MODULE 3. CELLULAR CONCEPTS AND ACCESS TECHNIQUES

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- Frequency reuse
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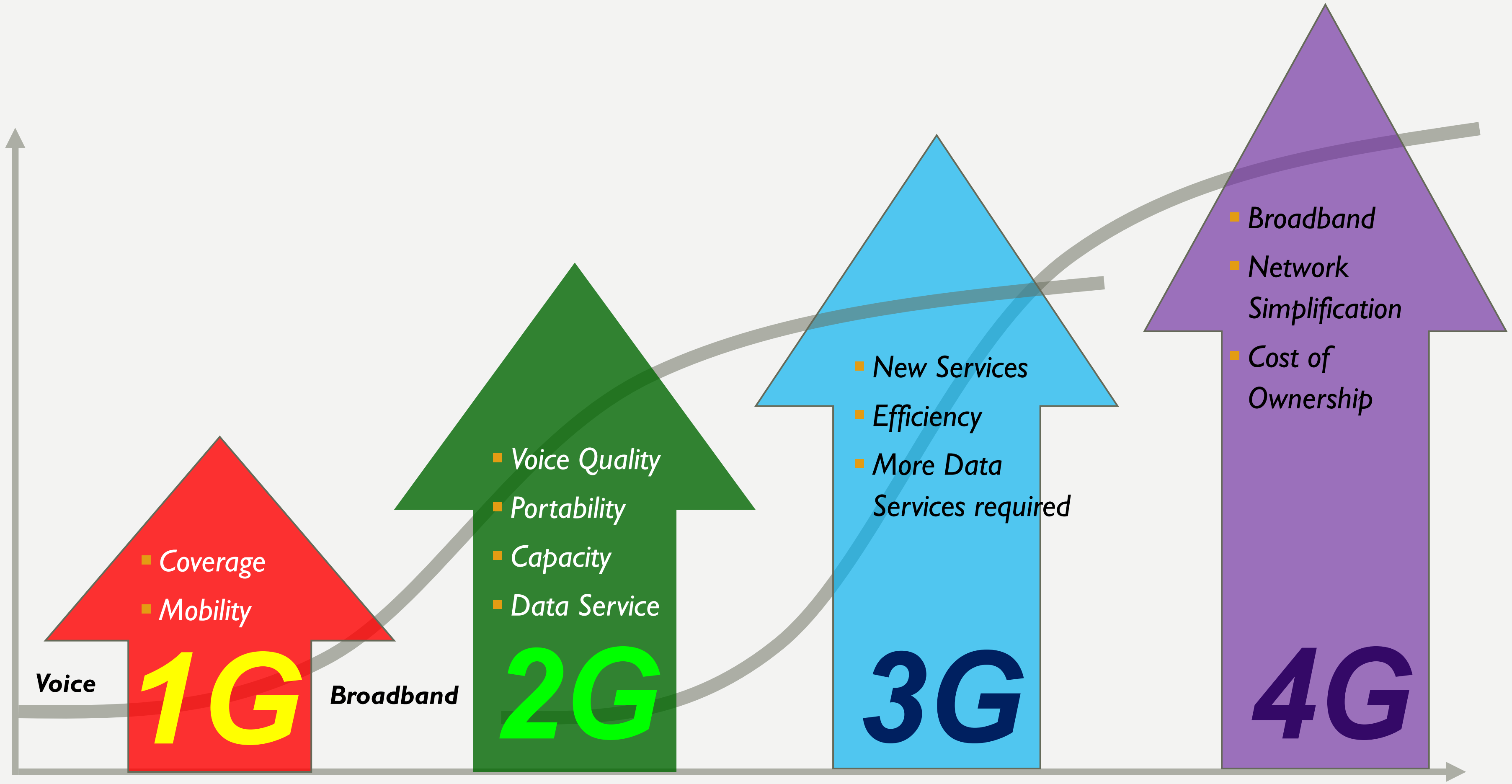
INTRODUCTION

- A cellular network or mobile network is a communication network where the **last link is wireless**. The network is distributed over land areas called **cells**.

- These base stations provide the cell with the network coverage which can be used for transmission of **voice, data, and other types of content**.

- Major telecommunications providers have deployed voice and data cellular networks over most of the inhabited land area of Earth. This allows mobile phones and mobile computing devices to be connected to the public switched telephone network and public Internet.
- Cellular networks offer a number of desirable features:
  - ✓ More capacity
  - ✓ Less power
  - ✓ Larger coverage area

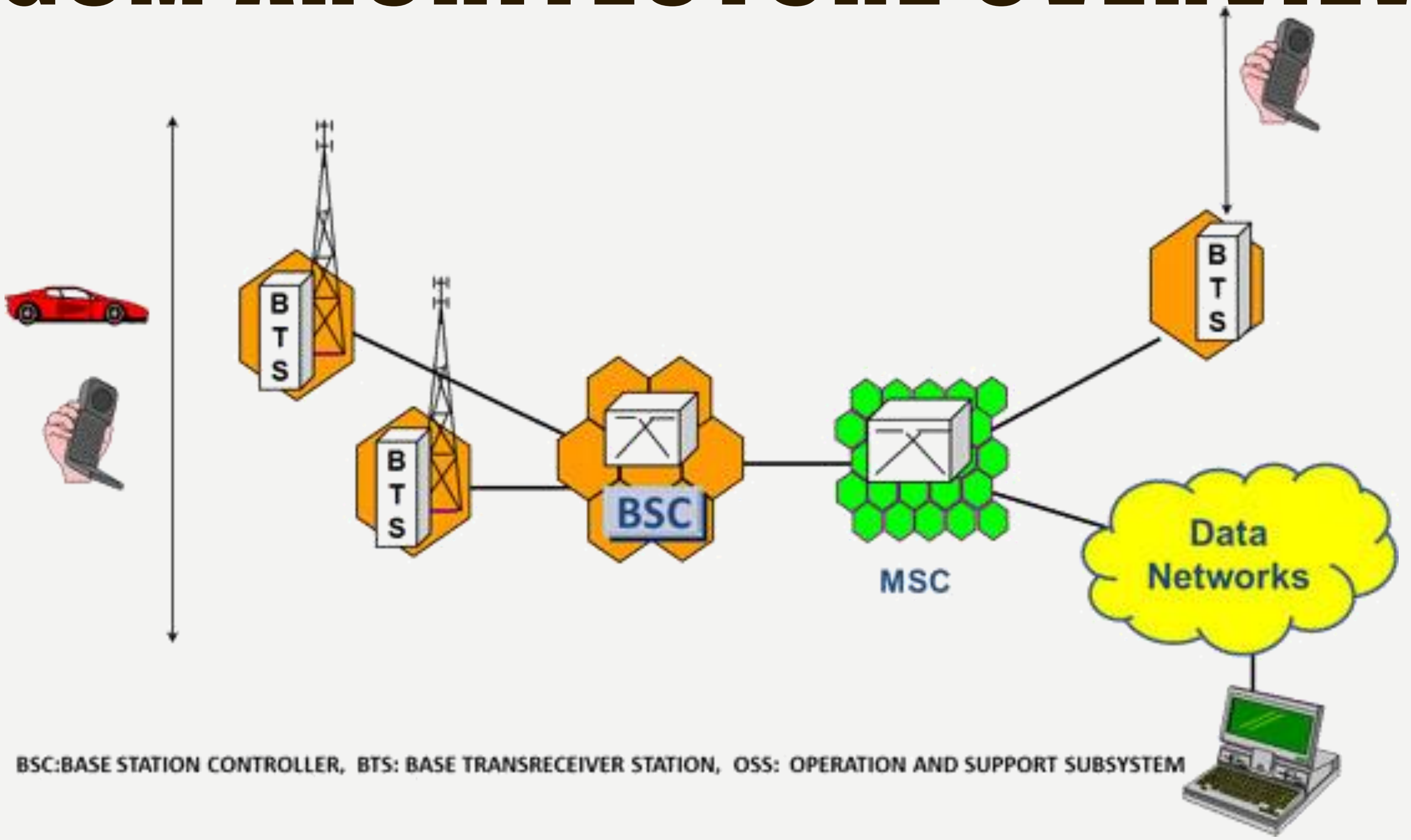
WIRELESS ACCESS EVOLUTION



WIRELESS ACCESS EVOLUTION

- Global System for Mobile is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe the protocols for second-generation (2G) digital cellular networks used by mobile devices.
- 2G networks developed as a replacement for first generation (1G) analog cellular networks, and the GSM standard originally described a digital, circuit-switched network optimized for full duplex voice telephony. This expanded over time to include data communications, first by circuit-switched transport, then by packet data transport via GPRS (General Packet Radio Services) and EDGE (Enhanced Data rates for GSM Evolution, or EGPRS).
- Subsequently, the 3GPP developed third-generation (3G) UMTS standards, followed by fourth-generation (4G) LTE Advanced standards.

GSM ARCHITECTURE OVERVIEW



- The mobile station (MS)
- BSS Base Station Subsystem (BTS+BSC)
- MSS Mobile Station Subsystem (MSC/HLR, ..)

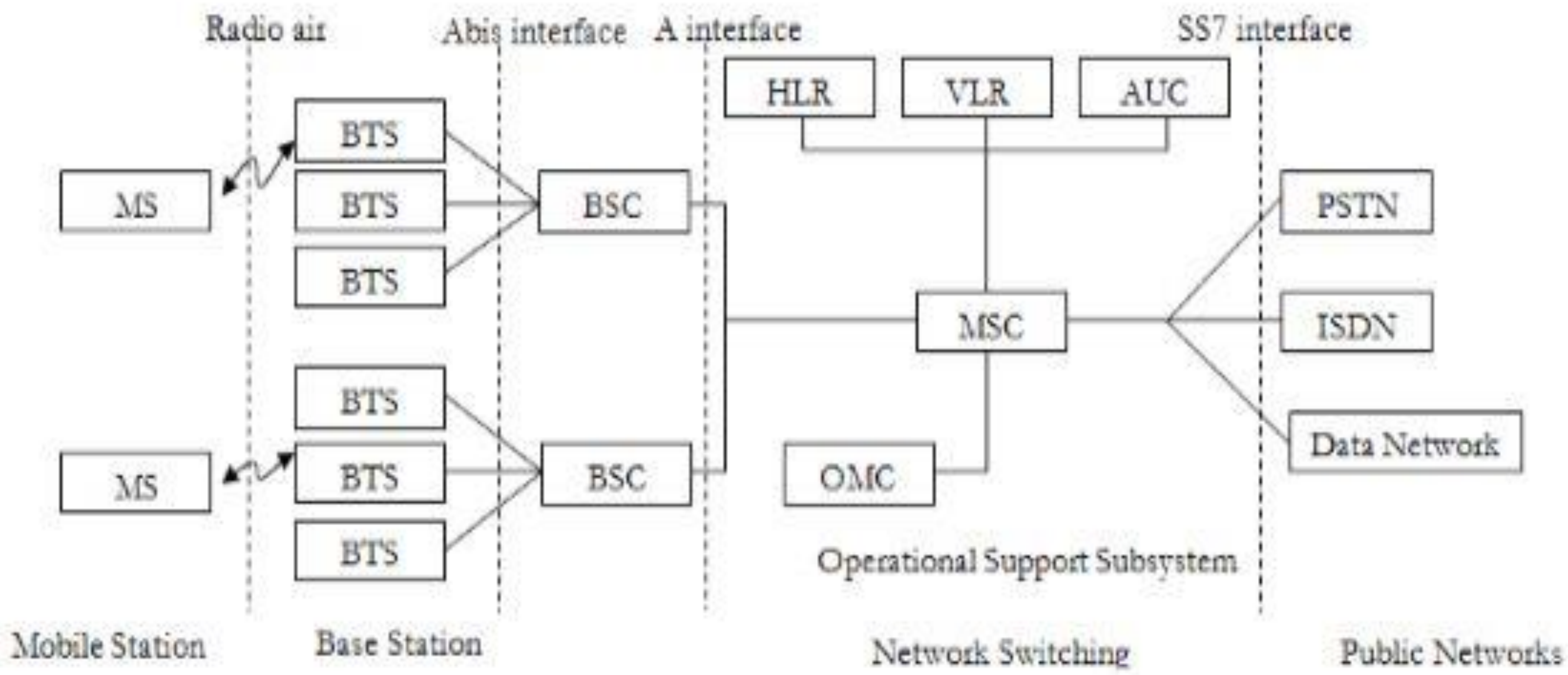


Fig: GSM Architecture

Base Transceiver Station (BTS):

- It encodes, encrypts, multiplexes, modulates and feeds the RF signal to the antenna.
- It consists of transceiver units.
- It communicates with mobile stations via radio air interface and also communicates with BSC via Abis interface.

Base Station Controller (BSC):

- It manages radio resources for BTS. It assigns frequency and time slots for all mobile stations in its area.
- It handles call set up, transcoding and adaptation functionality handover for each MS radio power control.
- It communicates with MSC via A interface and also with BTS.

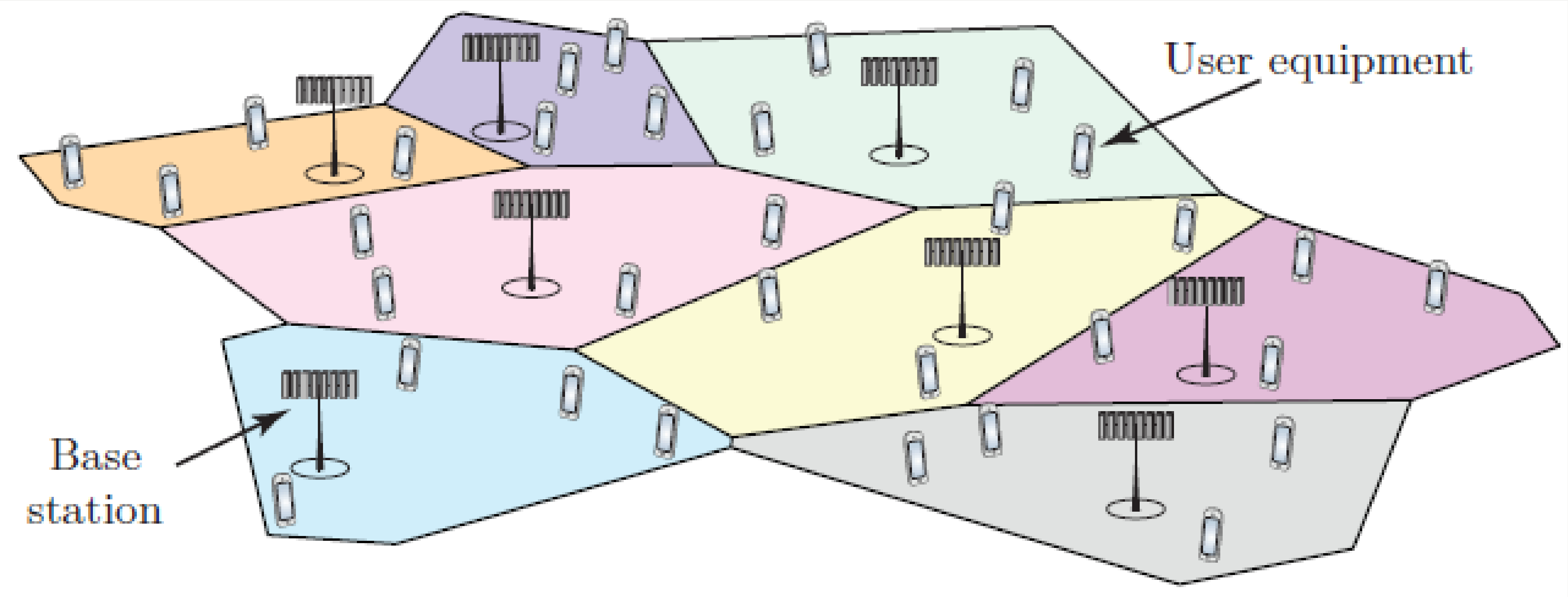
Mobile switching Centre:

- It is a heart of the network. It manages communication between GSM and other networks.
- It manages call set up function, routing and basic switching.
- It performs mobility management including registration, location updating and inter BSS and inter MSC call handoff.
- It provides billing information.
- MSC does gateway function while its customers roam to other network by using HLR/VLR.

CELL CONCEPT

The cellular system concept was a major breakthrough in solving the problems of spectrum congestion and user capacity.

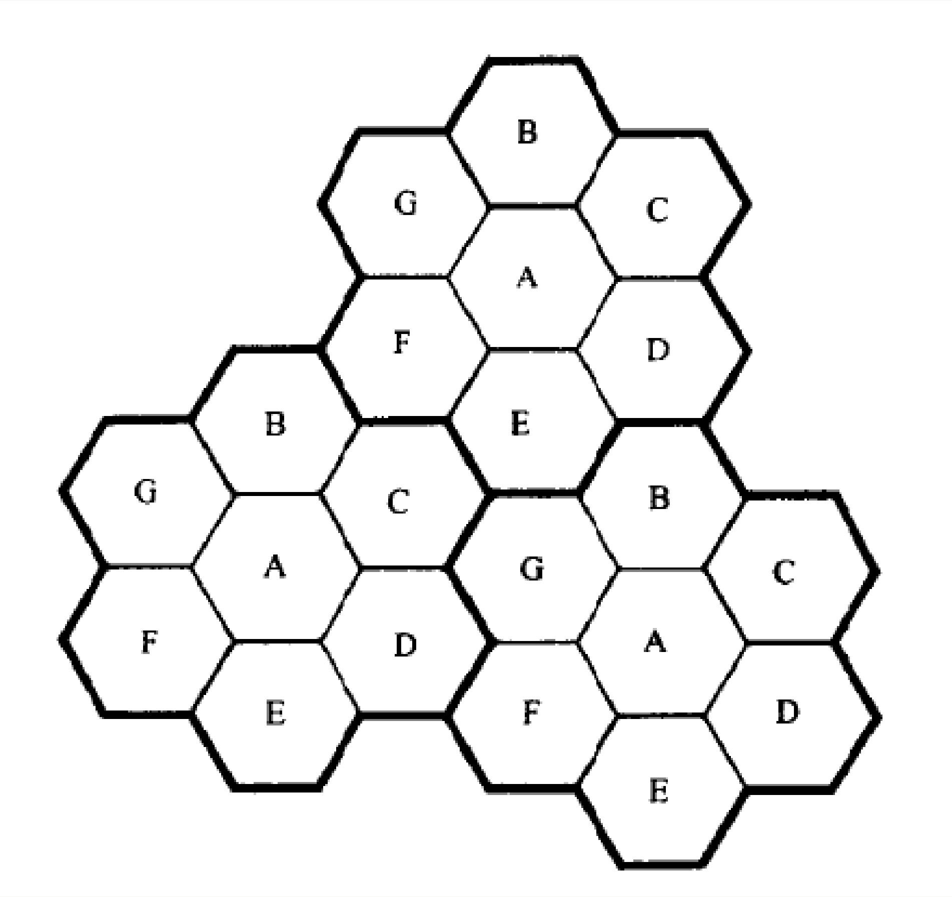
- The cellular system concept calls for **replacing a single high power transmitter (large area)** with many low power transmitters (small areas).
- **Each transmitter (base station)** is allocated a portion of the total number of available channels to the entire system.
- **Neighboring base stations** are allocated **different groups of channels**.
- As the demand for services grows, the number of base stations may be increased. This results in **additional radio capacity with no additional increase in radio spectrum**.



CELL - A cell is the basic unit of a cellular system and is defined as the radio coverage given by one BTS

FREQUENCY REUSE

- Frequency reuse or frequency planning is a technique used to improve the radio capacity and spectral efficiency
- Frequency reuse is one of the fundamental concepts on which commercial wireless systems are implemented and involves partitioning of a group of radio channels within a small geographical area called a cell.
- The increased capacity in a commercial wireless network, compared with a network with a single transmitter, comes from the fact that **the same radio frequency can be reused in a different area for completely different transmission.**

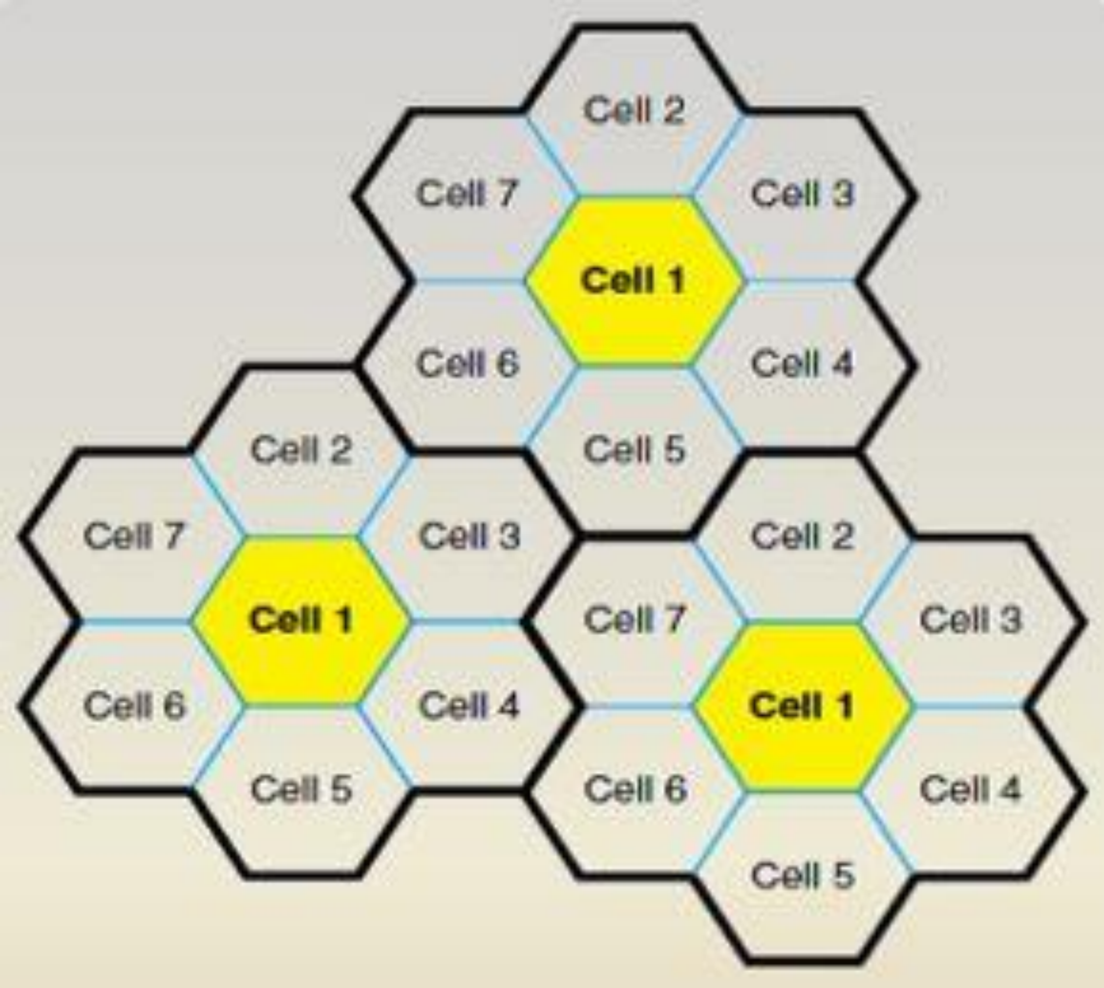


- Each cell is **designed to use frequencies only within its boundaries**; the same frequencies can be reused in other cells not far away without interference, in another cluster.
- Such cells are **called co-channel** cells.
- **The reuse of frequencies enables a cellular system to handle a large number of calls** with a limited number of channels.

- The **closest distance between the co-channel cells** (in different clusters) is determined by:
  - The choice of the cluster size
  - The layout of the cell cluster

Cluster:

A collection of cells (non repetitive) frequencies.



- To understand the frequency reuse concept, consider a cellular system with S duplex channels available for use. Let N be the number of cells within a single cluster (N = cluster size)
- If **each cell is allocated a group of K duplex channels** (K<S), the total number of available channels can be written as
- $S = KN$
- Now, if the clusters are repeated M times within the total area, the **total number of duplex channels in the system** is simply given by
- $C = MS = KMN$
- Therefore, if K and N remain constant, then, we **can achieve a capacity gain by increasing the number of times a cluster is repeated**.
- The factor N is called the cluster size and is typically equal to 4, 7, or 12.

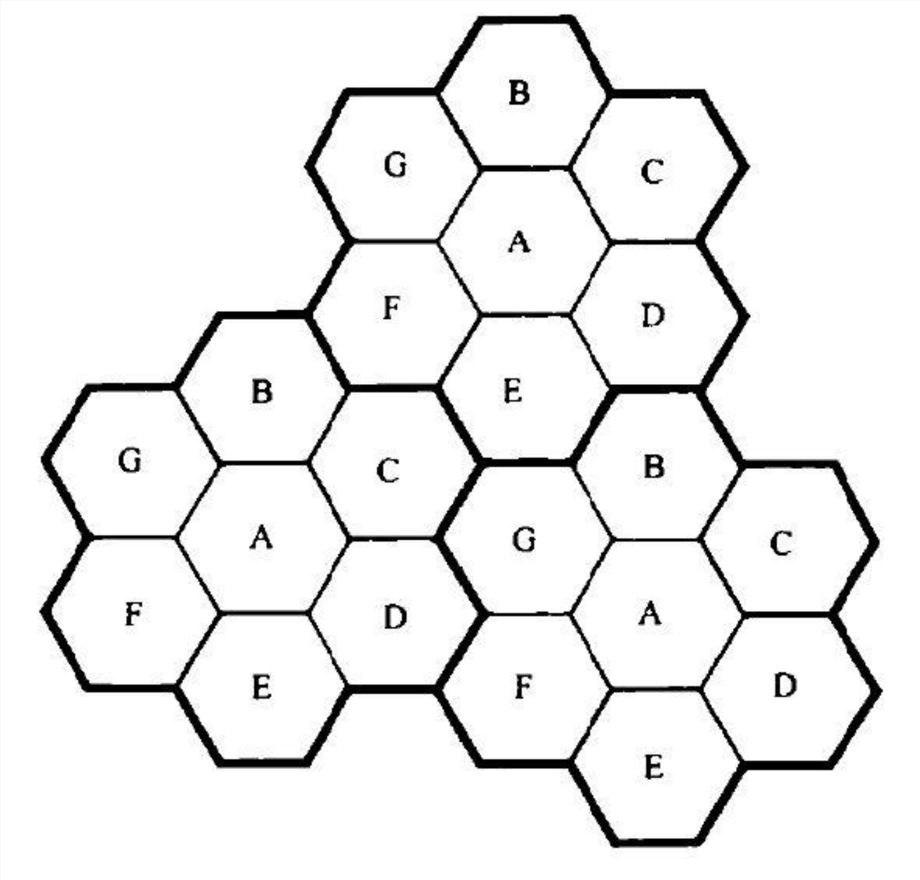


Illustration of the cellular frequency reuse concept.

Cells with the same letter use the **same set of frequencies.** A cell cluster is outlined in bold and replicated over the coverage area. In this example, **the cluster size, N, is equal to seven**, and the **frequency reuse factor is 1/7** since each cell contains one-seventh of the total number of available channels

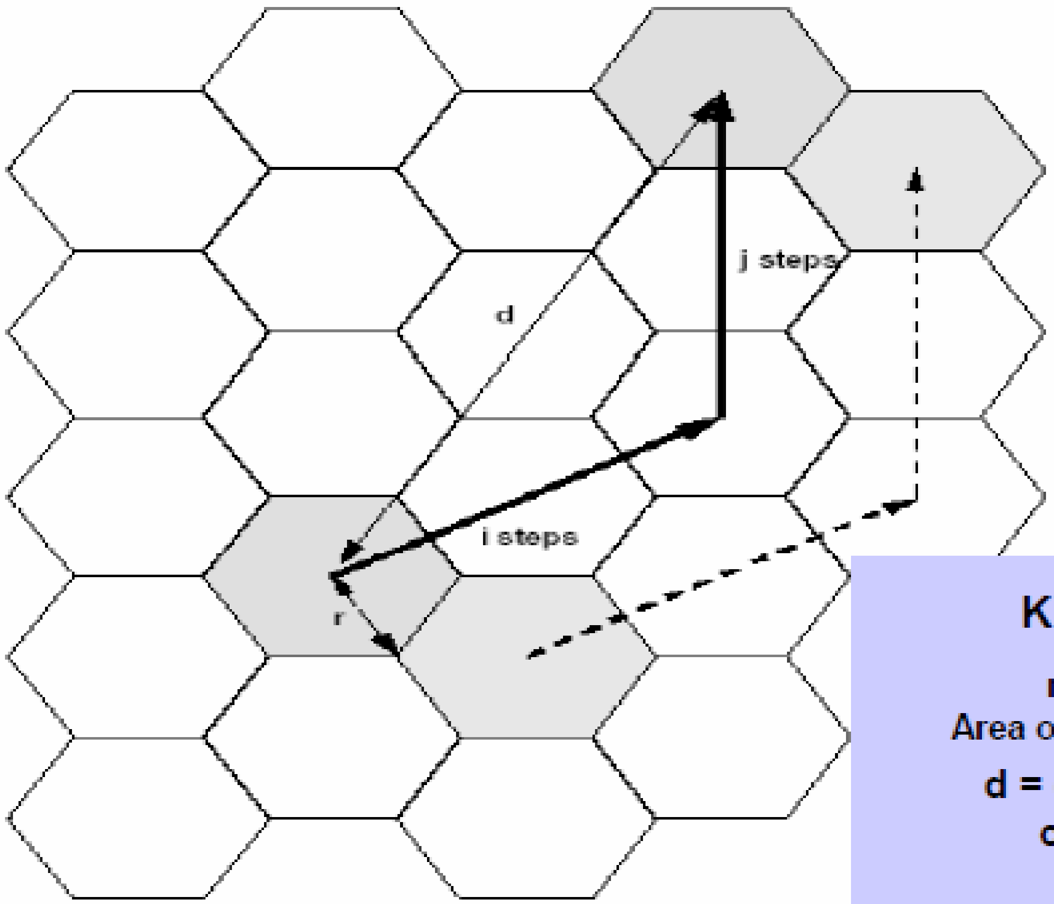
- If the **cluster size N is reduced while the cell size is kept constant**, more clusters are required to cover a given area and hence more capacity (a larger value of C- or capacity) is achieved
- A large cluster size indicates that the ratio between the cell radius and the distance between co-channel cells is large
- Conversely, a small cluster size indicates that co-channel cells are located much closer together
- The value for **N is a function of how much interference** a mobile or base station can tolerate while maintaining a sufficient quality of communications

- 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:
- **To find the nearest co-channel neighbors** of a particular cell, we must do the following:
    (1) **move i** cells along any chain of hexagons
    (2) then turn 60 degrees counter-clockwise and **move j cells**.

- To find co-channel neighbors of a cell, move i cells along any chain of hexagons, turn 60 degrees counterclockwise, and move j cells (example: i=2, j=2, K=12)



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

r = cell radius
Area of hexagon = 2.61 r^2

d = distance to co-channel cell

CHANNEL ASSIGNMENT

- For efficient utilization of the radio spectrum, a frequency reuse scheme

that is consistent **with the objectives of increasing capacity and minimizing**

interference is required

- **A variety of channel assignment strategies** have been developed to achieve these objectives
- Channel assignment strategies can be classified as **either fixed or dynamic**
- The choice of channel assignment strategy impacts the performance of the system, particularly as to how calls are managed when a **mobile user is handed off from one cell to another**

FIXED CHANNEL ASSIGNMENT STRATEGY

- In a fixed channel assignment strategy; each cell is allocated a predetermined

set of voice channels

- Any call attempt within the cell can only be served by the unused channels in that particular cell
- If **all the channels in that cell are occupied, the call is blocked** and the subscriber does not receive service
- **Several variations of the fixed assignment strategy exist**
- In one approach, called the **borrowing strategy**, a cell is allowed to borrow **channels from a neighboring cell if all of its own channels are already occupied**
- The **mobile switching center (MSC)** supervises such borrowing procedures and ensures that the borrowing of a channel **does not disrupt or interfere with any of the calls in progress in the donor cell**

DYNAMIC CHANNEL ASSIGNMENT STRATEGY

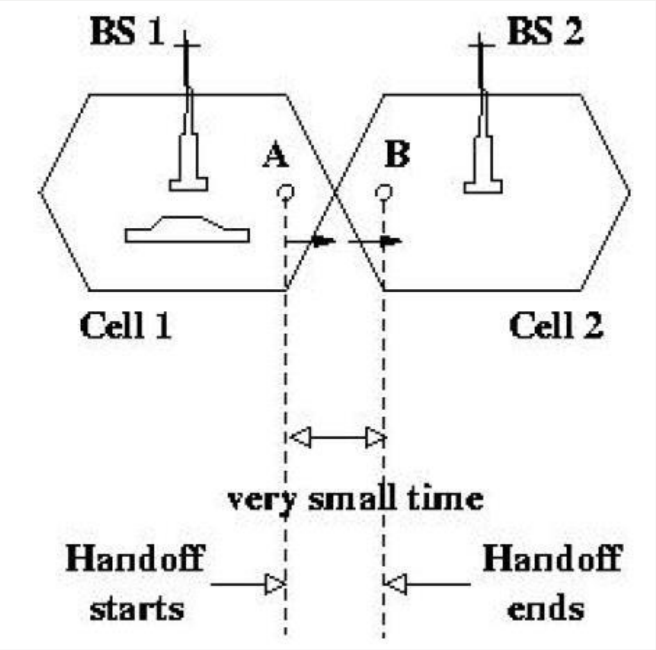
- In a dynamic channel assignment strategy, voice **channels are not allocated to different cells permanently**
- Instead, each time a call request is made, the serving base station requests a channel from the MSC
- The switch then allocates a channel to the requested cell following an algorithm that takes **into account the likelihood of fixture blocking within the cell, the frequency of use of the candidate channel, the reuse distance of the channel, and other cost functions.**
- Accordingly, the MSC only allocates a given frequency, **if that frequency is not presently in use in the same cell or any other cell which falls within the minimum restricted distance of frequency reuse to avoid co-channel interference**.

Cont…

- Dynamic channel assignment reduce the likelihood of blocking, which increases the trucking capacity of the system, since all the available channels in a market are accessible to all of the cells
- Dynamic channel assignment strategies require the MSC to collect real-time data on channel occupancy, traffic distribution, arid radio signal strength indications (RSSI) of all channels on a continuous basis.
- This increases the storage and computational load on the system but provides the advantage of increased channel utilization and **decreased probability of a blocked call.**

HANDOFFS

- When a **mobile moves into a different cell** while a conversation is in progress, the **MSC automatically transfers the call to a new channel** belonging to the new base station.
- This handoff operation **not only involves identifying a new base station**, but also requires that the voice and control signals be allocated to channels associated with the new base station.
- **Processing handoffs** is an important task in a wireless cellular communication system.
- As a mobile travels beyond the coverage region of its serving base station, it must be transferred to a base station which provides a better received power to the mobile.



- Many handoff strategies prioritize handoff requests over call initiation requests, when allocating unused channels in a cell site.
- **Handoffs must be performed successfully** and as infrequently as possible, and **be unnoticeable to the users**.
- In order to meet these requirements, system designers must specify an **optimum signal level at which to initiate a handoff**.
- If the received power drops too low prior to handoff, the call is “dropped” reducing the quality-of-service (QoS).
- Poorly designed handoff schemes tend to generate very heavy signaling traffic and significantly decrease the quality-of-service (QoS).
- Minimum usable signal for voice quality at the base station receiver normally taken as between -90 dBm and -100 dBm

- Let us denote this **minimum received power, below which a call cannot be received as**: $P_{r,\text{min useable}}$

- It is **desirable to initiate a handoff much before this point**, so we set a higher threshold:

$$P_{r,\text{hand off}}$$

at which the mobile switching center (MSC**) initiates the handoff procedure**

Because **power may attenuate quickly**, particularly at high mobile speeds, handoff process needs to happen in a reasonable quick time.

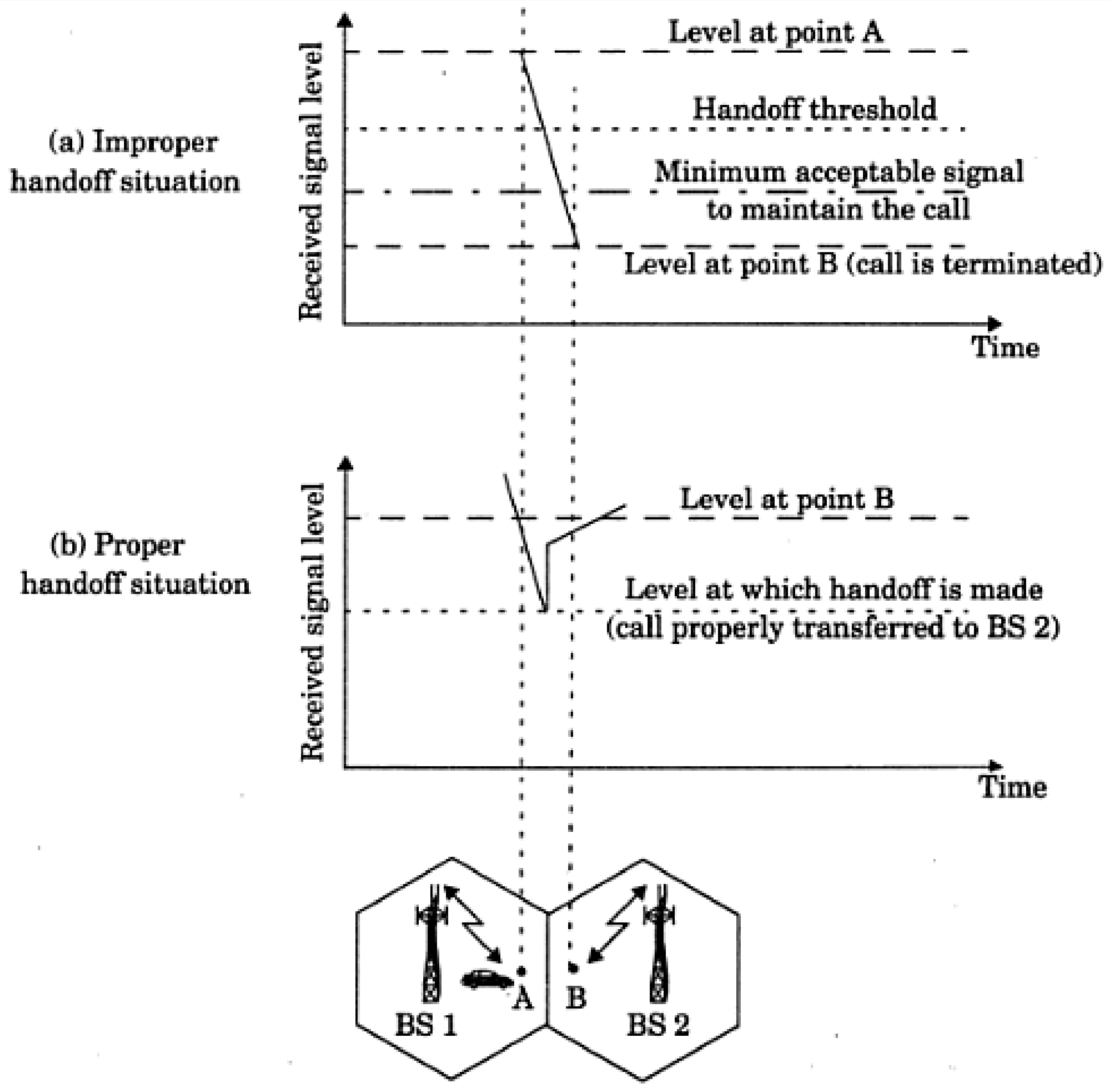
In GSM, **handoff is typically within 1-2 seconds**.

Define handoff margin as: $\Delta = P_{r,\text{hand off}} - P_{r,\text{min useable}}$

Cont…

- If **Δ is too small**
  - Then there **may not be enough time to complete the handoff and the call might be lost** due to weak signal conditions.
- If Δ **is too high**
  - Then MSC has to be burdened with unnecessary handoffs.

Cont…



Improper handoff and proper handoff

Hard Handoff “Break before Make”

- In the case of a hard handoff, **link to the current base station is terminated** or as the mobile is transferred to the new cell’s base station.
- Hence at a given time, a mobile is connected to one more than one base station.
- Initiation of the handoff may begin **when the signal strength at the mobile received from Base Station 2 is greater than that of Base Station 1**.
- A major issue with hard handoff approach is that the **received signals of both base stations often fluctuate**. Mobile can switch links with either base station several times!
- This is called the **ping-pong effect**.

Cont…

Soft Handoff "Make before Break"

- Soft handoff is a feature used in CDMA systems. The mobile is simultaneously connected to two or more cells (or cell sectors)

Soft handover results in a diversity gain called soft handover gain.

Handoff Decision

MSC Controlled Handoff

- The base station measure the **Received Signal Strength Indication** (RSSI) of calls in progress within the cell.
- In addition, a spare receiver in each base station cell called the "**locator receiver**" is used to scan the users in neighboring cells which appear to be in need of handoff.
- The locator receiver is controlled by the MSC.
- The MSC decides when to handoff. In general the handoff process takes 100-200 ms. This method was adopted in 1G analog cellular systems.

Cont…

Mobile-assisted Handoff (MAHO)

- Mobile measures the forward control channel (FCC) from neighboring base stations, and *reports them to the base station.* Measurements are in the form of RSSI-**Received Signal Strength Indication** (RSSI) or the bit error rate.
- MAHO is used in **2G systems**. It results in faster handoffs. As compared to 1G systems, handoff was reduced to 1-5 seconds. The value of Δ was in the order of 0-5 dB

Mobile Controlled Handoff (MCHO)

- In 3G systems, the user **measures the power from adjacent base stations and automatically upgrades the channels to its nearer base station**
- When compared to the 1G and 2G systems, delay during handoff of MCHO is only **100 ms and the value of Δ is around 20 dBm**
- The above handoff procedure assumes that there is a channel in the new base station to offer the entering mobile!
- However there may not be, and the call may be dropped for this reason
- Some base stations may reserve "guard channels" purely for handoff purposes, which then are not offered to mobiles making new calls

Factors Influencing the Handoff

- **Transmitted power:** If the transmission power is different for different cells, the handoff threshold or the power margin varies from cell to cell.

- **Received power:** The received power mostly depends on the line-of-sight (LoS) path between the user and the base station.

- **Area and shape of the cell:** Apart from the power levels, the cell structure also a plays an important role in the handoff process.

- **Mobility of users:** The number of mobile users entering or going out of a particular cell also fixes the handoff strategy of a cell.

Practical issues with Handoff

- Different Speeds of Mobile Users
- The users with **high speed frequently crossing the micro-cells** become a burden to the MSC as it has to take care of handoffs.
- Several schemes have been designed to handle the simultaneous traffic of high speed and low speed users while minimizing the handoff intervention from the MSC, one of them being the Umbrella Cell approach.
- The umbrella cell approach provides large area coverage to high speed users while providing small area coverage to users traveling at low speed.
- By using different antenna heights and different power levels, it is possible to provide larger and smaller cells at a same location.

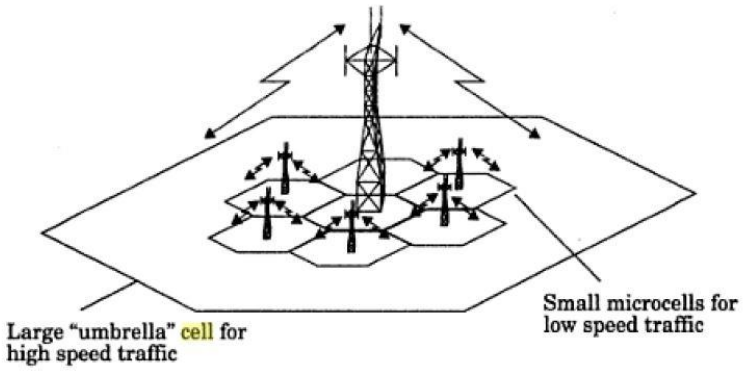


Figure 4: Umbrella cell approach

INTERFERENCE

- **Interference** is a major **limiting factor** in the performance of the cellular radio. **Its limits capacity** and **increases the number of dropped calls**.
- **Sources of interference** include:
  - Another mobile in the same cell
  - A call in progress in a neighboring cell
  - Other BS operating in the same frequency band
- **Interference is more severe in urban areas** due to greater RF noise floor and more number **of MS and BS**.

Effect of the interference

- Interference of **voice channels** causes:

    Crosstalk - in wireless communication, **crosstalk** is a signal transmission issue that **causes a disruption in another circuit or channe**l. For example, crosstalk could cause **you can hear someone else's conversation**

    Noise in the Background

- Interference of **Control channels** causes:

Error in Digital signaling, which causes;

Missed calls

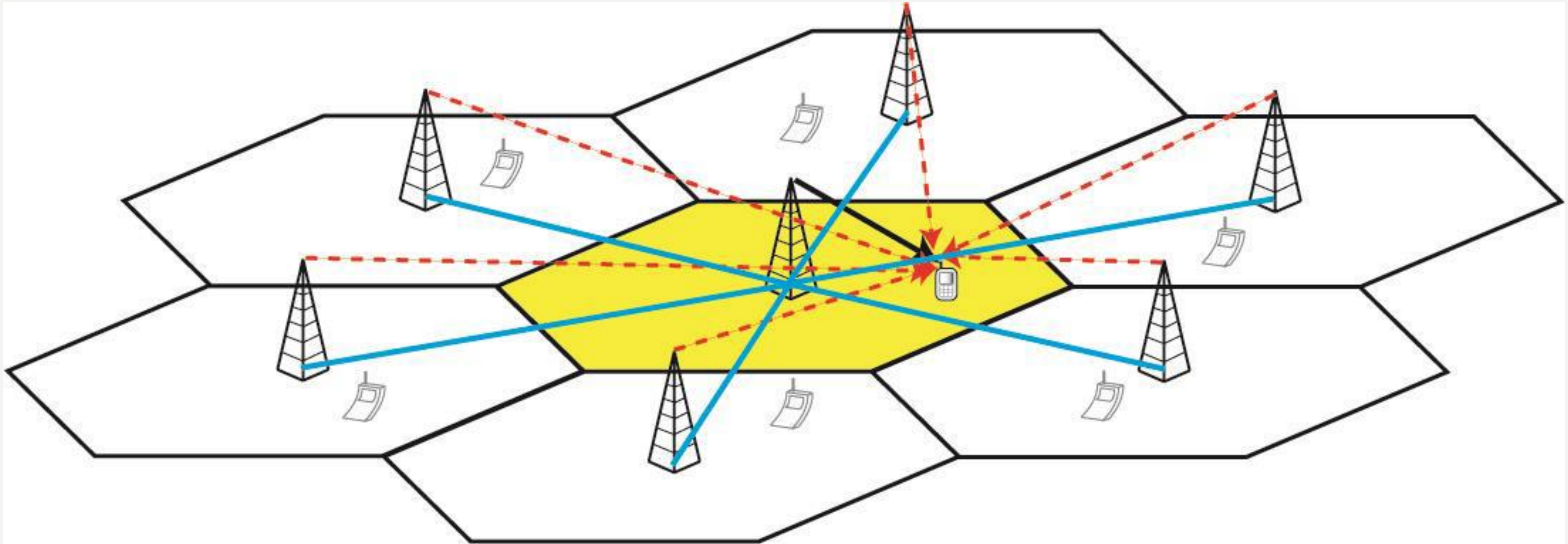
Blocked calls

Dropped calls

- Which means you can see interference causes **decrease the Quality of Service(QoS)**

Co-channel interference (CCI)

- Increasing frequency reuse also increases interference **which decreases system capacity and user quality-of-service (QoS)**
- The cells where the **same set of frequencies is used are called co-channel** cells.



Cont…

- There are several **reasons for co-channel interference** to be present in wireless systems such as:
  - **Adverse weather conditions**
  - **Poor frequency planning**
  - **Overly crowded radio spectrum**
- Unlike **Thermal noise**, The adverse effect of CCI **cannot be eliminated by simply increasing the carrier power of a transmitter**.
- Increasing the **carrier power in one cell, increase the interference to the neighboring cells**.
- CCI cells must be separated by a **minimum distance to provide sufficient isolation due to propagation**.

Cont…

- When the **sizes of the cells are approximately the same** and the **base stations** transmit with the **same power**:
  - CCI ratio will become **independent** of the **transmitted power**
  - **CCI becomes a function of the cell radius (R)** and the **distance between the centers of the nearest co-channel cells (D)**
- **By increasing the D/R ratio**, the **separation between co-channel cells relative to the coverage distance of a cell is increased.** Therefore, **interference is reduced** due to better isolation of the co-channel cell.

- The **parameter Q is called the frequency reuse ratio** and is related to the cluster size N.

Cont…

In the case of the hexagonal geometry we have:

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

- A small value of **Q provides larger capacity since the cluster size N is small but higher CCI.**
- Whereas a **large value of Q** improves the **transmission quality**, due to a smaller level of co-channel interference

Cont…

- In an actual cellular system design, **a trade-off between these two objectives** must be made.

	Cluster Size (N)	Co-channel Reuse Ratio(Q)
$i = 1, j = 1$	3	3
$i = 1, j = 2$	7	4.58
$i = 2, j = 2$	12	6
$i = 1, j = 3$	13	6.24

- Let i_0 be the number of co-channel interfering cells. Then **the signal-to-interference ratio** (S/I or SIR) for a mobile receiver which monitors the forward (downlink from the base station to the user) channel can be written as:

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i0} I_i}$$

- where **S is the signal power(Received by the mobile) from the desired base station** and I_i is the interference power(Received by mobile) due to i-th interfering base station

Cont…

- If the received signal levels of co-channel cells are known, then the S/I ratio for the forward link can be found using above equation.
- Propagation measurements in a radio channel show that **the average received signal power at any point decays as the power law of the distance of separation between the transmitter and the receiver.**

The **average received power Pr** at a **distance d** from the transmitting antenna is approximated by

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

- Where P0 is the **received power at a close reference point at a distance d0** from the transmitter **and "n" is the path loss exponent.**

Or

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

- n- determines the how fast **signal strength decays** when moving away from the BS. IT has bigger number 4 in urban areas. In rural areas it can be taken as 2

Cont…

- Now let us consider the forward (downlink) channel.
- If **Di is the distance of the i-th interferer** from the receiver (mobile)
- **The received power** (by the mobile)due to the i-th interferer will be:

$$\propto (D_i)^{-n}$$

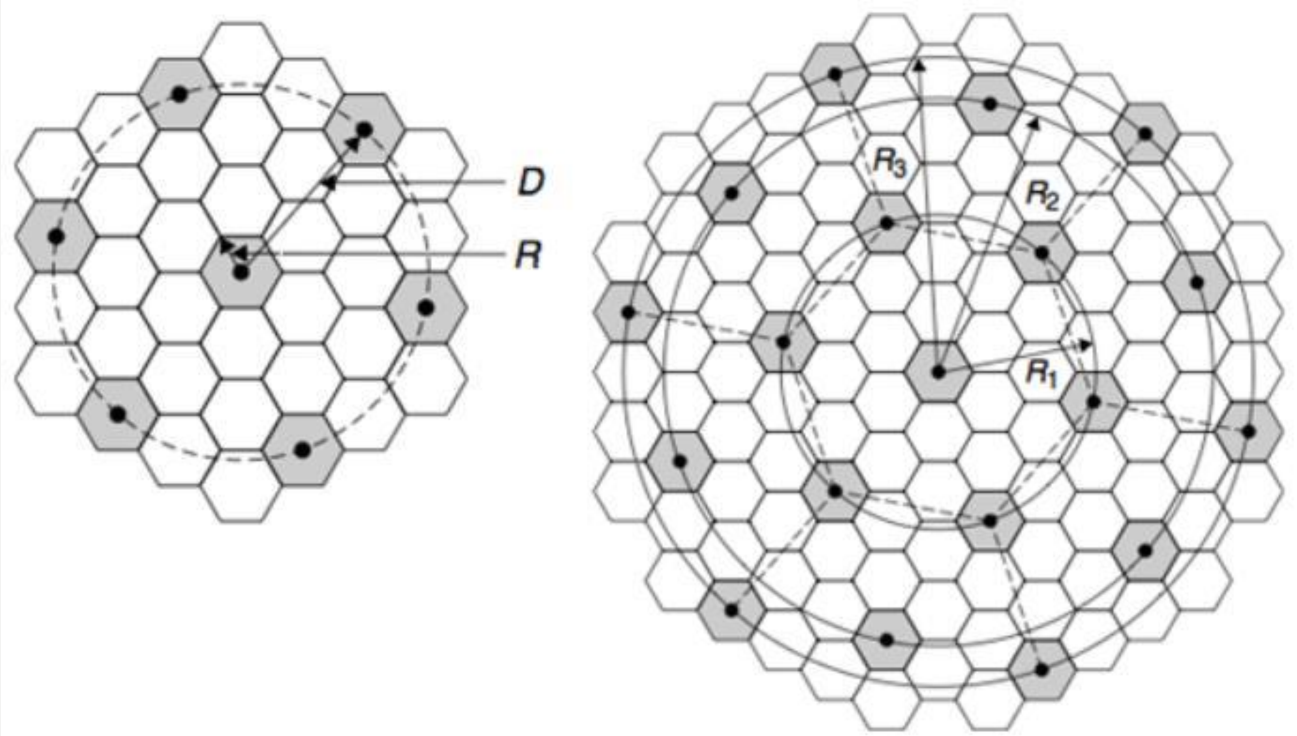
- When the **path loss exponent is same throughout the coverage area** and the **transmit power of each base station is equal** we can write ;

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i0} (D_i)^{-n}}$$

Cont…

- Now consider only **the first tier of interfering** cells.
- If all the **base stations are equidistant** from the desired base station, and if this distance is equal to the distance "D" between cell centers, then the above equation can be simplified as:

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



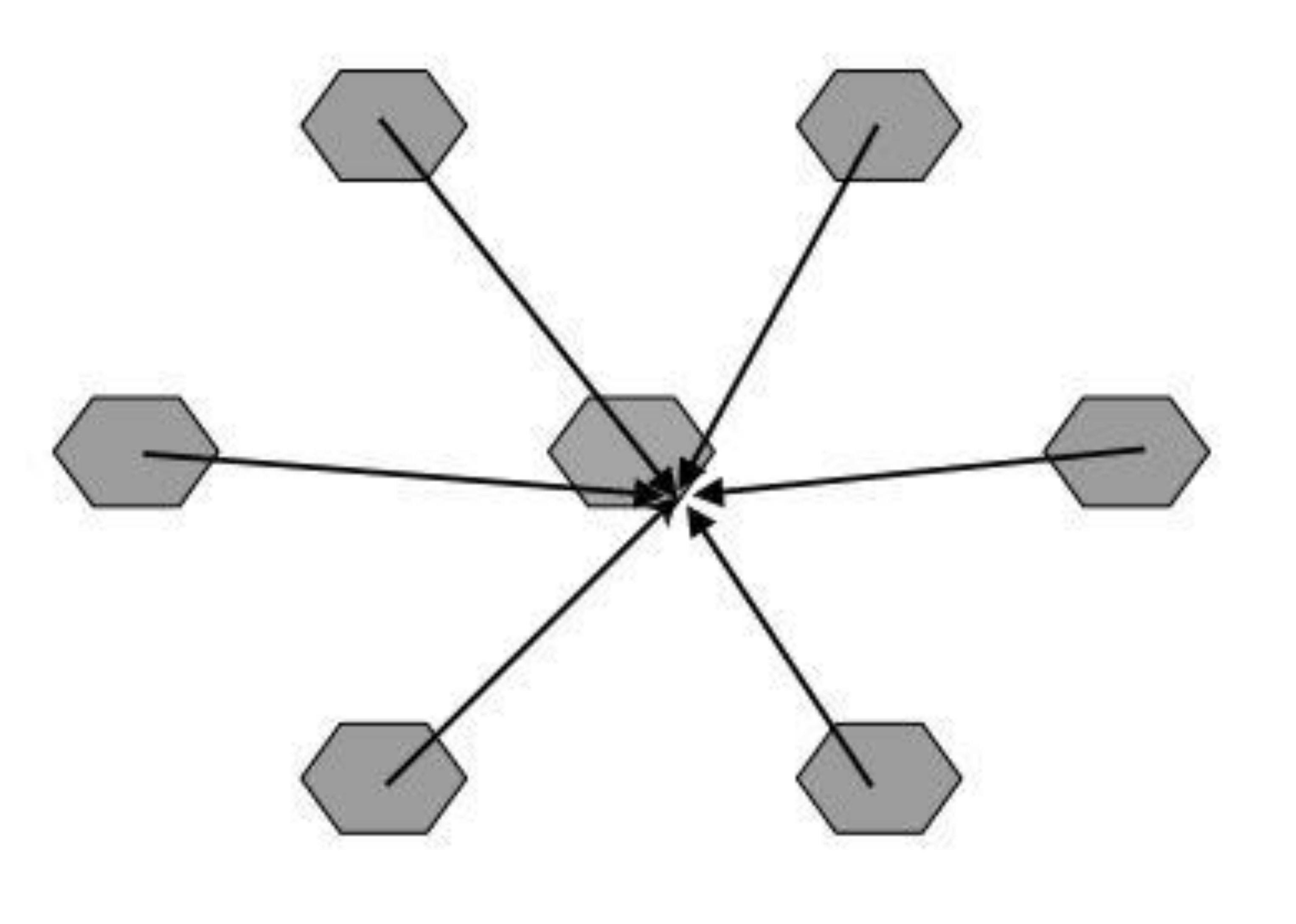
Question: 1

If a signal to interference ratio of 15 dB is required for satisfactory forward channel performance of a cellular system, what is a frequency reuse factor and cluster size that should be used for maximum capacity if the path loss exponent is

a) $n = 4$,

b) $n = 3$.

Assume that there are six co-channel cells in the first tier, and all of them are the same distance from the mobile. Use suitable approximations.



6 Nearest co channel cells in the first tear

- When path loss exponent n=3

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{\left(\sqrt{3N}\right)^n}{6}$$

$$S/I = 15dB = 31.63$$

$$31.63 = \frac{\left(\sqrt{3N}\right)^3}{6} \Rightarrow N = 11.01 \Rightarrow N = 12 \text{ should be used}$$

$$N = 12 \Rightarrow S/I = 36 = 15.56dB$$

- When path loss exponent n = 4

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{\left(\sqrt{3N}\right)^n}{6}$$

$$S/I = 15dB = 31.63$$

$$31.63 = \frac{\left(\sqrt{3N}\right)^4}{6} \Rightarrow N = 4.59 \Rightarrow N = 7 \text{ should be used}$$

$$N = 7 \Rightarrow S/I = 75.3 = 18.66dB$$

- Question 2

A receiver in an urban cellular radio system detects a 1 mW signal at d=d0 =1 m from the transmitter. It is observed the received power at given distance D is –100 dBm. A measurement team has determined that the average path loss exponent in the system is n=3. Determine the major radius of each cell if a 7-cell reuse pattern is used. What is the major radius if a 4- cell reuse pattern is used?

- **Given Parameters:**

$P_r(d_0)$=1mW $\Leftrightarrow$ 0 dBm

d_0=1 m, Reference distance

$P_r(D)$= -100 dBm,

n=3, Path loss exponent

N=7, N=4, Cluster size

$$P_r(D) = P_r(d_0) - 10n\log\left(\frac{D}{d_0}\right) \Rightarrow -100 = 0 - 30\log\left(\frac{D}{d_0}\right)$$

$$D = d_0 10^{100/30} = 2154.4m$$

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

For N=7

$$R = \frac{2154.4}{\sqrt{3\times 7}} = 470.13m$$

For N=4

$$R = \frac{2154.4}{\sqrt{3\times 4}} = 621.93m$$

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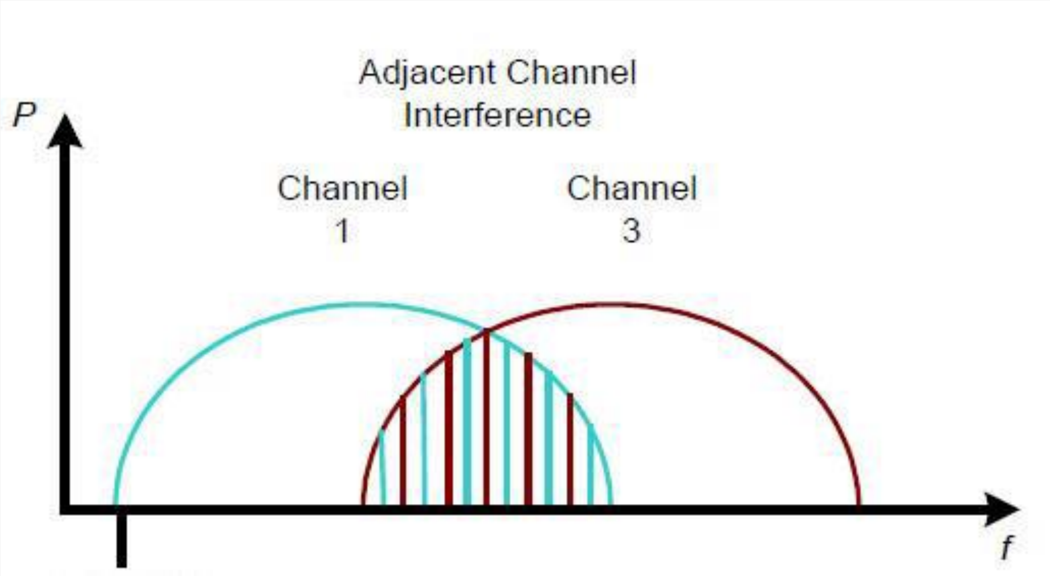
Adjacent Channel Interference (ACI)



- This type of interference is caused by adjacent channels: (due to the channels in adjacent cells)
- It is the signal impairment which occurs to one frequency due to presence of another signal on a nearby frequency.
- This occurs when imperfect receiver filters allow nearby frequencies to leak into the pass band.

Cont…

- This problem is enhanced if the adjacent **channel user is transmitting in a close range compared to the subscriber's receiver frequency** while the receiver attempts to receive a base station on the channel. This is called **near-far effect**.
- The more adjacent channels are packed into the channel block, the higher the spectral efficiency, provided that the performance degradation can be tolerated in the system link budget.
- **ACI occurs more frequently in small cell clusters and heavily used cells.** I f the frequency separation between the channels is kept large this interference can be reduced to some level.
- **If the frequency reuse factor is small then distance between the adjacent channels cannot put the interference level within tolerance limits.**

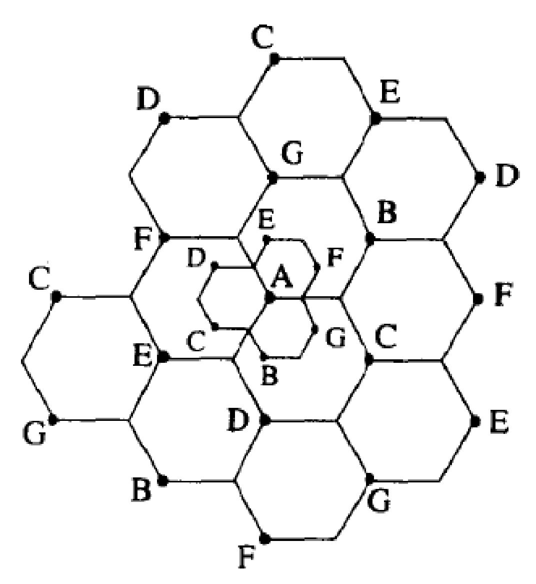
IMPROVING COVERAGE

- As the demand increases, the number of channels assigned to a cell becomes insufficient to support the required users
- Cellular design techniques used to expand the capacity include:
  - Cell splitting
  - Cell sectoring
  - Coverage zone approaches
- **Cell splitting** allows an orderly growth of the cellular system (it increases the number of base stations in order to increase the capacity)
- **Cell sectoring** uses directional antennas to further control the interference and frequency reuse of channels.
- **Zone microcell concept** distributes the coverage of a cell and extends the cell boundary to hard-to-reach places.

Cell Splitting

- Cell splitting is the process of **subdividing a congested cell into smaller cells**.
- Each **subdivided cell will have its own base station** (which results in the **reduction of antenna height and transmit power**)
- **Cell splitting increases the capacity** (as it increases the number of times that the channels are reused)
- New cells (**called micro cells**) have smaller radius.
- Cell splitting allows a system to grow by **replacing large cells with smaller cells,** while not altering the channel allocation scheme required to maintain a minimum co-channel reuse ratio (Q)

- Note that the area covered by a circle with radius R is four times that of an area covered by a circle with radius R/2.
- Example: Figure below shows an example of cell splitting



- At figure base stations are placed at the corners
- Assume that Base Station **A is saturated with traffic**. Hence new base stations are needed to increase the number of channels in the area and also to reduce the area served by a single base station

- With cell splitting we see that the original base station is now surrounded by six new base stations
- These new base stations are added in such a way that the original frequency re-use plan is preserved. (In the figure, new base station G is placed half-way between two larger base stations using the same frequency set G)
- We must make sure that the new **microcells after cell splitting exactly behaves as the original cells**
- Therefore, the transmit power of the new cells can be found by finding the received power, Pr at the **new and old cell boundaries**

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

- And

$$P_r[\text{at new cell boundary}] \propto P_{t2}(R/2)^{-n}$$

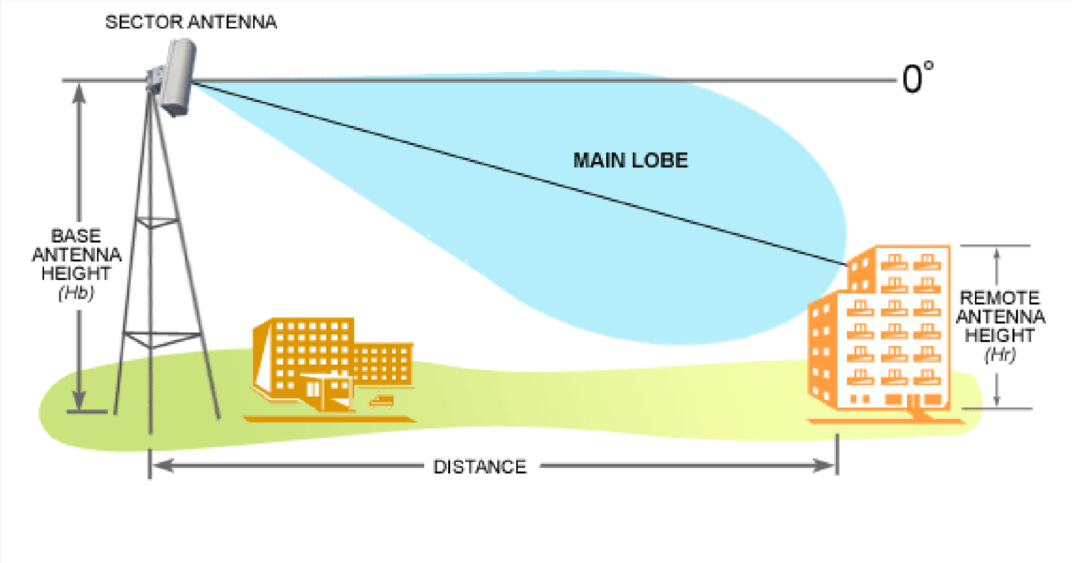
- Pt1 – transmit powers of the larger cell base station
- Pt2 – transmit powers of the smaller cell base station
- n – path loss exponent
- If n=4, we see that

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

Challenges of Cell Splitting

- In practice all the cells are not split at the same time. Therefore different cell sizes will exist at the same time.
- In such cases frequency assignment is more complicated, since special care needs to be applied to keep the distance between co-channel cells at the required minimum.
- Also handoff procedure must be carefully addressed.
- The larger cell is normally dedicated to handle the high speed traffic so that hand offs will occur less frequently.

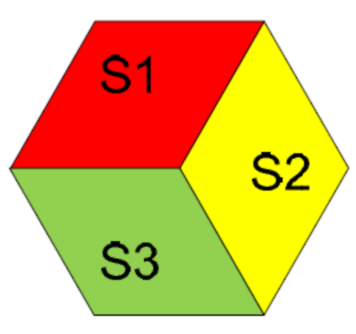
- Channels in the old cell must be broken down into two channel groups – one that corresponds to the smaller cell reuse requirements and other to cater for large cell requirements.
- Antenna down tilting which focuses radiated energy from the base stations towards ground is used to limit the coverage of the newly formed micro cells.



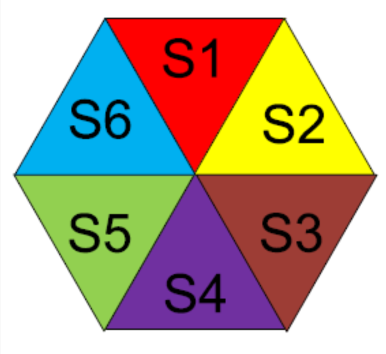
Cont…

Cell Sectoring

- With cell sectoring we increase the capacity using a different strategy
- In the cell sectoring method, a cell has the same coverage space. But seek methods to decrease the D/R- frequency reuse ratio.
- Instead of using a single omni-directional antenna that transmits in all directions, use either 3 or 6 directional antennas such that each of these antennas provides coverage to a sector of the hexagon
- When 3 directional antennas are used, 120 degree of sectoring is achieved.
- When 6 directional antennas are used, 60 degrees of sectoring is achieved.



120 degree cell sectoring



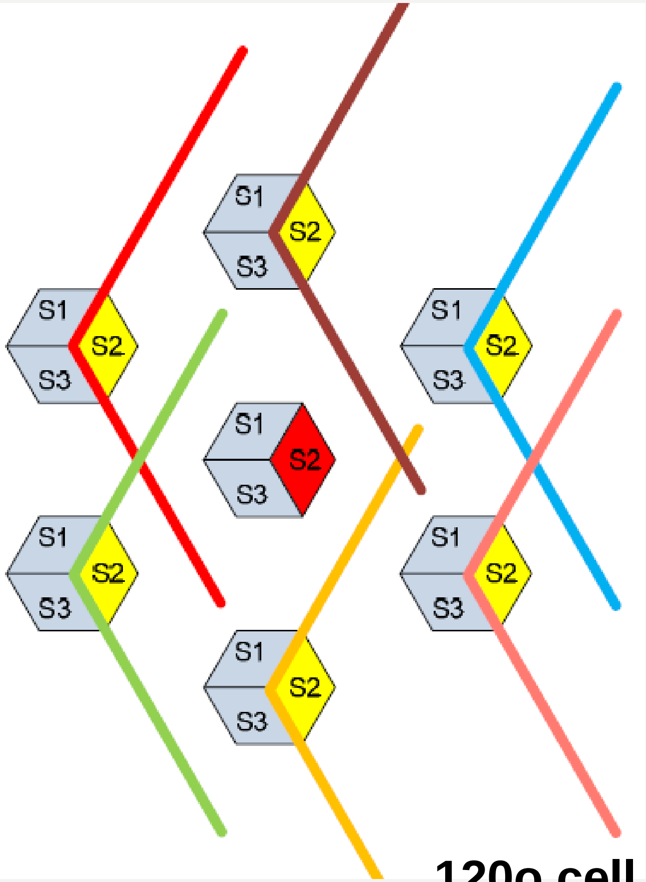
60 degree cell sectoring

Cell Sectoring – Cont…

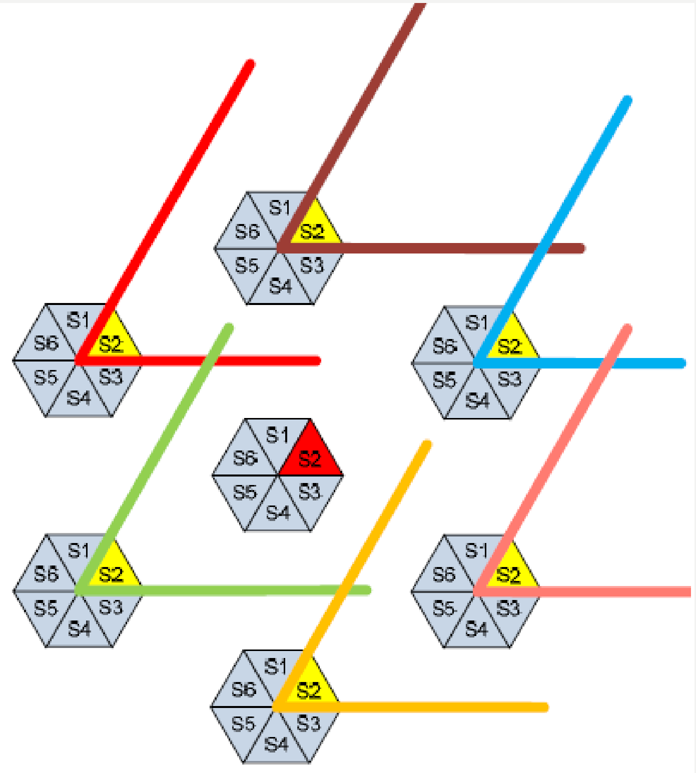
- The handoff occurs when a cell phone moves from one sector to another in the same cell
- Dividing the cells into sectors reduces the network capacity. The reason for capacity reduction is the channels allocated to a cell are now divided among the different sectors
- However, **cell sectoring reduces the number of co-channel interferers** and therefore, we can get a capacity gain
- If sectoring is performed in a way that channels assigned to a particular sector are always at the same direction in the different cells, **each sector causes interference to the cells that are in its transmission angle only**.
- With 120° cell sectoring, 2 or 3 co-channel cells cause interference and with 60° cell sectoring, 1 or 2 co-channel cells cause interference (as opposed to 6 co-channel interferers in the omni-directional case)

Cell Sectoring – Cont…

- As a result, the SIR is increased for the same cluster size. This allows the designer to reduce the cluster size and achieve the same original SIR.
- Reducing the cluster size result in a network capacity increase.



120o cell sectoring



60o cell sectoring

TRUKING & GRADE OF SERVICE (GOS)

- Cellular radio systems rely on trunking to accommodate a large number of users in a **limited radio spectrum.**

- The concept of trunking allows a large number of users to **share the relatively small number of channels in a cell** by providing access to each user, on demand, from a pool of available channels (As the name implies ,the system is like a tree with one trunk and many branches).

- In a trunked radio system (TRS), **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**.
- The telephone company uses trunking theory **to determine the number of telephone circuits that need to be allocated for office buildings** with hundreds of telephones, and this same principle is used in **designing cellular radio systems**
- In a trunked mobile radio system , 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 becomes available

Definitions of Common Terms Used In Trunking Theory

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

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

- **Holding Time:** Average duration of **a typical call**. Denoted by H (in seconds).

- **Request Rate**: The average number of call requests per unit time (λ).

- **Traffic Intensity:** Measure of channel time utilization, which is the average channel occupancy measured in Erlangs. This is **a dimensionless quantity** and may be used to measure the time utilization of single or multiple channels. Denoted by A.
- **Load**: Traffic intensity across the entire trunked radio system, measured in Erlangs

Erlang - a unit of traffic

- The fundamentals of trunking theory were developed **by Erlang, a Danish mathematician**, the unit bears his name.
- An Erlang is a unit of telecommunications traffic measurement.
- Erlang represents the continuous use of one voice path.
- It is used to describe the total traffic volume of unit time
- **A channel kept busy for one hour** is defined as having a **load of one hour**
- For example, a radio channel that is occupied for thirty minutes during an hour carries 0.5 Erlangs of traffic
- For 1 channel
  - Min load=0 Erlang (0% time utilization)
  - Max load=1 Erlang (100% time utilization)

THE GRADE OF SERVICE (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 busy hour is based upon customer demand at the busiest hour during a week, month, or year
- 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
- It is the wireless designer's job **to estimate the maximum required capacity** and to allocate the proper number of channels **in order to meet the GoS**.
- GOS is typically given as the **likelihood that a call is blocked**, or the **likelihood of a call experiencing a delay greater than a certain queuing time**.

Traffic Measurement (Erlangs) :

The traffic intensity offered by each user (Au) is equal to the **call request rate** multiplied by the **holding time**

- That is, each user generates a traffic intensity - **Au** Erlangs given by:

$$A_u = \lambda H$$

Where: H - is the average duration of a call (Holding Time)

λ - is the average number of call requests per unit time

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

$$A = U A_u$$

- Furthermore, in a **C** - channel trunked system, if the traffic is equally distributed among the channels, then the **traffic intensity per channel - Ac** , is given as

$$A_c = U A_u / C$$

- The probability of a call being blocked
- **Blocked calls cleared(BCC) or Lost Call Cleared (LCC) or Erlang B systems**

- The probability of a call being delayed beyond a certain amount of time before being granted access
- **Blocked call delayed or Lost Call Delayed(LCD) or Erlang C systems**

Blocked Call Cleared – (BCC) Systems

- When a user requests service, there is a minimal call set-up time and the user is given immediate access to a channel if one is available
- If all channels are already in use and no new channels are available, **call is blocked without access to the system**
- The user **does not receive service**, but is free to try again later

The Erlang B model is based on following assumptions :

- There are nearly an infinite number of users
- Call requests are memory less ,implying that all users, including blocked users, may request a channel at any time
- All free channels are fully available for servicing calls, until all channels are occupied
- The probability of a user occupying a channel (called service time) is exponentially distributed. Longer calls are less likely to happen.
- There are a finite number of channels available in the trunking pool.
- Inter-arrival times of call requests are independent of each other

Erlang B formula is given by

$$Pr[blocking] = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} = GOS$$

- where ***C*** *is the number of trunked channels offered by a trunked radio system and* ***A*** *is the total offered traffic.*

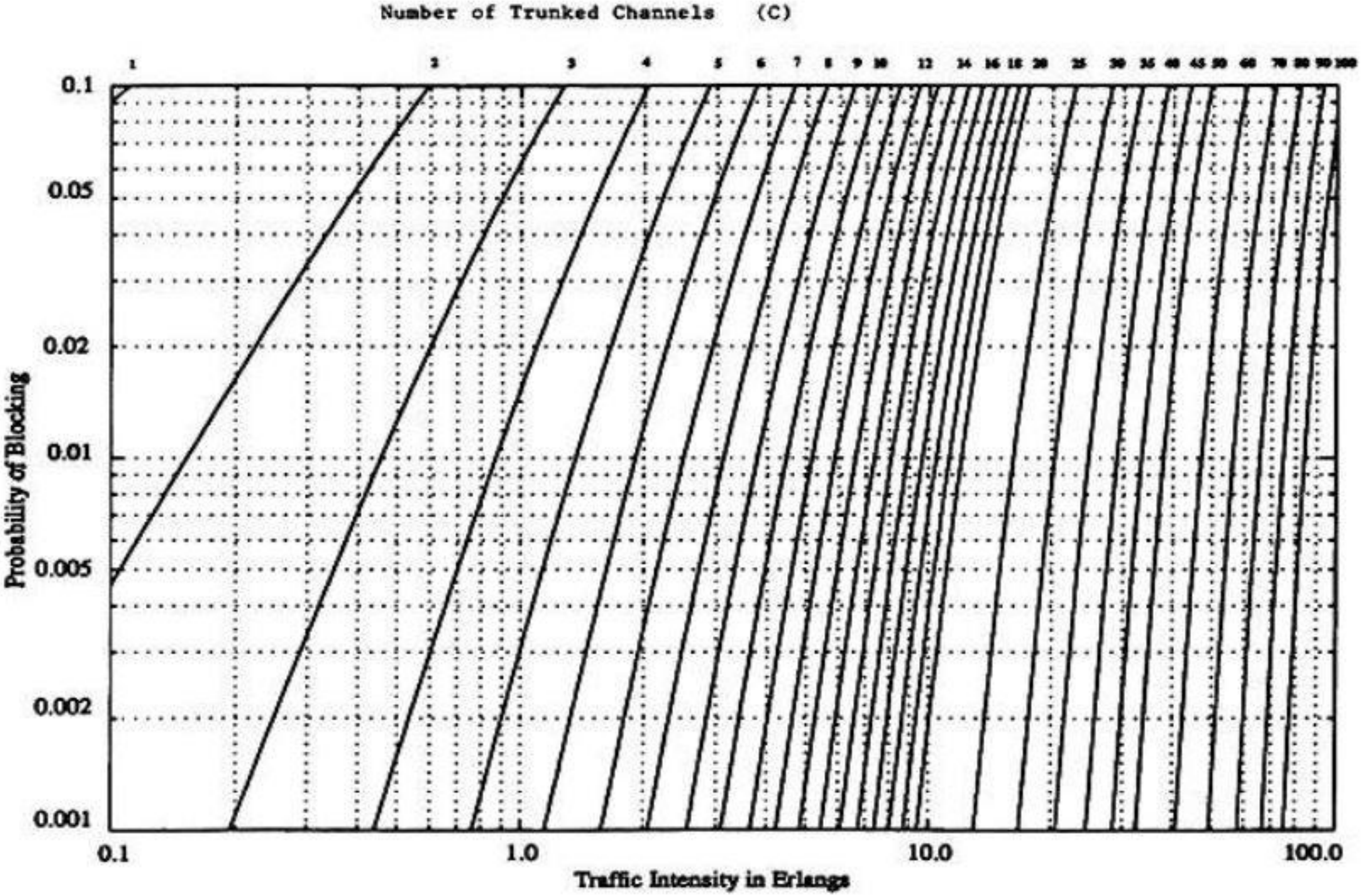


Figure 3.6 The Erlang B chart showing the probability of blocking as functions of the number of channels and traffic intensity in Erlangs.

Table 3.4 Capacity of an Erlang B System

Number of Channels C	Capacity (Erlangs) for GOS = 0.01	= 0.005	= 0.002	= 0.001
2	0.153	0.105	0.065	0.046
4	0.869	0.701	0.535	0.439
5	1.36	1.13	0.900	0.762
10	4.46	3.96	3.43	3.09
20	12.0	11.1	10.1	9.41
24	15.3	14.2	13.0	12.2
40	29.0	27.3	25.7	24.5
70	56.1	53.7	51.0	49.2
100	84.1	80.9	77.4	75.2

Question 1 : How many users can be supported for **0.5% blocking probability** for the following number of trunked channels in a Blocked called Cleared **- BCC** system? (a) 5, (b) 10, (c) 20. Assumed that each user generates 0.1 Erlangs of traffic.

Question 2 : Assuming that each user in a system generates a traffic intensity of 0.2 Erlangs, **how many users can be supported** for 0.1% probability of blocking in an Erlang B system for a number of trunked channels equal to 60.

Solution – Qu 1

- **Given C=5, GOS=0.005, Au=0.1,**

From graph/Table using C=5 and GOS=0.005,A=1.13

Total Number of users U=A/Au=1.13/0.1=11 users

- **Given C=10, GOS=0.005, Au=0.1,**

From graph/Table using C=5 and GOS=0.005,A=3.96

Total Number of users U=A/Au=3.96/0.1=39 users

- **Given C=20, GOS=0.005, Au=0.1,**

From graph/Table using C=20 and GOS=0.005,A=11.10

Total Number of users U=A/Au=11.10/0.1=1101users

- **Solution – Question 2:**

System is an Erlang B

- *Au* = 0.2 Erlangs
- Pr [Blocking] = 0.001=GOS
- *C = 60 Channels*
- From the Erlang B figure, we see that
- *A ≈ 40 Erlangs*

Therefore U=A/Au=40/0.2=200users.

TRANSMISSION CONTROL SCHEMES

- In wireless communications systems, it is often desirable to allow the subscriber to **send simultaneously** information to the base station **while receiving information from the base station**.

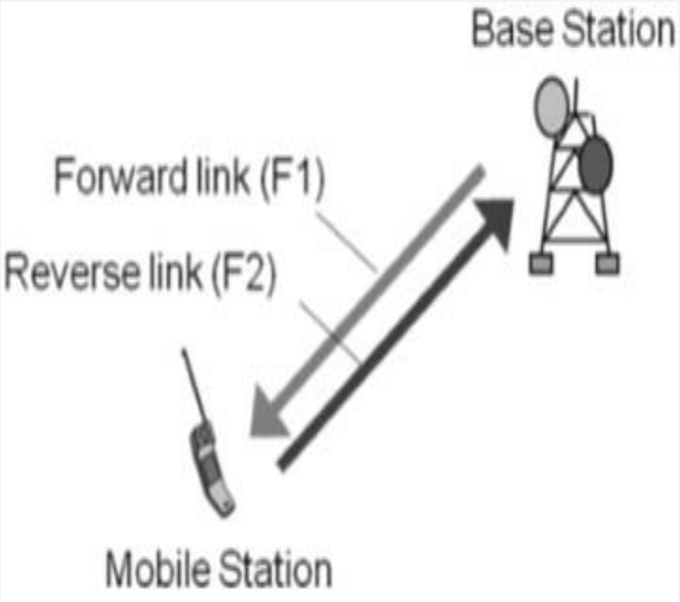
- This is called **duplexing**. It is done using time or frequency domain techniques.

There are Two Kinds of Duplexing

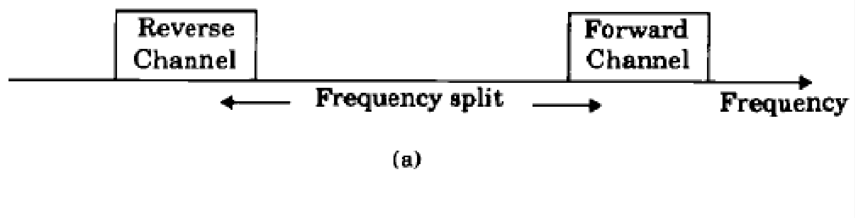
FDD – Frequency Division Duplexing

TDD – Time Division Duplexing

FDD – Frequency Division Duplexing

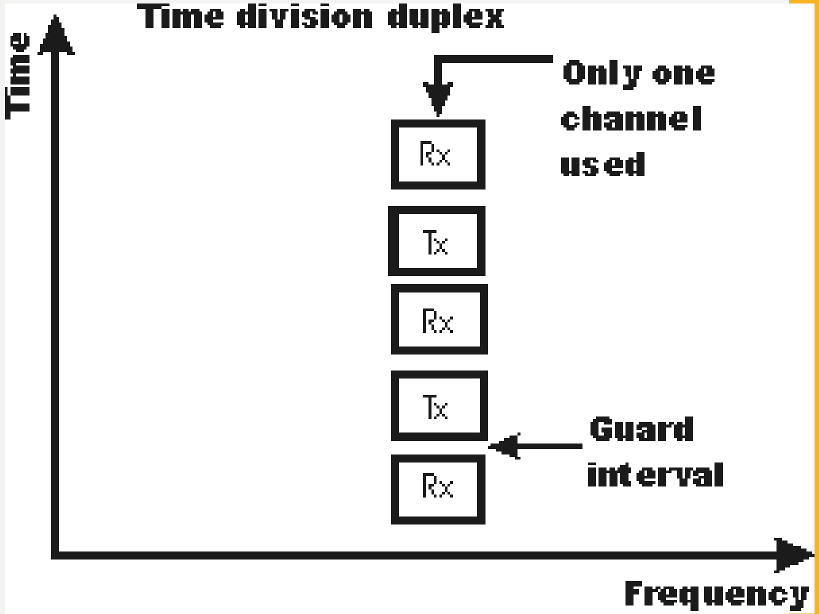


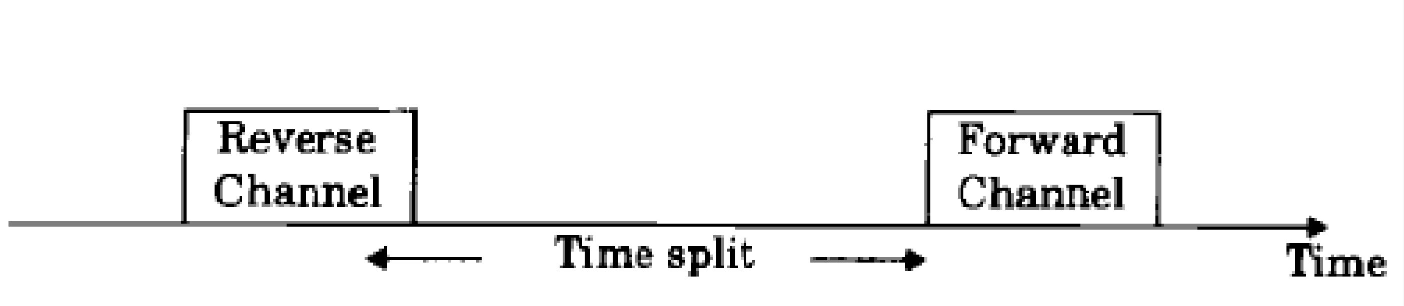
- In Frequency Division Duplexing (FDD) **two different bands of frequencies** for every user is provided.
- The **forward band** provides traffic from **the base station to the mobile**, and the reverse band provides traffic from the **mobile to the base Station.**
- In FDD, **any duplex channel actually consists of two simplex channels**, and a device called a **duplexer is used inside each subscriber** unit and base station to allow simultaneous radio transmission and reception on the duplex channel pair.
- The **frequency split between the forward and reverse channel is constant** throughout the system, regardless of the particular channel being used.



Time Division Duplexing (TDD)

- Time Division Duplexing (TDD) uses **time**, instead of frequency to provide both a forward and reverse link
- If the time split between the forward and reverse time slot is small, then the transmission and reception of data appears simultaneous to the user
- TDD allows communication **on a single channel** (as opposed to requiring two simplex or dedicated channels) and **simplifies the subscriber equipment** since a **duplexer is not required** and cost effective than **FDD.**





(b)

- FDD is geared toward radio communications systems that provide individual radio frequencies for each user. Because each transceiver simultaneously transmits and receives radio signals and the **frequency allocation used for the forward and reverse channels must be carefully coordinated** with out-of-band users that occupy spectrum between these two bands.
- Furthermore, the frequency separation must be coordinated to permit the use of inexpensive RF technology.
- TDD enables each transceiver to operate as either a transmitter or receiver on the **same frequency**, and **eliminates the need for separate forward and reverse frequency bands**. However, there is a time latency due to the fact that communications is not full duplex in the truest sense.

Multiple Access Techniques for Wireless Communications

- Multiple access techniques are used to **allow many mobile users to simultaneously share a finite amount of spectrum**.
- Spectrum sharing is necessary to achieve **high capacity by simultaneously allocating the Available bandwidth** (or **available number of channels**) to multiple users
- Most common kinds of multiple access techniques include:
  - Time division multiple access (TDMA)
  - Frequency division multiple access (FDMA)
  - Code division multiple access (CDMA)
  - Space division multiple access (SDMA)

Difference between multiplexing and multiple access

Multiplexing :

Multiplexing is process to combine multiple signal for transmit it over a single channel or media. generally multiplexing combines several low-speed signals for transmission over a single high-speed connection.

Multiple Access:

Multiple-access is a techniques that permit many users to simultaneously access a given frequency allocation.

MULTIPLE ACCESS TECHNIQUES USED IN DIFFERENT WIRELESS COMMUNICATION SYSTEMS

Cellular System	Multiple Access Technique
Advanced Mobile Phone System (AMPS)	FDMA/FDD
Global System for Mobile (GSM)	TDMA/FDD
U.S. Digital Cellular (USDC)	TDMA/FDD
Japanese Digital Cellular (JDC)	TDMA/FDD
CT2 (Cordless Telephone)	FDMA/TDD
Digital European Cordless Telephone (DECT)	FDMA/TDD
U.S. Narrowband Spread Spectrum (IS-95)	CDMA/FDD

These techniques can be arranged as narrowband or wideband depending upon how **the available bandwidth is allocated** to the users.

Narrowband systems:

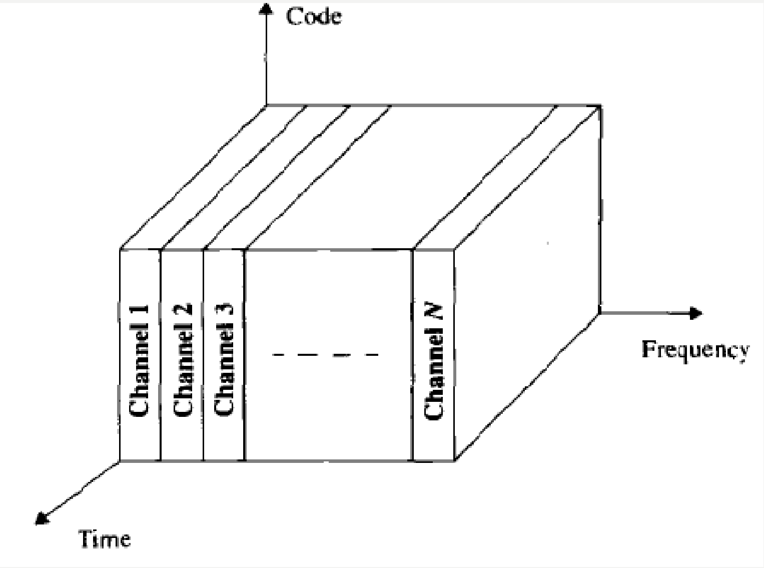
- The available spectrum is **divided into large number** of narrowband channels.
- In narrowband FDMA, in order to minimize the interference between forward and reverse links, the **frequency split is made as large as possible**.
- Narrowband TDMA allows **users to share the same channel but allocates a unique time slot to each user** in a cyclical fashion on the channel

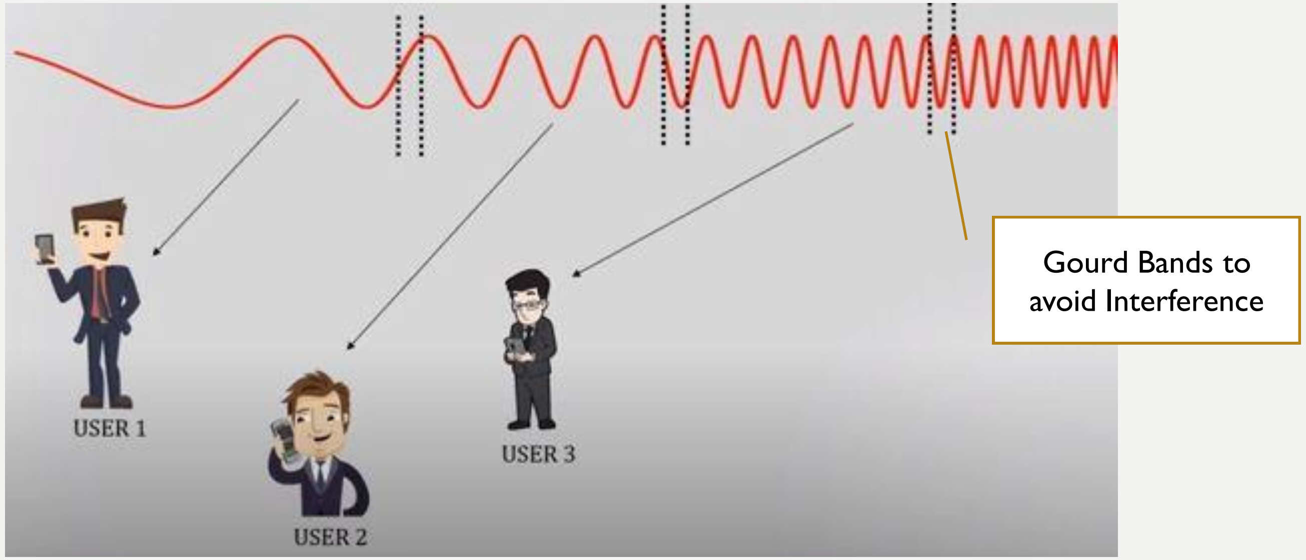
<u>Wideband systems</u>:

- In wideband multiple access systems, the **users are allowed to transmit in a large part of the spectrum**.
- TDMA allocates time slots to the many transmitters on the same channel and allows only one transmitter to access the channel at any instant of time.
- CDMA allows all of the transmitters to access the channel at the same time.

Frequency Division Multiple Access

FDMA assigns **individual non overlapping channels** to different users





- It can be seen from above Figures that each user is allocated a unique frequency band or channel.
- These channels are assigned **on demand to users who request service**
- During the period of the call, **no other user can share the same frequency band**.
- **Gourd Bands are introduced** to avoid interferences between different users.

- In FDD systems, the users are assigned a channel as a pair of frequencies; one frequency is used for the **forward channel**, while the other frequency is used for the **reverse channel**

Features of FDMA

- A FDMA channel carries **only one phone circuit** at a time. Means each user is allocated separate frequency band or channel.
- The channels often have guard bands between them to compensate for imperfect filters, adjacent channel interference.
- If an FDMA channel is not in use, then it is idle and **cannot be used by other users to increase or share capacity**.
- FDMA is usually implemented in narrowband systems. The bandwidth of FDMA channels are relatively narrow **(30 KHz)**

- The **complexity of FDMA mobile systems is lower** when compared to TDMA systems.
- Since **FDMA is a continuous transmission scheme**, fewer bits are needed for overhead purposes.
- The FDMA mobile unit uses duplexers **since both the transmitter and receiver** operate at the same time. This results in an **increase in the cost** of FDMA subscriber limits and base stations.
- FDMA requires tight RF filtering to minimize adjacent channel interference.

- **The number of channels** that can be simultaneously supported in a FDMA system is given by

$$N = \frac{B_t - 2B_{\text{Guard}}}{B_c}$$

Where;

Bt : Total spectrum allocation

BGourd: Guard band allocated at the edge of the allocated spectrum

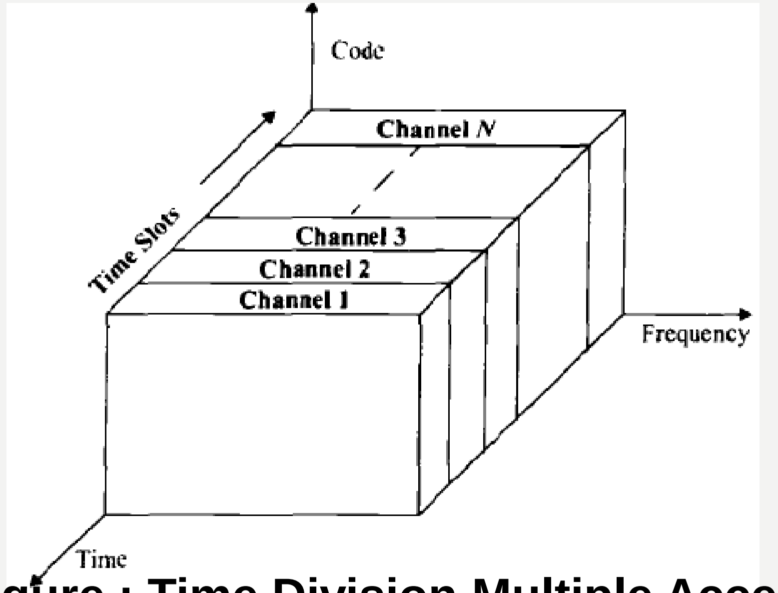
Bc: Channel bandwidth

Question:

If B_t is 12.5 MHz, B_{guard} is 10 kHz, and B_c is 30 kHz, find the number of channels available in an FDMA system.

Time Division Multiple Access

- TDMA divides the radio spectrum into **time slots**, and in each slot **only one user is allowed to either transmit or receive.**
- Each user occupies a **cyclically repeating time slot**. TDMA systems transmit data in a buffer – and **-** burst method, thus the transmission for any user is non-continuous.
- The transmission from various users is interlaced into a **repeating frame structure**.



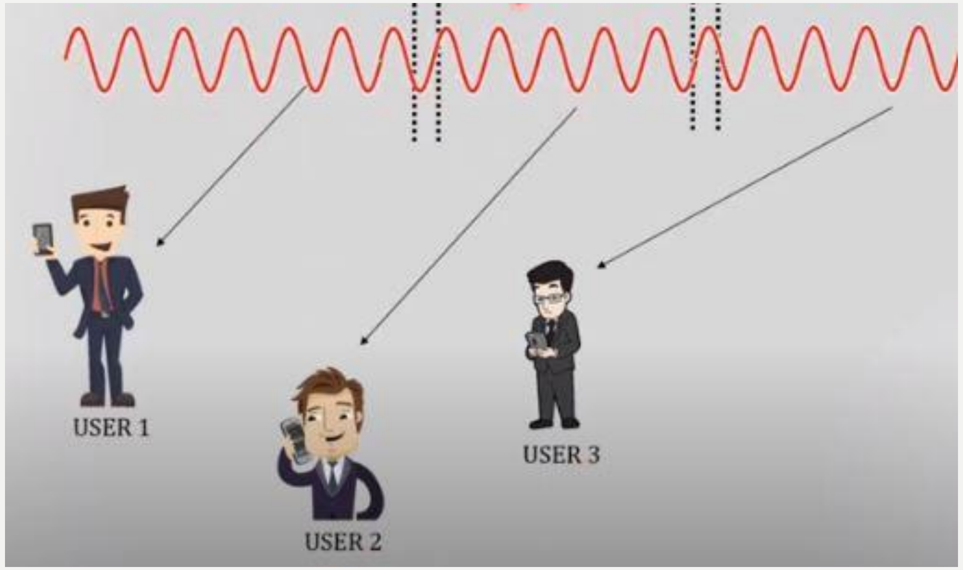
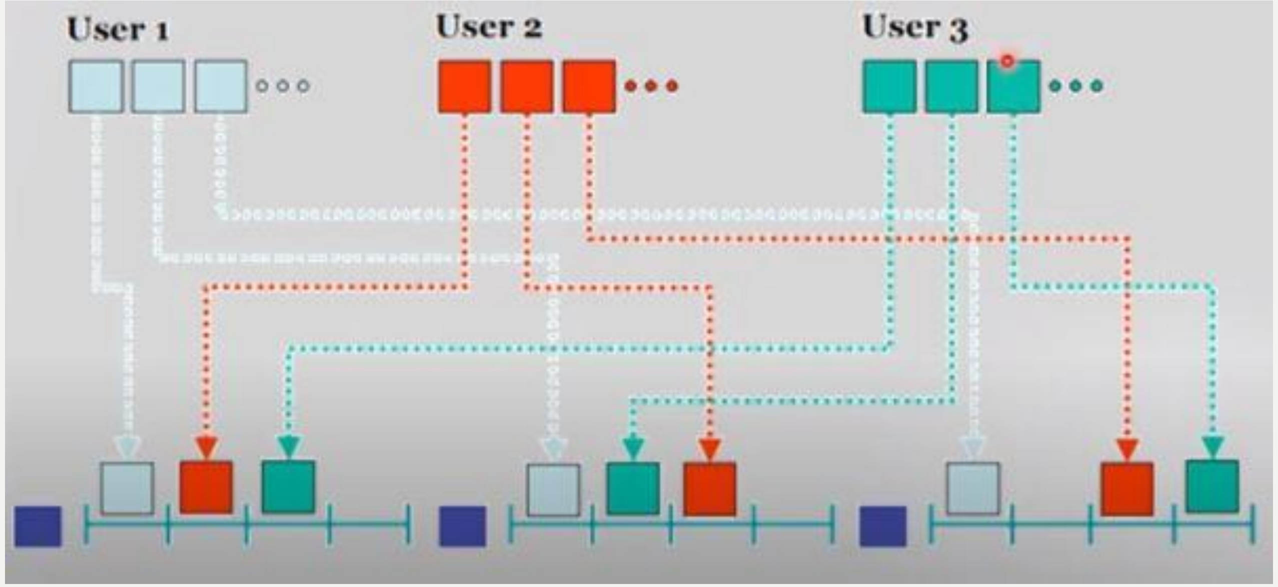


Figure : Time Division Multiple Access



TDMA - Frame Structure

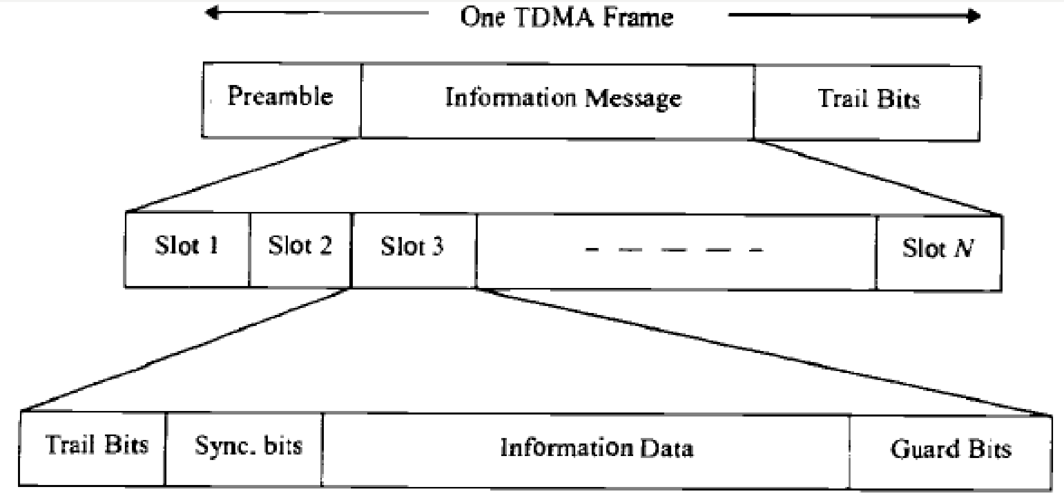


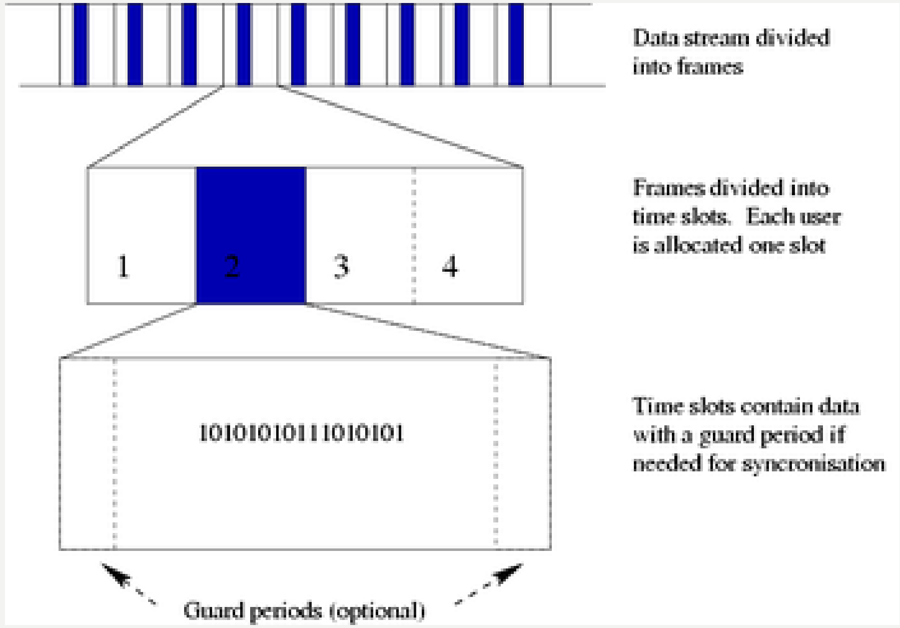
Figure : TDMA Frame Structure

Preamble : Consists of Address and Synchronization bits, which is used by Base stations to identify different subscribers.

Information massage : Contains multiple slots of user information.

Each Bit will have:

- Trail bits – Error detection Bits
- Synchronization Bits
- Information
- Gourd Bits



Features of TDMA

- The number of time slots per frame depends on several factors, such as modulation technique, available bandwidth etc
- Data transmission for users of a TDMA system occurs in bursts. This results in low battery consumption, since the **subscriber transmitter can be turned off when not in use**
- The **handoff process of TDMA is much simpler for a user unit**, since it is able to listen for other base stations during idle time slots

- In TDMA, if the transmitted signal at the edges of a time slot is suppressed sharply in order to shorten the guard time, the transmitted spectrum will expand and cause interference to adjacent channels
- High **synchronization overhead** is required in TDMA systems because of burst transmissions
- TDMA has an advantage in that it is **possible to allocate different numbers of time slots per frame to different users**. Thus bandwidth can be supplied on demand to different users

Efficiency of TDMA

- The efficiency of a TDMA system is a measure of **the percentage of transmitted data that contains information** as opposed to providing overhead.
- The number of overhead bits per frame is given by

$$B_{\mathrm{OH}} = N_r b_r + N_t b_p + N_t b_g + N_r b_g$$

Nr - Number of reference bursts per frame

Nt - Number of traffic bursts per frame

br - Number of overhead bits per reference burst

bp - Number of overhead bits per preamble in each slot

bg - Number of equivalent bits in each guard time interval

- The total number of bits per frame is given by

$$b_T = T_f R$$

Tf - is the frame duration and R is the channel bit rate

- Therefore the frame efficiency is given by

$$\eta_f = \left(1 - \frac{b_{\mathrm{OH}}}{b_T}\right) \times 100\%$$

Number of channels in TDMA System

- The number of TDMA channel slots that can be provided in a TDMA system is found from

$$N = \frac{m(B_{tot} - 2B_{guard})}{B_c}$$

where ; m is the maximum number of TDMA users supported on each radio channel.

Example 1

Consider Global System for Mobile, which is a TDMA/FDD system that uses 25 MHz for the forward link, which is broken into radio channels of 200 kHz. If 8 speech channels are supported on a single radio channel, and if no guard band is assumed, find the number of simultaneous users that can be accommodated in GSM.

Example 2

If GSM uses a frame structure where each frame consists of 8 time slots, and each time slot contains 156.25 bits, and data is transmitted at 270.833 kbps in the channel, find (a) the time duration of a bit, (b) the time duration of a slot, (c) the time duration of a frame, and (d) how long must a user occupying a single time slot must wait between two simultaneous transmissions.

Example 3

If a normal GSM time slot consists of 6 trailing bits, 8.25 guard bits, 26 training bits, and 2 traffic bursts of 58 bits of data, find the frame efficiency.

Space Division Multiple Access

- SDMA controls the radiated energy for each user in space. SDMA serves different users by using spot beam antennas.
- These different areas covered by the antenna beam may be served by the same frequency (in a TDMA or CDMA) or different frequencies (in FDMA).
- Sectorized antennas may be thought of as a basic application of SDMA
- For mobile users SDMA must adapt as user angles change
- If directionality is achieved via sectorized antennas, then a user must be handed off to a new sector when it moves out of its original sector