers the call to a new channel belonging to the new base station. This handoff needs to identify the new base station and see that voice and control signals are allocated to the new base station.
- The handoff must be accurate, at correct time instant in order to avoid any call termination when there is conversation between two users. But if there is excessive delay at the Mobile Switching Center (MSC) in assigning handoff, the signal will drop below the minimum acceptable predetermined level in order to enable channel in active status can lead to a improper handoff. This minimum acceptable level refers to **"acceptable audio quality level"** at the Base Station (BS) receiver side.
- A stronger signal that is slightly stronger than this acceptable audio quality is used as threshold and handoff has to be done at this threshold level (Δ). The "Δ" level must be optimum and it must not be too large or too small from the desired level. It is expressed as,

$$\Delta = P_{rH} - P_{rM}$$

Where, P_{rH} = received handoff signal power

P_{rM} = received minimum usable signal power

- If Δ is too small then there is insufficient time to complete a handoff before call is lost because of weak signal conditions and if Δ is too large then the unnecessary handoffs can burden the mobile switching center. Hence, Δ must be carefully chosen. Fig. 2.10.1 shows the handoff situation at cell boundary.
- Fig. 2.10.1(a) shows situation where handoff is not done. The signal level drops below the minimum acceptable level to keep the channel active. If there is excessive delay introduced by the MSC is assigning the handoff or if the threshold Δ is small then dropped call event occurs.

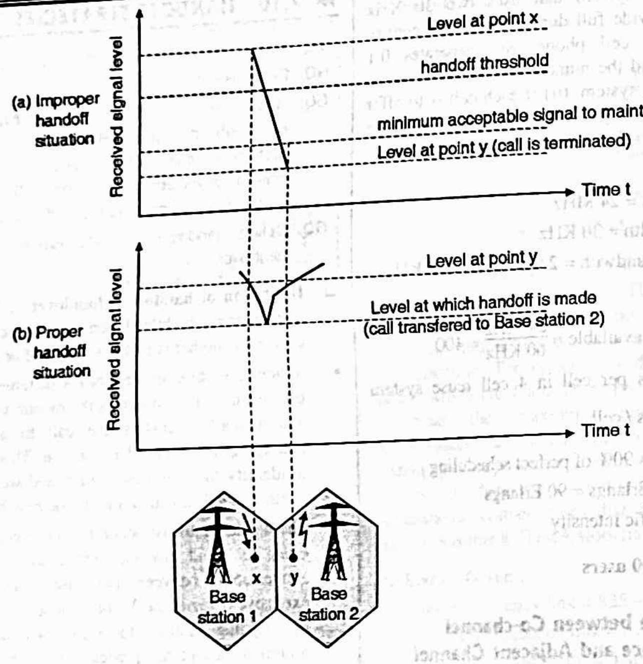


Fig. 2.10.1 : Handoff situation at cell boundary

☞ RSSI (Radio Signal Strength Indications)

GQ. Explain the term : RSSI.

Radio signal strength indication is defined as the measured power of the signal that is received at the mobile terminal or at the base station.

2.10.1 Dwell Time

GQ. Define term : (i) Dwell time.

- As the mobile moves from the serving Base Station (BS) there will be drop in the signal level. Therefore, the base station generally monitors and measures the signal level before initiating a handoff for continuing with the call in progress.
- The time period for which a call is maintained in a cellular region is called as **'dwell time'**.
- The factors that influence the dwell time are :
  (i) Propagation
  (ii) Interference
  (iii) Distance between the subscriber and the base station.

2.10.2 Mobile Assisted Handoff (MAHO)

GQ. Define term : (iii) Mobile assisted handoff

- In the first generation cellular systems the Mobile Switching Center supervises the signal strength measurement done by base stations and in the second generation cellular systems the handoff decisions are mobile assisted.
- In mobile assisted handoff, each mobile station measures the received power from surrounding base stations and gives the data to reporting base station. When the power received from the base station of a cell exceeds the power received from current base station then a handoff is initiated.
- The handover is done at a faster rate. MAHO is used for microcellular environments where handoffs are frequently done.

2.10.3 Intersystem Handoff

- During a call in progress, if a mobile moves from one cellular system to a different cellular system controlled by a different MSC, an **intersystem handoff** is essential.

- The MSC does an intersystem handoff when a mobile signal becomes weak in a given cell and MSC cannot find other cell in its system to transfer that call. e.g. roaming when mobile moves out of its home system.
- Before implementing the intersystem handoff the compatibility between the two MSCs must be known.

2.10.4 Prioritizing Handoffs

- In order to improve the quality of service, various methods have been developed to prioritize handoff requests over call initiation requests while allocating voice channels.
- One method is **guard channel concept.** In this method a part of the total available channels in a cell is reserved for handoff requests from ongoing calls that can be handed off into the cell. However, it has the drawback of reducing the total traffic as few channels are allocated to the originating calls. They offer efficient spectrum utilization if dynamic channel assignment strategy is used.
- Another method is **queuing of handoff requests.** It decreases the probability of termination of call because of lack of available channels. It is possible because of the fact that there is finite time interval between the time the received signal level drops below the handoff threshold and the time the call is terminated because of insufficient signal level.

2.10.5 Cell Dragging

GQ. Explain the term : Cell dragging.

- It is a practical handoff problem in the microcell systems **cell dragging** is a result of call of in progress in the cellular region. The handoffs threshold level and the radio coverage parameters are the main factors that need to be considered to avoid **"cell dragging".**
- It may result from pedestrian users that provide strong signal to be base station, when there is Line of Sight (LOS) path between the base station and the subscriber.
- When the user moves away from the base station the average signal strength slowly decays and as the user moves far from the base station, the signal received at the base station will be above the handoff threshold level.
- So, handoff need not be done and finally there will be traffic management problem and potential interference generated resulting in "cell dragging". Thus, to solve the problem of cell dragging, the handoff thresholds and the radio coverage parameters should be carefully adjusted.

2.10.6 Umbrella Cell Concept

GQ. Explain the concept of Umbrella cell.

- Practically in cellular systems there are several problems e.g. Pedestrian users may never need a handoff during a call, high speed vehicles pass through different cells quickly.
- The addition of microcells to increase the capacity has burdened the MSC.
- In cellular communication there is a possibility in which by using different antenna heights and different power levels to meet the traffic requirements i.e. large and small cells are colocated in a single location.
- The smaller cells are grouped and assumed to be under a larger cell.
- The cells with low traffic are called as **"microcells"** and cells with large high speed traffic are called as **"macrocells".**
- This method is called as **umbrella cell concept** as shown in Fig. 2.10.2.
- It is used to provide large coverage area to high speed users while providing small area coverage to users that travel at low speeds.

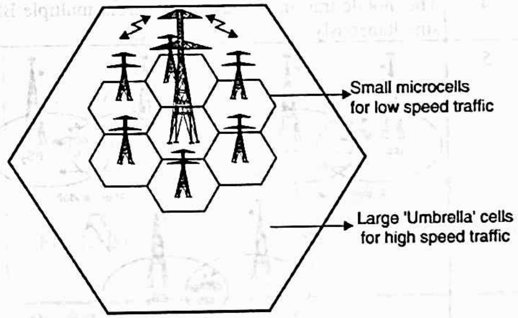


Fig. 2.10.2 : Umbrella cell concept

☞ Advantages

(i) It provides large coverage area to high speed users.
(ii) It ensures that the number of handoffs is minimized for high speed users.
(iii) It provides additional microcell channels for the pedestrian users.
(iv) If a high speed user in large umbrella cell is near the base station and if its velocity is decreasing then the base station can decide whether to hand the user into the co-located microcell without the intervention of the Mobile Switching Centre (MSC).

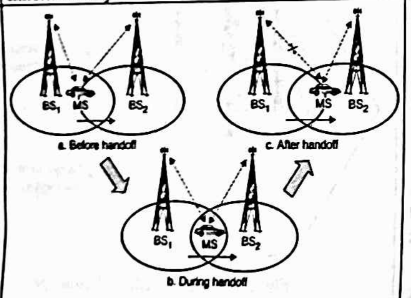
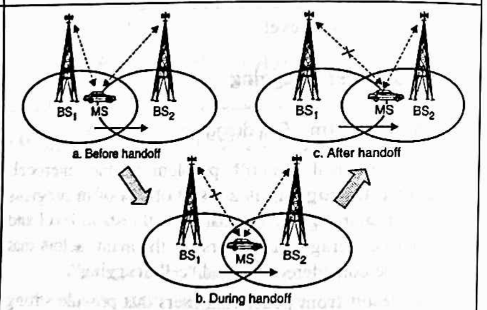
2.10.7 Hard and Soft Hand-off

GQ. Define term : (ii)Soft handoff.

- In the first generation analog cellular systems, the time to make a handoff is 10 seconds.
- In the digital cellular systems like GSM the mobile assists the handoff procedure by determining the hand off users and the decision needs only 1 or 2 seconds.
- Another feature in the newer cellular systems is their ability to make handoff decisions depending on parameters other than the signal strength.
- Different base stations handle the different radio channels during a handoff called hard handoff. It does not refer to the physical changes in the assigned channel, but a different base station takes care of the radio communication.
- **Soft handoff** refers to the ability of the Mobile Switching Center (MSC) for selecting amongst the different received signals from the base stations. It allows the MSC to make a "soft" decision as to which of the user's signal will pass to the PSTN at a glance.

2.10.8 Difference between Hard and Soft Handoff

Table 2.10.1 : Comparison of hard handoff and soft handoff

Sr. no.	Soft Hand-off	Hard Hand-off
1	Soft handoff refers to the ability of the Mobile Switching Center (MSC) for selecting amongst the different received signals from the base stations.	Different base stations handle the different radio channels during a handoff called hard handoff.
2	It allows the MSC to make a "soft" decision as to which of the user's signal will pass to the PSTN at a glance.	It does not refer to the physical changes in the assigned channel, but a different base station takes care of the radio communication.
3	It is make before break process.	It is break before make process.
4	The mobile transmits and receives from multiple BSs simultaneously.	The mobile connects to single BS at a time.
5		

2.10.9 Solved Examples on Handoff

List of Important Formulae

(1) The average received power P_r is,

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

or $P_r(\text{dBm}) = P_0(\text{dBm}) - 10\, n \log\left(\frac{d}{d_0}\right)$

Where, d : distance from the transmitting antenna.

P_0 : power received at a close-in reference point in the far field region of the antenna at small distance do from the transmitting antenna.

n : path loss component.

Ex. 2.10.1 : Suppose that a mobile station is moving along a straight smooth surface between base stations BS_1 and BS_2. The distance between BS_1 and BS_2 is 2000 m. Assume that the received power in dBm at Base station is given by $P_r = P_0 - 10{*}n{*}\log(d/d_0)$, where d is the distance between mobile station and base station in meters. P_0 is the power at distance d_0 from the mobile. Assume that $P_0 = 0$ dBm and $d_0 = 1$ m. Let n denote path loss exponent which is 2.9. Given that the minimum usable level of signal is – 88 dBm and the mobile is currently connected to BS_1, determine the hand-off margin if hand-off time is 4.5 second and the mobile speed is 100 km/hr.

Soln. : Given : Mobile speed v = 100 km/hr

$$P_0 = 0 \text{ dBm} \quad d_0 = 1 \text{ m}$$

$$n = 2.9 P_{r,\min} = -88 \text{ dBm}$$

$$\text{Hand off time} = 4.5 \text{ s}$$

$$P_{r,\min} = P_0 - 10\, n \log\left(\frac{d_{\min}}{d_0}\right)$$

$$-88 = 0 - 10 \times 2.9 \log\left(\frac{d_{\min}}{1}\right)$$

$$\therefore d_{\min} = \text{antilog}\left(\frac{88}{29}\right) = 1082.63 \text{ m}$$

$P_{r,HO}$ is received signal power at handoff threshold.

$$P_{r,HO} = P_0 - 10\, n \log\left(\frac{d_{r,HO}}{d_0}\right)$$

$$= 0 - 10 \times 2.9 \log\left(\frac{d_{r,HO}}{1}\right)$$

$$P_{r,HO} = -29 \log(d_{r,HO})$$

$$d_{r,HO} = \text{antilog}\left(\frac{-P_{r,HO}}{29}\right)$$

During hand-off calls are not lost due to weak signal condition if,

$$\frac{\text{Distance travelled during hand-off}}{\text{Mobile speed}} \geq \text{hand-off time}$$

$$\frac{d_{\min} - d_{r,HO}}{100 \text{ km/hr}} \geq 4.5 \text{ s}$$

$$\frac{1082.63 - \text{antilog}\left(\frac{-P_{r,HO}}{29}\right)}{\frac{100 \times 10^3}{60 \times 60} \text{ m/s}} \geq 4.5 \text{ s}$$

$$\therefore 1082.63 - \text{antilog}\left(\frac{P_{r,HO}}{29}\right) \geq 124.96$$

$$\therefore -\text{antilog}\left(\frac{-P_{r,HO}}{29}\right) \geq -957.66$$

Taking log of both sides we get,

$$\frac{-P_{r,HO}}{29} \geq \log(957.66)$$

$$P_{r,HO} \geq -29 \times 2.9812\, P_{r,HO} \geq -86.455 \text{ dBm}$$

$\therefore \Delta$ = hand-off margin $= P_{r,HO} - P_{r,\min} = -86.455 - (-88)$

$\Delta \geq$ **1.544 dBm** ...**Ans.**

2.11 IMPROVING COVERAGE AND CAPACITY IN CELLULAR SYSTEMS

GQ. Mention the techniques to improve the capacity in cellular system and explain any one.

- To increase the coverage area in a cellular system, it is important to allocate more number of radio channels to a cell so as to meet the mobile traffic.
- More number of channels indicates that the coverage distance will be large leading to higher coverage capacity.
- Inorder to enhance the cellular coverage capacity many methods are used in practice.

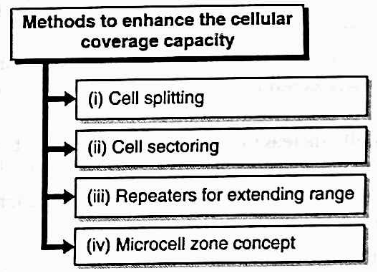


Fig. 2.11.1 : Methods to enhance the cellular coverage capacity

2.12 CELL SPLITTING

GQ. Explain the concept of cell splitting with require figure.

GQ. Describe Cell Splitting with its limitations in detail.

- **Cell splitting** is a method of subdividing the congested cell into smaller cells, each within its own base station following a decrease in the transmitter power and the height of the antenna.
- The parent cell that was originally congested is called as **"macrocells"** and the smaller cells are called **"microcells"**.
- The main **advantage** of cell splitting is that it increases the cellular capacity of the system where the frequency reuse technique can be efficiently implemented.

- Cell spitting has specific hierarchy
- Refer Fig. 2.12.1
  (i) Macrocell (ii) Microcell
  (iii) Picocell (iv) Femtocell

(i) Macrocells

- Usually they are used in rural areas to cover longer distances and traffic is less.
- The antenna for macrocells are mounted on ground based masts, rooftops and other existing structures, at a height that provides a clear over view of the surrounding buildings and land. Generally they are mounted along highways.
- Macrocell base stations have power outputs of typically tens of watts.

Disadvantage of a Macrocell network

- Macrocell networks provide indoor coverage. To improve indoor coverage more number of macrocells needs to be used. But that increases system cost.

(ii) Microcell

- Macrocells are further divided into microcells with smaller radii in highly populated areas by cell splitting technique.
- It uses low power cellular base stations. A microcell uses power control to limit the radius of its coverage area.
- Microcells increase capacity of the channel, but radio resource management becomes more difficult.
- They are more sensitive to traffic variations and interference issues as compared to macrocell.

Disadvantage of a micro cell

- The number of handoffs increases per cell.

(iii) Picocells

- These cells generally cover a small area such as in buildings (shopping malls, train stations, offices, airports etc.) or more recently in aircrafts. They are used for improving indoor coverage in densely populated areas like train stations etc. Typically range of picocells is 200 meters.
- Picocells are available cellular technologies like GSM, CDMA, UMTS and LTE.

Advantages

(1) Less costly systems
(2) Allows the operator to have more cells and thus increases the capacity of the network inside the building.
(3) It can be used where localization is important.
(4) Also helps in improvement of outdoor coverage little bit.

Disadvantage

Coverage area is small hence requires more number of picocells.

(iv) Femtocell (Small Cell)

- A femtocell is a small cellular device base station designed for use in residential or small business environments. It is connected to the service provider's network such as broadband (DSL or cable) and typically supports 2-4 active mobile phones in a residential areas, and 8-16 active mobile phones.
- It routes the mobile traffic through IP network. It increases indoor coverage.

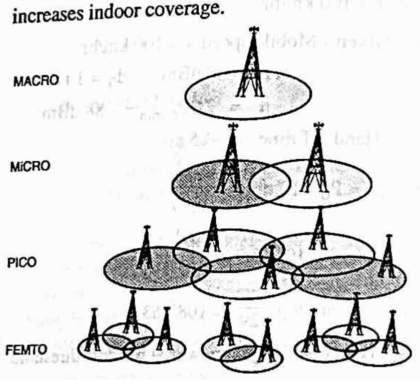


Fig. 2.12.1 : Different cells

Advantages

(1) It can provide indoor coverage for places where macrocells cannot reach.
(2) Low cost systems.
(3) Provides faster data rates.
(4) It helps in improvement of macrocell capacity.
(5) To cover the entire service area with the new microcells, four times as many cells are required. The increased number of cells will increase the number of clusters over the coverage area and will increase the number of channels per unit area. This indicates that the capacity of the system is increased.

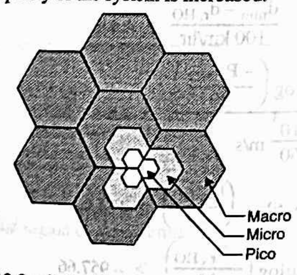


Fig. 2.12.2 : Cell splitting (Macro, Microcells and picocells)

- Cell splitting improves capacity by replacing large cells with smaller cells, while disturbing the channel allocation method to maintain the minimum co-channel reuse ratio.
- For the new cells to be smaller in size, the transmitted power must be decreased.
- Assuming P_{r0} as the received power at the old cell boundary and P_{rN} as the received power at new cell boundary.

$$\left.\begin{array}{l} P_{r0} \propto P_{t1} R^{-n} \\ P_{rN} \propto P_{t2}\left(\frac{R}{2}\right)^{-n} \end{array}\right\} \quad ...(2.12.1)$$

where, P_{t1} : Transmit power of macrocell.
P_{t2} : Transmit power of microcell.
n : Path loss exponent.

- If n = 4 and if we assume that the received powers are same, then

$$P_{t2} = \frac{P_{t1}}{16} \quad ...(2.12.2)$$

- This indicates that the transmit power must be reduced by 12 dB inorder to fill in the original coverage area with microcells for maintaining the $\frac{S}{I}$ requirement.
- In cell splitting process the large macrocells are dedicated to high speed traffic. The reason is the number of "hand offs" will be less in larger cell and the call progress can be smoothly carried in larger cells.
- Also the channels in the old cells need to be divided into two groups because of following points:
  (i) If a large transmission power is used for the cells that are available then some of the channels used by smaller cells may not be completely separated by the co-channel cells. It may lead to interference.
  (ii) If smaller transmission power is used for the available cells then there is probability of "unserved" problem. That is some parts of the larger cells would be left out "unserved". It is also not acceptable.
- Hence, the channels of macrocells have to be divided into macrocells and microcells. The macrocells are dedicated to high speed traffic and microcells are dedicated to low speed traffic regions.

2.13 CELL SECTORING

GQ. Explain sectoring to improve coverage and capacity of a system.
GQ. Describe Cell Sectoring with its limitations in detail.

- By reducing the cell radius R and keeping the same co-channel reuse ratio $\frac{D}{R}$, the cell splitting technique increases the number of channels per unit area.
- **Cell sectoring** is another method to increase the capacity. It keeps the radius of the cell constant and decreases the co-channel reuse ratio $\frac{D}{R}$ to reduce the cluster size N.
- The size of clusters in a particular service area can be reduced because the **cell sectoring increases the Signal to Interference Ratio (SIR).**
- In cell sectoring the $\frac{S}{I}$ ratio is improved using directional antennas and then capacity improvement is obtained by reducing the number of cells in a cluster, thus increasing the frequency reuse.
- At the base station if several directional antennas (each of which that radiates within a specified sector) are replaced by a **single omnidirectional** antenna then the cochannel interference can be reduced.
- Only a given cell will receive interference and transmit only a part of the available cochannel channels with the directional antennas.
- Thus, the method of decreasing the cochannel interference value and enhancing the system performance by using the directional antennas is called as **"Cell Sectoring".**
- The reduction in the cochannel interference is dependent on the amount of sectoring used.
- A cell is generally divided into 120° sectors or 60° sectors. If the sectoring is 120° then the hexagon cell consists of three sectors as shown in Fig. 2.13.1.
- If the sectoring is 60° then the hexagonal type cell consists of six sectors as shown in Fig. 2.13.2.

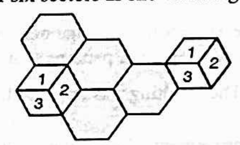


Fig. 2.13.1 : 120° Sectoring

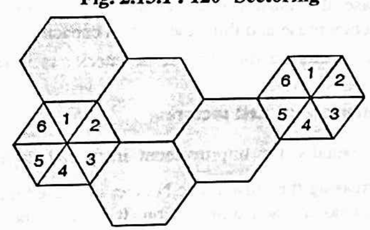


Fig. 2.13.2 : 60° Sectoring

- If cell sectoring is employed then the channel used in a cell will be divided into groups i.e. sectored groups as they are used only within a sector.
- Fig. 2.13.3 shows a 7-cell reuse pattern with 120° sectoring. The possible number of interferers in the first tier will be two.
- This indicates that only two cells of the six cochannel cells get interfered from a particular sectored cell.
- Consider Fig. 2.13.3 the interference experienced by mobile located in the right most sector in the center cell labelled "A".

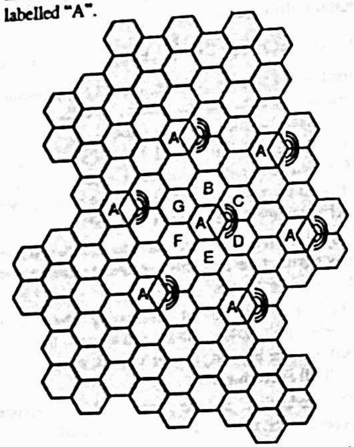


Fig. 2.13.3 : Cochannel interference reduction using 120° sectoring

- There are three cochannel sectors labelled "A" to the right of the center cell and three to the left of center cell.
- Out of these six cochannel channels, only two cells have sectors with antenna patterns that radiate into the centre cell. The resulting $\frac{S}{I}$ is improved.
- The $\frac{S}{I}$ improvement allows the cellular provider to decrease the cluster size N inorder to improve the frequency reuse and thus, the system capacity.
- In 60° sectoring the number of interferers is reduced from 6 to 1.

☞ **Limitations of Cell sectoring**

- The penalty for improvement in $\frac{S}{I}$ and capacity by decreasing the cluster size N is an increased number of antennas at each base station. It reduces the trunking efficiency because of channel sectoring at the base station.
- Sectoring decreases the coverage area of a specific group of channels. This increases the number of hand-offs.
- If the total number of channels in a cell is subdivided and allotted to different sectored areas then the trunking efficiency decreases.

2.13.1 Difference between Cell Splitting and Cell Sectoring

Sr. No.	Cell splitting	Cell sectoring
1.	Cell splitting is a method of subdividing the congested cell into smaller cells, each with its own base station and a correction reduction in the antenna height and transmitter power.	Cell sectoring is a method of decreasing the cochannel interference and enhancing the system performance by using directional antennas.
2.	The radius of the cell is decreased and the cochannel reuse ratio $\frac{D}{R}$ is kept constant to improve the capacity.	The radius of the cell is kept constant and the cochannel reuse ratio $\frac{D}{R}$ is decreased to improve the capacity.
3.	The cell is divided into smaller cells (microcells).	The cells are divided into 120° and 60° sectors.
4.	In cell splitting the transmit power must be reduced to maintain the $\frac{S}{I}$ ratio.	Cell sectoring improves the $\frac{S}{I}$ ratio using directional antennas.
5.	In cell splitting large macrocells are dedicated to high speed traffic. The reason is number of hand-offs will be less and call progress can be smoothly done.	Cell sectoring decreases the coverage area of a group of channels and increases the number of hand-offs.

2.14 REPEATERS

- The users of wireless networks require dedicated coverage for coverage in areas like mountains, valleys, buildings etc. To provide such range capabilities radio retransmitters called as **"repeaters"** are used.
- Repeaters are bidirectional. They simultaneously transmit and receive signals from the serving base station. They operate using over-the-air signals so that they can be installed anywhere.

- Repeaters are capable of repeating an entire cellular band.
- When the signals from base station are received, the repeater amplifies and reradiates the base station signals to that particular coverage region.
- The noise that is received and interference are reradiated by the repeater on the forward and the reverse link. So, repeaters must be carefully installed to adjust the forward and reverse link amplifier levels and antenna patterns.
- Directional antennas are connected to the inputs or outputs of repeaters for localized spot coverage in tunnels or buildings.
- If the coverage of a cell that is in use is modified then the user can allocate some base stations traffic to areas covered by the repeater.
- The repeater does not add capacity to the system. They are used to provide coverage into and around buildings where the coverage is weak. Repeaters with DAS (Distributed Antenna Systems) network are installed within the buildings to provide coverage into targeted areas.
- Knowledge of correct location for repeaters and distributed antenna systems within the building needs planning, because into the building the interference levels are reradiated into the building from the base station and from the interior of the building to the base station.

2.15 MICROCELL ZONE CONCEPT

GQ. Explain microcell zone concept to improve coverage and capacity of a system.

- We know that cell sectoring decreases the coverage area of group of channels thereby increasing the number of hand-offs. This is one of the problems associated with cell sectoring. It results in increased load on the switching and control link elements of the mobile system.
- To minimise this problem **Microcell zone concept** was presented by Lee. Fig. 2.15.1 shows the microcell zone concept. As shown in Fig. 2.15.1 there are three zones with T_x/R_x set up. All are connected to a single base station and share the same radio equipment.
- The antennas are placed at the edges of each zone such that when the user moves from one zone to the other zone the signal strength does not reduce.
- For establishing the connection between these zones and base station microwave link or coaxial cable or fiber optic cable is used. Such an arrangement of multiple zones and a single base station constitute a cell.
- When a mobile user travels i.e. roams from one zone to the other zone 2 then zone 1 will have strongest signal with respect to the base station. However, the cell retains the same channel.
- When the mobile travels between zone 1 within the cell, a hand-off is not required. Microcell zone concept is useful along highways or urban traffic corridors.

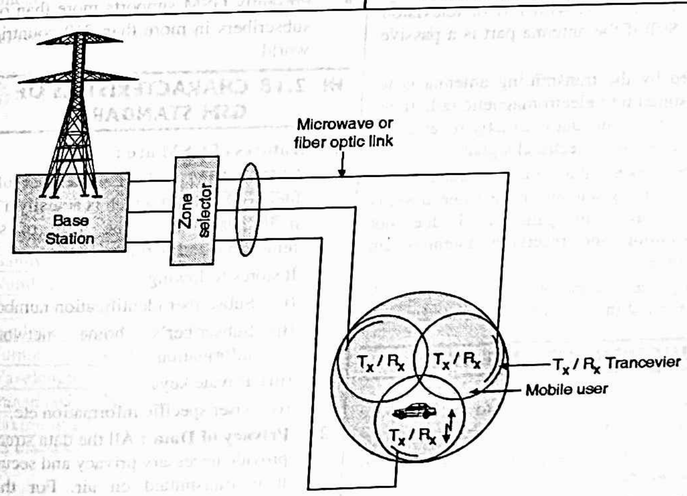


Fig. 2.15.1 : Microcell zone concept

2.15.1 Advantages

(i) Improved signal quality is possible.
(ii) Reduced number of hand-offs when a call is in progress.
(iii) When the mobile user travels from one zone to another zone within the same cell the same channel is maintained for call progress.
(iv) As low power transmitters are used in each zone apart from control base station the effect of interference is reduced.
(v) As the cell maintains a specific coverage radius, the cochannel interference in the cellular system is reduced.

2.15.2 Applications

(i) Highways (ii) Urban traffic corridors

2.16 ANTENNA

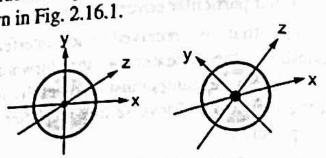
- **Definition :** The antenna is a wire structure used to convert high frequency current into electromagnetic radiations and vice versa.
- The antenna is very important part of the communication path.
- It is a passive device therefore the power entering the transmitter device is always more than the power radiated by the transmitting antenna. It is less because of losses present in the device.
- The term active antenna means combination of a receiving antenna with a low noise preamplifier. This term is usually used in context with FM or television broadcast receiver. Still if the antenna part is a passive device.
- The task performed by the transmitting antenna is to convert electrical signal into electromagnetic radiations and the task of receiving antenna is exactly reverse i.e. it coverts EM radiations into electrical signal.
- Antennas are reciprocal that means transmitting antenna and the receiving antenna have same designs and generally they have same gain also. It does not mean that transmitting and receiving antennas are identical to each other.
- The spacing, length and shape of an antenna depends upon the wavelength of the signal being radiated.

2.16(A) FUNCTIONS OF ANTENNA

(i) It couples the transmitter signal output to the free space or the received input signal to the receiver.
(ii) It is capable of transmitting and receiving the electromagnetic waves.
(iii) It converts high frequency current into electromagnetic waves.

2.16.1 Isotropic Radiator

- It is the theoretical reference antenna. It is the point in the space radiating equal power in all directions.
- The radiation pattern is symmetric in all directions as shown in Fig. 2.16.1.



(5A21)Fig. 2.16.1 : Radiation pattern of the isotropic antenna

2.17 INTRODUCTION TO GSM

- GSM stands for Global System for Mobile. It is second generation digital cellular technology used for mobile voice and data services.
- It is originally developed by ETSI (European Technical Standards Institute) in Europe to solve fragmentation problems of the first generation networks. GSM is the name of a standardization group established in 1982 to create a common European mobile telephone standard.
- GSM uses narrowband Time Division Multiple Access (TDMA) for providing voice and text based services over mobile phone networks.
- It is the first cellular system to use digital modulation schemes and network level architectures.
- Presently GSM supports more than one billion mobile subscribers in more than 210 countries throughout the world.

2.18 CHARACTERISTICS OF GSM STANDARD

The features of GSM are :

1. **USE of SIM :** GSM makes use of SIM (Subscriber Identity Module) which is actually a storage device and it is available in the form of smart cards. It is removable and portable.
   It stores following :
   (i) Subscriber identification number
   (ii) Subscriber's home network and country information
   (iii) Private keys
   (iv) User specific information etc.
2. **Privacy of Data :** All the data streams are encrypted to provide necessary privacy and security to the data when it is transmitted on air. For this purpose specific cryptographic keys which are function of time are used which are known to the cellular device only.
3. GSM provides **improved spectrum efficiency.**
4. The facility of national and international **roaming** is provided.
5. GSM maintains **good speech quality.**
6. GSM is **compatible with ISDN, PSTN** and other telephone company services.
7. It can also be made **compatible to newer services.**

2.19 GSM SERVICES

GQ. State and explain data services in GSM.

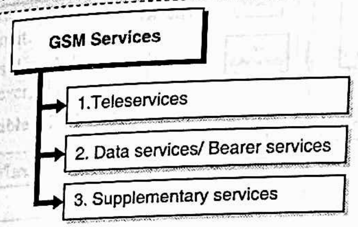


Fig. 2.19.1 : GSM Services

1. Teleservices

- These services allows subscriber to use terminal equipment functions for communication with other subscribers.
- It supports emergency calling, FAX services, Videotex and Teletex services though they are not integral part of the GSM standard.

2. Data services/ Bearer services

- These services allow subscriber to transmit appropriate signals across user network interfaces.
- It supports packet switched protocols and data rates from 300 bps to 9.6 kbps. New developments are going on to increase the data rate further.
- Data can be transmitted in two modes :
  (i) **Transparent mode :** GSM network provides standard channel coding method for user data.
  (ii) **Non-transparent mode :** GSM network provides special coding methods based on particular data interface.

3. Supplementary services

- These services supplements the teleservices and are offered with basic teleservices.
- They are digital in nature.
- These services include caller identification, call forwarding, call waiting, multiparty conversations, and barring of outgoing (international) calls, among others.
- It also includes SMS (Short Messaging Service) service is a text messaging service that allows sending and receiving text messages on your GSM mobile phone.
- Some of the supplementary services examples are :
  (i) Call conferencing (ii) Call waiting
  (iii) Call barring (iv) Call forwarding
  (v) Number identification (vi) Advice of charge
  (vii) Closed user groups

2.20 GSM FREQUENCY BANDS

GQ. Compare between GSM 900 and DCS 1800.

- It is frequency and time division system.
- Each physical channel have unique frequency and time slot number.
- **GSM Triband** frequencies are 900MHz, 1800MHz and 1900MHz. They are generally referred as GSM 900 and DCS 1800 systems.

Table 2.20.1 : Comparison between GSM 900 and ~~DCS~~ GSM 1800

Sr. no	Parameter	GSM 900	~~DCS~~ GSM 1800
1	Uplink frequency	890-915 kHz	1710-1785 MHz
2	Downlink frequency	935-960 kHz	1805-1880MHz
3	Bandwidth	25 MHz X2	75 MHz X2
4	Number of carriers used	124	374
5	Carrier spacing	200 kHz	200 kHz
6	Duplex channel spacing	45 MHz	95 MHz
7	Number of time slots used per channel	8	8
8	Wavelength	~33cm	~17cm
9	Transmission Data rate	270 kbps	270 kbps
10	Maximum BS power	55 dBm	43 dBm
11	MS classes	I-20 W (not implemented) II- 8 W (car/transportable phone) III- 5 W (car/transportable phone) IV- 2 W (handheld) V- 0.8 W (handheld)	I- 1 W (handheld) II- 0.25 W (handheld)

Syllabus Topic : GSM – System Architecture, GSM Radio Subsystem

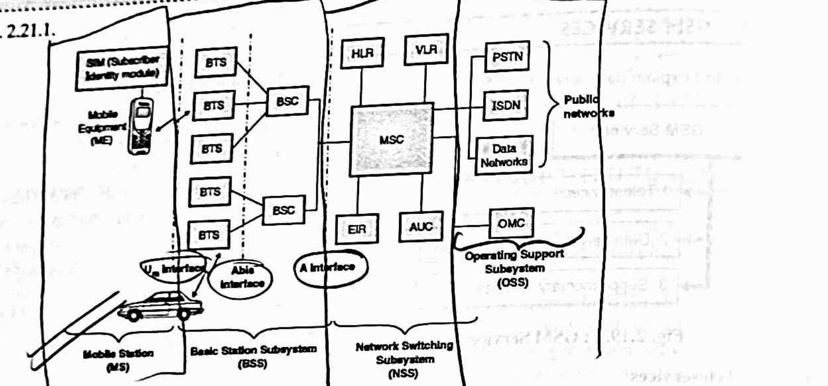
VVImp [IOM]

2.21 GSM ARCHITECTURE

GQ. Draw neat diagram of GSM Architecture and explain the function of each block in it.

GQ. Explain with a neat block diagram the architecture of GSM.

Refer Fig. 2.21.1.



BTS : Base Transceiver Station
VLR : Visitor Location Register
AUC : Authentication Center
BSC : Base Station Controller
MSC : Mobile Switching Centre
OMC : Operation Maintenance Center
HLR : Home Location Register
EIR : Equipment Identity Register

Fig. 2.21.1 : GSM Architecture

- GSM architecture shows various functional entities and three main subsystems.
  1. BSS : Base Station Subsystem
  2. NSS : Network and Switching Subsystem
  3. OSS : Operational Subsystem (support)
- MS is also a subsystem, but generally considered as an integral part of BSS.
- The BSS is also known as radio subsystem interlinks and manages links between MS and NSS. It is comprised of many BSC (Base Station Controllers).
- NSS controls all the switching functions of the system. It also supports communication between MSCs (Mobile Switching Center) with other networks like PSTN, ISDN etc.
- OSS manages operation and maintenance of GSM. It also administers the monitoring and controlling operations in the system. Actually in GSM interaction between the subsystems can be categorized as :
  1. **Operational** : Provides transmission and reception paths between NSS, BSS, MS and subscriber.
  2. **Control** : Manages all the traffic handling activities of the operational part and maintains, modifies and controls the traffic related functions.
- Refer Fig. 2.21.2 which shows interconnection between various subsystems. These subsystems are explained in detail in following sections.

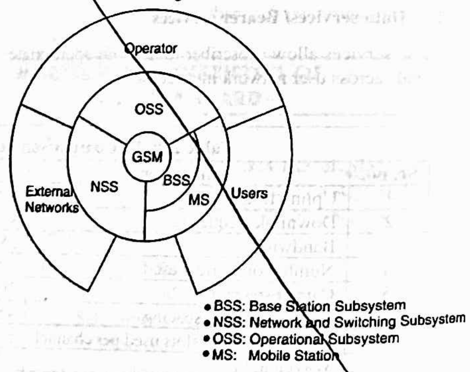


Fig. 2.21.2 : GSM subsystems

2.21.1 MS (Mobile Station)

- It consists of the physical mobile handset or equipment used by the subscriber to access the GSM network.

- It includes :
  1. MT : Mobile Termination
  2. TE : Terminal Equipment
  3. TA : Terminal Adapter
- Types of MS are :
  1. Vehicle mounted station
  2. Portable station
  3. Handheld station
- Generally MS is available in five power classes as shown in Table 2.21.1. It provides information about the maximum power level the mobile equipment can transmit.
- Class I and II refers to vehicular or portable units however, classes III, IV and V refers to handheld units.

Table 2.21.1 : Maximum RF power for MS

Class	Maximum RF power transmitted by MS (watts)
I	20 (not yet implemented)
II	8
III	5
IV	2
V	0.8

- In practice MS is divided in two parts :
  1. Mobile terminal
  2. SIM (Subscriber Identity Module)

1. Mobile terminal

It is the combination of hardware and software. It manages all the radio and human interface functions. It is nothing but mobile handset.

2. SIM (Subscriber Identity Module)

It is plugged into mobile terminal. Without the SIM card MS cannot communicate with any user or network. It is provided by the mobile service providers. It is microprocessor based entity implemented on smart card.

- Types of SIM cards used in GSM are :
  1. **ID-1 SIM card :** Credit card size.
  2. **Plug in SIM :** Normal SIM used in commercial GSM phones.
- SIM carries information like :
  1. IMSI
  2. TMSI
  3. Authentication key
  4. Cipher key
  5. Location area identity
  6. Access control class
  7. Administrative information etc.

- MS has various number identities like :

1. IMSI (International Mobile Subscriber Identity)

- It is provided to MS at the time of subscription.
- It uniquely identifies a given MS.

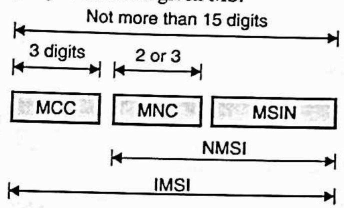


Fig. 2.21.3 : IMSI structure

- Refer Fig. 2.21.3 of IMSI structure. It contains 15 digits. They include :
  - Mobile Country Code (MCC) : 3 digits (home country)
  - Mobile Network Code (MNC) : 2 digits (home GSM network)
  - Mobile Subscriber Identification (MSIN)
  - National Mobile Subscriber Identity (NMSI)

Example

IMSI : 310150123456789		
MCC	310	USA
MNC	150	AT&T Mobility
MSIN	123456789	

2. TMSI (Temporary Mobile Subscriber Identity)

- It is assigned to MS by VLR when it is in roaming i.e. it has only local significance and its on temporary basis.
- Maximum digits in TMSI are 32.
- It can be coded fully by hexadecimal representation.

3. IMEI (International Mobile Equipment Identity)

- It is assigned by mobile equipment manufacturer for its unique identification.
- It contains 15 digits.
  - TAC (Type Approval Code) : 6 digits
  - FAC (Final Assembly code) : 2 digits
  - SN (Serial Number) : 6 digits
  - SP (Spare Number) : 1 digit

4

2.21.2 BSS (Base Station Subsystem)

- It manages all the signalling and traffic between MS and NSS.
- Functions performed by BSS are :
  - Coding of speech channels.
  - Allocation of available radio channels to mobile on request.
  - Transmission of paging signals.
  - Transmission and reception over the air interface.

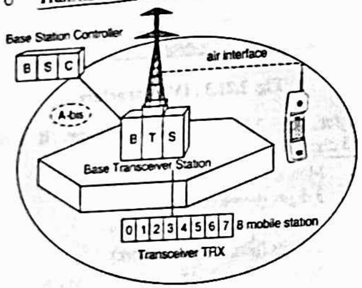


Fig. 2.21.4 : Base station subsystem

5

- It includes :
  - BTS (Base Transceiver Station)
  - BSC (Base Station Controller)

1. BTS → function : encode, encrypt, modulate, multiplex

6

- It consists of an antenna equipment responsible for transmission and reception of radio signals. Generally it uses directional antennas.
- The transceiver (TRX) is the central unit of the BTS. It manages links between maximum of 8 MSs with the use of single pair of frequencies. (8 MSs are handled at the maximum because in GSM, each carrier is divided into 8 time slots).
- It also has very important device known as TRAU (Transcoder Rate Adaptation Unit). TRAU performs encoding and decoding of the speech and rate adaptation function of the data.
- Multiple BTSs are connected and controlled by BSC. Some of the BTSs are co-located at the BSC and others may be remotely distributed and physically connected to the BSC with the use of microwave links or may be by dedicated lease lines.

2. BSC

7

- It is a high quality switch. It controls several typically hundreds of BTSs. The mobile handovers between two BTSs which are under control of the same BSC are handled by the BSC itself and not the MSC. This reduces burden on the MSC.

- It provides cell configuration data and control of RF power levels in BTSs.
- The BSC assigns free radio channels in the TRX for the link to the mobile station.
- BSC is also responsible for maintaining the radio path between MSs during the call and disconnection of the path when the call is over.

2.21.3 NSS (Network Switching Subsystem)

8

- BSS forwards the signals to NSS.
- It consists of main switching functions, various databases and mobility management units.
- It manages the communication between GSM network and users from other networks like PSTN.
- The main unit of NSS is MSC (Mobile Switching Center).
- Functions performed by MSC are :
  1. All the necessary switching functions required by MSs located in MSC area are performed by MSC.
  2. It communicates with other MSCs in GSM network.
  3. It also communicates with the other networks like PSTN etc.
  4. It always tracks the location of the subscriber so that to carry out the necessary handover mechanism.
  5. Performs all the interworking functions needed.
  6. Call routing functions and echo control functions are also performed by MSC.

9

- There are five functional entities associated with the MSC. They are :

1. HLR : Home Location Register
2. VLR : Visitor Location Register
3. EIR : Equipment Identity Register
4. AUC : Authentication Center
5. GMSC : Gateway MSC

1. HLR

10

- HLR is the database of permanent subscriber information.
- It contains user information like address etc., account status and preferences.
- There are two types of information stored in HLR.
  1. Subscriber information 2. Mobile information
- **Functions performed by HLR are :**

1. **Identification :** It stores IMSI and MSISDN (Mobile Station International Subscriber Directory Number) are used in call routing between MSC and particular MS. Using these unique numbers particular MS is identified.

2. **Subscriber service provision :** It provides information about the offered services like teleservices, bearer services or supplementary services.
3. **VLR address :** It is needed when MS is in roaming. These are temporary data. It also provides cipher keys.

2. VLR

11

It is the database of local subscribers when the subscriber enters the VLR area.

- Whenever the roaming MS enters the new MSC area it undergoes registration process as follows :
  (i) VLR identifies that MS belongs to other MSC area.
  (ii) VLR then identifies and communicates with MS's HLR in its home network.
  (iii) VLR constructs the GT (Global Title) from IMSI so that it can allow communication between VLR and Home HLR.
  (iv) VLR generates MSRN (Mobile Subscriber Roaming Number) to allow MS to use the network when in roaming.
  (v) MSRN is sent to home HLR also.
- VLR stores :
  (i) MSRN (ii) TMSI
  (iii) Home location of the MS
  (iv) Supplementary services data of MS
  (v) MSISDN (vi) IMSI
  (vii) GT (viii) Local MS identity if used
- VLR works in association with HLR and AUC.

3. EIR

12

- It is the database of all the legitimate, fraudulent and faulty MSs. It keeps track of all the valid and invalid mobile equipment in the area.
- It stores IMEI provided by the equipment manufacturer.

4. AUC

13

- It is the database that contains secret authentication keys for each subscriber and it generates security related parameters for protection purposes.
- The same secret key is found in SIM card. And it is never passed on air for security reasons.
- For carrying out authentication, it is always associated with HLR.

5. GMSC

- All the calls to the GSM network are routed through GMSC. It first identifies the right HLR and authenticates it.
- It also communicates with other networks and provides gateway function for external network communication with GSM network.

2.21.4 OMSS : Operation and Maintenance Subsystem

There are three functional entities mainly in OMSS.

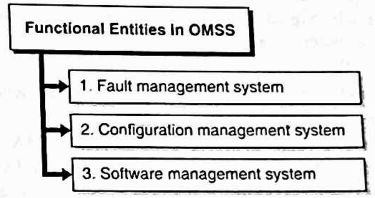


Fig. 2.21.5 : Functional entities in OMSS

1. The Fault Management system

It invokes alarms from the BSS elements when faults occurs. These faults are then resolved by software or by technicians.

2. The Configuration Management

This functional unit is for installation and maintenance of the software of the newly setup BSS network elements. It also manages hardware inventory list and changes operation parameters like frequencies of BTS etc.

3. The Software Management system

This functional unit is used to install new software or updates and manages the software inventory lists.

2.22 GSM INTERFACES AND GSM PROTOCOL ARCHITECTURE

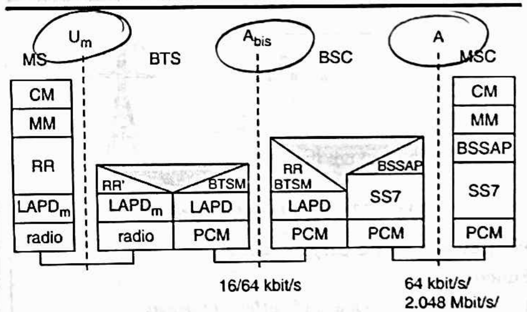


Fig. 2.22.1 : Protocol architecture for GSM signalling showing various radio interfaces

14

There are three different interfaces present in GSM system they are :

1. U_m : Interconnection between MS and BTS
2. A_{bis} : Interconnection between BTS and BSC
3. A : Interconnection between BSC to MSC

Module 2

2.22.1 U_m Interface

defines modulation, access type, time slot structure, etc.

- In GSM network the interconnection between the different subsystems are connected via wireless channels. Signal processing through wireless channels has to undergo various regulations and standards are set up for that.
- 15 The radio interface between MS and base transceiver station is known as Um radio interface.
- The GSM radio interface depends on TDMA (Time Division Multiple Access), FDD (Frequency Division Duplexing). [TDMA : frequency is shared among different users by dividing the time in slots. FDD : it allows the use of two different frequencies for uplink i.e. from MS to BTS and downlink i.e. BTS to MS.]
- Three layers :
  1. Physical layer (L1)
  2. Link access Protocol on D channel modified (LAPDm) (L2)
  3. The network layer (L3)

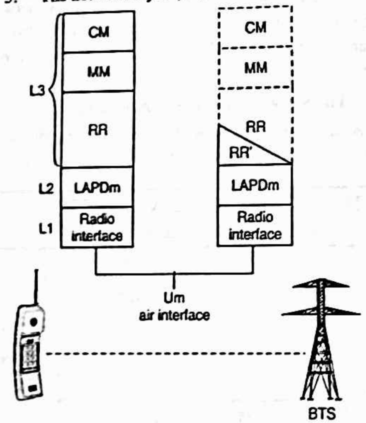


Fig. 2.22.2 : U_m interface protocol

Layer 1 : The physical layer

Functions

1. Formation of bursts in 5 different formats.
2. Formation of TDMA frame by multiplexing of bursts.
3. Synchronisation with BTS with timing advance technique.
4. Monitoring the quality of channel on the downlink path.
5. Identification of idle channels.
6. Interfacing to the data link layer and radio resource management sublayer for traffic management.
7. Encryption and decryption of data between MS and BSS using FEC (Forward Error Correction).
8. Digital modulation with the use of GMSK modulation scheme.

Layer 2 : LAPDm layer

This is based on ISDN LAPD protocol.

Functions

1. Reliable data transfer between GSM network and MS.
2. Arrangement of sequencing of data frames.
3. Flow control.
4. Segmentation and reassembly of the data.

LAPDm has to follow frame structures as there is no buffering between layer 1 and layer 2 in Um.

Layer 3 : The network layer

It consists of three sublayers :

1. RR : Radio Resource Management Sublayer
2. MM : Mobility Management Sublayer
3. CM : Call Management Sublayer

1. **RR**

   It is used for setup, maintenance and disconnection of radio channels. It can directly access the physical layer and provides reliable communication path for upper layers.

2. **MM**

   It supports the functions of location updating, authentication and encryption, allocation of TMSI. It also supports reliable connection to upper layer.

3. **CM**

   It consists of three functional entities namely :

   - **Call control (CC) :** Support for end to end call setup and management.
   - **SMS (Short Message Service) :** transfers and manages SMS services.
   - **Supplementary service (SS) : Manages** supplementary service.

2.22.2 A_{bis} Interface

16 It provides the interface between BTS and ~~M~~SC. B

Functions

1. Radio channel management.
2. Traffic channel management.
3. Terrestrial channel management.

It supports two different links :

- 64 kbps link (full rate or half rate carrying speech or user data)
- 16 kbps link (control information link between BSC-BTS and BTS-MSC)

Three layers are present in this :

1. The physical layer : typically uses PCM for modulation purposes.
2. The LAPD layer
3. Network layer - RR' is used, it is only part of radio resource management sublayer. All the functions of RR' are supported by BTSM (BTS management).

Transparent messages and non transparent messages between MS and BSC/MSC are handled by the traffic management.

Transparent messages : BTS analysis is not required.

Non-transparent messages : BTS analysis is required.

2.22.3 A Interface

- It provides the interconnection between BSS and MSc.
- SS7 is used for communication between MS and MSC.
- 17 This interface supports identification of channels, timeslots being serviced by BSS.
- The messaging required within the network to enable handover etc to be undertaken is carried over the interface.

2.22.4 Interfaces used within NSS

1. B interface

- It interconnects MSC and VLR. It is purely an internal interface.
- Protocol used : MAP/B protocol.
- It is used to access data regarding MS located in MSC area.

2. C interface

- It interconnects HLR and GMSC.
- Protocol used : MAP/C
- The MSC may optionally forward billing information to the HLR after the call is completed and cleared down.

3. D interface

- It interconnects HLR and VLR.
- Protocol used : MAP/D
- It supports functions like exchange of the data related to the location of the ME and to the management of the subscriber.

4. E interface

- It interconnects two MSCs.
- Protocol used : MAP/E
- The E interface exchanges data related to handover between two MSCs.

5. F interface

- It interconnects MSC and EIR.
- Protocol used : MAP/F.
- The communications along this interface are used to confirm the status of the IMEI of the ME gaining access to the network.

6. G interface

- It interconnects two VLRs of different MSCs.
- Protocol used : MAP/G
- It is used to access subscriber information. e.g. during a location update procedure.

7. H interface

- It interconnects MSC and SMSC (SMS center).
- Protocol used : MAP/H
- It is used to support SMS services.

8. I interface

- It interconnects MSC and ME.
- It is used for exchange of transparent messages.
- Refer Fig. 2.22.3, it shows all the radio interfaces used in GSM architecture.

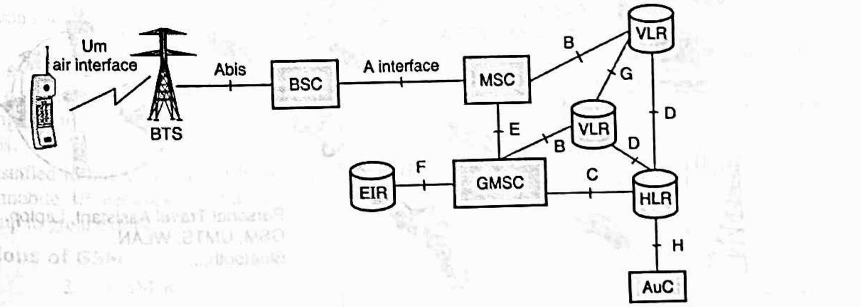


Fig. 2.22.3 : GSM architecture showing radio interfaces between various functional entities

2.23 BASIC RADIO TRANSMISSION PARAMETERS IN GSM 900

GQ. Write a short note on basic radio transmission parameters of the GSM system.

Table 2.23.1 : GSM radio parameters

Parameter	Specifications
Forward channel frequency	935 – 960 MHz
Reverse channel frequency	890 – 915 MHz
ARFCN Number	0 to 124 and 975 to 1023
Tx / Rx Frequency spacing	45 MHz
Tx / Rx Time slot spacing	3 Time slots
Modulation Data Rate	270.83 kbps
Frame period	4.615 ms
Modulation	0.3 GMSK
Users per frame	8
Time slot period	576.92 μs
Channel spacing	200 kHz
Interleaving delay (maximum)	40 ms
Voice Coder Bit Rate	13.4 kbps
Reverse and Forward Channel Bandwidth	25 MHz
Bit period	3.692 μs
Frequency deviation	67.708 kHz
Slow frequency hopping	217 hops per second

2.24 APPLICATIONS OF GSM

There are various applications available for GSM network. Few of them are given below.

2.24.1 Vehicles

Refer Fig. 2.24.1.

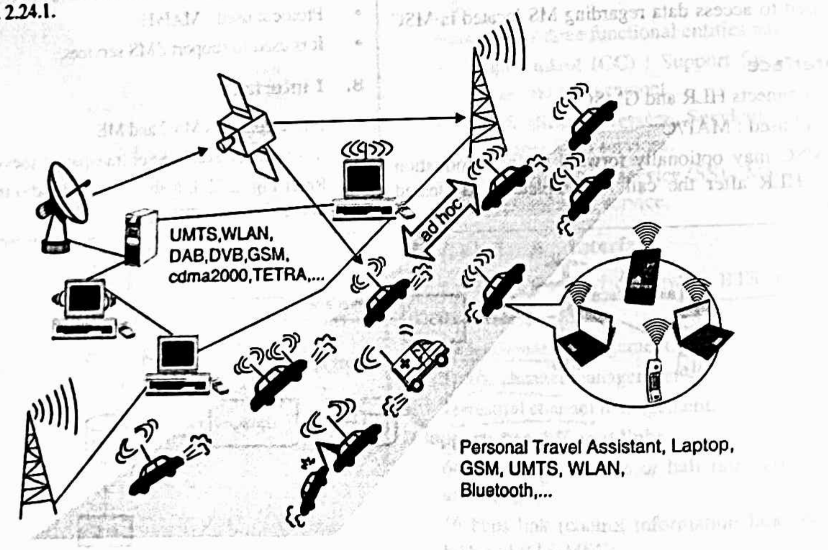


Fig. 2.24.1 : Typical scenario of GSM applications in road traffic

- It shows typical road traffic scenario all the vehicles are equipped with wireless devices. The networks between cars and inside the cars are mostly ad-hoc type.
- When some accident happens immediately the wireless devices communicates with to the hospital, ambulance, home devices of the person so that immediate help could be arranged.
- In this type of scenario not only GSM but also many other telecommunication systems are used like satellite links etc. similarly the same can be adopted in rail traffic or air traffic.

2.24.2 Emergencies

- The emergency services like ambulance can be equipped with GSM modems so that real time information about the ill person or patient can be immediately communicated with the hospital. Doctors can also track the patient's health by continuous messages and can provide their support and consultation in case of emergency.
- In case of natural calamities like earthquakes wireless communication is the only means available as it is not affected by failure of all cable systems. But crash of BTSs may affect the system. GSM systems can be designed to give intimations of these natural disasters so that necessary preparations can be done.

2.24.3 Business

- When the businessman is travelling using GSM and GPRS data services he can access his company's database to keep track of his routine work, employees, salaries etc.
- Mobile communication always provide good connectivity.
- He can also get information about current trends in business which will help him grow.

2.24.4 Security

- Now-a-days GSM technology is used widely in home automation systems. Even though the person is not at home, he can still control his electrical appliances using his mobile phone.
- Various different sensors used in home like smoke sensor etc. can be connected to GSM network and can be controlled using mobile. This is known as home automation systems.
- CCTV cameras installed in home, offices or banks can be connected to mobile IP network so that security issues are resolved up to great extent.

Other applications of GSM

1. Mobile telephony
2. GSM-R
3. Telemetry system
4. Automatic meter reading
5. Fleet management
6. Toll collection
7. Value added services
8. Forest fire and rainfall detection systems using GSM
9. Health monitoring using GSM
10. Weather monitoring using GSM etc.

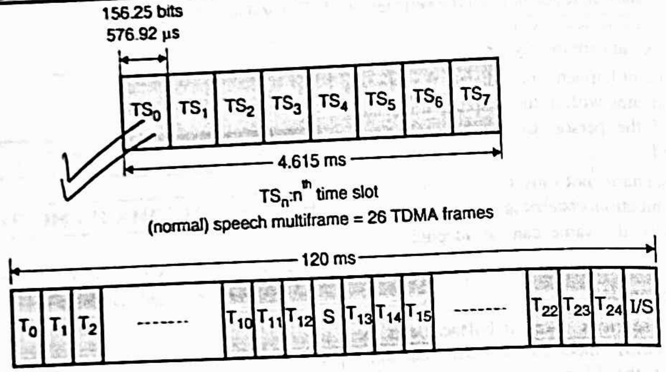
Syllabus Topic : GSM –Frame Structure;

2.25 GSM TDMA FRAME STRUCTURE

GQ. With a proper diagram explain the time slot hierarchy of GSM system.

GQ. Write short note on : GSM time hierarchy.

- GSM standard is based on TDMA technique in which each requesting user is allocated with one time slot. Radio interface parameters are already explained in previous chapter.
- In GSM available frequency spectrum is divided into 200 kHz channels and is allocated for forward and reverse links. They are separated by spacing of 45 MHz.
- Each channel pair is given ARFCN (Absolute Radio Frequency Channel Number). So all 8 subscribers uses same ARFCN but are allotted with different time slot.
- Refer Fig. 2.25.1, it shows typical TDMA frame used.
- TCH data is transmitted in consecutive frames.
- Every 13th and 26th frame is SACCH (explained later in this chapter) data and idle frame respectively.
- Details of TDMA frame are shown in Fig. 2.25.1 and 2.25.2.
  1. Total number of time slots per frame : 8
  2. Total number of consecutive frames in one multi-frame : 26
  3. Total duration of the multiframe : 120 ms
  4. Total number of multiframes in one superframe : 51
  5. Total time duration of the superframe : 6.12 seconds
  6. Total number of superframes in one GSM hyperframe : 2048
  7. Total time duration of the hyperframe : 3 hours 28 minutes and 54 seconds
  8. Number of bits in one time slot : 156.25
  9. Number of bits for guard time : 8.25 (guard time is the difference between the effective burst length and the time slot length).
  10. Total number of start and stop bits : 6
  11. Total time duration of the time slot : 576.92μs
  12. Total duration of GSM TDMA frame : 4.615ms



T_n: n^{th} TCH frame
S : Slow associated control channel frame
I : Idle frame

Fig. 2.25.1 : GSM TDMA Speech frame and multi-frame

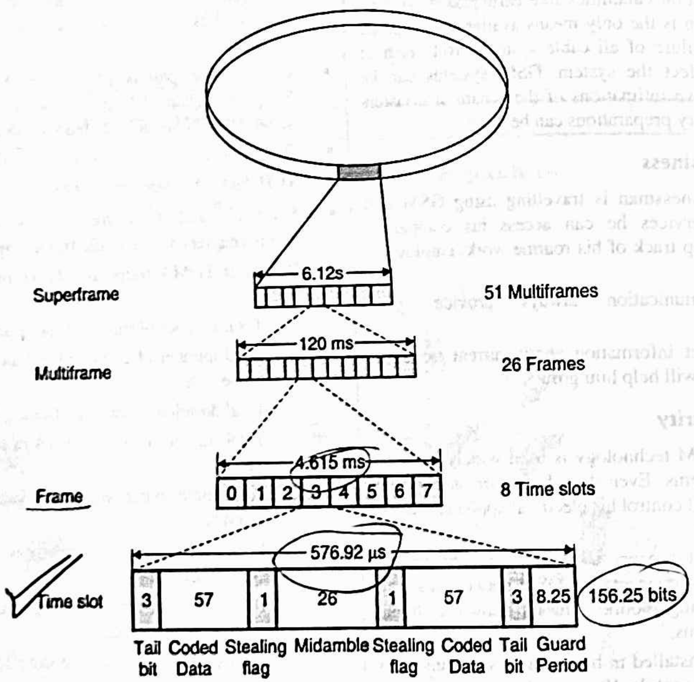


Fig. 2.25.2 : GSM time slot hierarchy

Normal Burst structure of GSM

- Fig. 2.25.2 shows normal GSM burst structure. There are total 148 bits per time slot, out of which 114 bits are information bits. These 114 bits are divided into block of 2 bearing 57 bits each and then transmitted.
- 26 **Midamble** bits are used by adaptive equalizer in mobile or BS receiver to analyze the radio channel characteristics before decoding the user data.
- Stealing bits are inserted at the start and end of the midamble bits. They are used as flag bits to indicate whether the TS contains voice or control data.
- Within frame GSM subscriber unit utilizes one TS for transmission and reception respectively and remaining six TS are used to measure the signal strength on 5 adjacent BS and its own BS as well.

2.26 GSM CHANNELS

Types of channels

(1) Physical channels (2) Logical channels

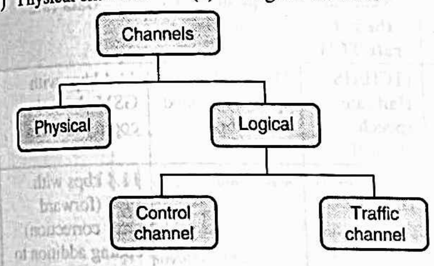


Fig. 2.26.1 : Types of GSM channels

2.26.1 Physical Channels

- The combination of ARFCN and TS (time slot) is known as the physical channel for GSM.
- One RF channel will support eight physical channels in time slot zero (TS0) through seven (TS7).
- Each physical channel can be mapped into different logical channels. This can be done at different times i.e. specific time slot or frame may be used to carry traffic data, control data or signalling data.

2.27 LOGICAL CHANNELS

GQ. Explain the classification of logical channels in GSM and describe each GSM logical channel in brief.

Two types :

1. Traffic channels
2. Control channels

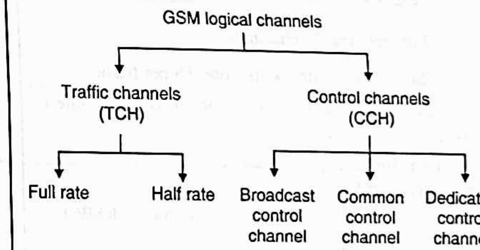
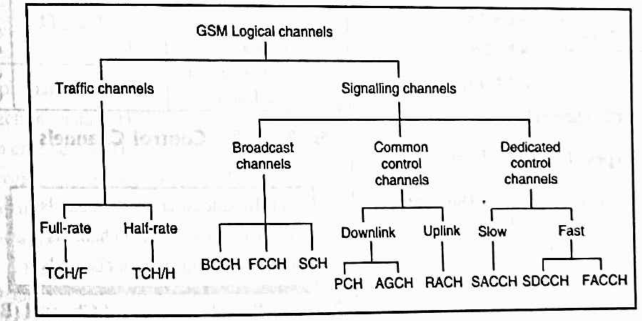


Fig. 2.27.1 : Types of GSM logical channels



TCH/F : Traffic channel full rate
BCCH : Broadcast control channel
SCH : Synchronization channel
AGCH : Access grant channel
SACCH : Slow associated control channel
FACCH : Fast associated control channel
TCH/H : Traffic channel half rate
FCCH : Frequency correction channel
PCH : Paging channel
RACH : Random access channel
SDCCH : Standalone dedicated control channel

Fig. 2.27.2 : Logical Channel structure of GSM

2.27.1 Traffic Channels

- They are used to carry user data or speech on forward and reverse links.
- Formats and the frame structures used on both the links are identical.
- TCH data may not be sent in TS0 time slot as it is reserved for control signaling data.
- They can be further categorized as :
  - o Full rate traffic channels
  - o Half rate traffic channels

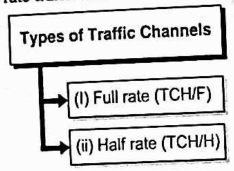


Fig. 2.27.3 : Types of traffic channels

(i) Full rate traffic channels

- User data is transmitted within one TS per frame.
- 26th frame of TDMA frame is zero if TCH full rate is used.
- TCH/FS (full rate speech channel)
  Refer Table 2.27.1.

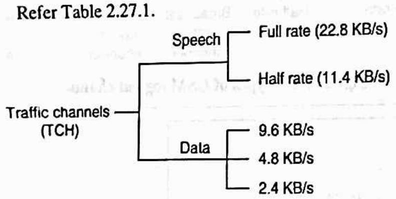


Fig. 2.27.4 : Traffic channel structure

Table 2.27.1 : Types of full rate TCH

Sr. No.	Name of the full rate TCH	Type of signal carried	Data rate
1	(TCH/FS) full rate speech channel	Digitized user speech encoded at 13kbps	22.8kbps with GSM channel coding addition
2	(TCH/F9.6) Full rate data channel for 9.6 kbps	User data	22.8 kbps with FEC (forward Error Correction) coding addition to GSM
3	(TCH/F4.8) Full rate data channel for 4.8 kbps	User data	22.8 kbps with FEC (Forward Error Correction) coding addition to GSM.
4	(TCH/F2.4) Full rate data channel for 2.4 kbps	User data	22.8 kbps with FEC (Forward Error Correction) coding addition to GSM.

(ii) Half rate traffic channels

User data is mapped on the same TS (time slot) but sent in alternate different frames. Refer Table 2.27.2.

Table 2.27.2 : Types of half rate TCH

Sr. No.	Name of the half rate TCH	Type of signal carried	Data rate
1.	(TCH/HS) Half rate speech channel	Digitized user speech encoded at 6.5kbps	11.4 kbps with GSM channel coding addition
2.	(TCH/H4.8) Half rate data channel for 4.8 kbps	User data	11.4 kbps with FEC (forward error correction) coding addition to GSM
3.	(TCH/H2.4) Half rate data channel for 2.4 kbps	User data	11.4 kbps with FEC (forward error correction) coding addition to GSM

2.27.2 Control Channels

Three types :

(A) Broadcast control channels
(B) Common control channels
(C) Dedicated control channels

(A) Broadcast Control Channel (BCCH)

- It is forward control channel with time slot TS0 allocated to it.
- It is simplex channel and its functions are :
  - o It serves as beacon channel to locate nearby mobile.
  - o It provides synchronization for all MS in same cell.

- Rarely monitors for received power of MS that belongs to neighbouring cells so that handover decision could be taken.
- Three types : Refer Fig. 2.27.5.

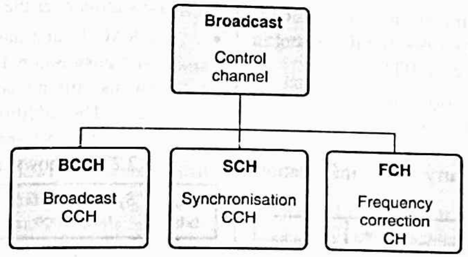
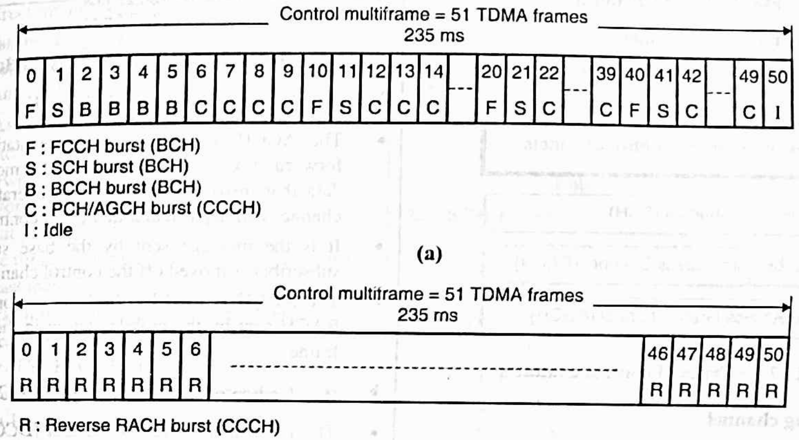


Fig. 2.27.5 : Broadcast channel structure



(a)

(b)

Fig. 2.27.6 : (a)The control channel multi-frame for forward link TS0
(b) The control channel multi-frame for reverse link TS0

- Broadcast control channel (BCCH)
- Frequency correction channel (FCCH)
- Synchronization channel (SCH)
- BCCH data provides information needed to set up call
- BCCH data contains :
  1. Cell and network identity.
  2. Operating characteristics of the cell (current control channel structure, channel availability, situation of congestion).
  3. List of currently engaged channels in the cell.
- Refer Fig. 2.27.6(a) and (b), it shows the control channel frame for forward and reverse links.
- Frame 2 to frame 5 carries BCCH data on forward link.

Frequency correction channel

- It occupies first frame in TS0 and it is repeated after every 10 frames in control channel multi-frame.
- It carries the frequency information so that mobile unit can synchronise its local oscillator's frequency with the base station frequency. Fig. 2.27.7 shows typical FCCH burst.

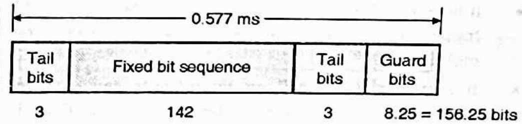


Fig. 2.27.7 : FCCH burst

Synchronization channel (SCH)

- It takes the next to FCCH frame position in the control channel multiframe time slot TS0. It is sent once after every ten frames in control multiframe.

- It provides signalling data useful for synchronism between MS and BS.
- The frame number (FN ranging from 0 to 2715647) along with Base Station Identity Code (BSIC) is sent in SCH burst. BSIC is unique for each BTS.
- When the mobile unit is far away (maximum 30 km) from the BS, it becomes necessary to adjust its clock with the BS clock to reduce timing errors and SCH burst signal is used to carry this information. Fig. 2.27.8 shows SCH burst.

Tail bits	Coded Data	Synchronization sequence	Coded Data	Tail bits	Guard Bits
3	39	64	39	3	8.25

Fig. 2.27.8 : SCH burst

(B) Common control channels

- It occupies TS0 of every GSM frame.
- There are three types of CCCH. Refer Fig. 2.27.9.

Types of Common Control Channels

- (i) Paging Channel (PCH)
- (ii) Random Access Channel (RACH)
- (iii) Access Grant Channel (AGCH)

Fig. 2.27.9 : Types of control channels

(i) Paging channel

- It is used to provide paging signals from BS to all MS in the cell.
- It carries the notification information regarding the call originated from PSTN.
- The paging message is generated by IMSI of the target subscriber and the acknowledgement request from the mobile unit which is sent on RACH on reverse link.
- It may carry the cell broadcast ASCII text messages to all the subscribers when used in SMS feature.

(ii) Random Access Channel (RACH)

- It is reverse link channel and occupies TS0 of the GSM frame and carries acknowledgement messages by mobile units.
- It also carries the call set up requests generated by subscriber units. Access scheme used by RACH: slotted ALOHA
- At the BTS each frame will accept the RACH transmissions from the mobiles during TS0. The base station responds to the RACH transmission by allocating a channel and a Stand-alone Dedicated Control Channel (SDCCH) for signaling in the presence of a call. The connection is confirmed by the base station over the Access Grant Channel (AGCH).
- The RACH burst has longer guard period to protect for burst transmission from Mobile station that does not know the timing advance when it first accesses the system. The additional guard time allows a distance upto 35 km between base station to mobile station. Fig. 2.27.10 shows the Random access burst.

Tail bits	Synchronization sequence	Coded Data	Tail bits	Additional guard bits
8	41	36	3	68.25

156.25 bits (0.577 ms)

Fig. 2.27.10 : Random Access Burst

(iii) Access grant channel (AGCH)

- The AGCH is used by the base station to provide forward link communication to the mobile. It carries data that instructs the mobile to operate in a specific channel with a particular dedicated control channel.
- It is the message sent by the base station before a subscriber is moved off the control channel.
- The AGCH is used by the base station to respond to RACH sent by the mobile station in the earlier CCCH frame.

(C) Dedicated Control Channels (DCCHs)

- The Dedicated Control Channels (DCCHs) come into picture after a call is established. The dedicated control channels are bidirectional. They have same formats and functions in the forward and the reverse links.
- There are three different dedicated control channels. They are :

Types of Dedicated Control Channels

- (i) Stand-alone Dedicated Control Channel (SDCCH)
- (ii) Slow Associated Control Channel (SACCH)
- (iii) Fast Associated Control Channel (FACCH)

Fig. 2.27.11 : Types of Dedicated Control Channels

(i) Stand-alone Dedicated Control Channels (SDCCH)

- The Stand-alone Dedicated Control Channel (SDCCH) is allocated for every mobile station.

- It contains the signaling data that follows the connection of the mobile with the Base Station (BS), prior to the allocation of TCH by the Base Station (BS) to the MS.
- It guarantees that the Mobile Station (MS) and base station (BS) will remain connected. The Base Station and Mobile Switching Center will verify subscriber unit and assign the needed resources to the mobile.
- This channel that accepts the newly completed call from the BCH. It holds the traffic while waiting for the base station to assign a TCH channel.
- The SDCCH is also used to transmit authentication and alert messages as the mobile synchronizes itself with the frame structure and waits for TCH.
- SDCCHs can be assigned their own physical channel. Also they can occupy the TS0 slot of the BCH if there is low demand for BCH or CCCH traffic.

(ii) Slow Associated Control Channel (SACCH)

- It is related to traffic channel or SDCCH.
- On the forward link it is used to send regularly changing information like :
  - o Transmit power level.
  - o Specific timing advance instructions for each user.
  - o Broadcast messages.
- On the reverse link it carries information about
  - o Received signal strength.
  - o Quality of TCH and BCH
  - o Measurement results from neighbouring cells.
- It is used to inform the base of power measurements mode by the mobile of signal strength in the adjacent cells.
- It is transmitted during the 13th frame (and on the 26th frame when half rate traffic is used) of every dedicated control channel multi frame.
- SACCH exchanges control information between base station and mobile station during a call or call set up.

(iii) Fast Associated Control Channels (FACCHs)

- FACCH carries important messages. It is used for exchange of time critical information between the mobile and the base station during the progress of the call.
- The FACCH is assigned whenever SDCCH is not dedicated to a user and there is an urgent message like hand-off request.
- The FACCH transmits control information by stealing capacity from the associated traffic channel. It is done by setting two special bits called stealing bits. In the TCH forward channel burst.
- If a stealing bit is set, the time slot contains FACCH data for that frame.

2.28 GSM TIME HIERARCHY

GQ. Write short note on : GSM burst structure.

Each logical channel carries specific type and format of burst in the allotted time slot. Normal GSM burst is already explained in previous sections. (please refer section 2.25)

1. FCCH burst

- Refer Fig. 2.28.1, it contains 3 start bits and 3 stop bits. It has 142 zero bits between start and stop bits. This long stream of zeros in GMSK modulator gives output of unmodulated sinusoidal frequency which is shifted by 1625/24 kHz from carrier frequency. It helps in identification of the broadcast carrier. Thus MS carrier frequency is tuned.

T	Binary bits for frequency correction	T	G
3	142	3	8.25

Fig. 2.28.1 : FCCH burst

2. SCH burst

- It contains 3 start bits and 3 stop bits. It has 39 bits of encrypted data twice in the burst and in between those data bits 64 training bits are inserted. The data bits are used to identify the BS colour code (0-7) and colour code of PLMN (public land mobile network). This identifies the service provider of the user.
- Frame numbers are needed in the process of data encryption and decryption.
- Total number of frames is 26(frames) × 51(multiframes) × 2048 (superframes) = 2715648 TDMA frames. Now these frames are numbered from 0 to 2715647. Current frame number is transmitted in synchronization burst in a reduced form which is known as Reduced Frame Number (RFN).
- This training sequence is applied to determine the samples of the channel impulse response which are used in detection process.
- These training bits ensures more precise channel estimation and more reliable detection. Refer Fig. 2.28.2

T	Information	Training bits	Information	T	G
3	39	64	39	3	8.25

Fig. 2.28.2 : SCH burst

3. RACH burst

- System access request and acknowledgements are carried in this burst on reverse link.
- It is shortest burst of the system.

- It has 8 start bits followed by 41 bits of synchronization. These 41 bits are used to identify the channel properties and synchronization of BS receiver.
- After synchronization bits 36 bits of encrypted data are added. And then 3 stop bit are present in the burst.
- It consists of long guard period of 68.25 bits for timing advance information. Refer Fig. 2.28.3.

T	Synchronization seq	Encrypted bits	T	G
8	41	36	3	68.25

Fig. 2.28.3 : RACH burst

4. Dummy burst

- Its structure is same as that of normal burst. Only difference is that encrypted data bits does not carry useful information.
- Dummy bursts are placed in the time slots which are currently idle and not allotted to any user.
- Dummy bursts are useful in maintaining the high mean power of the broadcast channel by providing stuffing sequence. Refer Fig. 2.28.4.

T	Mixed bits	Training bits	Mixed bits	T	G
3	58	26	58	3	8.25

Fig. 2.28.4 : Dummy burst

5. The control channel multiframes are already explained in Section 2.27.2.

2.29 DESCRIPTION OF CALL SETUP PROCEDURE

GQ. With a proper flow diagram explain :
(i) Mobile station registration in GSM network
(ii) Mobile call set up and termination.

It can be divided in three different parts.

1. MS registration in the GSM network
2. Mobile originated call
3. Mobile terminated call

2.29.1 MS Registration in GSM Network

GQ. With proper diagram explain MS registration in GSM network.

Refer Fig. 2.29.1, it shows typical flow diagram of MS registration in the GSM network.

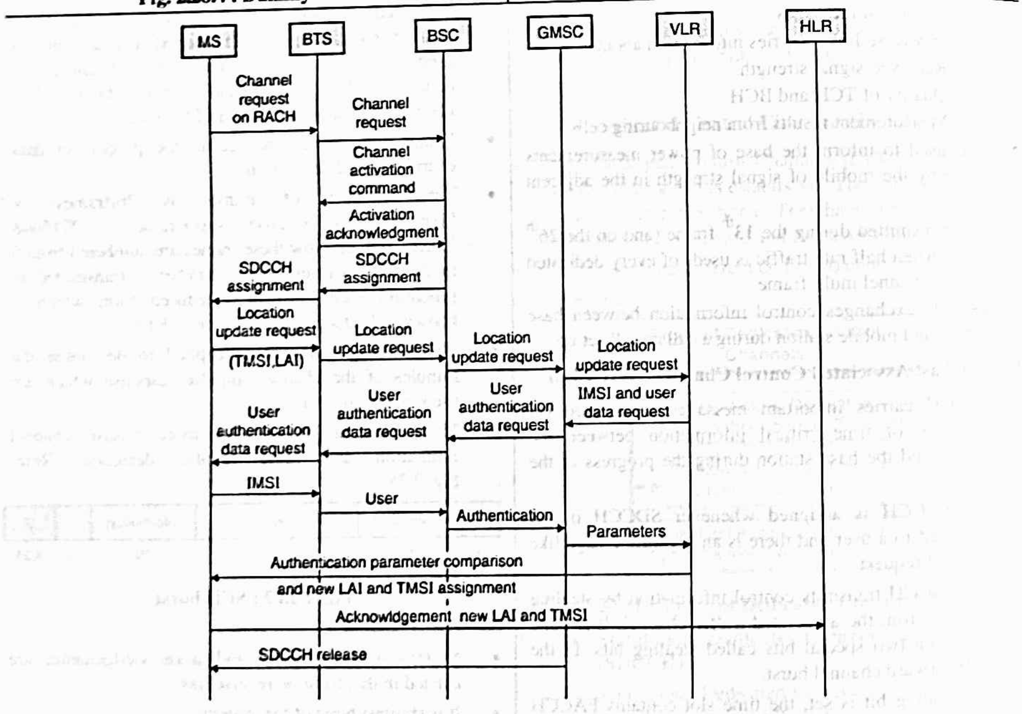


Fig. 2.29.1 : MS registration in GSM network

1. When the mobile is switched on it first looks for the carrier on which BSS is transmitting the broadcast channel. This is done by measuring the received power of all 124 carriers present in the GSM system. This is because carrier containing broadcast channel is transmitted at high power compared to others.
2. Next MS finds TS0 of broadcast channel so that it can identify FCCH burst. Then in TS0 of the next frame MS finds out Synchronization burst for identification of BSIC and RFN.
3. MS decodes information carried by BCCH. It contains neighbouring cell identification, cell global identity (CGI : a sequence consisting of country code, mobile code, location area code, cell identity etc.), the number of common control channels available in the cell, the maximum power that can be used during call set up process etc. this finishes passive activation of MS
4. If the Location Area Identity (LAI) sent by BS differs from the latest one which is stored in MS then registration takes place. Location updation is also necessary for monitoring MS's current location.

MS registration process

- Once the mobile is switched ON, it sends the channel request on RACH required for registration process to BSC through BS.
- BSC commands BS to allocate free SDCCH. BS acknowledges this command and informs MS about this SDCCH on ACGH.
- MS now uses SDCCH to send location updation request to BS. This request contains type of location update required, TMSI and LAI. This request is carried to VLR through BS-BSC-MSC-VLR.
- If the user's TMSI already exists in VLR, it updates his data about his activity. If the TMSI is not available with VLR then LAI sent by user is decoded, his IMSI and data required for authentication is identified with the help of last VLR served. But if previous VLR also does not have necessary parameters then MSC request MS to send IMSI on SDCCH. Once it is received VLR communicates with home HLR and MS is authenticated. Now this information is updated in VLR.
- After this new user parameters are set. They are TMSI, LAI. These parameters are updated in HLR and VLR. Acknowledgement from the MS is then received.
- SDCCH channel is then released and now MS is ready for call set up.

2.29.2 Mobile Originated Call

- Fig. 2.29.2 shows mobile originated call to PSTN. After registration once the MS is allocated with SDCCH, MS issues CM (Connection Management) request to MSC. This consists of the type of service MS wants to invoke.
- Once the CM request is received based on location update information, if needed MSC will invoke authentication process.
- Upon reception of authentication response from MS, MSC starts ciphering of voice and data for encryption and decryption purpose. For this MSC passes cipher key (Kc) to BSS. BSS then instructs MS to start ciphering.
- MS then generates cipher key (Kc) independently and it is not sent on air. Only information regarding completion of ciphering at MS is sent to MSC through BSS. Now MS sends call setup request to MSC. This request contains all information required for call set up like dialled number etc.
- Upon reception of all the required necessary information by MSC, it sends MS a call proceeding message.
- After that connection circuit between MSC and MS is freeze by sending the assignment request by MSC to BSS.

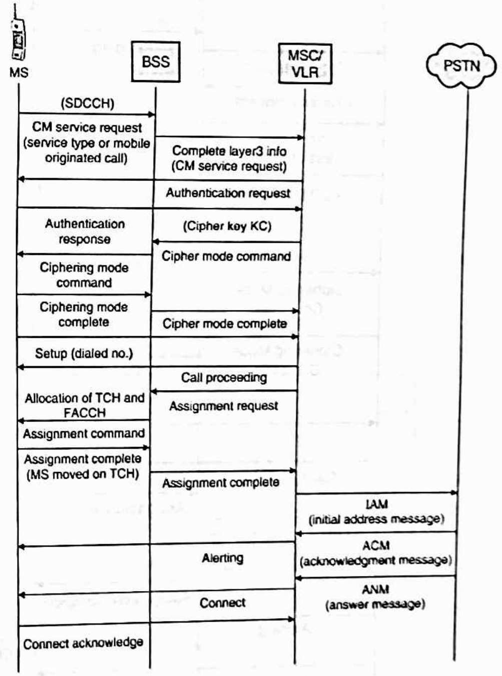


Fig. 2.29.2 : Mobile originated call

- BSS then send assignment command message to MS and instructs it move from SDCCH to TCH. FACCH will now carry all control signals hereafter.
- MS sends assignment complete message to MSC through BSS indicating that it has moved to TCH.

- Once MSC receives assignment complete message, it sends IAM (Initial Address Message) to PSTN network.
- PSTN then sends ACM (Acknowledgement Message) indicating that destination phone is ringing.
- This is informed to MS by alerting message.
- Once the called party picks up the phone ANM (Answer Message) is sent to MSC. MSC initiates connect message to MS and MS respond this by an acknowledgement. Now the call is set up.

2.29.3 Mobile Terminated Call

- Refer Fig. 2.29.3. it shows typical scenario of mobile terminated call.

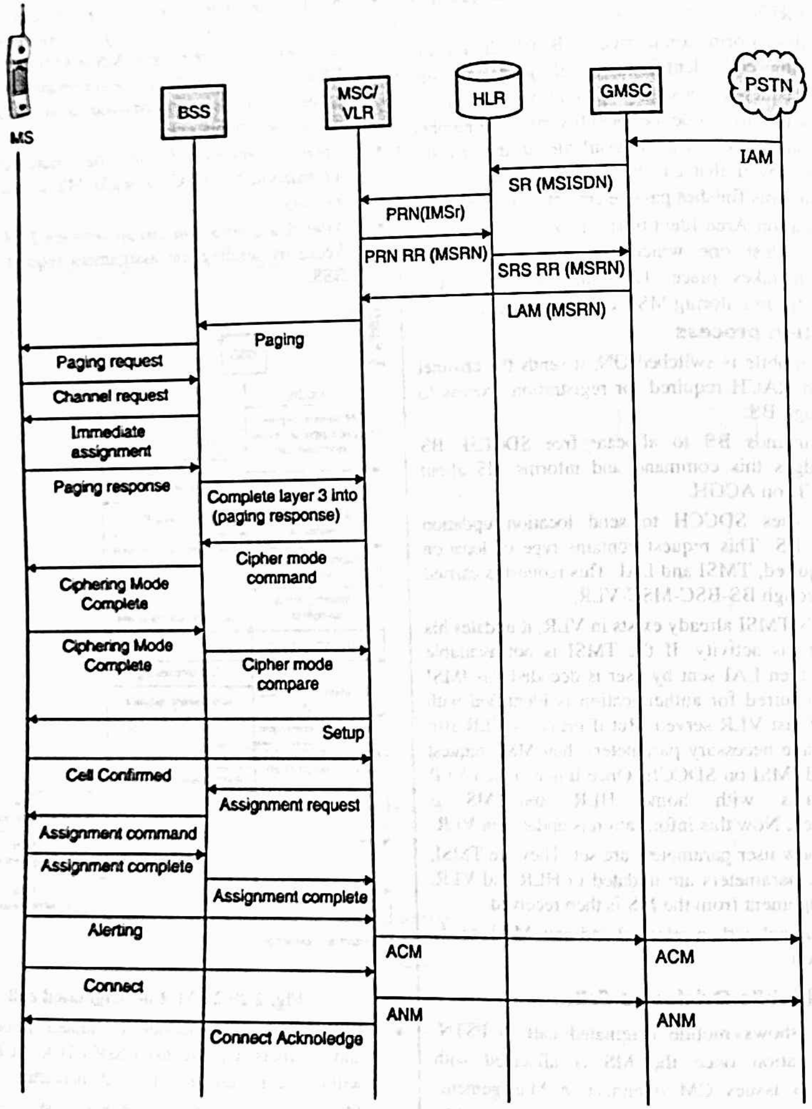


Fig. 2.29.3 : Mobile terminated call

- IAM (Initial Address Message) is received by GMSC. This IAM contains MSISDN (Mobile Station ISDN Number which means the Directory Number) of the called party.
- From this information GMSC identifies home HLR of the called party and invokes MAP (Mobile Application Part : used to invoke authentication information if not available) by sending SRI command (Send Routing Information). SRI consists of MSISDN of the called party.
- Once HLR receives MSISDN then it retrieves IMSI of that subscriber and forwards the PRN (Provide Roaming Number) request along with IMSI to the MSC.
- MSC then allocates MSRN (Mobile Station Roaming Number) form the available pool. MSRN is temporary number. MSC sends it to GMSC through HLR.
- Now GMSC forwards the IAM with the allocated MSRN to the MSC. MSRN is returned to the pool.
- MSC sends paging request to MS via BSS using PCH. This paging request contains location area to which subscriber belongs.
- After receiving the paging request MS requests for channel on RACH. In response to that immediate assignment of channel is done by BSS. And now MS moves to allocated SDCCH and then sends the paging response to MSC through BSS.
- MSC the commands for ciphering. MS receives this and generates Kc on its own and send cipher complete command to MSC through BSS.
- Then MSC generates set up message which contains calling party's number and bearer capabilities etc.
- Upon reception of set up message, MS generates call confirmed message which indicates that it has all the necessary information required for the call.
- As soon as MSC receives call confirmation message, it starts assignment process. It comprises of assignment request message from MSC to BSS and allocation of TCH by BSS to MS. Hence further signalling will be using TCH and FACCH.
- Once MS is moved on TCH it starts ringing, and sends the alerting message to the MSC. MSC then forwards acknowledgement message (ACM) to the PSTN via GMSC.
- Once the called party picks up the phone, connect message is given by MS to MSC and then MSC sends ANM (answer message) to PSTN to which PSTN responds by connect acknowledge message. Then call is established.

2.30 HANDOVER MECHANISM IN GSM

GQ. With a neat diagram explain :
(i) Intra cell handover
(ii) Inter cell handover

- The concept of Handover (Handoff) is explained in detail in Chapter 3 - Section 3.7.
- There are two basic reasons of the requirement of handovers.
  1. The MS moves out of range of BTS and hence received signal level decreases. The error rate may increase due to increased interference. This will degrade the quality of the radio link.
  2. If the traffic in one cell is too high then some MSs may be shifted to other cell if possible. This is known as load balancing.
- MS regularly performs check of 16 strongest carrier transmitting the BCCH. Out of this six strongest carriers are transmitted to currently assigned BS after every 0.48 seconds. BS also checks for the interference levels of the free time slots. OSS subsystem monitors the current traffic loads of the cell. These are the measurement values which are used in handover mechanisms in GSM.
- Typically it is expected that handover should finish in one second. If the handover error occurs the connection is overtaken by previous BS.
- This section refers to typical situations of handovers in GSM :

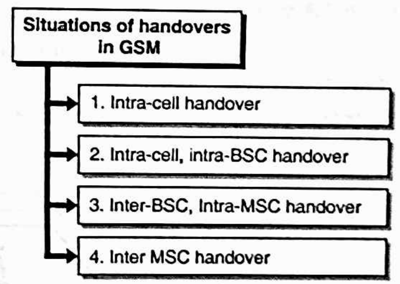


Fig. 2.30.1 : Situations of handovers in GSM

1. Intra-cell handover

This handover is performed to optimize the traffic load and to improve quality of the connection. Within a cell, transmission at certain carrier frequencies become impossible due to narrowband interference and hence carrier frequency is changed i.e. handover is performed for improvement. Refer Fig. 2.30.2.

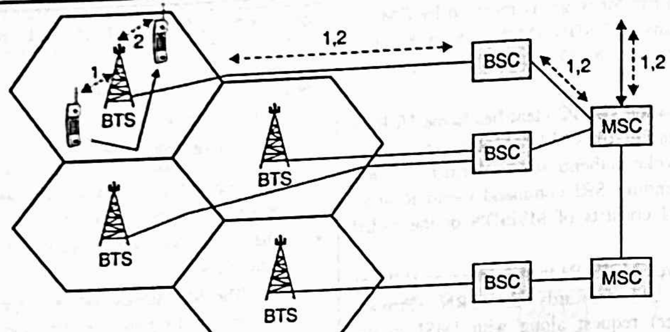


Fig. 2.30.2 : Intra-cell handover

▶ 2. **Inter-cell, Intra-BSC handover**

When the MS moves from one cell to another cell but both the cells are under control of same BSC then this type of handover is performed and MS is allocated with new carrier in new cell. Refer Fig. 2.30.3.

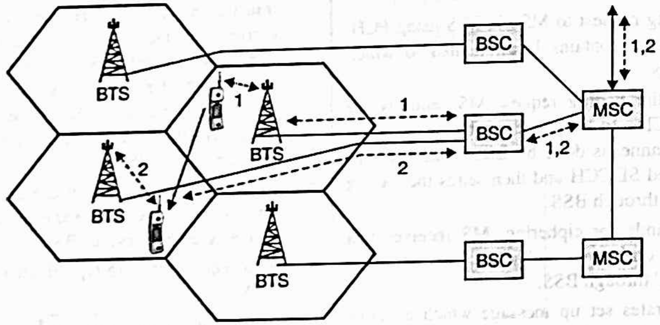


Fig. 2.30.3 : Inter-cell, Intra-BSC handover

▶ 3. **Inter-BSC, Intra-MSC handover**

This is performed when mobile moves from one cell to another which are under control of different BSCs but same MSC. Refer Fig. 2.30.4.

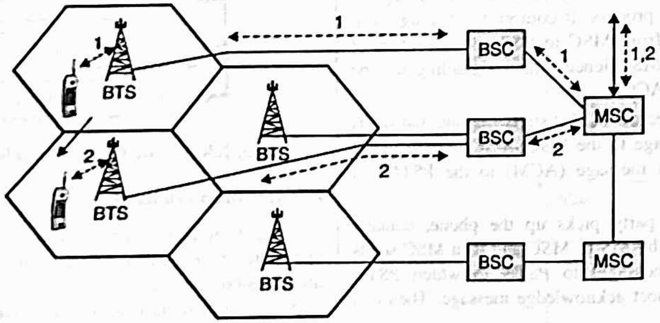


Fig. 2.30.4 : Inter-BSC, Intra-MSC

▶ 4. **Inter MSC handover**

This is performed when MS is moving from one MSC area to another. In this situation both the MSCs has to perform handover at same time. Refer Fig. 2.30.5.

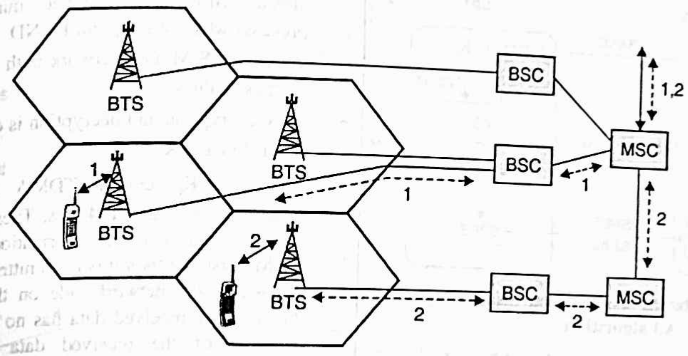


Fig. 2.30.5 : Inter MSC handover

2.31 SECURITY IN GSM

- In any of the digital cellular systems, security provision is relatively easy compared to analog systems. Methods like encryption, scrambling, FEC etc. can be employed to ensure security in the system.
- GSM offers several security services based on the information stored in AUC and SIM. The security services offered by GSM are :

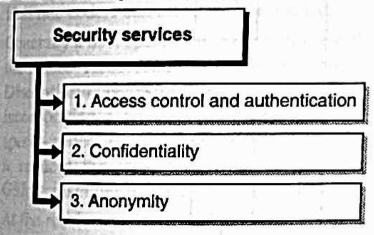


Fig. 2.31.1 : Security services

▶ 1. **Access control and authentication**

Access to the GSM network is allowed only through user authentication process. For this first user needs to have valid PIN to access the SIM and then using challenge response scheme authentication is done in mobile originated and mobile terminated calls.

▶ 2. **Confidentiality**

Once the authentication is done all the user data, voice etc. are encrypted to provide confidentiality. It exists only between MS and BTS.

▶ 3. **Anonymity**

- User's real identity is never transmitted on air. Every user is allocated with TMSI which is unique for each call. And VLR can change TMSI at any time.
- These three services are achieved by three algorithms in GSM network.
  1. A3 algorithm for authentication
  2. A5 algorithm for encryption
  3. A8 algorithm for generation of a cipher key

2.31.1 Authentication using A3 Algorithm

- Authentication is done with the help of SIM. SIM stores authentication key Ki and the user IMSI.
- Authentication is done by challenge response or request response method between MS and BTS.
- RAND random number is generated by AC (access control) which acts as a challenge and SIM responds to it by SRES (signed response).
- AUC generates RAND, SRES and cipher key Kc for each IMSI received and then forwards this to HLR. VLR may ask for these values from HLR.
- This RAND is sent to SIM by VLR for authentication purpose.
- On network side as well as on SIM side algorithm A3 is carried out on the RAND and Ki. Then MS sends SRES generated by SIM on air and VLR compares this received value with the one generated in the network.
- If both the values matches, subscriber is allowed to access the network otherwise he is denied the access. Refer Fig. 2.31.2.

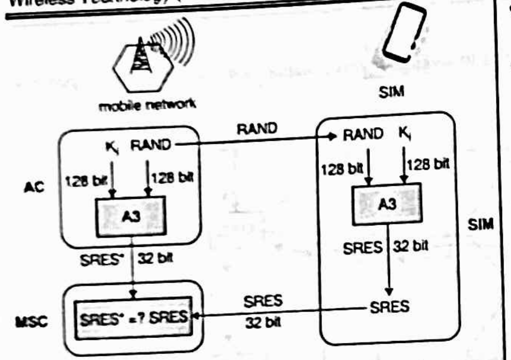


Fig. 2.31.2 : Subscriber's authentication using A3 algorithm

2.31.2 Data Encryption using A5 and A8 Algorithm

- All the user information is always encrypted before it is sent on air. For encryption A_5 algorithm is used which is an European standard. Only manufacturers of the cellular devices has access to this algorithm.
- Entire encryption is based on encryption key or cipher key K_c which is never sent on air to maintain secrecy.
- 64 bit Cipher key K_c is generated using the values already SIM has (received during authentication process) which are K_i and RAND. This is done by A8 algorithm. SIM and Network both calculates K_c based on these values.
- Now encryption and decryption is carried out using A_5 algorithm and K_c.
- Based on K_c, current TDMA frame number, A_5 algorithm generates 114 bits. These 114 bits are then modulo 2 added to the information bits in the normal GSM burst and then it is transmitted. Same operation is carried at the network side on the received Normal burst. If the received data has no errors the modulo 2 addition of the received data and the generated encrypted data gives out the original data sequence. This is decryption process.
- Refer Fig. 2.31.3.

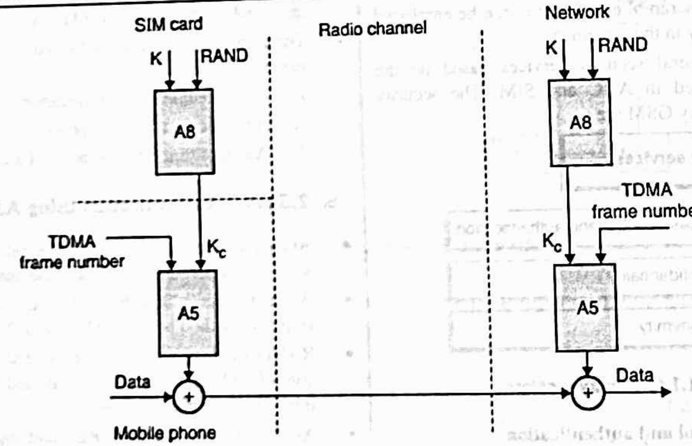


Fig. 2.31.3 : Data encryption using A5 and A8 algorithms

2.32 SIGNAL PROCESSING IN GSM

Following operations are done in GSM.

Refer Fig. 2.32.1.

1. Speech coding	2. Channel coding
3. Interleaving	4. Burst formatting
5. Ciphering	6. Modulation

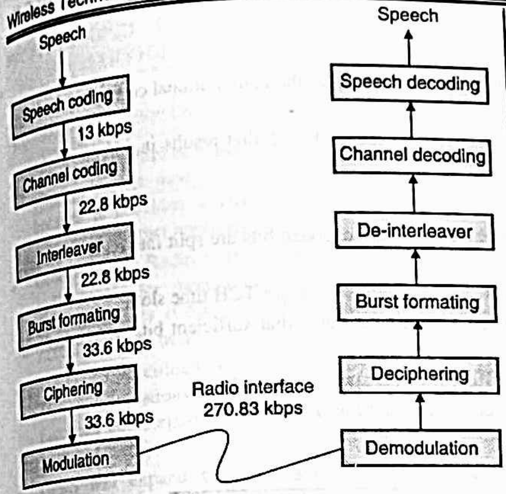


Fig. 2.32.1 : Signal processing in GSM

1. Speech Coding

- The GSM speech coder uses **Residually Excited Linear Predictive Coder (RELP)**. The operation of the coder can be enhanced with a Long Term Predictor (LTP).
- The RELP provides 260 bits for each 20 ms blocks of speech. This gives a bit rate of 13 Kbps.
- Half rate coders can also be incorporated.
- Generally a user speaks on average for less than 40% of the time. Hence, a GSM system can operate in **Discontinuous Transmission Mode (DTX)** by incorporating a voice activity detector (VAD) in the speech coder. This provides a longer battery life. Also it reduces the instantaneous radio interference. The GSM transmitter is inactive in silent period.
- At the receiver end a **Comfort Noise System (CNS)** is used to introduce background acoustic noise to compensate for the annoying switched muting that occurs because of DTX.

2. Channel Coding

- The speech coder output bits are grouped for error protection, according to their significance in the speech quality.
- The quality of speech produced by encoding the 260 bits in a frame are divided into three classes. They are :
  - Class Ia : 50 bits (Most sensitive to bit errors)
  - Class Ib : 132 bits (Moderately sensitive to bit errors)
  - Class II : 78 bits (Least sensitive to bit errors).
- In class Ia bits, there are 3 parity check (CRC) bit added to them for detecting the non correctable errors at the receiver.
- The class Ib 132 bits along with the first 53 (50 Ia bits + 3 parity bits) are reordered and appended by four trailing zero bits making a data block of 189 bits.
- The block is encoded for error protection using $\frac{1}{2}$ rate convolutional encoder with constraint length K = 5. It provides a sequence of 378 bits.
- The last 78 bits do not have any error protection. They are concatenated to the existing sequence to form a block of 456 bits in a 20 ms frame.
- The error protection coding method increases the data rate of GSM speech signal with channel coding to 22.8 Kbps.
- Fig. 2.32.2 shows the error protection for speech signals.

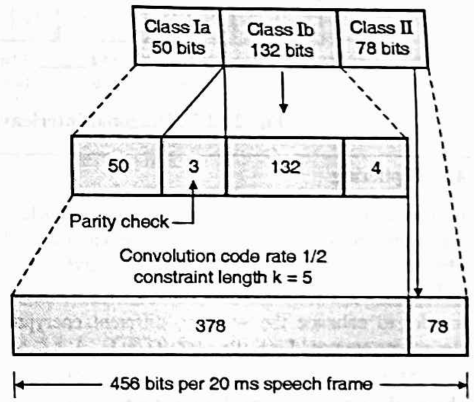


Fig. 2.32.2 : Error Protection for Speech Signals in GSM

A. Channel Coding for Data Channels

- For full rate data channels (TCH/F9.6) the coding is dependent on handling 60 bits of user data at intervals of 5 ms. 240 bits of user data are applied with four tail bits to a $\frac{1}{2}$ rate convolutional coder with constraint length K = 5.
- The resulting 488 coded bits are decreased to 456 through puncturing. The data is split into four 114 bit data bursts that can be applied in interleaved manner.

B. Channel Coding for Control Channels

- The control channel messages are of 184 bits. They are encoded with the help of a shortened binary cyclic fire code, followed by a half rate convolutional coder.

- The fire code uses generator polynomial

$$G_5(x) = (x^{23}+1)(x^{17}+x^3+1) = x^{40}+x^{26}+x^{17}+x^3+1$$

- This polynomial results in 184 message bits, followed by 40 parity bits. To clear the convolutional coder that results in 228 bit block, four tail bits are added.
- The block is applied to a half rate convolutional coder with constraint length K = 5 that results in 456 encoded bits. These bits are interleaved onto eight successive frames.

3. Interleaving

- To minimize the effect of sudden fades on the data that is received, the 456 encoded bits are split into eight 57 bit sub-blocks.
- The eight blocks comprise a single speech frame. They are spread over eight successive TCH time slots.
- If any burst is lost because of fading or interference, the channel coding ensures that sufficient bits will be received correctly to allow error correction to operate.
- A TCH time slot carries two 57 bit blocks of data from two different 20 ms speech segments.

Fig. 2.32.3 shows how speech frames are diagonally interleaved within the time slots.

Frame Number

i+0	i+1	i+2	i+3	i+4	i+5	i+6	i+7
0a 4b	1a 5b	2a 6b	3a 7b	4a 0b	5a 1b	6a 2b	7a 3b
114 bits	114 bits	114 bits	114 bits	114 bits	114 bits	114 bits	114 bits

Fig. 2.32.3 : Diagonal Interleaving for TCH / SACCH / FACCH data

4. Ciphering

- It changes the contents of eight interleaved blocks by using the encryption methods that are known to the Mobile Station (MS) and the Base Transceiver Station (BTS).
- Inorder to enhance the security, different encryption algorithms are used for different calls.
- In GSM there are two ciphering algorithms A3 and A5. These algorithms are used to prevent unauthorized network access and radio transmission privacy.
- The A3 algorithm provides authentication to each mobile by verifying the passcode with the SIM with a cryptographic key at the Mobile Service Centre (MSC).
- The A5 algorithm provides scrambling of 114 coded data bits that are sent in each time slot.

5. Burst Formatting

- Burst formatting adds binary digits to the ciphered blocks inorder to help the synchronization and equalization of the received signal.

6. Modulation

- The GSM uses 0.3 GMSK modulation. 0.3 describes the 3 dB bandwidth of the Gaussian pulse shaping filter in relation to the bit rate. (e.g. BT = 0.3).
- GMSK is a type of digital FM modulation. The binary ones and zeros are represented in GSM by shifting the RF carrier by ± 67.708 KHz.
- The GSM channel data rate is 270.833 Kbps. It is four times that of the RF carrier shift. This minimizes the bandwidth occupied by the modulation spectrum. Also, it improves the capacity of the channel.
- The MSK modulated signal is passed through the Gaussian filter inorder to smoothen the rapid frequency transitions that will spread the energy into the adjacent channels.

7. Equalization

- At the receiver end equalization is performed through training bits that are transmitted in the middle of each time slot.

8. Demodulation

- The part of the transmitted forward channel signal that is important to a user is determined by the assigned TS and ARFCN.
- The correct TS is demodulated with the help of synchronization data provided by burst formatting.
- After demodulation, the binary information is deciphered, deinterleaved, channel decoded and finally the speech signal is decoded.

2.33 GPRS (GENERAL PACKET RADIO SERVICE)

GQ. Write short notes on GPRS services.

- The **General Packet Radio Service (GPRS)** provides efficient packet mode of data transfer. It is popular because it provides a cost effective packet service supporting internet applications.
- General Packet Radio System (GPRS) provides **packet radio access** for mobile Global System for Mobile Communications (GSM) and Time-Division Multiple Access (TDMA) users.
- The GPRS specifications are written by the European Telecommunications Standard Institute (ETSI), the European counterpart of American National Standard Institute (ANSI).
- GPRS will expand in both vertical and horizontal markets where high speed data transmission over wireless networks is a need.
- GPRS networks support many of new applications ranging from mobile e-commerce to mobile corporate VPN access.
- GPRS network can offer data speeds of 14.4 kbps to 171.2 kbps.
- GPRS allows short "bursty" traffic like email, web-browsing etc. No dial-up modem connection is essential for GPRS.
- GPRS devices can be connected very fast and provide a feeling of being "always on" Hence, the GPRS devices are called "always connected".
- GPRS allows other services like,

  (a) Unicast
  (b) Multicast and
  (c) Broadcast

Features of GPRS

The features of GPRS are :

(i) It overlays on the existing GSM network to provide high-speed data service.
(ii) GPRS devices can be connected very fast and provide a feeling of being "always on" hence, the GPRS devices are called **"always connected"**.
(iii) Depending on the coding method, it is possible to have data rate upto 150 kbps with GPRS.
(iv) GPRS is independent of the characteristics of the radio channel.
(v) GPRS supports point-to-point packet transfer service and point-to- multipoint packet service.
(vi) GPRS supports demand based time slot allocation.
(vii) The GPRS system has the ability to offer data speeds of 14.4 kbps to 171.2 kbps that allow comfortable internet access.
(viii) GPRS is designed to support bursty applications like email, traffic telematics, telemetry, broadcast services and web browsing.
(ix) GPRS follows three types of data services.
They are :
  (a) **WAP (Wireless Application Protocol) :** It uses WML (Wireless Markup Language) and a WAP gateway. It is a data bearer service over HTTP protocol.
  (b) **SMS (Short Message Service) :** GPRS supports SMS as a bearer.
  (c) **MMS (Multimedia Messaging Service) :** It is the next generation messaging service. Video, audio pictures or clip can be sent through MMS.
(x) GPRS based networks have high bandwidth.
(xi) The security services provided by GPRS are :
  (a) Authentication
  (b) access control
  (c) user information confidentiality
  (d) user identity security

Syllabus Topic : GPRS – System Architecture

2.33.1 GPRS System Architecture

GQ. Draw and explain GPRS architecture.

- GPRS provides many services without restricting data rates of transmission. The service precedence namely high, low, normal, reliability, class, throughput and delay are determined by QoS profile.
- For voice calls the GPRS systems uses the GSM architecture. However, for packet data transmission GPRS includes a new set of network nodes called as GPRS Support Nodes (GSN).
- The main **function** of the GSN is to route and deliver the data packets between the Packet Data Network (PDN) and the mobile stations. GPRS supports two support nodes. They are :
  (i) SGSN (Serving GSN)
  (ii) GCSN (Gateway GSN)
- Fig. 2.33.1 shows the GPRS system architecture.

Module 2

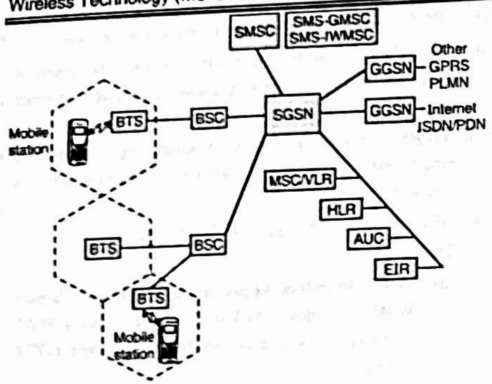


Fig. 2.33.1 : GPRS architecture

AUC : Authentication Center
BTS : Base Transceiver Station
HLR : Home Location Register
GGSN : Gateway GPRS support Node
MSC : Mobile Switching Center
PLMN : Public Land Mobile Network
SMS : GMSC : SMS Gateway MSC
SGSN : Serving GPRS Support node
BSC : Base Station Controller
EIR : Equipment Identity Register
VLR : Visitor Location Register
ISDN : Integrated System Digital Network
PDN : Packet Data Network
SMSC : Short Message Service Center
SMS - IWMSC : SMS interworking MSC

In addition to the new GPRS components (SGSN and GGSN), some of the existing GSM elements must be enhanced to support packet data.

They are :

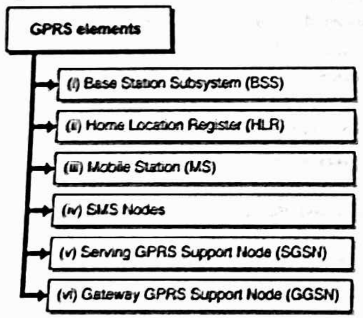


Fig. 2.33.2 : GPRS Elements

(i) Base Station Subsystem (BSS)

In order recognize and send packet data, the base station subsystem requires new functionalities that upgrade the BTS such that it supports transmitting the user data to the SGSN and between BTS and MS over radio network.

(ii) Home Location Register (HLR)

For registering the GPRS user profiles and providing response to the GPRS queries originating from GSNs in regards to the user profiles the HLR also needs to be upgraded or enhanced.

(iii) Mobile Station (MS)

The mobile station or the mobile phone for GPRS is different from that of GSM.

(iv) SMS Nodes

SGSN support SMS transmission. The SMS-GMSCs and SMS-IWMSCs are enhanced. For efficient co-ordination of GPRS and non-GPRS services the MSC/VLR also needs to be upgraded.

(v) Serving GPRS Support Node (SGSN)

- It functions similar to the GSM-MSC. The functions that GSM-MSC supports for voice are supported by the SGSN for packet data.
- They comprise functions like :
  (a) Packet switching,
  (b) Data transfer
  (c) Routing
  (d) Mobility management
  (e) Logical link management
  (f) Authentication and security
  (g) Billing /charging functions.
  (h) Registration of new mobile subscribers and track of their location for a given service area.
- The SGSN location register is responsible for storing the location information and user profiles of all GPRS users that are registered with SGSN.
- For acquiring the profile data of the subscribers it sends queries to the Home Location Register (HLR)
- SGSN is connected to the base station with frame Relay.

(vi) Gateway GPRS Support Node (GGSN)

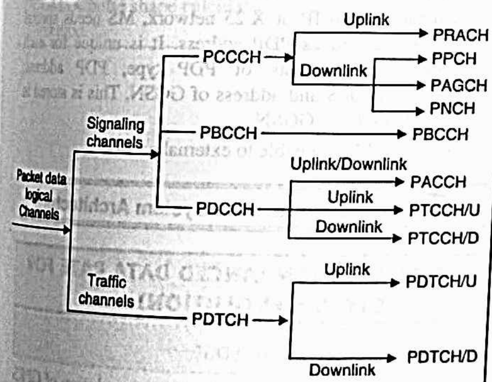
- A gateway GPRS support node (GGSN) acts as an interface between the external packet data networks and the GPRS backbone network.

- The functions of the GGSN are identical to that of router in a LAN. Functions of GGSN are :
  (a) To maintain the information related to routing for tunnelling the Protocol Data Units (PDUs) to the SGSNs service specific mobile stations.
  (b) To convert the GPRS packets into correct packet data protocol (PDP) format for data networks like IP or X.25.
  (c) Perform authentication
  (d) Perform billing / charging
- PDP sends these packets to the **PDN (Packet Data Network)**. The packets received from PDN are converted to the GSM addresses of the destination user.
- The readdressed packets are sent to the SGSN in-charge of it.
- The GGSN needs to store the address of current SGSN and also the user address along with his/her location in the location register.

2.33.2 GPRS Logical Channels

GQ. State and explain different logical channels used in GPRS.

- GPRS supports multi slot operation in which 8 time slots can be used by single MS. As the packet traffic is usually asymmetric, different resource allocation is necessary for uplink and downlink.
- The channel allocation is limited only for duration of the packet transmission or reception. Hence capacity on demand is implemented in GPRS channel allocation. The channels are shared among the GSM and GPRS networks.
- Refer Fig. 2.33.3. It shows logical channel structure of GPRS.



PDCH: packet data channel
PDTCH: packet data traffic channel
PCCCH: packet common control channel
PBCCH: packet broadcast control channel
PDCCH: packet dedicated control channel
PRACH: packet random access channel
PPCH: packet paging channel
PAGCH: packet access grant channel
PNCH: packet notification channel
PACCH: packet associated control channel
PTCCH/U: packet timing advance control channel for uplink
PTCCH/D : packet timing advance control channel for downlink

Fig. 2.33.3 : Logical channel structure of GPRS

1. **PDTCH/u and PDTCH/D :** It carriers user traffic to and from Ms to BSS i.e. on uplink as well as downlink. One or more PDTCHs can be assigned to GPRS terminal.
2. **PBCCH :** It is unidirectional and carries signal from BSS to MS. It is used to inform all the MS about the organization of GSM and GPRS network. It is used when MS wants to register on the network. If it is not available the MS will use conventional BCCH or CCCH of GSM network.
3. **PCCCH :** It is common control channel which is divided into
   - PRACH : It carries messages regarding request for traffic channels by MS. It is unidirectional and uplink channel.
   - PAGCH : It is downlink channel. It carries confirmation about traffic channel allocation messages from BSS to MS.
   - PPCH : It is downlink channel. It is used by BS to send paging messages to concerned MS and find the cell site in which the MS is currently located.
   - PNCH : It is downlink channel. It carries information about messages in multicast or group calls.
4. **PACCH :** It carries signalling in both the directions. It is used to send control information associated with the traffic channels used by MS.
5. **PTCCH/U and PTCCH/D :** It is used for adjusting the timing advance of the frame clock. It helps in maintenance of the synchronism.

2.33.3 GPRS Frame Structure and Channel Coding

Fig. 2.33.4 shows the GPRS multiframe structure.

1 multiframe = 52 frames = 12 blocks (B0-B11)

In GPRS frame 1 block (1 unit) = 4 subsequent GSM bursts = 4 frames

Two frames are idle and other two frames are used for frame timing advance.

1 GSM burst = 114 bits, therefore 1 block = 4GSM burstsx114 bits = 456 bits.

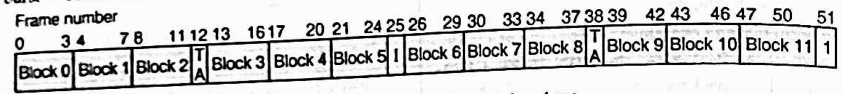


Fig. 2.33.4 : GPRS multiframe structure

Channel coding

- Channel coding is used to protect the transmitted data packets against errors. The channel coding method in GPRS is same as that in standard GSM systems.
- Reliable coding method is used in conditions when channel is bad for data recovery from burst errors.
- In the reliable coding method a data rate of 9.05 kbps can be obtained per time slot.
- When the channels conditions are favourable and no encoding method is used we can obtain a higher data rate of 21.4 kbps per time slot. If there are eight time slots, a maximum data rate of 171.2 kbps can be obtained.
- Generally two level channel coding is used.
- For outer code block code schemes are used. Tail bits are added at the end of the code word. Then this code word is coded using convolutional codes and some bits are punctured to maintain the code length of 456 bits.
- The coding scheme is decided based on channel conditions and service requirements.
- Table 2.33.1 shows different coding schemes used and its basic parameters.

Table 2.33.1 : Different coding schemes used in GPRS and its basic parameters

Coding scheme	USF precoding	RLC block	CRC bits	Tail bits	Conv. Code output	Punc. bits	Code rate	Data rate
CS-1	3	181	40	4	456	0	1/2	9.05
CS-2	6	268	16	4	588	132	2/3	13.4
CS-3	6	312	16	4	676	220	3/4	15.6
CS-4	12	428	16	0	456	0	1	21.4

- As the Table 2.33.1 shows, CS-1 is the strong coding scheme, therefore it will be used for poor channel conditions and CS-4 is the weak coding scheme so it will be used for good channel conditions.

Convolutional coding is not used in this case.

- Coding schemes decide the quality of service in the system. Quality of service in GPRS depends on the reliability, delay, priority of service and throughput.

2.33.4 GPRS Transmission Management

GPRS attach

- The process in which the MS registers with SGSN is called as GPRS attach. Before this MS is in idle state. Once it is done MS switches to ready state.
- The network authenticates the user with the help of HLR and sends it to SGSN where he will be allocated PTMSI (packet TMSI). Combined registration of GSM and GPRS is also supported by few MS classes.
- SGSN keeps track on the location of the MS and it is ready to send or receive packets. But if it does not participate in data exchange then it goes into standby mode. The location of the MS in standby mode is tracked by cell group RA (routing area). For this paging is required.
- PDP address (Packet Data Protocol) : For data exchange with IP or X.25 network, MS needs special address called as PDP address. It is unique for each session. It consists of PDP type, PDP address, requested QoS and address of GGSN. This is stored in MS, SGSN and GGSN.

Now the MS is visible to external network.

Syllabus Topic : EDGE – System Architecture

2.34 EDGE (ENHANCED DATA RATE FOR GLOBAL EVOLUTION)

GQ. Write a short note on EDGE.

- Previously it was assumed to be an evolution of GPRS and HSCSD so it was named as EGPRS or ECSD. It is also known as enhanced data rate for GSM evolution.

- It allows improved data transmission rate and reliability.
- It is considered as pre 3G technology.
- In USA EDGE is actually the extension of TDMA personal mobile communication system IS 136 and named as IS 136HS (high speed).
- EDGE for TDMA has two operational modes
  1. EDGE compact 2. EDGE classic
- We will be considering the European standard EDGE.
- With some improvements in the existing GSM network, it can be used for obtaining high data rates.

2.34.1 Features of EDGE

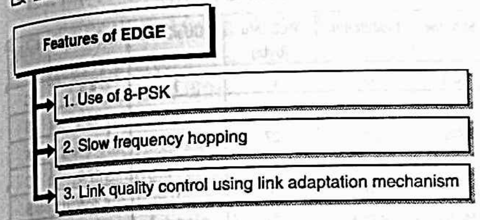


Fig. 2.34.1 : Features of EDGE

1. Use of 8-PSK

- For high data rate modes instead of GMSK, 8-PSK is used. At lower data rate GMSK is used.
- In 8-PSK, 3 bits are transmitted per data symbol hence high data rate is achieved with the same 200kHz channel spacing. Hence data rate also increases by factor of 3.
- In 8-PSK, to maintain the shape of the GMSK spectrum and to fit into the same 200kHz channel spacing, the baseband pulse is applied. It is the linear version of the GMSK pulse shape calculated according to the Laurent method.
- In 8-PSK the number of states of the Viterbi algorithm applied at the receiver are more as compared to GMSK modulation. Hence to avoid this, it uses selected suboptimum algorithm.

2. Slow frequency hopping

- It is also present in GSM but it is an optional feature.
- In this technique, different carriers are used for each encoded block. These carriers are allocated according to the hopping pattern generated. It provides security to the data alongwith the increase in system capacity.
- Frequency hopping is actually the form of the frequency diversity and it helps in reducing the channel fading. It also deals with the cochannel interference upto some extent.

3. Link quality control using link adaptation mechanism

- Based on the data received by MS, BS determines the modulation and channel coding to be used in EDGE as it has two modulation schemes namely GMSK and 8-PSK.
- Also it employs nine channel coding methods.

2.34.2 EDGE Data Burst Structures

- Refer Fig. 2.34.2.
- The data burst applied in EDGE is very much similar to the GSM data burst.
- When 8-PSK is used, 8 level data symbols are used instead of binary symbols. The burst consists of
  1. 3 Tail bits on both the sides of the burst
  2. 58 data symbols of user data on both the sides
  3. 26 training bits same as in GSM burst
  4. 8.25 guard bits

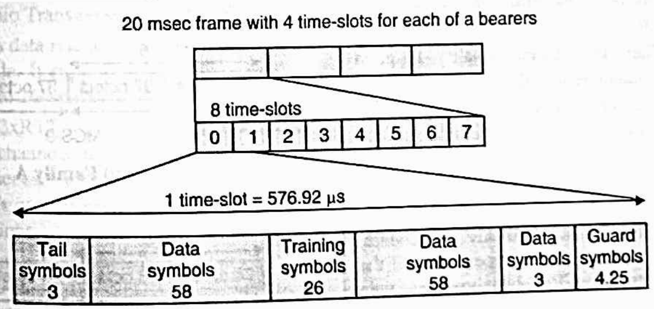


Fig. 2.34.2 : Data burst structure in EDGE

Module 2

- In EDGE total information bits are 348 if 8-PSK is used and 116 information bits are present if GMSK is used.
- Multiframe structure is similar to that of GPRS.

  One multiframe = 52 frames

  Number of data blocks = 12
- Every 13[th] frame carries timing advance information.
- Hence the maximum data rate is 59.2kbps if 8-PSK is used and it is 185.6kbps if GMSK is used.
- Radio blocks in EDGE: it is the smallest data unit transmitted in EDGE system. It contains one or two PDU (Packet Data Units). Radio blocks are sent after interleaving of four frames. Each radio block is transmitted over different carriers as frequency hopping is used.
- Each encoded radio block =1392 bits when 8-PSK is used and 464 bits when GMSK is used.
- The user channel coding rates are in between 0.38 to 1.

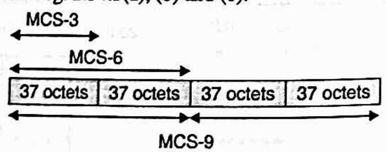
2.34.3 Modulation and Coding Scheme in EDGE

- Refer Table 2.34.1, it shows the modulation and coding scheme in EDGE or EGPRS.
- Bit error rate is significantly depends upon the channel conditions hence link quality control can be thought of function of modulation and coding schemes. It depends upon the adaptive selection of the modulation and coding schemes.
- Link Adaptation (LA) which is part of LQC (Link Quality Control) allows changes in modulation and coding scheme whenever channel quality changes. Link adaptation scheme regularly determines the link quality and selects the modulation and coding scheme accordingly to enhance the user bit rate.
- For obtaining maximum throughput and robustness of the channel, there are two possibilities of the quality of the channel. They are :
  1. **Case I :** When the channel quality is good i.e. high SNR : data rate is high.
  2. **Case II :** When the channel quality is not good i.e. low SNR : data rate is less temporarily so more robust coding scheme is chosen.
- In case of non-transparent data transmission ARQ protocols are applied. It allows addition of CRC bits to the original data block. In standard ARQ procedure, CRC bits are again calculated at the receiver and if the transmitted and received CRC bits matches then positive ACK (acknowledgement) is sent otherwise whole data block is discarded and retransmission of the same data block is invoked. But in EDGE incremental redundancy is used instead of standard ARQ processes.
- Incremental redundancy : It is another way to achieve to cope up with link quality variations. In this scheme, information is first sent with very little coding, yielding a high bit rate if decoding is immediately successful.
- If decoding fails, additional coded bits (redundancy) are sent until decoding succeeds i.e. it reuses the erroneous block of data in repeated error detection. The more coding that has to be sent, the lower the resulting bit rate and the higher the delay. For initial conditions the incremental redundancy is based on link quality parameters.
- EGPRS supports a combined link adaptation and incremental redundancy scheme. In this scheme

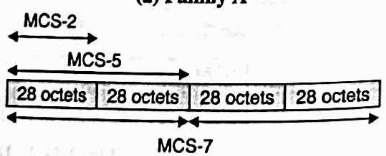
Table 2.34.1 : Modulation and coding schemes used in EDGE

Scheme	Modulation	RLC info (byte)	PDUs/20ms	Data rate (kbps)	Family
MCS 1	GMSK	22	1	8.8	C
MCS 2	GMSK	28	1	11.2	B
MCS 3	GMSK	37	1	14.8 (13.6)	A
MCS 4	GMSK	44	1	17.6	C
MCS 5	8-PSK	56	1	22.4	B
MCS 6	8-PSK	74	1	29.6 (27.2)	A
MCS 7	8-PSK	2x56	2	44.8	B
MCS 8	8-PSK	2x68	2	54.4	A
MCS 9	8-PSK	2x74	2	59.2	A

- MCS 1 to MCS 4 uses GMSK and almost equal coding schemes as that of GPRS providing data rate of maximum 17.6kbps. MCS 5 to MCS 9 use 8-PSK and gives data rate of almost 59.2 kbps per time slot.
- MCS are divided into three different families depending on difference in payload sizes namely A, B and C.
- Example of basic block sizes in MCS families A, B and C
- Refer Fig. 2.34.3(a), (b) and (c).

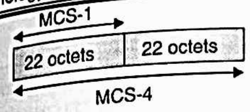


(a) Family A



(b) Family B

Fig. 2.34.3



(c) Family C

Fig. 2.34.3

- It contains 4 basic units of 37 octets each, whereas MCS 6 has 2 basic units and MCS 3 has only single basic unit. Similarly radio blocks of other families are shown. As different number of PDUs are transmitted in 20ms of radio block duration, different data rates are achieved.
- For retransmissions same MCS or different MCS of the same family is permitted.

Coding and puncturing for MCS

- In the coding process at the output of convolutional encoder two or three different schemes namely P1, P2 or P3 for puncturing of data bits is applied. First encoded block undergoes P1 puncturing.
- If there are errors in it, the bits obtained by P2 puncturing are transmitted and previously received data block is decoded again. As it has more number of parity bits, high quality of error correction is achieved.

Syllabus Topic : CDMA 2000 - Network Architecture

2.35 CDMA 2000

- CDMA 2000 is a upgradation for 2G and 2.5G CDMA standards. It is supposed to be an advancement of IS 95 A and IS 95 B. therefore it shows backward compatibility with cdmaone (IS 95 A) and IS 95B.
- The first 3G CDMA air interface CDMA 2000 1×RTT indicates that a single 1.25 MHz radio channel is used. RTT stands for Radio Transmission Technology.
- CDMA 1x supports data rate upto 307 kbps for a single user in packet mode. It supports twice the number of users as compared to 2G standards.
- The CDMA 2000 3xRTT standard uses three adjacent 1.25 MHz radio channels that are used together to provide instantaneous packet data. The actual throughput depends on cell loading, vehicle speed and propagation conditions.
- Three non-adjacent radio channels can be operated simultaneously and in parallel as individual 1.25 MHz channels, or adjacent channels can be combined into a single 3.75 MHz super channel. With peak user data rates in excess of 2 Mbps, the CDMA 2000 3x has a similar user data rate throughput.
- CDMA 2000 allows the same spectrum, bandwidth, RF equipment and air interface framework to be used at each station. Upgrades are introduced over the time as compared to CdmaOne system.

2.35.1 CDMA 2000 Features

1. Supports high speed data services (upto 2Mbps).
2. It is a global standard.
3. It has flexibility for evolution.
4. It has improved spectrum efficiency.
5. It supports a data rates of 384 kbps for pedestrian use, 144 kbps for vehicular use and 2 Mbps for fixed environment.
6. It is packetized network.
7. It has backward compatibility for IS 95 A and B. Only software upgradation is necessary.
8. Duplexing method used : TDD and FDD.
9. Uplink is implemented by simultaneous combination of multi carrier or direct spreading techniques whereas downlink is implemented using either multi carrier or direct spreading.
10. Carries both voice and data services on the same carrier.

2.35.2 Advanced Versions of CDMA 2000

- The advancement in the CDMA2000 was due to the high speed requirement.
- Previously CDMA 1x was used. It supports data rate upto 307 kbps for a single user in packet mode. It supports twice the number of users as compared to 2G standards.
- Later on the advancement of CDMA 2000 3xRTT is invented.
- CDMA 2000 3xRTT standard uses three adjacent 1.25 MHz radio channels that are used together to provide instantaneous packet data. The actual throughput depends on cell loading, vehicle speed and propagation conditions.
- There are actually two phases of 1xEV (EV stands for evolution). The phases are 1x evolution data only, 1xEV-DO and 1x evolution data and voice, 1xEV-DV.
- Overall the advanced versions of cdma2000 are :

  1. CDMA 2000 1xRTT
  2. CDMA 2000 1xEV
  3. CDMA 20003xRTT

Mod 2

1. CDMA 2000 1xRTT

- It is the core CDMA 2000 wireless interface standard. 1xRTT stands for one times radio transmission technology.
- 1xRTT actually uses 1X1.25MHz FDD carrier. It indicates the same carrier as that of IS 95.
- 1xRTT has almost twice the capacity as that of IS 95.

CDMA 2000 1xRTT features

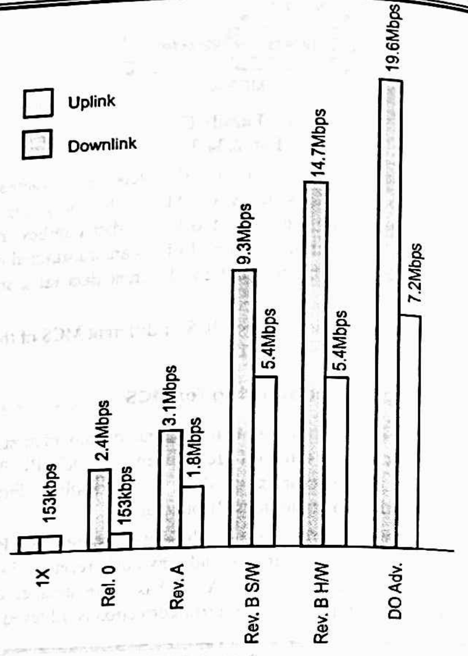
- Duplexing method used : FDD
- Additional 64 voice channels are provided to already existing IS 95 system. This supports increased capacity. These additional 64 channels are orthogonal to existing channels.
- Data rate : 153 kbps
- Frame length : 20ms

2. 1xEV-DO features

- Peak data rate on downlink is 3.1 Mbps and uplink data rate is 1.8 Mbps.
- Separate carrier is needed for carrying data only traffic at each cell location where high speed data services are needed.
- Seamless handover between 1x and 1xEV DO carrier.
- Designed for broadband internet access.
- Multiple access scheme used : CDMA and TDMA.
- Low latency that is low overall propagation delays in the system.
- Lower end to end call connection delay.

There are various releases of EVDO as explained below :

- Refer Fig. 2.35.1. It shows various releases of EVDO and its data rate upgradation.
  - o **EV-DO Release 0 (Rel. 0) :** This was the first release of the EV-DO standard.
  - o **EV-DO Revision A (Rev. A) :** This revision of the standard was advancement in data rates.
  - o **EV-DO Revision B (Rev. B) :** The EV-DO Rev. B version of the standard introduced multicarrier operation support. Software update was necessary for this. It made use of higher order modulation with a bit enhancement in new hardware.
  - o **EV-DO Advanced :** Number of smart features are introduced just by software.
  - o **EV-DO Revision C (Rev. C) :** This is the Ultra-Mobile Broadband (UWB) standard. This is not actually considered as the evolution from EV-DO is now to LTE for 4G services.



Data rates for CDMA 2000 1xEV.DO

Fig. 2.35.1 : Aadvanced versions of cdma2000

- Features of various releases are summarized in Table 2.35.1.

Note

Table 2.35.1 : Advanced versions of cdma2000 and its features

Sr. No.	Cdma2000 1xEVDO release version	Maximum uplink data rate	Maximum downlink data rate	Features
1.	Release 0	153.4kbps (70-90kbps)	2.4 Mbps (300-600 kbps)	1. First release of EVDO 2. Carrier frequency : 1.25 MHz 3. duplexing : FDD
2.	Release A	1.8 Mbps (500-800 kbps)	3.1 Mbps (600-1400kbps)	1. Backwards compatible with EV-DO Rel. 0. 2. Carrier frequency : 1.25 MHz 3. Duplexing : FDD channels.
3.	Release B	5.4 Mbps	9.3 Mbps	1. Spectrum used : 5 MHz 2. Duplexing : FDD channel 3. The software upgrade provides the multi-carrier facility.
4.	DO Rev. B hardware	5.4 Mbps	14.7 Mbps	1. The data rates given are achieved after software and hardware upgrade. 2. The hardware upgrade allows higher order modulation (up to 64QAM) to be used.
5.	DO Advanced	7.2 Mbps	19.6 Mbps	1. Speed is 4 times more than that of 1x EVDO that is 4 × 1.25MHz FDD channels.

2.35.3 Advantages of CDMA 2000 over GSM

1. Higher data rate as compared to second generation GSM and 2.5G mobile networks.
2. Bandwidth, security and reliability is more as compared to GSM.
3. Supports interoperability among service providers.
4. Supports video conferencing services. This feature is not supported by GSM.
5. Provides backward compatibility to GSM and CDMA networks.
6. Overcrowding of channels is reduced by change in the radio spectrum. The operating radio spectrum is of 5MHz.
7. It supports better voice quality.
8. It has a flexible architecture so evolution to next generation is easier.

2.35.4 Comparison between CDMA2000 and GSM

Table 2.35.2 : Comparison between CDMA2000 and GSM

Sr. No.	Parameter	GSM	CDMA2000
1.	Wireless standard generation	2G	3G
2.	Channel bandwidth	200kHz	1.25MHz
3.	Modulation used	0.3GMSK	QPSK/BPSK
4.	Support for broadband internet	No	Supported
5.	Support for video calling	No	Supported
6.	Multiple access technology used	TDMA	CDMA
7.	Flexibility in design	Less	More
8.	Voice quality	Poor as compared to CDMA 2000	Better than GSM
9.	Switching method used	Circuit switching	Packet switching
10.	Security in the system	Poor as compared to CDMA 2000	Better than GSM

2.35.5 Comparison of CDMA 2000 and WCDMA/UMTS

Table 2.35.3 : Comparison between UMTS and CDMA2000

Sr. No.	Parameter	WCDMA/UMTS	CDMA2000
1.	carrier frequency used	5MHz	1.25MHz in case of 1xRTT
2.	Chip rate	3.84Mcps	1.2288Mcps
3.	Duplexing used	FDD	FDD
4.	Frame length used	10ms	20ms
5.	Modulation used	QPSK/BPSK	QPSK/BPSK
6.	Channel coding	Convolutional code, turbo codes	Convolutional code, turbo codes
7.	Power control	Open loop + fast closed loop	Open loop + fast closed loop
8.	Backward compatibility standard	GSM	IS-95 A and IS-95 B

2.35.6 CDMA 2000 Architecture

- Refer Fig. 2.35.2. It shows CDMA 2000 architecture. Following are the new network components in CDMA 2000 architecture.

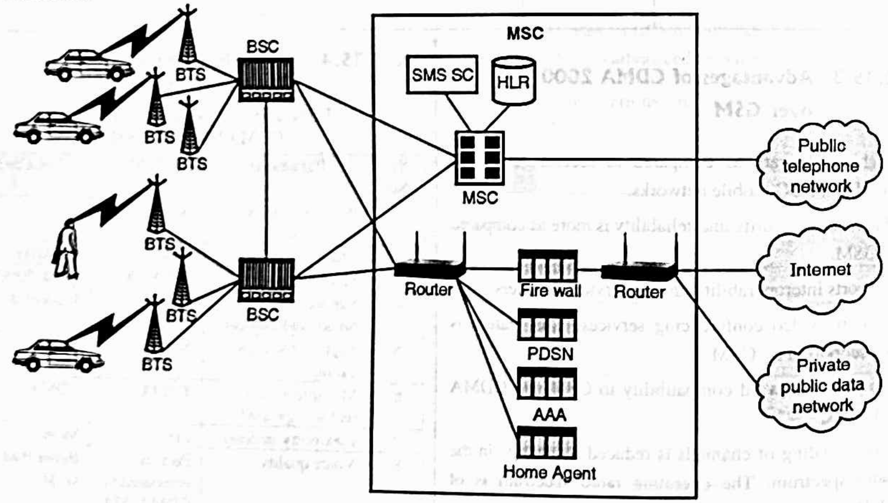


Fig. 2.35.2: CDMA 2000 Architecture

I. PDSN (packet data serving node)

- It is the heart of the system.
- It performs following functions :
  a. Establishes, maintains and terminates point to point (PPP) protocol sessions with the subscriber.
  b. Supports both Simple and Mobile IP packet services.
  c. Initiates Authentication, authorization and accounting (AAA) for the mobile station client to the AAA Server.
  d. Receives service parameters for the mobile client from AAA server.
  e. Routes packets to and from the external packet data network.
  f. Collects usage data that are relayed to AAA server.
- The overall capacity of the PDSN is determined by throughput and number of PPP sessions that are being served.

II. AAA (Authentication, authorization and accounting)

- This is another new component associated with CDMA 2000 as compared with cdma one
- It makes use of RADIUS (remote access dial in user service) protocol.
- It performs the following functions
  a. Authentication associated with PPP and Mobile IP connections
  b. Authorization
  c. Accounting

III. Home agent

- Location tracking of the user is one of the major function performed by HA in CDMA 2000. Since the Mobile IP subscriber moves from one packet zone to another, location tracking is very important. In this process HA ensures that the packet is sent to itself.

IV. Router

- Its function is to route the packet within various network elements.
- Firewall is the software needed to ensure the security of the packets. It is necessary to install firewall in the network for better quality of service

V. HLR (Home Location Register)

- Compared to IS 95, HLR used in CDMA 2000 network, has some additional capabilities like handling packetized data.
- HLR performs functions like registration, location updating etc. this is same as all 2G systems.

VI. BTS (Base Transceiver Station)

- It performs functions like allocation of resources (channel allocation) to subscribers. It is also responsible for allocation of power and Walsh codes to the subscribers.
- It also comprises of radio equipment used for sending and receiving signals in network.
- It is upgraded to handle packetized data.

VII. BSC (Base Station Controller)

- BSC controls the BTSs under its territory.
- The BSC routes the packets to and from the BTS and PDSN in the network. It also handle TDM data and circuit switched data.
- It is upgraded to handle packetized data

2.36 UMTS (UNIVERSAL MOBILE TELECOMMUNICATIONS SYSTEMS)

GQ. Write short notes on : UMTS.

- UMTS is used for variety of data services as well as speech services. It is the standard evolution for TDMA based GSM. It has provided fixed and mobile access for public and private networks.
- The Universal Mobile Telecommunication System (UMTS) is 3G standard that has developed in late 1996 under the European Telecommunication Standards Institute (ETSI). UMTS was submitted by ETSI to ITU's IMT-2000 body in 1998 for consideration as a world standard.
- Earlier UMTS was called as UMTS Terrestrial Radio Access (UTRA). It was designed to provide a high capacity upgrade path for GSM. Further several other competing wideband CDMA (W-CDMA) proposals agreed to merge into a single W-CDMA standard. This resulted W-CDMA standard is now called UMTS.
- UMTS or W-CDMA, assures backward compatibility with second generation GSM, IS-136 and PDC TDMA technologies and also the 2.5G TDMA technologies.
- The UMTS is being developed for wide area mobile cellular coverage and indoor cordless applications.
- The UMTS air interface standard had been designed for "always-on" packet-based wireless service, so that computers, entertainment devices and telephones can all share the same wireless network and be connected to the Internet, anytime and anywhere.

- UMTS will support packet data rates up to 2.048 Mbps per user. It also allows high quality data, multimedia, streaming audio, streaming video and broadcast-type services to consumers.
- UMTS provides features like video conferencing and virtual home entertainment (VHE), interactive video, mobile commerce (m-commerce) and broadcasting will be possible using a small portable wireless device.

2.36.1 Features

1. Works with both TDD and FDD duplexing schemes
2. Backward compatibility with GSM/DCS1900
3. Data rate - up to 2.048kbps
4. Minimum Forward channel bandwidth - 5MHz
5. Network structure and bit level packaging remains same as that of GSM.
6. Always on packet based wireless network.
7. Maximum 350 voice calls are supported simultaneously.
8. Better spectrum efficiency
   Improvements over core network/ evolution of core network

1. *Release 99 or R99*

- *Initial release of the UMTS standard is known as release 99 or R99. The name given so, because this specification is finalized in the year 1999.*
- It defines new radio access technologies UTRA FDD and UTRA TDD. It standardizes the use of GSM/GPRS network as core within 440 separate specifications. It also suggest the cost effective migration from GSM to UMTS.
- In this core network supports subscriber control and circuit and packet switching. The core network also supports interfacing with the external networks.

2. Release 2000 or R00

- As it was difficult to finalize the specification in the year 2000, 3gpp has decided to split the standard into two releases as release 4 and release 5.

(i) Release 4

- Release 4 supports quality of service in the fixed network plus several execution environments like MExE, mobile execution environment etc. It also supports new service architectures. In this Chinese standard TD-SCDMA was also added as low chip rate option to UTRA-TDD. This release consists of over 500 specifications and finalised in year 2001.
- In this core network supports both UMTS and GSM/GPRS radio access network. The core network in this introduces changes in circuit switched domain.
- It offers scalability and lower cost. As many component in this network are IP based, shared and cheaper IP transport is very well supported.

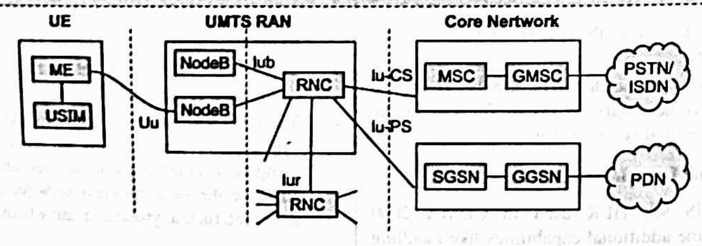
(ii) Release 5

- In this GSM/GPRS based core network is replaced by all-IP core. Radio interfaces remain same. This release is finalised in year 2002.
- This standard integrates IP based multimedia services (IMS) controlled by SIP (session initiation protocol).
- HSDPA (high speed downlink packet access) with speeds of about 8-10 Mbps was added. For better audio quality wideband 16kHz AMR codec was also added.
- End to end QoS messaging and several data compression techniques are also supported.
- Release 6 is based on MIMO antenna. It aims to develop enhanced MMS services, security enhancements, WLAN/UMTS interworking, broadcast multicast services etc.

Syllabus Topic : UMTS – Network Architecture

2.36.2 UMTS Architecture

GQ. Explain UMTS architecture.



(5830)Fig. 2.36.1 : UMTS Architecture

- Refer Fig. 2.36.1. It shows UMTS architecture.
- It is partially based on 3G technologies while keeping few features of 2G technology i.e. GSM.
- The main blocks in the architecture are

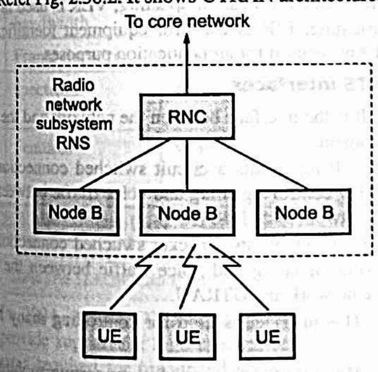
1. UE (User Equipment)
2. UTRAN (UMTS Terrestrial Radio Access Network)
3. CN (Core network)

1. UE (User Equipment)

- It is subdivided between user equipment and SIM same as that of GSM system.
- It is assigned to the single user. It comprises of all the functions which are needed to access the UMTS network.
- The SIM present here, performs the functions like encryption and authentication of users. It stores all the user related data for UMTS network.
- Generally SIM belongs to the service provider. It consists of microprocessor. This microprocessor is responsible for enhanced program execution environment like USAT, UMTS SIM application toolkit etc.
- The user equipment has all the functions needed for radio transmissions as well as user interfaces.
- UE performs the signal quality measurements, power control upto some extent, spreading and modulation and rate matching functions.
- UE also takes part in radio resource allocation process.
- It also has to take care of mobility management functions.

2. UTRAN (UMTS Terrestrial Radio Access Network)

- Refer Fig. 2.36.2. It shows UTRAN architecture.



(5831)Fig. 2.36.2 : UTRAN Architecture

- It comprises of several RNS (radio network subsystem). Each RNS is controlled by RNC (radio network controller). It is also comprised of several components called as Node B.
- If we compare with GSM architecture, RNC is analogous to BSC and Node B to that of BTS.
- RNS comprises of

a) Node B b) RNC (radio network controller)

a) Node B

- Radio cell is controlled by Node B. This means it actually controls the several antennas which are located in the cell sites.
- UE is connected with the one or more antennas. Node B also takes care of the handovers required.

b) RNC (Radio Network Controller)

- RNC is connected to the CN (core network) with the air interface I_u. It is connected to the node B via air interface I_{ub}.
- Two RNCs are interconnected with radio interface I_{ur}.
- The tasks performed by RNC are

1. Call admission control
2. Congestion control
3. Encryption and decryption
4. Multiplexing of signals and protocol conversion
5. Radio resource management
6. Radio bearer setup and release
7. Code allocation
8. Power control
9. Handover control and RNS relocation
10. Management

1. Call admission control

To keep the interference level low, RNC calculates the traffic intensity. It then decides whether to accept the call or not.

2. Congestion control

RNC allocates bandwidth to each node in the network in cyclic fashion. It also regulates quality of service.

3. Encryption and decryption

RNC encrypts the data incoming from fixed network before transmission and decrypts it before detection.

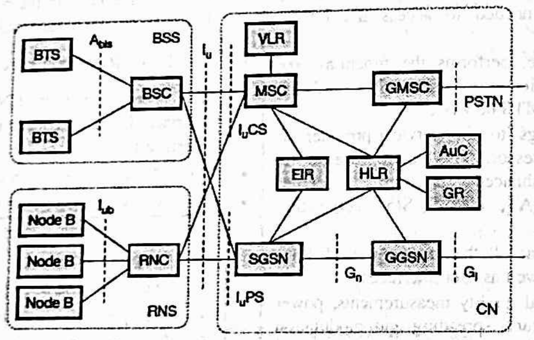
4. Multiplexing of signals and protocol conversion

The interconnection between RNCs, node Bs and the CN has to be switched to multiplex the various data streams

Module 2

5. **Radio resource management :** The RNC controls all the radio resources. It is done considering priorities.
6. **Radio bearer setup and release :** RNC sets up, maintains and releases a logical data connection to UE.
7. **Code allocation :** Codes required by CDMA are selected by RNC. These may vary during transmission.
8. **Power control :** RNC keeps an eye on the transmission power based on the interference values from other cell sites. But this is not the tight power control mechanism.
9. **Handover control and RNS relocation :** based on the signal strengths received by node B and UE, RNC decides the handover.
10. **Management :** The RNC provides the information like current load, current traffic, error states etc. to the network operator. This information is needed for management of the network.

3. **Core Network (CN)**



(5832)Fig. 2.36.3 : UMTS core network with 3G RNS and 2G BSS

- The core network is divided in two parts :
  1. CSD (circuit switched domain
  2. PSD (packet switched domain)

1. CSD (circuit switched domain)

- It consists of earlier circuit switched services like signalling.
- It has the same blocks as that of GSM architecture like MSC, HLR, VLR etc. They have the same functions also.
- The CSD is connected to RNS via I_u interface and it is known as I_uCS. It is actually the old 2G infrastructure with additional functionalities and features.

2. PSD (packet switched domain)

- It is the part that resembles GPRS network. In GPRS network SGSN (serving GPRS support node) and GGSN (gateway GPRS support node) are present.
- These are capable of handling packetized data.
- SGSN has the same tasks that of MSC. Only difference is that it is able to handle packets.
- The SGSN and GGSN are connected to RNS via I_u interface and it known as I_uPS.
- Both the CSD and PSD need databases HLR, VLR, EIR and AuC.
- HLR is used for location updating; VLR is used in case of roaming. EIR is used for equipment identification and AuC is used for authentication purposes.

The UMTS interfaces

(i) U_u : It is the interface between the network and the user equipment.
(ii) I_uCS : It represents a circuit switched connection for carrying control signaling and voice traffic between the core network and UTRAN.
(iii) I_u PS : It represents a packet switched connection for carrying signaling and voice traffic between the core voice network and UTRAN.
(iv) I_{ub} : This interface is used for controlling many Node B.
(v) I_{ur} : This interface is used for supporting mobility of MSCs. When subscriber moves I_{ur} transfers subscriber data to new RNC as UE moves.

2.36.3 UMTS air Interface Specification

GQ. State various UMTS air interface specification.

Sr. No.	Parameter	Specification
1.	Multiple access scheme used	Direct sequence- CDMA with QPSK
2.	Chipping rate	3.84Mchips/s
3.	Coding method used	OVSF (orthogonal variable spreading factor method is used
4.	Duplexing method used	FDD/TDD
5.	Frequency spectrum	Uplink : 1920 MHz-1990MHz Downlink:
6.	Frame length	10 ms with 15 time slots
7.	Channel separation	5MHz
8.	Detection	Coherent detection method
9.	Service type	Multirate and multiuser
10.	Type of handover	Soft handover, interfrequency handover

2.36.4 Comparison between GSM and UMTS

Sr. No.	Parameter	GSM	UMTS
1.	Generation	2 G	3 G
2.	Data rate	14.4 kbps	2 Mbps
3.	Access technique used	TDMA	CDMA
4.	Switching methods used	Circuit switching	Packet switching
5.	Carrier bandwidth	200kHz	5 MHz
6.	Frame duration	4.615ms	10ms
7.	spectrum	800MHz, 1800 MHz	2100MHz
8.	Features	Voice calls, SMS	Video calls

2.37 INTRODUCTION OF LTE

GQ. State the specifications of 4G LTE.

- In 2004, as WCDMA systems were inefficient to provide support for high spectral efficiencies and data rates required for broadband access, the 3GPP (Third Generation Partnership Project) started developing new technology evolution.
- They developed entirely new packet data network with MIMO (Multiple Input Multiple Output), OFDMA and OFDM support. It is 4G LTE.
- The evolution towards LTE leads to the better spectrum efficiency, higher bandwidths, better coverage and interworking with other access or backend systems. It proposes this achievement with All-IP network.
- LTE supports better mobile broadband. Later releases of LTE are known as LTE advanced.
- Refer Table 2.37.1, it shows the specifications of LTE technology.

Table 2.37.1 : Specifications of LTE

Sr. No.	Parameter	Specification
1.	Switching method	Packet switching for both voice and data.
2.	Duplexing	FDD/TDD
3.	Channel bandwidth	1MHz, 3MHz, 4 MHz, 5MHz,10 MHz,15 MHz, 20 MHz
4.	Peak data rate	For uplink - 75 Mbps For downlink - 300 Mbps
5.	Peak spectrum efficiency (bps/Hz)	For uplink - 3.75 (64 QAM SISO) For downlink - 15 (4X4 MIMO)
6.	Access technology used	Uplink - SC-FDMA Downlink - OFDMA
7.	Modulation	QPSK, 16 QAM, 64 QAM
8.	Spectrum	Licensed 2000 band
9.	Mobility	Full 3Gpp mobility with target upto 350 km/h

Syllabus Topic : LTE – Network Architecture

2.38 LTE NETWORK ARCHITECTURE

GQ. Explain LTE network architecture.

- Refer Fig. 2.38.1, it shows architecture of LTE network.
- The network architecture of LTE is based on functional decomposition principles. Hence the required specifications are decomposed into different functional entities.
- Therefore 3GPP developed a new packet core, the Evolved Packet Core (EPC), network architecture to support the E-UTRAN.

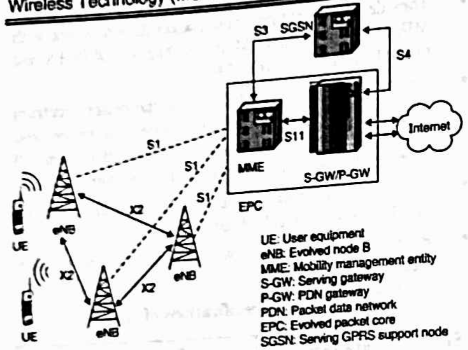


Fig. 2.38.1 : LTE network architecture

- Interfaces S1 to S11 and X2 are used for reliable packet routing and seamless integration in the network.
- The main components of the network are :
  1. User equipment (UE)
  2. Evolved nodeB (eNB)
  3. Evolved packet core (EPC)
  4. Mobility management entity (MME)
  5. Serving gateway (S-GW)
  6. PDN gateway (P-GW)

1. User equipment (UE)

This is the device connected to the BS which is an integral part of the eNB via RF channel.

2. Evolved nodeB (eNB)

- It consists of Base station. The communicating base station is known as serving eNB. It connects to the EPC through S1 interface and it is connected to other base stations through X2 interface. It's functions are :
  (i) Radio resource management for both uplink and downlink
  (ii) IP header compression
  (iii) Encryption of user data
  (iv) Routing of user data
  (v) Selection of MME
  (vi) Paging
  (vii) Measurement
  (viii) Scheduling
  (ix) Broadcasting

3. EPC

- It comprises of
  1. MME
  2. Serving gateway (S-GW)
  3. PDN gateway (P-GW)
- The functions of EPC are :
  1. Subscriber charging,
  2. Subscriber management,
  3. Policy control for user data flow,
  4. Providing quality of service,
  5. Connecting to external servers.

4. MME

- Functions performed by it are
  (i) Signalling and security control,
  (ii) Tracking area management,
  (iii) Inter core network signalling for mobility between 3GPP access networks,
  (iv) EPS (evolved packet system) bearer management,
  (v) Roaming and authentication with the help of HSS (Home Subscriber Server). [HSS is the database of subscribers and it helps MME in user authentication, mobility management, call setup and access authorization.]

5. S-GW (serving gateway)

- This gateway performs functions like
  (i) Handles eNB handovers
  (ii) Packet data routing
  (iii) Quality of service (QoS)
  (iv) User billing activities
  (v) Lawful interception
  (vi) Transport level packet marking
- It actually serves as a router for forwarding the data packets between the user equipment and PDN gateway.

6. P-GW (PDN gateway)

- This gateway is connected to the outside global network e.g. internet. Its functions are
  (i) IP address allocation
  (ii) Routing packets to and from PDN
  (iii) Subscriber charging.

2.39 LTE FRAME STRUCTURE

GQ. Explain the LTE frame structure in detail.
GQ. Discuss frames and slots in LTE. Also explain resource block.

- Frame structures in LTE system is different for FDD and TDD schemes.
- For FDD type 1 frame structure is used and for TDD type 2 frame structure is used.

2.39.1 FDD Frame Structure in LTE

GQ. Explain FDD frame structure in LTE.

- Refer Fig. 2.39.1 and Fig. 2.39.2.
- Downlink and uplink frames are allocated in different carriers.
- As LTE uses OFDM with multiple subcarriers, the spacing used between carriers is equal to 15 kHz as shown in Fig. 2.39.1.

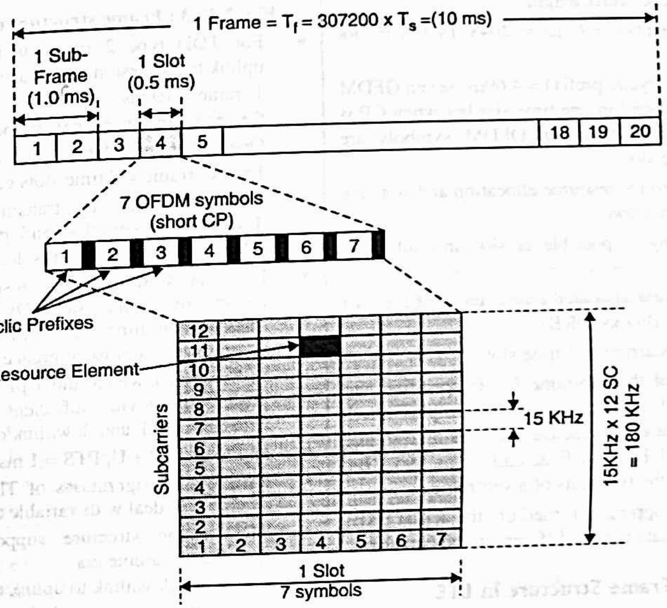


Fig. 2.39.1 : LTE frame structure in FDD mode (Type 1 frame)

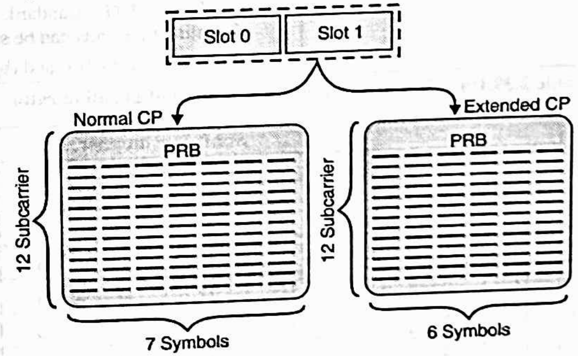


Fig. 2.39.2 : Resource allocation in FDD mode

Radio frame duration - 10ms

1 frame = 20 slots

1 frame = 10 subframes

Subframe duration: 1ms

Single time slot = 0.5ms

Each subframe = twox 0.5 ms time slots

- Single time slot = six or seven OFDM symbols depending on cyclic prefix length.
- Single OFDM symbol = 67μs = 2048 Ts (Ts = slot duration)
- Since normal CP (cyclic prefix) = 4.69μs, seven OFDM symbols can be placed in one time slot but when CP is extended to 16.67μs then six OFDM symbols are placed in one time slot.
- Subframes are used for resource allocation and slots are used for synchronization.
- Frequency hopping is possible at slot and subframe level.
- In LTE resources are allocated on the basis of units of Physical Resource Blocks (PRB).
- One PRB = 12 subcarriers = 1 time slot
- For the first slot of the subframe UE is specified and second slot onwards implicit allocation is implemented. For example, if the eNB specifies one RB as resource allocation for the UE, the UE actually uses two RBs, one RB in each of the two slots of a subframe.
- When frequency hopping is turned on, the actual PRBs that carry the UE data can be different in the two slots.

2.39.2 TDD Frame Structure in LTE

GQ. Explain TDD frame structure in LTE.

- Refer Fig. 2.39.3.

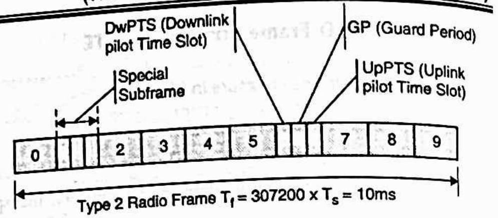


Fig. 2.39.3 : Frame structure of LTE in TDD mode

- For TDD type 2 frame is used. For downlink and uplink transmission same carrier is used.

  1 frame = 10 ms

  One radio frame = 2 half frames

  One half frame = 5 ms = five 1ms subframes

  1ms subframe = 8 time slots each of 0.5 ms
- Slots are used to transmit uplink transmission, downlink transmission and pilot signal transmission. Pilot signal transmission is done periodically.
- Each pilot time slot consists of downlink pilot transmission time slot (DwPTS) and uplink pilot transmission time slot (UpPTS). They are used for downlink and uplink reference purpose.
- In between DwPTS and UpPTS guard period (GP) is present to provide sufficient time gap for switching between uplink and downlink carriers.
- DwPTS + GP + UpPTS = 1 ms
- Different configurations of TDD frame structures are available to deal with variable traffic conditions.
- TDD frame structure supports two switch point periodicity parameters :

  (i) 5 ms (downlink to uplink transition occurs 5 ms)

  (ii) 10 ms (uplink to uplink transition occurs 10 ms)
- Different configurations from zero to six are defined by 3GPP for LTE standard. The ratio of uplink to downlink time slots can be set from 1:1 to 1:8.
- Refer Table 2.39.1(a) and (b) for TDD configurations.

Table 2.39.1(a) : Uplink downlink subframe configuration ratio

Uplink-downlink configuration	Downlink-to-Uplink periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms (2 : 6)	D	S	U	U	U	D	S	U	U	U
1	5 ms (4 : 4)	D	S	U	U	D	D	S	U	U	D
2	5 ms (6 : 2)	D	S	U	D	D	D	S	U	D	D
3	10 ms (6 : 3)	D	S	U	U	U	D	D	D	D	D
4	10 ms (7 : 2)	D	S	U	U	D	D	D	D	D	D
5	10 ms (8 : 1)	D	S	U	D	D	D	D	D	D	D
6	5 ms (3 : 5)	D	S	U	U	U	D	S	U	U	D

- Special subframe configuration can be described as shown in Table 2.39.1(b)

Table 2.39.1(b) : Subframe configuration

Configuration	3GPP release	Number of Dw	DM symbols /GP	SubframeUp
0	8	3	10	1
1	8	9	4	1
2	8	10	3	1
3	8	11	2	1
4	8	12	1	1
5	8	3	9	2
6	8	9	3	2
7	8	10	2	2
8	8	11	1	2
9	11	6	6	2

2.40 OVERVIEW OF LORA AND LORAWAN

2.40.1 What is LoRa?

Long Range

- LoRa is an RF modulation technology for low-power, wide area networks (LPWANs). It provides communication range upto 5km in urban areas and 15 kms in rural areas.
- LoRa is the physical layer or the wireless modulation utilized to create the long range communication link.
- It is based on chirp spread spectrum modulation. It helps to maintain low power characteristics as that of FSK modulation. Unlike FSK spread spectrum increases communication range.
- Single gateway or base station can cover entire cities or hundreds of square kilometers. Communication range depends upon the factors like environment, obstructions etc.
- In this technology battery life is for many years as the energy required to transmit a data packet is quite minimal given that the data packets are very small and only transmitted a few times a day.
- Its link budget is better than any other communication system.

2.40.2 What is LoRaWAN?

- LoRaWAN™ defines the communication protocol and system architecture for the network.
- LoRaWAN is an open networking protocol that delivers secure bi-directional communication, mobility, and localization services standardized and maintained by the LoRa Alliance.
- Refer Fig. 2.40.1. It shows LoRaWAN technology stack.

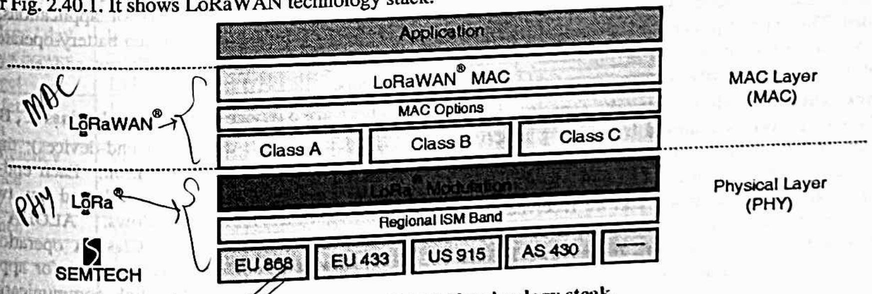


Fig. 2.40.1: LoRaWAN technology stcak.

2.40.3 LoRaWAN Network Architecture

- Refer Fig. 2.40.2. It shows LoRaWAN network architecture.

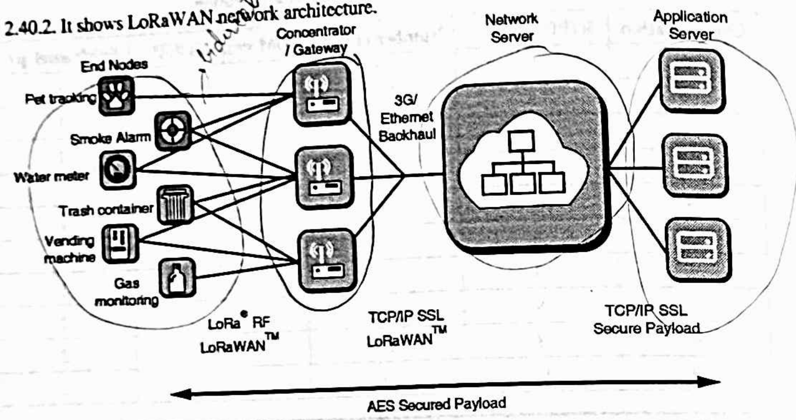


Fig. 2.40.2: LoRaWAN network architecture

- Star topology is used due to which, battery life is increased and long range of communication is achieved.
- In this network nodes are not associated with a specific gateway. Rather it is received by multiple gateways. Each gateway will forward the received packet from the end-node to the cloud-based network server via some backhaul (either cellular, Ethernet, satellite, or Wi-Fi).
- The network layer manages the network and filters out redundant received packets, perform security checks, schedule acknowledgments through the optimal gateway, and perform adaptive data rate, etc. If a node is mobile or moving there is no handover needed from gateway to gateway, which is a critical feature to enable asset tracking applications–a major target application vertical for IoT.
- **Battery lifetime:** The nodes in a LoRaWAN™ network are asynchronous and communicate when they have data ready to send whether event-driven or scheduled. This type of protocol is typically referred to as the Aloha method. It helps in saving battery power. LoRaWAN has resulted advantageous over GSMA.
- **Network capacity:** High network capacity in a LoRaWAN network is achieved by utilizing adaptive data rate and by using a multichannel multi-modem transceiver in the gateway so that simultaneous messages on multiple channels can be received. The factors affecting capacity are the number of concurrent channels, data rate (time on air), the payload length, and how often nodes transmit. Since it makes use of spread spectrum technology, the gateway can receive multiple different data rates on the same channel at the same time. If the node has good link and is close to a gateway then it may use high data rate. By shifting the data rate higher, the time on air is shortened opening up more potential space for other nodes to transmit. It also optimizes battery lifetime. In order to make adaptive data rate work, symmetrical up link and down link is required with sufficient downlink capacity. This provides network scalability. Other LPWAN alternatives do not have the scalability of LoRaWAN due to technology trade-offs, which limit downlink capacity or make the downlink range asymmetrical to the uplink range.
- **Device classes:** LoRaWAN utilizes different device classes. The device classes trade off network downlink communication latency versus battery lifetime. A LoRaWAN-enabled **end device** is a sensor or an actuator which is wirelessly connected to a LoRaWAN network through radio gateways using LoRa RF Modulation. In the majority of applications, an end device is an autonomous, often battery-operated sensor that digitizes physical conditions and environmental events.
- **There are 3 device classes namely class A , B and C.**
  1. Class A (Bi-directional end-devices): they allow bidirectional communication. Each end-device's uplink transmission is followed by two short downlink receive windows. ALOHA type of protocol is used. This Class A operation is the lowest power end-device system for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission. Downlink communications from the server at any other time will have to wait until the next scheduled uplink.
  2. Class B (Bi-directional end-devices with scheduled receive slots): Class B devices open extra receive windows at scheduled times upon receiving a time-synchronized beacon from the gateway. This allows the server to know when the end-device is listening.
  3. Class C (Bi-directional end-devices with maximal receive slots): These devices have almost continuously open receive windows, only closed when transmitting.
- **Security:** In LoRaWAN two layers of security are employed. One is used for network to check for authenticity and one for the application to maintain data privacy. AES encryption is used with the key exchange utilizing an IEEE EUI64 identifier.

2.40.4 LoRaWAN Specification in World

Refer Table 2.40.1. It shows LoRaWAN regional summary.

Table 2.40.1: LoRaWAN regional summary

	Europe	North America	China	Korea	Japan	India
Frequency band	867-869 MHz	902-928 MHz	470-510 MHz	920-925 MHz	920-925 MHz	865-867 MHz
Channels	10	64 + 8 + 8	In definition by Technical Committee	In definition by technical committee	In definition by technical committee	In definition by technical committee
Channel BW Up	125/250 kHz	125/500 kHz				
Channel BW Dn	125 kHz	500 kHz				
TX power up	+ 14 dBm	+ 20 dBm typ (+ 30 dBm allowed)				
TX power Dn	+ 14 dBm	+ 27 dBm				
SF UP	7-12	7-10				
Date rate	250bps-50kbps	980bps-21.9kpbs				
Link Budget Up	155 dB	154 dB				
Link Budget Dn	155 dB	157 dB				

2.40.5 Comparison between Various LPWAN Technologies

Feature	LoRaWAN	Narrow-Band	LTE Cat-1 2016 (Rel12)	LTE Cat-M 2018 (Rel13)	NB-LTE 2019 (Rel13+)
Modulation	SS Chirp	UNB/GFSK/BPSK	OFDMA	OFDMA	OFDMA
Rx bandwidth	500-125 kHz	100 Hz	20MHz	20-1.4 MHz	200 KHz
Date Rate	290 bps-50 kbps	100 bit/sec 12/8 bytes max	10 Mbit/sec	200kbps-1Mbps	~20K bit/sec
Max. # Msgs / day	Unlimited	UL : 140 msgs/ day	Unlimited	Unlimited	Unlimited
Max output power	20dBm	20 dBm	23-46 dBm	23/30 dBm	20dBm
Link budget	154 dB	151 dB	130 dB+	146 dB	150dB
Battery lifetime 2000mAh	105 months	90 months		18 months	
Power efficiency	Very high	Very high	Low	Medium	Med high
Interference immunity	Very high	Low	Medium	Medium	Low
Coexistence	Yes	No	Yes	Yes	No
Security	Yes	No	Yes	Yes	Yes
Mobility / localization	Yes	Limited mobility, no loc	Mobility	mobility	Limited mobility no loc