1 Introduction to Mobile Computing

- Mobile computing consist of two terms mobile and computing. Mobile means not stationary and Computing is the activity of developing using computer technology including hardware and software.
- Thus Mobile Computing is a technology that allows transmission of data, voice and video via a computer or any other wireless enabled device without having to be connected to a fixed physical link.
- The goal of mobile computing is to work toward true computing freedom (free from the tyranny of location) whereby users can connect to the network from anywhere, anytime- and operate as if they were sitting in the "home" office.
- The main concept involves:
  - ✓ Mobile Communication
  - ✓ Mobile Hardware
  - ✓ Mobile Software

❖ Mobile Communication

- The mobile communication in this case, refers to the infrastructure put in place to ensure that seamless and reliable communication goes on.
- These would include devices such as Protocols, Services, Bandwidth, and Portals necessary to facilitate and support of the stated services.
- The data format is also defined at this stage. This ensures that there is no collision with other existing systems which offer the same service.
- Since the media is unguided/unbounded, the overlaying infrastructure is more of radio wave oriented. That is, the signals are carried over the air to intended devices that are capable of receiving and sending similar kinds of signals.

❖ Mobile Hardware

- Mobile hardware includes mobile devices or device components that receive or access the service of mobility. E.g.- Portable laptops, Smartphones, Tablet Pc's, Personal Digital Assistants.
- These devices will have receptor medium that are capable of sending and receiving signals.
- These devices are configured to operate in full- duplex, whereby they are capable of sending and receiving signals at the same time.
- They don't have to wait until one device has finished communicating for the other device to initiate communications.
- Above mentioned devices use an existing and established network to operate on. In most cases, it would be a wireless network.

❖ Mobile Software

- Mobile software is the actual program that run on the mobile hardware.
- It deals with the characteristics and requirements of mobile applications.
- This is the engine of that mobile device. In other terms, it is the operating system of that appliance.
- It's the essential component that makes the mobile device operate.
- Since portability is the main factor, this type of computing ensures that users are not *tied or pinned* to a single physical location, but are able to operate from anywhere.
- It will incorporate all aspects of wireless communications.

2 Mobile and Wireless

- **Mobile:** There are two different types of mobility: user mobility and device mobility
  - ✓ **User mobility** refers to a user who has access to a same or similar telecommunications services at different places, i.e. the user can be mobile and the services will follow him or her. E.g.:-simple call-forwarding solutions known from telephones.
  - ✓ **Device portability**, the communication device moves (with or without the user). So mechanisms in the network and inside the device have to make sure that communication is still possible while

the device is moving. E.g.:- Mobile phone system where the system itself handle the device from one radio transmitter known as base station to next if the signal becomes too weak.

- **Wireless:** Wireless only describes the way of accessing a network i.e. without a wire.

3 Issues of mobile computing:

- Insufficient bandwidth
- Security standards
- Power consumption
- Transmission interferences
- Potential health hazards
- Human interface with device
- Loss of data

✓ **<u>Mobility Issues</u>**

- Bandwidth restrictions and variability
- Location-aware network operation
    - User may wake up in a new environment
    - Dynamic replication of data
- Querying wireless data & location-based responses
- Busty network activity during connections & handling disconnections
- Disconnection
    - OS and File System Issues - allow for disconnected operation
    - Database System Issues - when disconnected, based on local data

✓ **<u>Portability Issues</u>**

- Battery power restrictions
- Risks to data
    - Physical damage, loss, theft
    - Unauthorized access
    - encrypt data stored on mobiles
    - Backup critical data to fixed (reliable) hosts
- Small user interface
    - Small displays due to battery power and aspect ratio constraints
    - Cannot open too many windows
    - Difficult to click on miniature icons
    - Input - Graffiti, (Dictionary-based) Expectation
        - Gesture or handwriting recognition with Stylus Pen Voice matching or voice recognition

4 Application of Mobile Computing

✓ Vehicles

- transmission of news, road condition, weather, music via DAB
- personal communication using GSM
- position via GPS
- local ad-hoc network with vehicles close-by to prevent accidents, guidance system, redundancy
- vehicle data (e.g., from busses, high-speed trains) can be transmitted in advance for maintenance

✓ Emergencies

- early transmission of patient data to the hospital, current status, first diagnosis
- Replacement of a fixed infrastructure in case of earthquakes, hurricanes, fire etc.
- **crisis, war, ….**

- ✓ Travelling salesmen
  - direct access to customer files stored in a central location
  - consistent databases for all agents
  - mobile office

- ✓ Replacement of fixed networks
  - remote sensors, e.g., weather, earth activities
  - flexibility for trade shows
  - LANs in historic buildings

- ✓ Entertainment, education,
  - outdoor Internet access
  - intelligent travel guide with up-to-date location dependent information
  - ad-hoc networks for multi user games

5 Challenges of Mobile Computing

- ➢ Challenges in mobile computing can be categorized into three major areas as:
- ✓ Communication,
- ✓ Mobility, and
- ✓ Portability.

❖ **Wireless Communication**

- ➢ Generally wireless computers have fewer resources relative to stationary (wired) computers, this is because wireless computers are required to be smaller, lighter and consume less power than stationary computers.
- ➢ Wireless communication is more difficult to implement than wired communication because of the interaction of the surrounding environment with the message signal. Problems caused by the environment include blocked signal paths, echoes and noise. Hence wireless connections are more error prone, have much lower bandwidths, and have frequent spurious disconnections when compared to wired connections. These factors can increase communication latencies due to error control checks, retransmissions, time-out delays and brief disconnections

❑ **Disconnections:**

- ➢ Since wireless communication is so susceptible to disconnection, it is of great concern when designing successful mobile computers. Resources can be allocated to handle disconnections more elegantly, or to try and prevent those disconnections from happening. In environments with frequent disconnections it is better for the mobile computer to act as a stand-alone unit rather than a mobile terminal (i.e. splitting the application and the user interface across the network).

❑ **Low Bandwidth and Bandwidth Variability:**

- ➢ Wireless networks deliver lower bandwidth than wired networks, hence mobile computing designs need to be very concerned about bandwidth consumption. The deliverable bandwidth per user depends on the number of users sharing a cell. The network's capacity can be measured by its bandwidth per cubic meter.

❑ **Security Risk:**

- ➢ Precisely because connection to a wireless link is so easy, the security of wireless communication can be compromised much more easily than that of wired communication, especially if transmission extends over a large area. This increases pressure on mobile computing software designers to include security measures. Security is further complicated if users are allowed to cross security domains.

❖ **Mobility**

- ➢ The ability to change location while connected to the network increases the volatility of some information. Certain data considered static for stationary computing becomes dynamic for mobile computing.

- For example, a stationary computer can be configured statically to prefer the nearest server, but a mobile computer needs a mechanism for determining which server to use. As volatility increases, cost-benefit trade-off points shift, calling for appropriate modifications in the design.
- **Mobility introduces several problems: A mobile computer's network address changes dynamically, its** current location affects configuration parameters as well as answers to user queries, and the communication path grows as it wanders away from a nearby server.

- **Address Migration:**
  - **As people move, their mobile computers will use different network access points, or "addresses." Today's networking is not designated for dynamically changing addresses. Active network connections** usually cannot be moved to a new address. Once an address for a host name is known to a system, it is typically cached with a long expiration time and with no way to invalidate out-of-date entries. In the Internet Protocol, for example, a host IP name is inextricably bound with its network address; moving to a new location means acquiring a new IP name.
- **Location – dependent Information:**
  - Because traditional computers do not move, information that depends on location such as local name server, available printers, and the time zone, is typically configured statically. One challenge for mobile computing is to factor out this information intelligently and provide mechanisms for obtaining configuration data appropriate to each location.

- **Portability**
  - Conventional desktop computers are not meant to be carried, so design and heat dissipation. In contrast, designers of hand-held mobile computers should strive for the properties of a wrist watch: small, light, durable, operational under wide environmental conditions and requiring minimal power usage for long battery life.

- **Low Power:**
  - Batteries are the heart of any mobile device. Batteries are the largest single source of weight in a portable computer. While reducing battery weight is important, too small a battery can undermine the value of portability by causing users to recharge frequently, carry spare batteries, or use their mobile computers less. Minimizing power consumption can improve portability by reducing battery and lengthening the life of a charge. Power consumption of dynamic components is proportional to CV2F, where C is the capacitance of the circuit, V is the voltage swing and F is the clock frequency.
- **Small User Interface:**
  - For smaller and more portable devices current windowing techniques are inadequate. It is impractical to have several windows open at the same time on a small screen even at high resolutions. Due to a shortage of surface area of portable computers, it may be feasible to trade buttons for some other form of input. The forms that may be feasible are hand writing, voice and gesture recognition.
- **Small Storage Capacity:**
  - Storage space on a portable device is limited by physical size and power requirements. Traditionally, disks provide large amounts of nonvolatile storage. In a mobile computers computer, however, disk drives are a liability. They consume more power than memory chips, except when off line, and they may not really be nonvolatile when subject to the indelicate treatment a portable device receives. Hence, none of the PDA products have disk drives.

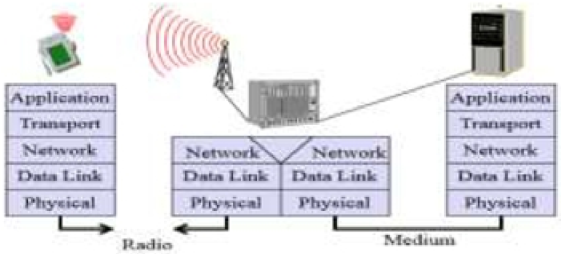
6 Advantages of Mobile Computing

- Mobile computing has changed the complete landscape of human being life. Following are the clear advantages of Mobile Computing:

- **Location flexibility:** This has enabled user to work from anywhere as long as there is a connection established. A user can work without being in a fixed position. Their mobility ensures that they are able to carry out numerous tasks at the same time perform their stated jobs.

- **Saves Time:** The time consumed or wasted by travelling from different locations or to the office and back, have been slashed. One can now access all the important documents and files over a secure channel or portal and work as if they were on their computer. It has enhanced telecommuting in many companies. This also reduces unnecessary expenses that might be incurred.
- **Enhanced Productivity:** Productive nature has been boosted by the fact that a worker can simply work efficiently and effectively from which ever location they see comfortable and suitable. Users are able to work with comfortable environments.
- **Ease of research:** Research has been made easier, since users will go to the field and search for facts and feed them back to the system. It has also made it easier for field officer and researchers to collect and feed data from wherever they without making unnecessary trip to and from the office to the field.
- **Entertainment:** Video and audio recordings can now be streamed on the go using mobile computing. It's easy to access a wide variety of movies, educational and informative material. With the improvement and availability of high speed data connections at considerable costs, one is able to get all the entertainment they want as they browser the internet for streamed data. One can be able to watch news, movies, and documentaries among other entertainment offers over the internet. This was not such before mobile computing dawned on the computing world.
- **Streamlining of Business Processes:**
    - Business processes are now easily available through secured connections. Basing on the factor of security, adequate measures have been put in place to ensure authentication and authorization of the user accessing those services.
    - Some business functions can be run over secure links and also the sharing of information between business partners. Also it's worth noting that lengthy travelling has been reduced, since there is the use of voice and video conferencing.
    - Meetings, seminars and other informative services can be conducted using the video and voice conferencing. This cuts down on travel time and expenditure.

7 Simplified Reference Model



- **Application Layer:**
    - Service location
    - New applications, multimedia
    - Adaptive applications
- **Transport Layer:**
    - Congestion and flow control
    - Quality of service
- **Network Layer:**
    - Addressing,
    - Routing,
    - Device location
    - Hand-over

- **Data Link Layer:**
  - Authentication
  - Media access
  - Multiplexing
  - Media access control
- **Physical Layer:**
  - Modulation
  - Interference
  - Attenuation
  - Frequency

8 Evaluation of Mobile Radio Communication

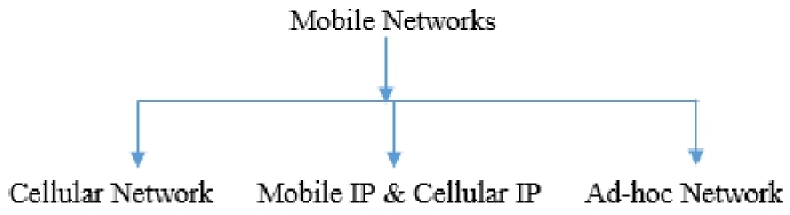
- The first wire line telephone system was introduced in the year 1877. Mobile communication systems as early as 1934 were based on Amplitude Modulation (AM) schemes and only certain public organizations maintained such systems.
- With the demand for newer and better mobile radio communication systems during the World War II and the development of Frequency Modulation (FM) technique by Edwin Armstrong, the mobile radio communication systems began to witness many new changes. Mobile telephone was introduced in the year 1946. However, during its initial three and a half decades it found very less market penetration owing to high costs and numerous technological drawbacks. But with the development of the cellular concept in the 1960s at the Bell Laboratories, mobile communications began to be a promising field of expanse which could serve wider populations. Initially, mobile communication was restricted to certain official users and the cellular concept was never even dreamt of being made commercially available.
- Moreover, even the growth in the cellular networks was very slow. However, with the development of newer and better technologies starting from the 1970s and with the mobile users now connected to the Public Switched Telephone Network (PSTN), there has been an astronomical growth in the cellular radio and the personal communication systems. Advanced Mobile Phone System (AMPS) was the first U.S. cellular telephone system and it was deployed in 1983. Wireless services have since then been experiencing a 50% per year growth rate. The number of cellular telephone users grew from 25000 in 1984 to around 3 billion in the year 2007 and the demand rate is increasing day by day.

9 Present Day Mobile Communication

- Since the time of wireless telegraphy, radio communication has been used extensively. Our society has been looking for acquiring mobility in communication since then. Initially the mobile communication was limited between one pair of users on single channel pair.
- The range of mobility was defined by the transmitter power, type of antenna used and the frequency of operation. With the increase in the number of users, accommodating them within the limited available frequency spectrum became a major problem. To resolve this problem, the concept of cellular communication was evolved.
- The present day cellular communication uses a basic unit called cell. Each cell consists of small hexagonal area with a base station located at the center of the cell which communicates with the user.
- To accommodate multiple users Time Division multiple Access (TDMA), Code Division Multiple Access (CDMA), Frequency Division Multiple Access (FDMA) and their hybrids are used.
- Numerous mobile radio standards have been deployed at various places such as AMPS, PACS, GSM, NTT, PHS and IS-95, each utilizing different set of frequencies and allocating different number of users and channels.

10 Cellular Network

- Mobile Networks are network of mobile devices, servers and distributed computing systems
- There are basic three type of network used as mobile network



- A cellular network is a radio network distributed over land area called cell, each served by atleast one fixed location transceiver known as cell site or base station.
- Thus a cellular system is characterized as a high capacity mobile system in which available frequency spectrum is partitioned or divided into discrete channels which are assigned in groups to geographic cell covering a Cellular Geographic Service Area (GSA).
- Cellular network offers a number of advantages such as:
    - Increased capacity
    - Reduced power use
    - Large coverage area
    - Reduced interference from other signals

11 Components and terminology used in cellular network

11.1 Cellular concept:

Cellular telephone systems must accommodate a large number of users over a large geographic area with limited frequency spectrum, i.e., with limited number of channels. If a single transmitter/ receiver is used with only a single base station, then sufficient amount of power may not be present at a huge distance from the BS. For a large geographic coverage area, a high powered transmitter therefore has to be used. But a high power radio transmitter causes harm to environment. Mobile communication thus calls for replacing the high power transmitters by low power transmitters by dividing the coverage area into small segments, called **cells**. Each cell uses a certain number of the available channels and a group of adjacent cells together use all the available channels. Such a group is called a cluster. This cluster can repeat itself and hence the same set of channels can be used again and again. Each cell has a low power transmitter with a coverage area equal to the area of the cell. This technique of substituting a single high powered transmitter by several low powered transmitters to support many users is the backbone of the cellular concept.

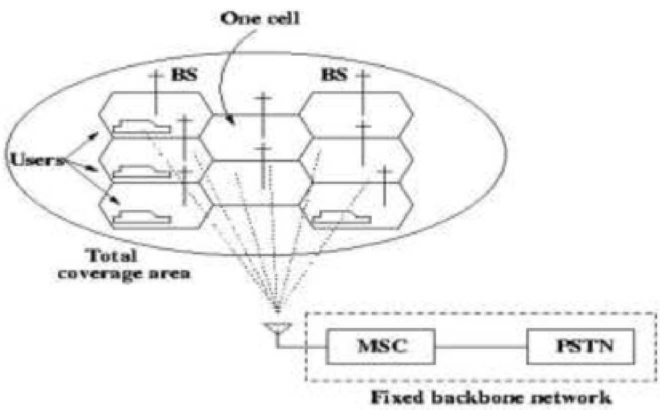


Figure 11.1: Basic Cellular Structure

11.2 Structure of cell

- The power of the radio signals transmitted by the BS decay as the signals travel away from it. A minimum amount of signal strength (let us say, x dB) is needed in order to be detected by the MS or mobile sets which may the hand-held personal units or those installed in the vehicles. The region over which the signal strength lies above this threshold value x dB is known as the coverage area of a BS and it must be a circular region, considering the BS to be isotropic radiator. Such a circle, which gives this actual radio coverage, is called the foot print of a cell (in reality, it is amorphous). 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. This is shown in Figure 11.2.
- Such a circular geometry, therefore, cannot serve as a regular shape to describe cells. We need a regular shape for cellular design over a territory which can be served by 3 regular polygons, namely, equilateral triangle, square and regular hexagon, which can cover the entire area without any overlap and gaps.
- Along with its regularity, a cell must be designed such that it is most reliable too, i.e., it supports even the weakest mobile with occurs at the edges of the cell. For any distance between the center and the farthest point in the cell from it, a regular hexagon covers the maximum area. Hence regular hexagonal geometry is used as the cells in mobile communication.

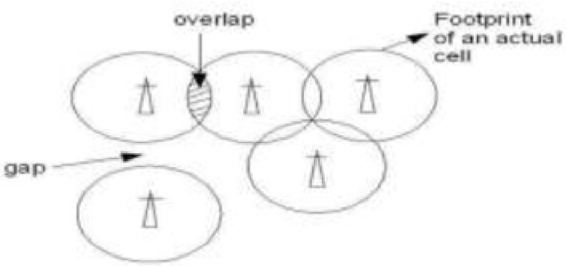
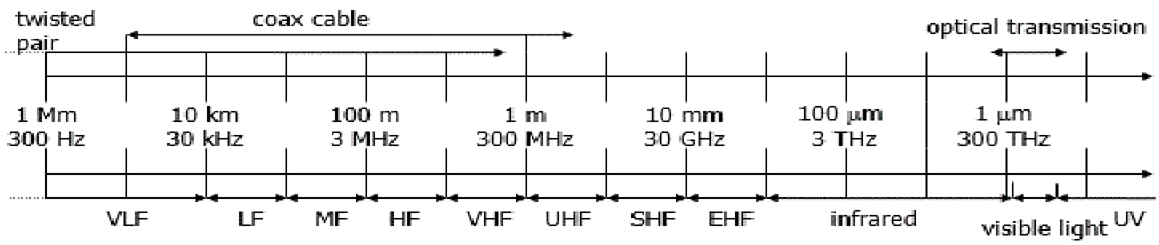


Figure 11.2: Footprint of cells showing the overlaps and gaps.

12 Frequency for Communication



VLF = Very Low Frequency
LF = Low Frequency
MF = Medium Frequency
HF = High Frequency
VHF = Very High Frequency
UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extra High Frequency
UV = Ultraviolet Light

Frequency and wave length:

$\lambda = c/f$

wave length λ, speed of light $c \cong 3\text{x}10^8$m/s, frequency f

12.1 Frequency for Mobile Communication

- VHF-/UHF-ranges for mobile radio
    - simple, small antenna for cars
    - deterministic propagation characteristics, reliable connections

- SHF and higher for directed radio links, satellite communication
    - small antenna, focusing
    - large bandwidth available

- Wireless LANs use frequencies in UHF to SHF spectrum
    - some systems planned up to EHF
    - limitations due to absorption by water and oxygen molecules (resonance frequencies)
    - Weather dependent fading, signal loss caused by heavy rainfall etc.

13 Frequency Reuse

- Each cellular base station is allocated a group of radio channels to be used within a small geographic area called a cell.
- The base station antennas are designed to achieve the desired coverage within the particular cell.
- By limiting the coverage area to within the boundaries of a cell, the same group of channels may be used to cover different cells that are separated from one another by distances large enough to keep interference levels within tolerable limits.
- The design process of selecting and allocating channels groups for all the cellular base stations within a system is called frequency reuse or frequency planning.
- Figure-1 below illustrates the concept of cellular frequency reuse, where cells labeled with the same letter use the same group of channels.
- The hexagonal shape shown in figure is conceptual and is simplistic model of the radio coverage for each base station.
- Hexagonal has been universally adopted since it permits easy and manageable analysis of a cellular system.

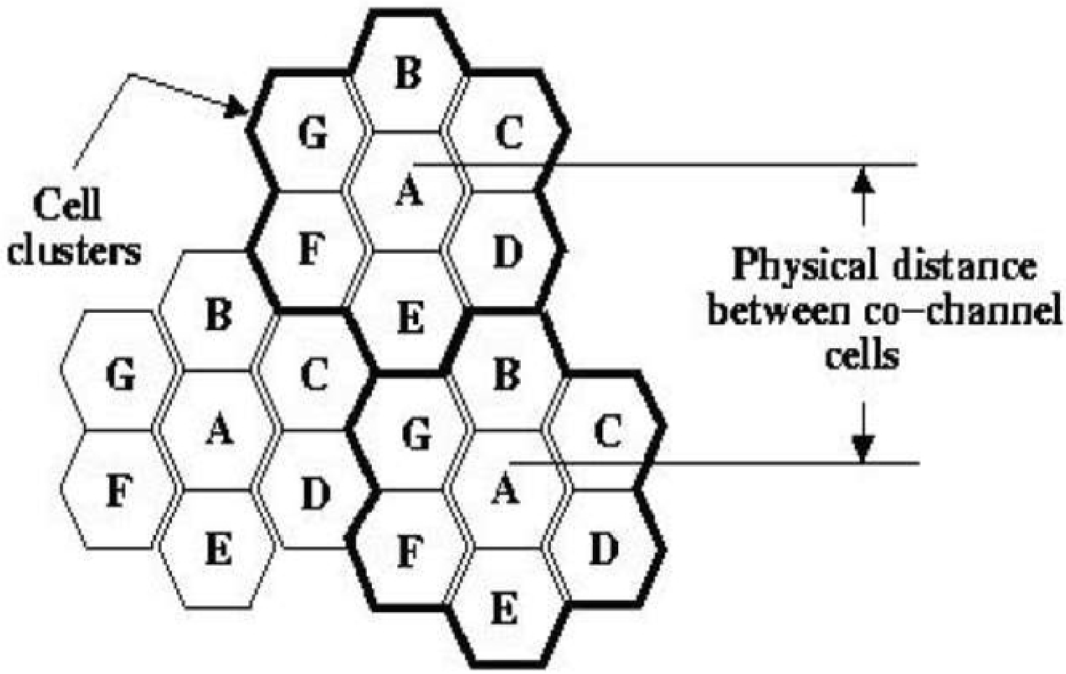


Figure: Hexagonal Cell Geometry illustrating frequency reuse

❖ Why to use Hexagonal Cell Geometry?

- While it might seem natural to choose a circle to represent the coverage area of a base station, adjacent circles cannot be overlaid upon a map without leaving gaps or creating overlapping regions.
- Thus when considering geometric shapes, which cover an entire region without overlap and with equal, there are three sensible choice- a square, an equilateral triangle and a hexagon.
- For a given distance between the center of polygon and its farthest perimeter points, the hexagone has the largest area of the three.
- Thus by using the hexagonal geometry, the fewest number of cells can cover a geographic region, and the hexagon closely approximates a circular radiation pattern, which would occur for an omni-directional base station antenna and free space propagation.

❖ Definition of Cluster

- Let, a total number of duplex channels available for use = S
- If each cell is allocated a group of k channels ($k<S$), and if the S channel are divided among N cells into unique and disjoint channel groups which each have the same number of channels, the total number of available radio channels can be expressed as $S=kN$
- The N cells which collectively use the complete set of available frequencies is called a cluster.

❖ Capacity

- If a cluster is replicated M times within the system, the total number of duplex channels, C, can be used as a measure of capacity and is given by
  - $C= MkN = MS$
  - So, the capacity of cellular system is directly proportional to the number of times a cluster is replicated in a fixed service area.
- The factor N is called the cluster size and is typically equal to 4, 7, or 12.
- From $C= MkN = MS$; also, $C= kN_{BS}$ where $N_{BS} = MN$ is the total number of base stations (cells).
- Largest capacity is achieved from the given spectrum if:
  - N_{BS} and M is increased (this is effectively cell splitting)
  - K is increased (equivalently decreasing the value of N, cluster size).

❖ Frequency Reuse Factor

- The frequency reuse factor of cellular system is given by $1/N$, since each cell within a cluster is only assigned $1/N$ of the total available channels in the system.
- Due to the fact that the hexagonal geometry in the figure has exactly six equidistant neighbors and that the lines joining the centers of any cell and each of its neighbors are separated by multiples of 60 degrees, there are only certain cluster sizes and cell layouts which are possible.
- To connect without gaps between adjacent cells –the geometry of hexagons is such that the number of cells per cluster, N, can only have values which satisfy Equation.
- $N= i^2 + ij +j^2$ where i and j are non-negative integers.

❖ Co-Channel Cell

- In a given coverage area there are several cells that use the same set of frequency, These cells are called co-channel cells.
- To find the nearest co-channel neighbors of particular cell, one must do the following:
  - Move i cells along any chain of hexagons and then
  - Turn 60 degree counter-clockwise or clockwise and move j cells.

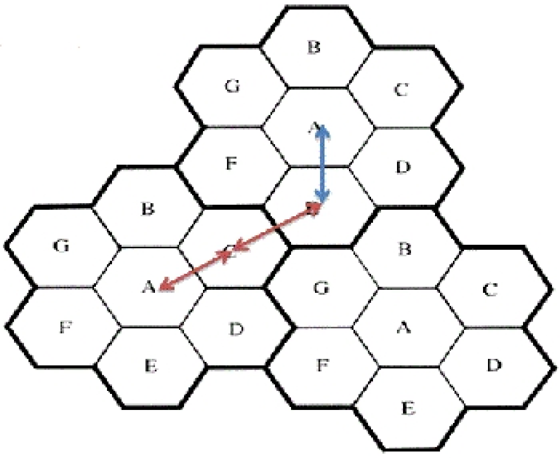


Figure -1: Method of locating co-channel cells in a cellular system for i=2 and j=1 (i.e. N=7)

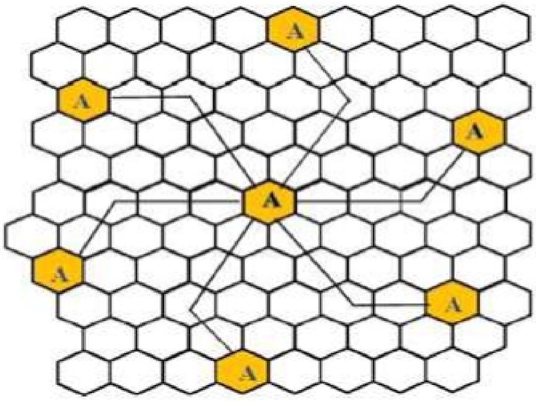


Figure -2: Method of locating co-channel cells in a cellular system for i=3 and j=2 (i.e. N=19)

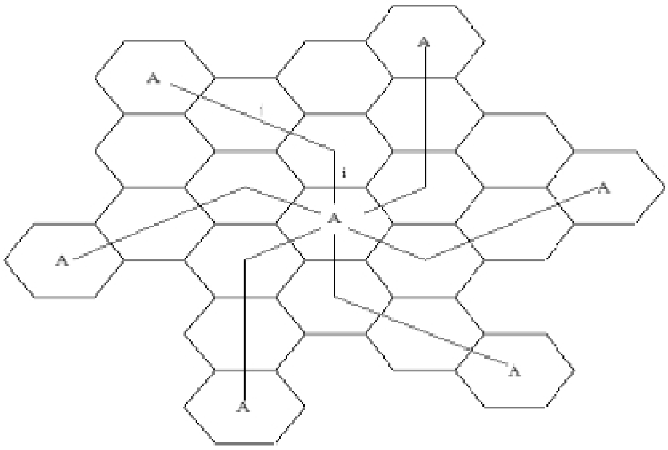


Figure -3: Method of locating co-channel cells in a cellular system for i=1 and j=2 (i.e. N=7)

- The center to center distance between two adjacent cells is $\sqrt{3}R$; where R is the radius of hexagon. The distance between the nearest co-channel cells is $\sqrt{3N}R$.

14 Interference

- Interference is a major limiting factor in the performance of cellular radio system. It is more sever in urban areas due to greater RF noise floor and large number of BS and MS.
- Source of interference
  - Another mobile in the same cell.
  - A call in progress in a neighboring cell
  - Other base stations operating in the same frequency band or
  - Any non-cellular system which leaks energy into the cellular frequency band.
- Two major types
  - Co-channel interference
  - Adjacent channel interference

14.1 Co-channel interference

- The interference between signals from the co-channel cells is called co-channel interference.
- Let S = desired signal power
  I = Power of co-channel interference
  i_0 = number of co-channel interfering cells
  I_i = interference power caused by i^{th} interfering co-channel cell BS.
- The signal to co-channel interference ratio at desired mobile receiver is

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{io} Ii}$$

- Specifically we assumed that
  - All co-channel BS have same transmission power
  - The path loss exponent, n is same throughout the coverage area Typically between 2-4 in urban cellular system
  - Cell radius is R and distance between co-channel cells is D and
  - All i_o interferer are equidistant from the desired MS.
- The signal to co-channel interference ratio (S/I) for a mobile receiver can be approximate by

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0}(D_i)^{-n}} = \frac{R^{-n}}{i_0 D^{-n}} = \frac{(D/R)^n}{i_0} = \frac{Q^n}{i_0}$$

  Where, co-channel reuse ratio, $Q = D/R = \sqrt{3N}$, where N= cluster size.

- In hexagon cell, there are 6 equidistance interferers at the channel (only first layer of interfering cell is considered).

$$\frac{S}{I} = \frac{(D/R)^n}{6} = \frac{(\sqrt{3N})^n}{6} \qquad D = R\cdot\sqrt[n]{6\cdot\frac{S}{I}} \qquad N = \frac{1}{3}\left(6.\frac{S}{I}\right)^{\frac{2}{n}}$$

- To reduce co-channel interference co-channel reuse ratio (D/R) should be increased. That is channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation.
- In practical cellular system, co-channel interference can be reduced by using directional antennas, lowered antennas heights, choice of BS locations and power control.

14.2 Adjacent channel Interference

- Interference due to signals which are adjacent in frequency (immediately preceding and following channels) to the desired signal is called adjacent channel interference.
- It results from imperfect receiver filters which allow nearby frequencies from the strong received signal to the weak received signal.

- Consider uplink transmission from two MSs using adjacent channel, one very close to BS (MS1) and other is close to cell boundary (MS2). Without proper transmission power control the receive power from the MS1 is much larger than MS2. So, BS is unable to detect the signal of MS2. This is called near far effect.
- ACI can be minimized through careful filtering and channel assignments.
  - Carefully design the bandpass filter at the receiver front end.
  - Use proper channel interleaving by assigning adjacent channels to different cells. For maximum frequency separation between channels. The frequencies k, $k+N$, $k+2N$ is assigned to the k^{th} cell, when frequency reuse factor is N.
  - Avoid using adjacent channel is adjacent cell if the cluster size is larger enough ($N=9$).
  - Separate uplink and downlink properly by TDD or FDD.
  - Use modulation schemes which have low out of band radiation.
  - Proper transmission power control.

15 Trunking and Grade of Service

- The concept of trunking allows a large number of users to share the relatively small number of channel in a cell by providing access to each user, on demand, from a pool of available channels.
- In a trunked radio systems, each user is allocated a channel on a per call basis, and upon termination of the call, the previously occupied channel is immediately returned to the pool of available channels.
- Trunking exploits the statistical behavior of users so that a fixed number of channels or circuits may accommodate a large, random user community.
- In a trunked mobile radio systems, when a particular user requests service and all of the radio channels are already in use, the user is blocked, or denied access to the system.
- In some systems, a queue may be used to hold the requesting users until a channel become available.
- One Erlang represents the amount of traffic intensity carried by a channel that is completely occupied (i.e. one call-hour per hour or one call-minute per minute).

❖ **GOS:**

- The grade of service (GOS) is a measure of the ability of a user to access a trunked system during the busiest hour.
- The grade of service is a benchmark used to define the desired performance of a particular trunked system by specifying a desired likelihood of a user obtaining channel access given a specific number of channels available in the system.
- Wireless designer estimates the maximum required capacity and allocate the proper number of channels in order to meet specific GOS.
- GOS is typically given as the likelihood that a call is blocked.
- The traffic intensity offered by each user (A_u) **is equal to the call request rate (λ) multiplied by the holding time**. That is, each user generates a traffic intensity of A_u Erlang given by

  $$A_u = \lambda * t_m$$

  Where t_m **is the average duration of a call and λ is the average** number of call request per unit time for each user.

- For a system containing U users and an unspecified number of channels, the total offered traffic intensity A, is given as

  $$A = U * A_u$$

- A GOS of 2% blocking implies that the channel allocations for cell sites are designed so that 2 out of 100 calls will be blocked due to channel occupancy during the busiest hour.
- There are two types of trunked systems which are commonly used.
  - Blocked calls cleared- Erlang B formula
  - Delayed calls cleared- Erlang C formula

- **Erlang B model**

Erlang B model is based on the following assumption

- Infinite numbers of users are in the system.
- Finite number of channels (C) are available in the trunking pool
- Arrival process has Poisson distribution.
- Service time is exponentially distributed.
- Blocked calls are cleared that is the system is memoryless.

Figure 2.8-1: State transition rate diagram

The probability of state x in Erlang model is

$$P_x = \frac{A^x/x!}{\sum_{i=0}^{C} A^i/i!}$$

The probability of blocking B is given by Erlang B formula

$$B = \frac{\text{Blocked calls}}{\text{Offered calls}} = \frac{\lambda P_c T}{\lambda T} = P_c = \frac{A^C/C!}{\sum_{i=0}^{C} A^i/i!}$$

Where A is total offered traffic in Erlang$=\lambda t_m$

- **Erlang C model**

- To decrease call blocking probability, buffers are provided for queuing.
- When all C servers are busy, a call request will join the queue and served as soon as the chanr becomes available.
- The probability that a call is delayed is given by
- $$P(delay > 0) = \frac{A^C}{A^C + C!\left(1+\frac{A}{C}\right)\sum_{i=0}^{C-1} A^i/i!}$$
- The probability that the delayed call has to wait more than t seconds is given by

$$P(delay > t) = P(delay > 0) \cdot P(delay > t \mid delay > 0)$$

$$P(delay > t) = P(delay > 0) \cdot \exp\left(-\frac{(C-A)t}{t_m}\right)$$

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

$$D = P(delay > 0)\frac{t_m}{C-A}$$

- $\frac{t_m}{C-A}$ is average delay experienced by delayed user

❖ **Trunking Efficiency**

- This is the measure of the number of users which can be offered a particular GOS with a particular configuration of fixed channels.
- The way in which the channels are grouped can substantially alter the number of users handled by a trunked system.
- For example, 10 trunked channels at GOS of 0.01 (i.e. 1%) can support 4.46 Erlangs of traffic, whereas two groups of 5 trunked channels can support 2*1.36 Erlangs or 2.72 Erlangs of traffic.
- Clearly 10 channel trunked together support 60% more traffic at a specific GOS than do two 5 channel trunks.
- Thus the allocation of channels in a trunked radio system has a major impact on overall system capacity.

16 Improving Capacity in Cellular System

- As the demand for wireless service increases, the number of channels assigned to a cell eventually becomes insufficient to support the required number of users.
- Therefore, cellular design techniques are needed to provide more channels per unit coverage area.
- Techniques used to expand the capacity of cellular system are
  - Cell splitting
  - Sectoring, and
  - Coverage zone approaches

16.1 Cell splitting

- A process of subdividing a congested cell into smaller cells, each with its own base station and a corresponding reduction in antenna height and transmitter power.
- By cell splitting, number of cells increase in the coverage area. This increases number of cluster in that coverage area i.e., replication factor increases. Thus capacity increases.
- It however increases number of handoff.

Transmit power reduction

- Let original large cell with radius R is split into the small cell with radius R/2.
- Let P_{t1} and P_{t2} be the transmit power of large cell and small cell BS.
- The received power,

$$P_r[\text{at old cell boundary}] \propto P_{t1}.R^{-n}$$

$$P_r[\text{at new cell boundary}] \propto P_{t2}.\left(\frac{R}{2}\right)^{-n} ; \quad \text{n is path loss exponent}$$

- On the basis of equal received power,

$$P_{t1}.R^{-n} = P_{t2}.\left(\frac{R}{2}\right)^{-n} \Rightarrow \frac{P_{t2}}{P_{t1}} = 2^{-n}$$

- Taking log, $10\log_{10}\left(\frac{P_{t2}}{P_{t1}}\right) = -10n\log_{10} 2 \cong -3n$ dB

- That is the transmit power must be reduced by 12 dB (for n = 4) to split the cell into new smaller cell with radius R/2 while maintaining the S/I requirements.
- Cells are split only when needed, so different sized cells will exist in a coverage area. So channel assignments become more complicated. Following points should be considered during cell splitting.

- The distance between co-channel cells should be kept at the required minimum.
- Different transmit power should be used in different sized cells.
- Umbrella cell approach is used to solve handoff issues.
- Channels in old cell are broken down into two channel groups, one for the smaller cell and other for the larger cell. Larger cell is dedicated to high speed users.
  - At beginning of the cell splitting process, fewer channels will be assigned to small cells. As demand grows, more channels will be required. This splitting process continues until all the channels in an area are used in the lower power group.
- Antenna downtilting is often used to limit the radio coverage of newly formed microcell.

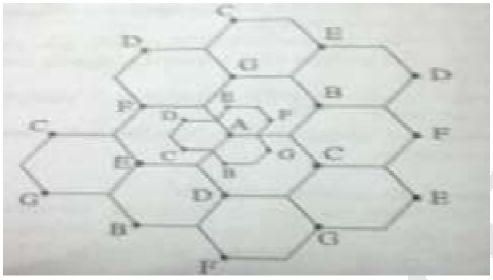


Figure: Illustration of cell splitting.

16.2 Sectoring

- The technique for increasing system capacity by decreasing co-channel interference by using directional antenna is called sectoring.
- By using directional antennas cochannel interference can be reduced. So, the number of cells in a cluster (cluster size) can be reduced and hence frequency reuse is increased. Thus capacity increases.
- A cell is normally partitioned in multiples of 60° (three 120° sectors or six 60° sectors).
- In 7 cell cluster, when 120° sectoring is used, the number of interferer reduces from 6 to 2.

$$\frac{S}{I} = \frac{\left(\sqrt{3N}\right)^{\gamma}}{i_0} = \frac{\left(\sqrt{3\times 7}\right)^{4}}{2} = \frac{(21)^{2}}{2} = 220.5(=10\log 220.5) = 23.43 \text{ dB}$$

- In practical systems, further improvement in S/I is achieved by down-tilting the sector antennas.
- Drawbacks:
  - Number of antennas at base station increases.
  - The channels used in a particular cell are broken down into sectored groups and are used only within a particular sector. So, trunking efficiency decreases.
  - Number of handoff increases. But many modern BSs support sectorization. So, handoff can be easily managed by BS without intervention from the MSC.

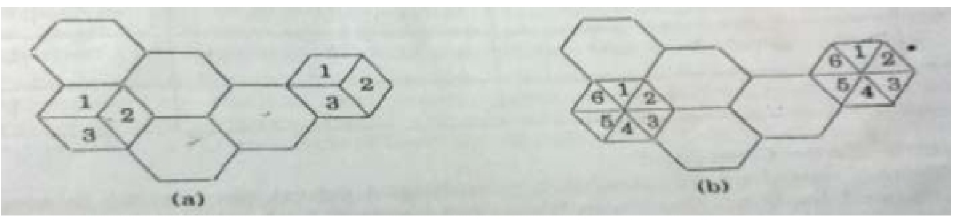


Figure: (a) 120° sectoring; (b) 60° sectoring

16.3 Microcell Zone Concept

- The increased number of handoffs due to sectoring results in an increased load on the MSC. This problem can be solved by implementing a microcell coverage zone concept.
- The cell is divided into number of zones (suppose 3).
- Each zone has an antenna placed at the outer edges of the cell.
- Each zone sites are connected to a single base station through zone selector and share the same radio equipment. The base station assigns any available channel to any zone.
- A mobile is served by the zone with the strongest signal. When a mobile user travels from one zone to another within the cell, it retains the same channel. So, handoff is not required; BS simply switches the channel to a different zone site.
- Since a given channel is active only in the particular zone in which the mobile is traveling, the base station radiation is localized and interference is reduced.
- This method is suitable along highways or along urban traffic corridor.
- The co-channel interference in the cellular system is reduced since a large central BS is replaced by several lower powered transmitters on the edges of the cell. So, the signal quality improves and capacity increases without degradation in trunking efficiency caused by sectoring.

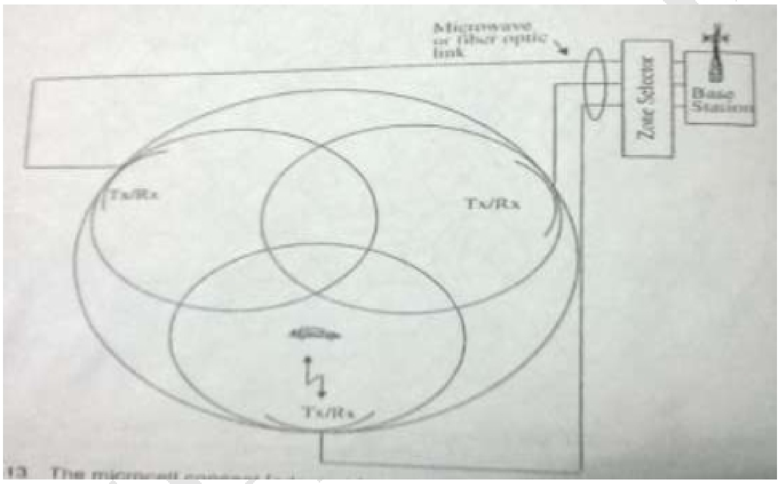


Figure: The microcell concept.

17 Frequency Planning

- As per ITU, for GSM
  - For uplink (mobile station to base station): 890 MHz to 915 MHz.
  - For downlink (base station to mobile station): 935 MHz to 960 MHz.
- There is difference of 45 MHz between uplink and downlink frequency.
- NTC is using following frequency
  - For uplink (mobile station to base station): 890 MHz to 897.2 MHz
  - For downlink (base station to mobile station): 935 MHz to 942.2 MHz
  - Bandwidth is 7.2 MHz in both case
  - 1 slot is 200kHz-> number of channel= $\frac{7.2\ MHz}{200\ kHz}$ = 36
- So frequency x is defined as

$$x = \begin{cases} 890 + 0.2n & ;for\ uplink \\ 935 + 0.2n & ;for\ downlink \end{cases}$$

Where, n=1 to 36

18 Frequency Management and Channel Assignment

- With the rapid increase in number of mobile users, the mobile service providers had to follow strategies which ensure the effective utilization of the limited radio spectrum.
- With increased capacity and low interference being the prime objectives, a frequency reuse scheme was helpful in achieving this objectives.
- The frequency management in a cellular system divides the entire channels available into the subsets that can be assigned to each cell in two modes.
- It may be either fixed or dynamic. A fixed channel that contains subsets are allocated to a cell site in a long term basis. But, when a call is on progress, a particular channel is allocated to a mobile unit in a short term basis.
- Frequency management and channel assignment are different
    - Frequency management includes operations such as,
        i. Designating set-up channels and the voice channels.
        ii. Numbering the channels
        iii. Grouping voice channels into the subsets etc.
    - Channel assignment does the allocation of specific channel to the cell sites and mobile units.

18.1 Fixed channel assignment scheme

- In Fixed channel assignment (FCA) schemes, a set of channels is permanently allocated to each cell in the network.
- If the total number of available channels in the system S is divided into sets, the minimum number of channel sets *N* required to serve the entire coverage area is related to the frequency reuse distance *D* as follows:

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

- A call attempt is served only if the cell has unused channel.
- If all channel are occupied, the call is blocked.
- To improve utilization borrowing strategy is used.

18.2 Dynamic channel assignment scheme

- Voice channels are not allocated to the cells permanently.
- Each time a call request is made, the serving base station request a channel from the MSC.
- MSC then allocates a frequency that is not presently in use in the cell or any other cell which within the minimum restricted distance of frequency reuse to avoid co-channel interference.
- Advantages:
    - It reduces the probability of blocking because all available channels are accessible to the cells.
    - Channel utilization increases.
- Disadvantages:
    - In this strategy, MSC has to collect real time data on channel occupancy, traffic distribution and radio signal strength indications (RSSI) of all channels on a continuous basis.
    - This increase the storage and computational load on the system.
- In DCA schemes, all channels are kept in a central pool and are assigned dynamically to new calls as they arrive in the system.
- After each call is completed, the channel is returned to the central pool. It is fairly straightforward to select the most appropriate channel for any call based simply on current allocation and current traffic, with the aim of minimizing the interference.
- DCA scheme can overcome the problem of FCA scheme. However, variations in DCA schemes center around the different cost functions used for selecting one of the candidate channels for assignment.
- DCA schemes can be centralized or distributed.
- The centralized DCA scheme involves a single controller selecting a channel for each cell;
- The distributed DCA scheme involves a number of controllers scattered across the network (MSCs).
- Centralized DCA schemes can theoretically provide the best performance. However, the enormous amount of computation and communication among BSs leads to excessive system latencies and renders centralized DCA

schemes impractical. Nevertheless, centralized DCA schemes often provide a useful benchmark to compare practical decentralized DCA schemes.

❖ **Centralized DCA**

- For a new call, a free channel from the central pool is selected that would maximize the number of members in its co-channel set.
- Minimize the mean square of distance between cells using the same channel.

Scheme	Description
First Available (FA)	Among the DCA schemes the simplest one is the FA strategy. In F A, the first available channel within the reuse distance encountered during a channel search is assigned to the call. The FA strategy minimizes the system computational time.
Locally Optimized Dynamic Assignment (LODA)	The channel selection is based on the future blocking probability in the vicinity of the cell where a call is initiated.
Selection with Maximum Usage on the Reuse Ring (RING)	A candidate channel is selected which is in use in the most cells in the co-channel set. If more than one channel has this maximum usage, an arbitrary selection among such channel is made to serve the call. If none is available, then the selection is made based on the FA scheme.

Scheme	Description
Mean Square (MSQ),	The MSQ scheme selects the available channel that minimizes the mean square of the distance among the cells using the same channel.
1-clique	This scheme uses a set of graphs, one for each channel, expressing the non co-channel interference structure over the whole service area for that channel.

❖ **Distributed DCA Schemes**

- Based on one of the three parameters:
    - Co-channel distance
      - co-channel cells in the neighborhood not using the channel
      - sometimes adjacent channel interference taken in to account
    - Signal strength measurement
      - anticipated CIR above threshold
    - Signal to noise interference ratio
      - satisfy desired CIR ratio

18.3 Comparison between FCA and DCA

FCA	DCA
▪ Performs better under heavy traffic	▪ Performs better under light/moderate traffic
▪ Low flexibility in channel assignment	▪ Flexible channel allocation
▪ Maximum channel reusability	▪ Not always maximum channel reusability
▪ Sensitive to time and spatial changes	▪ Insensitive to time and time spatial changes
▪ Not stable grade of service per cell in an interference cell group	▪ Stable grade of service per cell in an interference cell group
▪ High forced call termination probability	▪ Low to moderate forced call termination probability
▪ Suitable for large cell environment	▪ Suitable in microcellular environment
▪ Low flexibility	▪ High flexibility

FCA	DCA
▪ Radio equipment covers all channels assigned to the cell ▪ Independent channel control ▪ Low computational effort ▪ Low call set up delay ▪ Low implementation complexity ▪ Complex, labor intensive frequency planning ▪ Low signaling load ▪ Centralized control	▪ Radio equipment covers the temporary channel assigned to the cell ▪ Fully centralized to fully distributed control dependent on the scheme ▪ High computational effort ▪ Moderate to high call set up delay ▪ Moderate to high implementation complexity ▪ No frequency planning ▪ Moderate to high signaling load ▪ Centralized, distributed control depending on the scheme

18.4 Hybrid Channel Allocation (HCA)

- HCA schemes are the combination of both FCA and DCA techniques.
- In HCA schemes, the total number of channels available for service is divided into fixed and dynamic sets.
  - The fixed set contains a number of nominal channels that are assigned to cells as in the FCA schemes and, in all cases, are to be preferred for use in their respective cells.
  - The dynamic set is shared by all users in the system to increase flexibility.

  Example: When a call requires service from a cell and all of its nominal channels are busy, a channel from the dynamic set is assigned to the call.

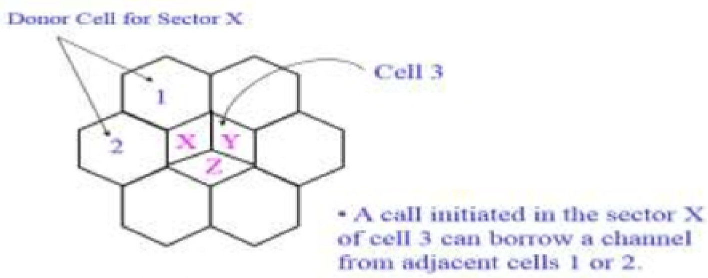
- Request for a channel from the dynamic set is initiated only when the cell has exhausted using all its channels from the fixed set.
- Optimal ratio: ratio of number of fixed and dynamic channels.
- 3:1 (fixed to dynamic), provides better service than fixed scheme for 50% traffic.
- Beyond 50% fixed scheme perform better.
- For dynamic, with traffic load of 15% to 32%, better results are found with HCA.

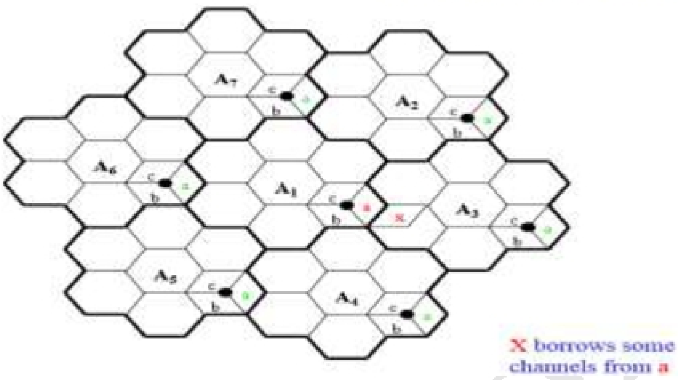
18.5 Flexible Channel Allocation (FCA)

- Similar to hybrid scheme with channels divided into fixed and flexible (emergency) sets.
- Fixed sets used to handle lighter loads.
- Variations in traffic (peaks in time and space) are needed to schedule emergency channels.
- Two types: Scheduled and Predictive
- *Scheduled*: Prior estimate is done about traffic change
- *Predictive*: Traffic intensity and blocking probability is monitored in each cell all the time.

18.6 Simple Channel Borrowing (CB) Schemes

- In CB schemes, cell (acceptor cell) that has used all its nominal channels can borrow free channels from its neighboring cell (*donor cell)* to accommodate new calls.
- Borrowing can be done from an adjacent cell which has largest number of free channels (*borrowing from the richest*).
- Select the first free channel found for borrowing using a search algorithm (*borrow first available scheme*).
- Return the borrowed channel when channel becomes free in the cell (*basic algorithm with reassignment*).
- MSC (Mobile Switching Center) supervises such borrowing procedures and also ensure the borrowing of channels does not interfere with any of the calls in progress in the cell.





Scheme	Description
Simple Borrowing (SB)	A nominal channel set is assigned to a cell, as in the FCA case. After all nominal channels are used, an available channel from a neighboring cell is borrowed.
Borrow from the Richest (SBR)	Channels that are candidates for borrowing are available channels nominally assigned to one of the adjacent cells of the acceptor cell. If more than one adjacent cell has channels available for borrowing, a channel is borrowed from the cell with the greatest number of channels available for borrowing.
Basic Algorithm (BA)	This is an improved version of the SBR strategy which takes channel locking into account when selecting a candidate channel for borrowing. This scheme tried to minimize the future call blocking probability in the cell that is most affected by the channel borrowing.
Basic Algorithm with Reassignment (BAR)	This scheme provides for the transfer of a call from a borrowed channel to a nominal channel whenever a nominal channel becomes available.
Borrow First Available (BFA)	Instead of trying to optimize when borrowing, this algorithm selects the first candidate channel it finds.

- It is a combination of fixed and dynamic channel assignment. A channel set is nominally assigned to each cell (like in FCA).
- When all the channels in a cell are occupied, the cell borrows channels from other cells to accommodate the incoming new/handoff calls, as long as the borrowed channels do not interfere with the ones used by existing calls (at this point it works like DCA). Otherwise the call is blocked.
- The channel borrowing schemes are more flexible in the sense that by "moving" (borrowing) channels from less busy cells to more busy cells, a balanced performance throughout in the system can be achieved.
- Borrowing a channel x carries a penalty: cells that were originally allocated this channel x, may not be able to use this channel, since they may be within the co-channel interference range of the cell that borrowed the channel.
- Thus the decreased blocking probability at the cell that borrowed a channel is obtained at the cost of decreasing the capacity of other cells, which in turn causes QoS degradation in these cells.

- The basic channel borrowing strategy gives better performance (lower blocking) than FCA strategy under light and moderate traffic conditions, especially under unbalanced traffic. In heavy traffic conditions channel borrowings may proliferate to such an extent that the channel usage efficiency drops drastically (so that FCA outperforms borrowing strategy).
- Combining the advantages of these two mechanisms: A set of nominal channels is assigned to each cell. This set is subdivided into two subsets A and B. Subset A channels are used in the local cell only, while subset B channels can be lent to the neighboring cells. The optimal ratio #A/#B depends on the traffic load.

- **Channel Borrowing Enhancements/Variations**
- **Borrowing with channel-ordering (BCO):** All channels are ordered and the first channel has the highest priority to be assigned to the next local call, while the last channel has the highest priority to be borrowed by the neighboring cells. As a result the ratio (#A/#B) varies according to the traffic load. After a channel is borrowed it is locked in the co-channel cells within the channel reuse distance of the borrowing cell.
- **Minimum influence borrowing:** The minimum influence borrowing algorithm aims to borrow the channel that has minimum impact on the overall performance of the system. When channel borrowing in necessary, all the borrow-able channels are compared in terms of the traffic conditions in the blocked cells of each borrow-able channel, and predictions are made accordingly. Then the channel that will cause the least QoS degradation in the expected future is chosen.
- **Channel Reallocation:** The channel reallocation process aims at minimizing the time that a borrowed channel is used. Instead of returning the channel when the call that uses the borrowed channel completes or hands off, if there is a channel that is released by another call in the borrower cell, the borrowed channel is returned and the released channel (which belongs to its nominal set) is allocated to this call.
- **Borrowing with directional channel locking (BDCL):** In the basic borrowing scheme after a channel is borrowed it is locked in the co-channel cells within the channel reuse distance of the borrowing cell. This is too stringent and therefore locking should refer only to those cells (in that direction) in the co-channel set that are actually affected by the borrowing of the channel.

19 Handoffs

- When a user/call moves to a new cell, then a new base station and new channel should be assigned (handoff).
- Handoffs should be transparent to users, while their number should be kept to minimum.
- A threshold in the received power (Pr, handoff) should be determined to trigger the handoff process. This threshold value should be larger than the minimum acceptable received power (Pr, acceptable).
- Define: Δ=Pr,handoff - Pr,acceptable
  - If Δ is large then too many handoffs
  - If Δ is small then insufficient time to complete a handoff
- If Δ is too large, unnecessary handoff which burden the MSC may occur, and if Δ is too small, there may be insufficient time to complete a handoff before a call is lost due to weak signal conditions.
- Therefore, Δ is chosen carefully to meet these conflicting requirements.
- In order to correctly determine the beginning of handoff, we need to determine that a drop in the signal strength is not due to the momentary (temporary) bad channel condition, but it is due to the fact that the mobile is moving away from BS.
- Thus the BS needs to monitor the signal level for a certain period of time before initiating a handoff. The length of the time (running average measurements of signal) and handoff process depends on speed and moving pattern.
- First generation systems typical time interval to make a handoff was 10 seconds (large Δ). Second generations and after typical time interval to make a handoff is 1-2 seconds (small Δ).
- First generation systems: handoff decision was made by BS by measuring the signal strength in reverse channels.
- Second generation and after: Mobile Assisted Hand-Off (MAHO). Mobiles measure the signal strength from different neighboring BSs. Handoff is initiated if the signal strength from a neighboring BS is higher than the current BS's signal strength.

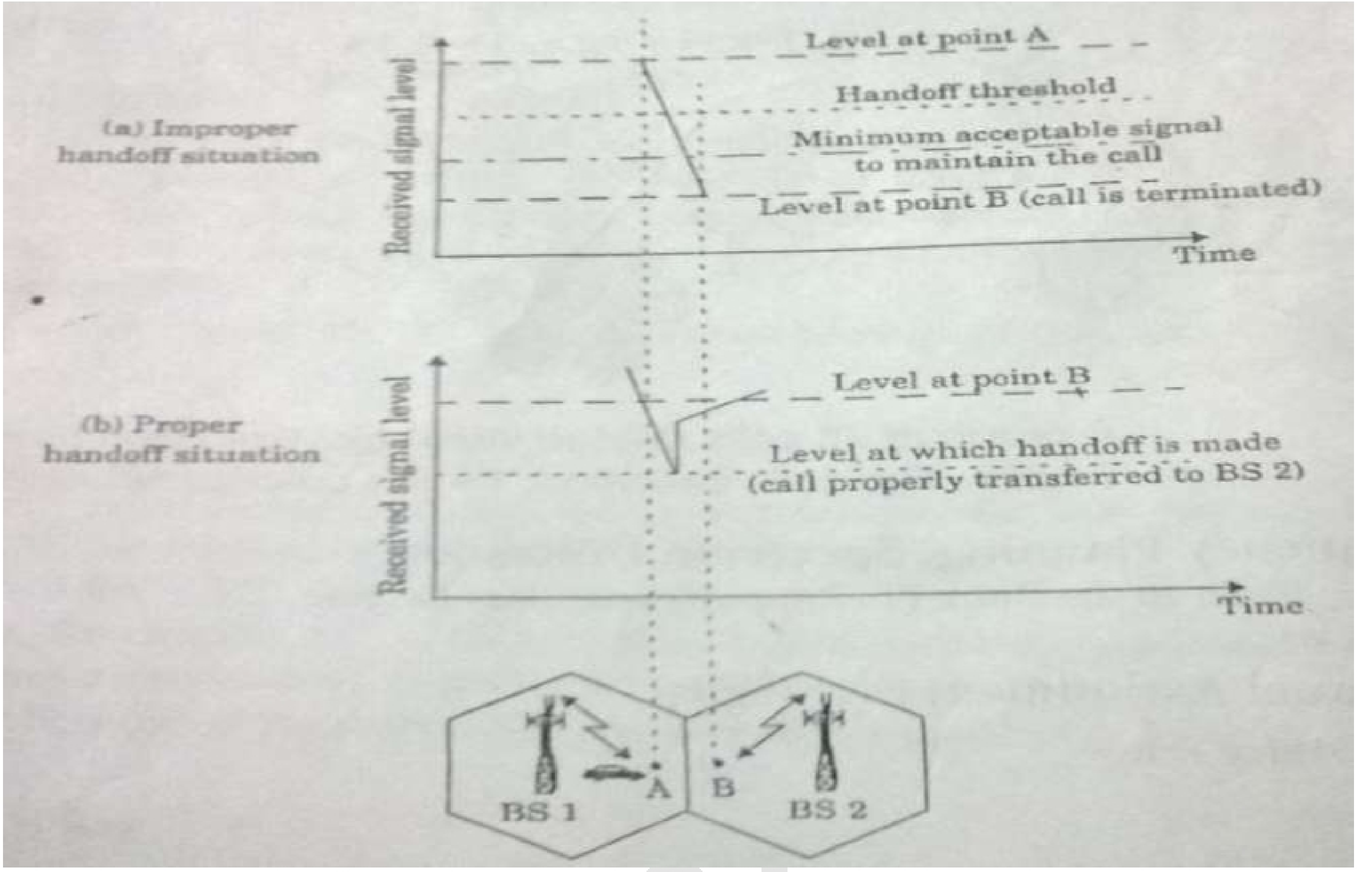


Figure: Illustration of a handoff scenario at cell boundary.

- Figure (a) above illustrates a case where a handoff is not made and the signal drops below the minimum acceptable level to keep the channel active.
- This dropped call event can happen when there is an excessive delay by the MSC in assigning a handoff or when the threshold Δ is set too small for the handoff time in the system.
- Excessive delays may occur during high traffic conditions due to computational loading at the MSC or due to the fact no channel s are available on any nearby base stations.
- By using different antenna heights (often on the same building or tower) and different power levels, it is possible to provide "large" and 'small" cells, which are co-located at a single location.
- This technique is called "umbrella cell approach" and used to provide large area coverage to high-speed users while providing small area coverage to users traveling at low speeds.
- This approach ensures that the number of handoffs is minimized for high-speed users.

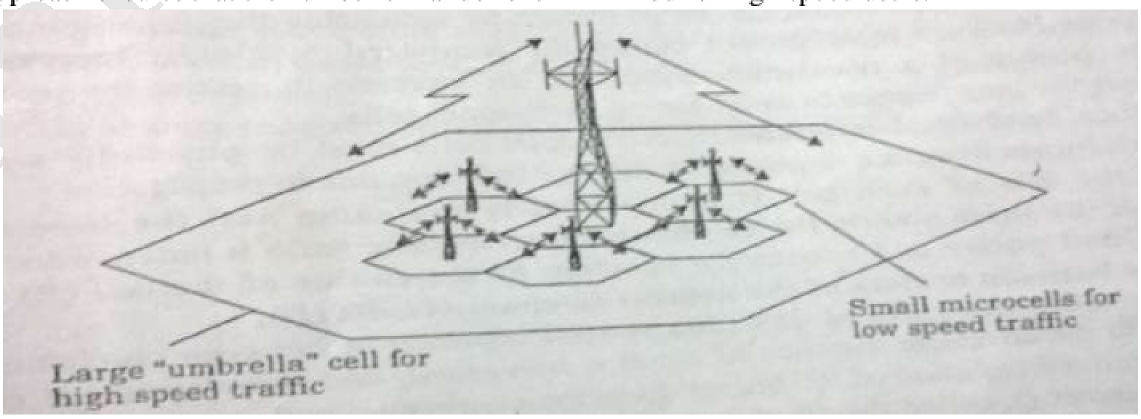


Figure: The umbrella cell approach.

❖ **Cell Dwell Time**

- It is the time over which a call maybe maintained within a cell (without handoff).
- It depends on: propagation, interference, distance between BS and MS, speed and moving pattern (direction), etc.
- Highway moving pattern: the cell dwell time is a r.v. with distribution highly concentrated around the mean.
- Other micro-cell moving patterns mix of different user types with large variations of dwell time (around the mean).

❖ **Call Admission Control**

- The function of call admission control is to determine whether or not to grant radio resources to a new incoming/handoff call based on information such as the current channel occupation, the bandwidth and QoS requirements of calls in service, and the characteristics of the call that requests admission
  – Call rejection (reject the admission of new call)
  – Call dropping (forcing an ongoing call to premature termination)

❖ **Intersystem Handoff**

- If mobile moves from one cellular system/cluster to a different cellular system/cluster controlled by different MSCs, connection status information has to be transferred from the current serving MS to the new MSC, such type of handoff is called an intersystem handoff. It takes longer time to make handoff.
- In intersystem handoff
  - A local call may become a long distance call as the mobile moves out of its home system and become a roamer in a neighboring system.
  - Compatibility between the two MSCs must be determined before implementing handoff.

❖ **Prioritizing Handoffs**

- **Guard Channels:** Fraction of total bandwidth in a cell is reserved for exclusive use of handoff calls. Therefore, total carried traffic is reduced if fixed channel assignment is used. However, if dynamic channel assignment is used the guard channel mechanisms may offer efficient spectrum utilization.
  - Number of channels to be reserved: If it is low (under-reservation) the QoS on handoff call blocking probability cannot be met. If reservation is high (over-reservation) may result in waste of resources and rejection of large number of new calls.
  - Static and Dynamic schemes: Advantage of static scheme is its simplicity since no communication and computation overheads are involved. However problems of under-reservation and over-reservations may occur if traffic does not conform to prior knowledge. Dynamic schemes may adjust better to changing traffic conditions.
- **Queuing Handoffs**: The objective is to decrease the probability of forced determination of a call due to lack of available channels. When a handoff call (and in some schemes a new call) cannot be granted the required resources at the time of its arrival, the request is put in a queue waiting for its admitting conditions to be met.
  - This is achieved because there is a finite time interval between the time that the signal of a call drops below the handoff threshold, and the time that the call is terminated due to low (unacceptable) signal level. Queuing and size of buffer depends on traffic and QoS. Queueing in wireless systems is possible because signaling is done on separate control channels (without affecting the data transmission channels).
- According to the types of calls that are queued, queuing priority schemes are classified as: handoff call queuing, new call queuing and handoff/new call queuing (handoff calls are given non-preemptive priority over new calls).

❖ **Types of Handoff**

❑ **Hard Handoff**

- A Hard handoff is one in which the channel in the source cell is released and only then the channel in the target cell is engaged. Thus the connection to the source is broken before the connection to the target is made. For this reason such handoffs are also known as break-before-make.

- Hard handoffs are intended to be instantaneous in order to minimize the disruption to the call and transparent to the users.
- Network engineers perceive a hard handoff as an event during the call.
- The phenomenon most common in non-CDMA networks.

Soft Handoff

- A Soft handoff is one in which the channel in the source cell is retained and used for a while in parallel with the channel in the target cell.
- In this case the connection to the target is established before the connection to the source is broken, hence this handoff is called make-before-break.
- The interval, during which the two connections are used in parallel, may be brief or substantial, for this reason the soft handoff is perceived by network engineers as a state of the call, rather than a brief event.
- When a call is in a state of soft handoff the signal of the best of all used channels can be utilized for the call at a given moment or all the signals can be combined to produce a clearer copy of the signal.

20 GSM System for mobile (GSM)

- GSM was the world's first digital cellular system (second generation cellular system) in Europe to specify the digital modulation and network level architectures and services.
- Before GSM, European countries used different cellular standards throughout the continent and it was not possible for customer to use a single subscriber unit throughout the Europe.
- GSM was originally developed to serve as pan-European cellular service in 900MHz (now also available in 1800MHz frequency band)
- GSM (standard set by ETSI) was first introduced into the European market in 1991 and how the world's most popular standard.

20.1 GSM Service and Features

- **GSM Services are classified as:**
  - **Teleservices:** includes standard mobile telephony (mobile originate or base-originated traffic)
  - **Data services:** computer to computer communication and packet switched traffic
- User Services, divided into three major categories:
  - **Telephone services** (including emergency calling and facsimile)
  - **Bearer services or Data services** (data rate from 300bps to 9.6kbps)
  - **Supplementary ISDN services** (includes call diversion, closed user group and caller identification, not available in analog mobile networks, Short messaging service (SMS)-pages of limited length 160 7-bit ASCII character-can be used for safety and advisory applications.
- **GSM Features**
  - **SIM:** One of the most remarkable features of GSM is the Subscriber Identity Module (SIM), which is a memory device that stores information such as subscriber's identification number, the networks and countries where the subscriber is entitled to service, privacy keys and other user-specific information.
  - **On-the-air Privacy:** Another remarkable feature is the On-the-air privacy which is provided by the system and therefore it is virtually impossible to eavesdrop (listen without the speaker's knowledge) on GSM radio transmission.
  - **Global roaming**

20.2 GSM System Architecture

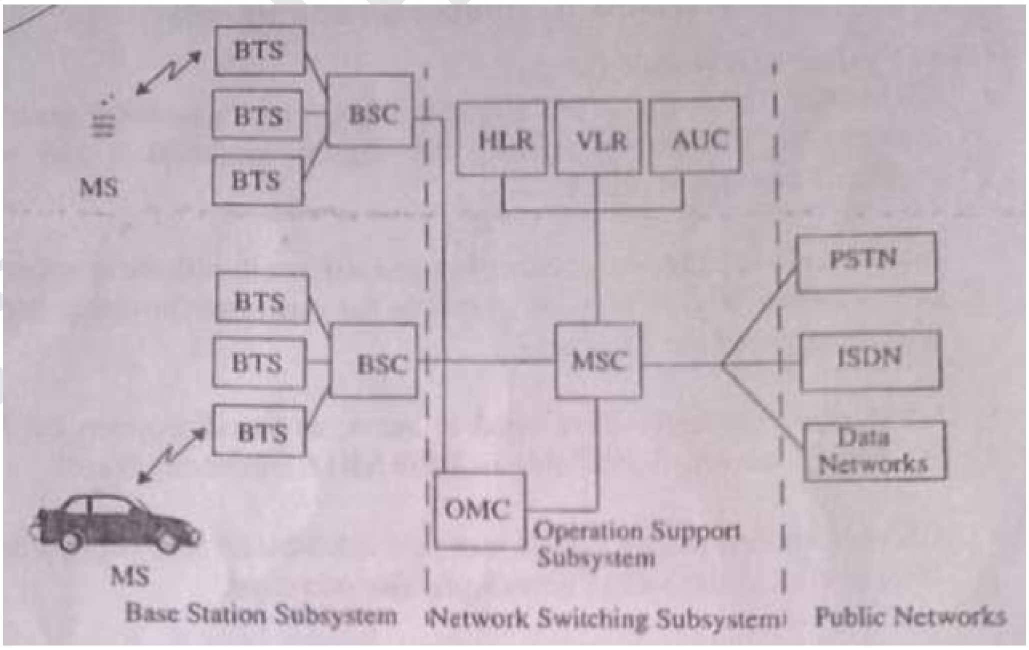


Figure: GSM system Architecture

- GSM system architecture consists of three major interconnected subsystems
  - Base Station Subsystem (BSS)
  - Network and Switching Subsystem (NSS)
  - Operation Support Subsystem (OSS)
- These subsystem interact between themselves and with the users through certain network interfaces.
- BSS, also known as radio subsystem
  - Provides and manages radio transmission paths between the mobile stations (MS) and the Mobile Switching Center (MSC).
  - Consist of many Base Station Controllers (BSCs) which connect the MS to the NSS via the MSCs.
- The NSS manages the switching functions of the system and allows the MSCs to communicate with other networks such as the PSTN and ISDN.
- The OSS supports the operation and maintenance of GSM and allows system engineers to monitor, diagnose and troubleshoot all aspects of GSM system.
- The MS communicate with the BSS over the radio air interface (called Um interface).
- The BSS consist of many BSCs which connect to a single MSC and each BSC typically controls up to several hundred Base Transceiver Stations (BTSs).
- Mobile handoffs (called handovers in GSM specification) between two BTSs under the control of same BSC are handled by the BSC and not by the MSC (this reduced switching burden to the MSC).

20.3 GSM Interfaces:

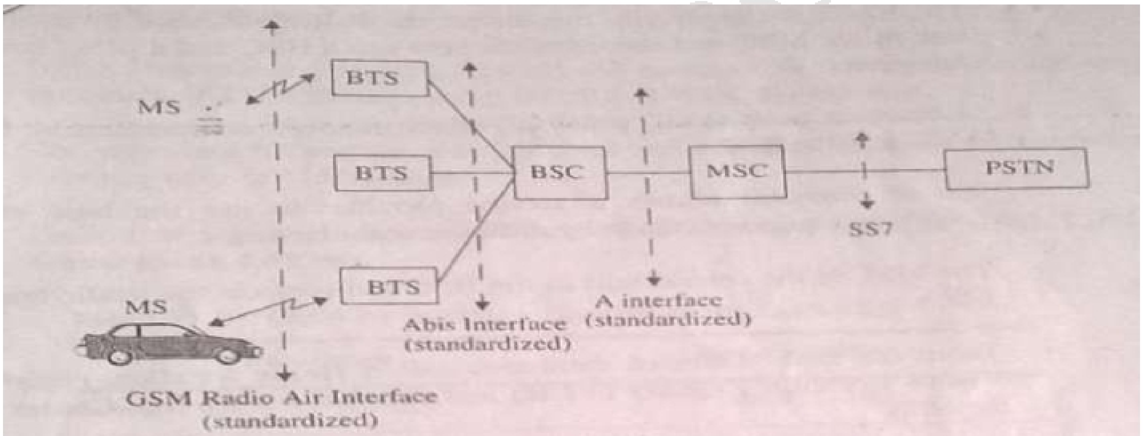


Figure: The various interfaces used in GSM

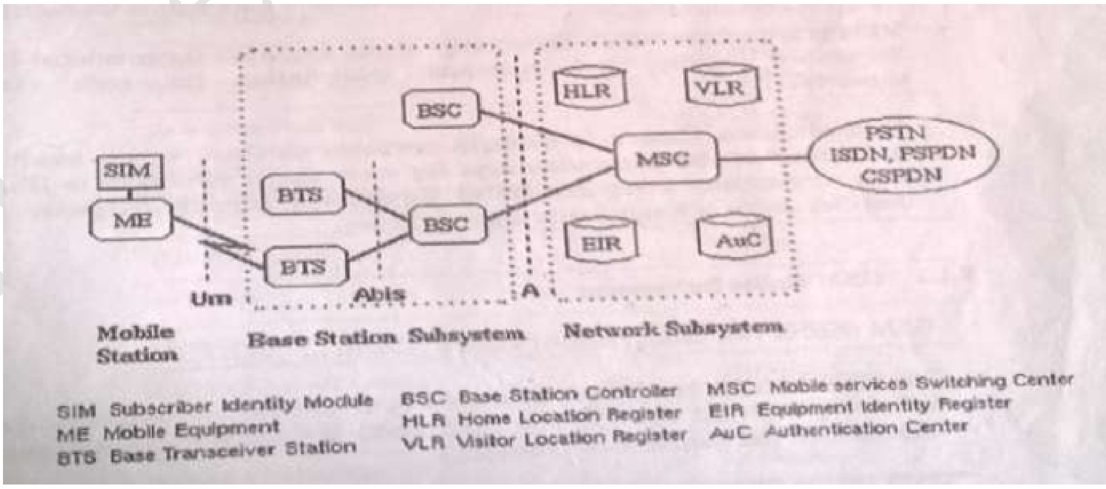


Figure: General architecture of a GSM network

- The interface that connect a BTS to a BSC is called Abis interface which carries traffic and maintenance data
- In practice the Abis for each GSM base station manufacturer has a subtle differences, and therefore, the service providers has to use the same manufacturer for the BTS and BSC equipment.
- The BSCs are physically connected via dedicated/leased lines or microwave link to the MSC and the interface between a BSC and a MSC is called the *A interface*.
- *A interface* uses an SS7 protocol which supports communication between the MSC and the BSS.
- The *A interface* allows a service provider to use the base stations and switching equipment made by different manufactures.
- The MSC is the central unit in the NSS and controls the traffic among all the BSCs.
- There are three different database called Home Location Register (HLR), Visitor Location register (VLR), and the Authentication Center (AUC) in the NSS.
- HLR contains subscriber information and location information for each user.
- VLR is a database which temporarily stores the IMSI (International Mobile Subscriber Identity) and customer information for each roaming subscriber.
- Authentication Center is strongly protected database which handles the authentication and encryption keys for every single subscriber in HLR and VLR. It contains a register called Equipment Identity Register which identifies stolen or fraudulently altered phones.

20.4 GSM Radio Subsystem

- GSM utilizes two bands (890-915 and 935-960) of 25 MHz
- The 890-915 MHz band is used for subscriber-to-base transmissions (reverse link or uplink) and is used for base-to-subscriber transmission (forwardlink or downlink)
- GSM used FDD and combination of TDMA and FHMA schemes to provide base stations with simultaneous access to multiple users.
- The available forward and reverse frequency bands are divided into 200KHz wide channels called ARFCN (Absolute Radio Frequency Channel Numbers)
- The ARFCN denotes a forward and reverse channel pair which is separated in 45 MHz
- Each of eight subscribers uses the same ARFCN and occupies a unique time slot (TS) per frame
- Radio Transmission on both forward and reverse link are made at a channel data rate of 270.833 kbps using BT=0.3GMSK modulation
- The signaling bit duration is 3.692 µs and effective channel transmission rate per user is 33.854 kbps
- Each time slot has a time duration of 576.25 µs and a single GSM TDMA frame spans 4.615 ms

Table: GSM Air interface Specifications Summary

Reverse Channel Frequency	890–915 MHz
Forward Channel Frequency	935–960 MHz
ARFCN Number	0 to 124 and 975 to 1023
Tx/Rx Frequency Spacing Tx/Rx Time Slot Spacing	45 MHz 3 Time slots
Modulation Data Rate	270.833333 kbps
Frame Period	4.615 ms
Users per Frame (Full Rate)	8
Time Slot Period	576.9 µs
Bit Period	3.692 µs
Modulation	0.3 GMSK
ARFCN Channel Spacing	200 kHz
Interleaving (max. delay)	40 ms
Voice Coder Bit Rate	13.4 kbps

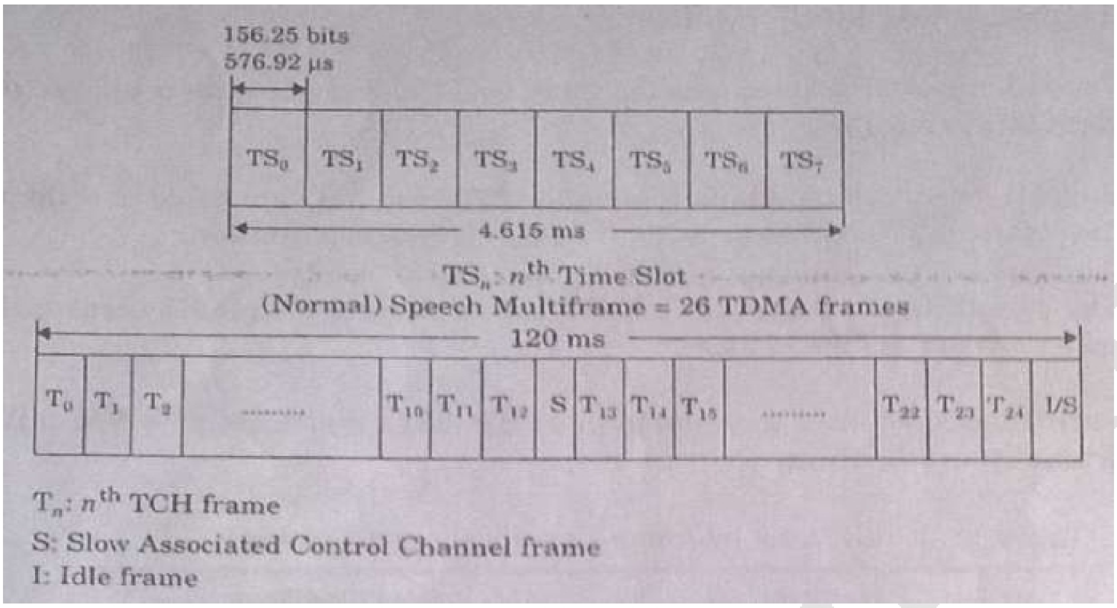


Figure: The speech dedicated control channel frame and multiframe structure

20.5 GSM Channel Types

- The combination of a *TS number and an ARFCN constitute a physical channel* for both forward and reverse link.
- Each physical channel can be mapped into different logical channels at different times i.e. each specific time slot or frame may be dedicates to handling traffic data, signaling data or control channel data.
- There are two types of GSM logical channels called traffic channels (TCH) and control channels (CCH).
- Traffic channels carry digitally encoded user speech or user data whereas control channels carry signaling and synchronizing commands between BTS and MS.
- GSM traffic channels may be either full-rate or half-rate and may carry either digitized speech or user data.
- When transmitted as full-rate, user data is contained within one TS per frame and when transmitted as half-rate, user data is mapped onto the same time slot but sent in alternate frames i.e two half rate channel users would share the same time slot.
- Broadcast channel (BCH), the command control channel (CCCH) and the dedicated control channel (DCCH) are the three main control channels.
- The BCH and CCCH forward control channels in GSM are allocated only ***TS0*** and are broadcast only during certain frames within a repetitive fifty-one frame sequence on those ARFCNs which are designated as broadcast channels.
- TS1 through TS7 carry regular TCH traffic.
- The GSM specification defines 34 ARFCNs as standard broadcast channels.
- DCCH data is sent during any time slot and any frame and entire frames are specifically dedicated to certain DCCH transmissions.

20.6 GSM Bursts

- Each user transmits a burst of data during the time slot assigned to it, which may have one of five specific formats as defined in GSM.
- **Normal bursts** are used for TCH and DCCH transmissions on both the forward and reverse link.
- **FCCH (Frequency correction channel)** and **SCH (Synchronization Channel)** bursts are used in TS0 of specific frames to broadcast the frequency and time synchronization control messages on the forward link.
- The **RACH (Random Access Channel) burst** is used by all mobiles to access service from any base station.
- **Dummy burst** is used as filler information for unused time slots on the forward link.

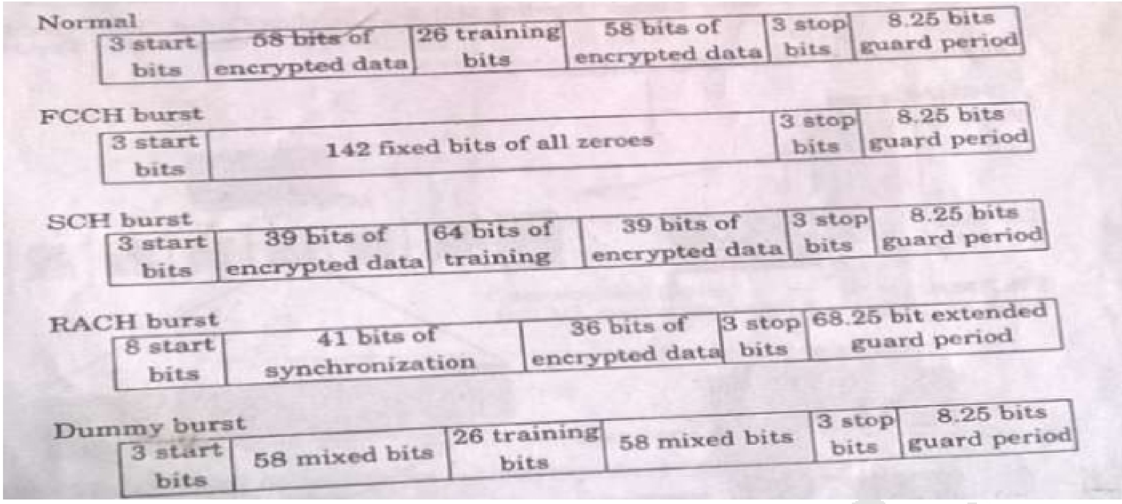


Figure: Time slot data bursts in GSM.

20.7 Frame Structure for GSM

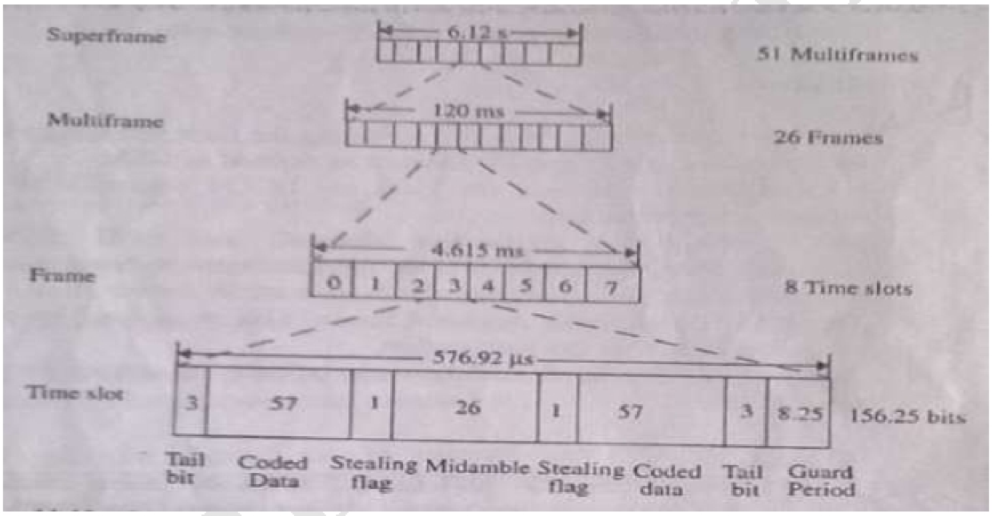


Figure: GSM frame structure

20.8 Signal Processing in GSM

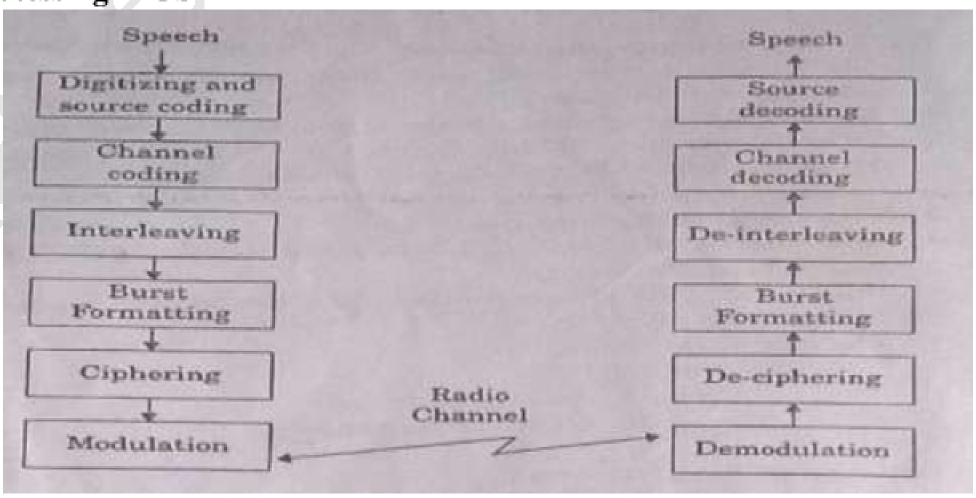


Figure: GSM operations from speech input to speech output

- The figure above indicates all of the GSM operations from transmitter to receiver.
- **Speech Coder:** Based on the Residually Excited Linear Predictive Coder (RELP), provides 260 bits for each 20ms blocks of speech, yields a bit rate of 13 kbps, uses VAD, operate in DTX and uses CNG.

Full Rate Speech Coding

- Used Residually Excited Linear Predictive Coder (RELP) enhanced by LTP (Long Term Predictor)
- Coder for 20ms segments-260 bits at the output.
- Yield bit rate 13 Kbps.
- Unequal error protection:
    - Out of 260 bits
        - 182 bits are protected.
        - 78 bits are not protected.

Coding and Error Control

- Type 1a - 3 parity bits from 50 bits.
- Type 1b - 132 bits are not parity checked, but fed to convolutional encoder.
- Type 2 - 78 bits are not protected.

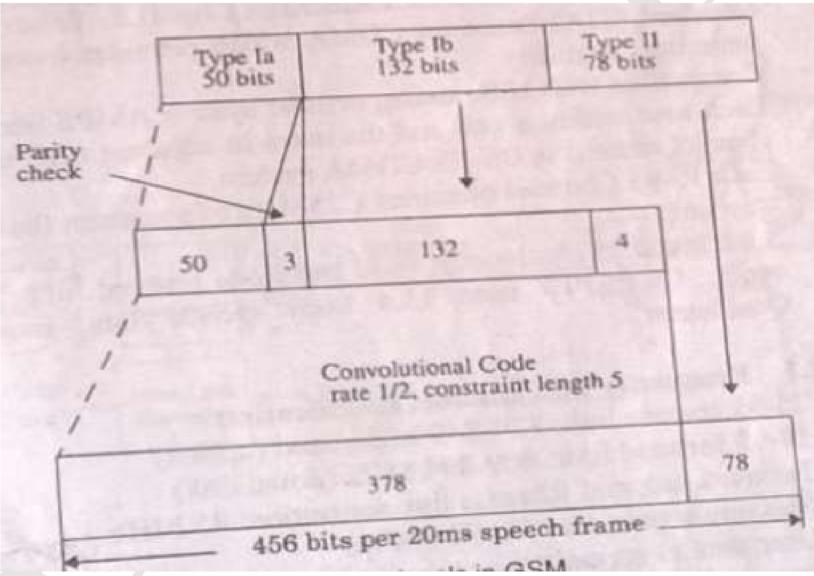


Figure: Error Protection for speech signals in GSM

21 CDMA

- Interim Standard (IS) 95 standardized by U.S. Telecommunications Industry Standard (TIA) based on CDMA which provides increased capacity and anti-jamming capability.
- Compatible with U.S. analog cellular system AMPS frequency band
- Each user within a cell and the users in adjacent cells can use the same radio channel since it is DS-SS CDMA system.
- Each IS-95 Channel occupies 1025 MHz of spectrum (bandwidth) on each one-way link.
- Speech coder: Qualcomm 9600 bps Code Excited Linear Predictive (QCELP) coder, QCELP13 uses 13.4 kbps speech data, introduced in 1995 by Qualcomm.

21.1 Frequency and channel specification

- IS-95 reverse link: 824-849 MHz band (uplink)
- IS-95 forward link: 869-894 MHz (downlink)
- Forward link and Reverse link separation: 45 MHz
- Maximum user data rate: 9.6 Kbps
- User data is spread to a channel chip rate of 1.2288 Mchip/s (total spreading factor of 128)
- Spreading technique is different for forward and reverse link.
- In forward link, user data stream is encoded using ½ convolution code, interleaved, and spread by one of sixty-four orthogonal spreading sequences (Walsh Code).
- Each mobile in a given cell is assigned a different spreading sequence, providing perfect separation among the signals from different users.

21.2 Forward CDMA channel

Table: IS-95 Forward Traffic Channel Modulation Parameters Summary (does not reflect new 13.4 kbps coder)

Parameter	Data Rate (bps)			
User data rate	9600	4800	2400	1200
Coding Rate	1/2	1/2	1/2	1/2
User Data Repetition Period	1	2	4	8
Baseband Coded Data Rate	19,200	19,200	19,200	19,200
PN Chips/Coded Data Bit	64	64	64	64
PN Chip Rate (Mcps)	1.2288	1.2288	1.2288	1.2288
PN Chips/Bit	128	256	512	1024

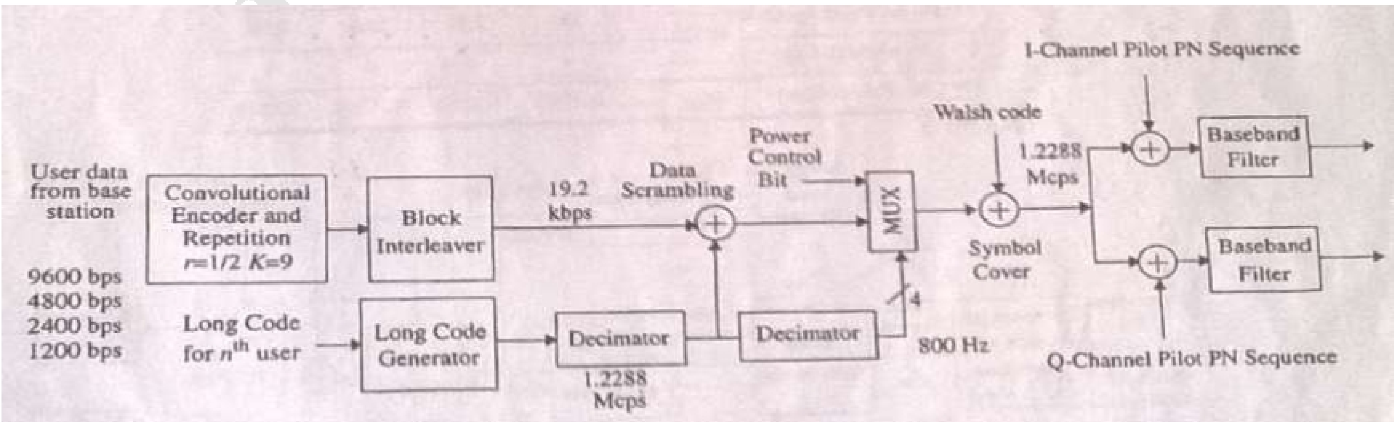


Figure: Forward CDMA channel modulation process

21.3 Reverse CDMA channel

- User data on the reverse channel are grouped into 20ms frames.
- All data transmitted on the reverse channel are convolutionally encoded, block interleaved, modulated by 64-ary orthogonal modulation and spread prior to transmission.
- The speech or user data rate in the reverse channel may be sent at 9600, 2400 or 1200 bps.
- The **reverse channel** is made up Access channel (AC) and reverse traffic channels (RTC).

Table: Reverse Traffic Channel Modulation Parameters Summary (does not reflect recent 13.4 kbps coder)

Parameter	Data Rate (bps)			
User data rate	9600	4800	2400	1200
Code Rate	1/3	1/3	1/3	1/3
TX Duty Cycle (%)	100.0	50.0	25.0	12.5
Coded Data Rate (sps)	28,800	28,800	28,800	28,800
Bits per Walsh Symbol	6	6	6	6
Walsh Symbol Rate	4800	4800	4800	4800
Walsh Chip Rate (kcps)	307.2	307.2	307.2	307.2
Walsh Symbol Duration (μs)	208.33	208.33	208.33	208.33
PN Chips/Code Symbol	42.67	42.67	42.67	42.67
PN Chips/Walsh Symbol	256	256	256	256
PN Chips/Walsh Chip	4	4	4	4
PN Chip Rate (Mcps)	1.2288	1.2288	1.2288	1.2288

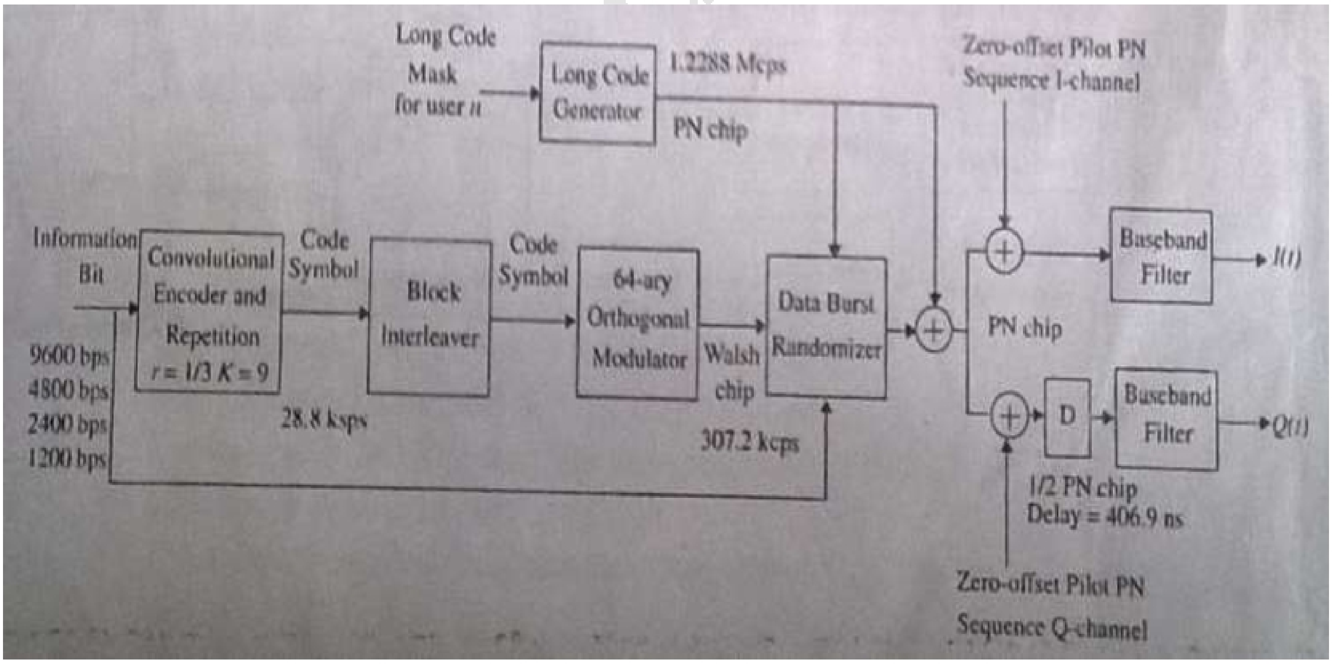


Figure: Reverse IS-95 channel modulation process for single user