UNIT II

CELLULAR ARCHITECTURE

Multiple Access Techniques:

- In order to accommodate many mobile users within the finite amount of radio spectrum, the multiple access techniques are used.

Three types of duplexing techniques are used. They are:

1. Simplex
2. Half duplex
3. Full duplex

The duplexing may be done by using frequency or time domain techniques.

FDD: The frequency division duplexing provides two distinct bands of frequencies for every user.

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<table>
<thead>
<tr>
<th>Reverse channel</th>
<th>Forward channel</th>
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<tbody>
<tr>
<td>← Frequency separation → Frequency</td>
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TDD: The time division duplexing uses time instead of frequency to provide a forward and reverse link.

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Types of Multiple access Techniques

3 major access techniques are used in wireless communication system. The types are

1. Frequency Division Multiple Access (FDMA)
2. Time Division Multiple Access (TDMA)
3. Code Division Multiple Access (CDMA)

- These techniques can be grouped as narrowband vs. wideband systems, depending upon how the available bandwidth is allocated to the users.

Narrowband Systems:

- In a narrowband multiple access system, the available radio spectrum is divided into a large no. of narrowband channels.
  The channels are operated by using F.D.D.
  - The interference between users in reverse channel on each channel is minimized by frequency separation made within the frequency spectrum.

Wideband Systems:

- In this system, the transmission B.W. of a single channel is much larger than the coherence B.W. of the channel. In this system, a large number of transmitters are allowed to transmit on the same channels.
  - TDMA allocates time slots to many transmitters on the same channel. CDMA allows only one transmitter to access the channel at any instant of time. But in CDMA, it allows all the transmitters to access the channel at the same time.
Frequency Division Multiple Access (FDMA)

In FDMA the individual channels are assigned to a single user.

- Each user is allocated a unique frequency band or channel.
- These channels are assigned on demand to users who request the service. During the period of the call, no other user can share the same channel.
- In FDMA/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:

1. The FDMA channel covers only one phone circuit at a time.
2. The FDMA is usually implemented in narrowband systems.
3. If an FDMA channel is not in use, then it sits idle and cannot be used by other users to use or share capacity. It is essentially a wasted resource.
4. After the assignment of a Voice channel, the base station enables the mobile to transmit simultaneously or continuously.
5. The complexity of FDMA mobile systems is lower when
6) FDMA is a continuous transmission scheme, fewer bits are needed for overhead compared to TDMA.

7) FDMA systems have higher cell site system costs as compared to TDMA systems, because of the single channel per carrier design and the need to use costly bandpass filters to eliminate spurious radiation at the base station.

8) The FDMA mobile units use duplexers since both the transmitters and receivers operate at the same time. This results in an increase in the cost of FDMA subscriber units & base stations.

9) FDMA requires tight RF filtering to minimize adjacent channel interference.

Non-linear effects of FDMA:

- In a FDMA system, many channels share the same antenna at the base station. The power amplifiers or the power combiners when operated at or near saturation for maximum power efficiency are non-linear.

- The non-linearities cause signal spreading in the frequency domain to generate intermodulation frequencies. IM can interfere with other channels in the FDMA systems.

- IM is the generation of undesirable harmonics. The number of channels that can be simultaneously supported in a FDMA system is given by

\[ N = \frac{B_t - 2B_{guard}}{B_c} \]

\[ B_t \rightarrow \text{Total spectrum allocation} \]

\[ B_{guard} \rightarrow \text{Guard band allocated at the edge of the allocated spectrum band} \]

\[ B_c \rightarrow \text{Channel bandwidth} \]
Time Division Multiple Access

- TDMA systems divide the radio spectrum into time slots, so in each slot only one user is allowed either to transmit or receive.

One TDMA Frame

- Preamble  - Information Message  - Trial Bits

Slot 1  Slot 2  Slot 3  Slot 4  ....  Slot N

Trial Bits  Sync Bits  Information Data  Guard Bits

TDMA frame structure

- TDMA systems transmit data in burst method, thus the transmission for any user is noncontinuous.

- The frame consists of a no. of slots. Each frame is made up of a preamble, an information message & trial bits.

- In TDMA/TDD, half of the time slots in the frame information message would be used for the forward link channel & half used for the reverse link channel.

- In TDMA/FDD, similar frame structure would be used for either forward or reverse transmission but the carrier frequency would be different for the forward vs reverse link.

- In TDMA frame the preamble contains the address & synchronization information that both the base station & the subscribers used to identify each other.
Guard times are utilized to allow synchronization of the receivers in different slots or frames. Different TDMA wireless standards have different TDMA frame.

Features of TDMA

1) In TDMA, the no. of time slots per frame depends on several factors such as modulation technique, available B-W etc.

2) Data Transmission for users of a TDMA system is not continuous but occurs in bursts. This results in slow battery consumptions, since the Subscriber terminal can be turned off when not in use.

3) TDMA uses different time slots for Transmission & Reception, thus duplexer are not required.

4) Adaptive equalization is usually necessary in TDMA systems, since the Transmission rates are generally very high as compared to FDM channels.

5) In TDMA, the guard time should be minimized.

6) High Synchronization Overhead is required in TDMA systems because of burst Transmissions.

Advantage: It is possible to allocate different number of time slots/frame to different users. Thus B-W can be supplied on demand to different users by concatenating time slots based on priority.

The no. of channel in TDMA system is given by

\[ N = \frac{m(B_{\text{tot}} - 2B_{\text{guard}})}{B} \]

m → Maximum no. of TDMA users supported on each radio
Efficiency of TDMA:-

The efficiency of TDMA system is a measure of the percentage of transmitted data that contains information as opposed to providing overhead for the access scheme.

The frame efficiency \( P_f \) is the percentage of bits/frame which contains transmitted data.

The no. of overhead bits/frame is

\[
boH = N_r b_r + N_p b_p + N_t b_g + N_r b_g
\]

- \( N_r \rightarrow \) No. of reference bursts/frame
- \( N_t \rightarrow \) No. of traffic burst/frame
- \( b_r \rightarrow \) No. of overhead bits/reference burst
- \( b_p \rightarrow \) No. of overhead bits/preamble in each slot
- \( b_g \rightarrow \) No. of equivalent bits in each guard time interval

The total no. of bits/frame is

\[
b_T = T_f R
\]

The frame efficiency \( P_f \) is given as

\[
P_f = \left( 1 - \frac{boH}{b_T} \right) \times 100\%
\]
Code Division Multiple Access

- In this system, the narrowband message signal is multiplied by a very large b.w. signal called the spreading signal.

- The spreading signal is a pseudo noise code sequence that has a chip rate which is orders of magnitude greater than the data rate of the message.

- Uses the same carrier frequency as may transmit simultaneously.

- Each user has its own pseudorandom codeword which is approximately orthogonal to all other codewords.

- Each user operates independently with no knowledge of the other users.

- The near far problem occurs when many mobile users share the same channel.

- In general, the strongest received mobile signal will capture the demodulator at a base station. To combat the near-far problem power control is used in most CDMA implementation.

- Power control is implemented at the base station by rapidly sampling the radio signal strength indicator levels of each mobile and then sending a power change command over the forward radio link.
Features of CDMA

1) The CDMA system many users share the same frequency either TDMA or FDMA may be used.

2) Unlike TDMA or FDMA, CDMA has a soft capacity limit.

3) Multipath fading may be substantially reduced because the signal is spread over a large spectrum.

4) Channel data rates are very high in CDMA systems.

5) CDMA uses co-channel cells it can use macroscopic spatial diversity to provide soft handoff. Soft handoff is performed by the Hsc (i.e.) The Hsc can simultaneously monitor a particular user from 2 or more stations. Then the Hsc may choose the best version of the signal at any time without switching frequencies.

6) Self-jamming is a problem in cdma system. It arises from the fact that the spreading sequences of different users are not exactly orthogonal hence in the de-spreading of a particular user, non-zero contributions to the receiver decision statistic for a denied user arise from the transmission of other users in the system.

7) The near far problem occurs at a CDMA receiver if an undenied user has a high detected power as compared to the denied user.
Cellular concept

In early mobile radio system large coverage area was achieved by using a single, high powered transmitter with an antenna mounted on a tall tower, but it was impossible to reuse those same frequencies throughout the system since any attempts to achieve frequency reuse would result in interference.

The cellular concept offered very high capacity in a limited spectrum allocation without any major technological changes. It is a system level idea which calls for replacing a single high power transmitter (large cell) with many low power transmitters (small cells) each providing coverage to only a small portion of the service area.

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 design process of selecting and allocating a channel groups for all of the cellular base stations within a system is called frequency reuse (or) frequency planning.
The concept of cellular frequency reuse where cells labelled with the same letter use the same group of channels.

The actual radio coverage of a cell is known as the footprint. When using hexagons to model coverage areas, base stations transmitters are depicted as either being in the centre of the cell (center-excited cells) or on three of the six cell vertices (edge-excited cells).

For center-excited cells, omnidirectional antennas are used. For edge-excited cells, sectorized directional antennas are used.

To understand the frequency reuse concept consider a cellular system which has a total of \( S \) duplex channels available for use. If each cell is allocated a group of \( K \) channels \( (K < S) \) and if the \( S \) channels are divided among \( N \) cells such that each have the same number of channels, the total number of available radio channels can be expressed as

\[
S = KN
\]

cluster:- The \( N \) cells which collectively use the complete set of frequencies is called cluster. The above figure using 3 clusters.

If a cluster is replicated \( H \) times within the system, the total number of duplex channels \( C \) can be used as a measure.
eqn $k = kN$ the capacity of a cellular system is directly proportional to number of times a cluster is replicated in a fixed service area.

$N$ - cluster size may be equal 4, 7 or 12.

Frequency reuse factor of a cellular system is given by $1/N$.

The number of cells per cluster is given by

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

where $i$ and $j$ are non-negative integers. To find nearest co-channel neighbors of a particular cell, one must do the following:

(i) Move $i$ cells along any chain of hexagons.
(ii) Turn $90^\circ$ counter clockwise & move $j$ cells.

Channel Assignment Strategies:

For efficient utilization of the radio spectrum a frequency reuse is used in order to increase the capacity & minimize the interference.

The channel assignment strategies can be classified into 2 categories:

1) Fixed Channel Assignment Strategy
2) Dynamic Channel Assignment Strategy
Fixed channel assignment strategy

- In this strategy, each cell is allocated a predetermined set of voice channels.
- Any cell 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 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

- 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.
- Dynamic channel assignment reduces the call blocking, which increases the trunking capacity of the system.
Handoff

When a mobile moves into a different cell while a conversation is in progress, the HSC automatically transfers the call to a new channel belonging to the new base station. This is called Handoff.

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.

Handoff must be performed successfully as infrequently as possible and be imperceptible to the user.

The margin level at which the handoff is made is given by

$$\Delta = P_r\text{ handoff} - P_r\text{ minimum usable}$$

$\Delta$ cannot be too large or too small.

- If $\Delta$ is too large, unnecessary handoffs which burden the HSC may occur.
- If $\Delta$ is too small, there may be insufficient time to complete a handoff before a call is lost due to weak signal conditions.

Handoff Scenario at Cell Boundary

[Diagram showing the handoff scenario at cell boundary]
Inter system handoff:

If a mobile moves from one cellular system to a different cellular system controlled by a different HSC during the process of a call, a handoff is made. This type of handoff is called "intersystem handoff."

- There are so many problems occur in this type of handoff when a mobile moves from one cellular system to another. The HSC cannot find another cell within its system to which it can transfer the call is in progress. And also a local call may become a long distance call as the mobile moves out of its home system and becomes a roamer in a neighboring system.

Guard channel concept:

One method for giving priority to handoffs is called guard channel concept (i.e.) out of total channels, the no. of channels are allocated for handoffs.

Disadvantage - Only fewer number of channels are used to originating
Dwell Time: The time over which a call may be maintained within a cell without handoff is called dwell time.

Mobile Assisted Handoff (MAHO): In this type, every mobile station measures the received power from surrounding base stations and continuously reports the results of these measurements to the serving base station. MAHO is particularly suited for microcellular environments. There are 2 types of handoffs are used.

1. Soft Handoff: The mobile communicates with 2 or more cells at the same time and finds which one is the strongest signal base station then it automatically transfers the call to that base station is called soft handoffs.

![Diagram of Soft Handoff]

2. Hard Handoff: In the HSC monitors the strongest signal base station & transfers the call to that base station then it is called hard handoff.

![Diagram of Hard Handoff]
- Another problem in the handoff is “cell dragging”.
- It results from the pedestrian users that providing a strong signal to the base station. This type of situation occurs in the urban environment where there is a los radio path b/w the subscriber & the base station.
- When the user travels away from the base station at a very low speed, the average signal strength does not decay rapidly.
- Even when the user has travelled well beyond the designed range of the cell, the received signal at the base station may be above the handoff threshold, thus a handoff may not be made. This creates a potential interference & traffic management problem that is called “cell dragging”.

To solve this problem, handoff thresholds & radio coverage parameters must be adjusted carefully.

Interference and system capacity:

Interference on voice channel causes cross talk where the subscriber hears interference in the background due to an undesired transmission.

There are 2 types of interference:
1) Adjacent channel interference
2) Co-channel interference
The co-channel reuse ratio is defined by

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

If $Q$ is smaller than cluster size, the reuse small that is providing

larger capacity

Let $I_i$ be the number of co-channel interfering cells, then the signal
to interference ratio for a mobile receiver is

$$\frac{S}{I} = \frac{S \sum_{j=1}^{I_i} I_j}{\sum_{j=1}^{I_i} I_j}$$

where $S \rightarrow$ signal power for desired base station

$I_i \rightarrow$ Interference power caused by interfering
cell $BS_i$.

The average received power $P_r$ at a distance $d$ from the transmitting
antenna is given by

$$P_r = P_0 \left(\frac{d}{d_0}\right)^{-n} \text{ or } P_r(dem) = P_0(dem) - 100 \log(d/d_0)$$

when the transmit power of each $BS_i$ is equal, the path loss
exponent is the same throughout the coverage area, $S/I$ for a
mobile can be approximated as

$$\frac{S}{I} = \frac{R^n}{\sum_{j=1}^{I_i} (D_j)^n}$$

- Considering only the first layer of interfering cells. If all the
interfering base stations are equivalent from the desired base
station $BS_i$, if this distance is equal to the distance $D$ below

$$\frac{S}{I} = \frac{(D/R)^n}{I_0}$$

$$\left(\frac{\sqrt[3]{3N}}{I_0}\right)^n$$
- Using an exact cell geometry layout it can be shown for a 7 cell cluster with the mobile unit at the cell boundary.
- The mobile is a distance D-R from the 2 nearest co-channel interfering cells so it is exactly D+R/2. D, D-R/2 & D+R from the other interfering cells.

\[
S/I = \frac{R^{-n}}{\sum_{j=1}^{10} \left( D_i \right)^{-n}} \cdot \frac{R^{-4}}{2(D-R)^4 + 2(D+R)^4 + 2D^4}
\]

Rewritten in terms of \( Q \)

\[
\frac{S}{I} = \frac{1}{2(Q-1)^4 + 2(Q+1)^4 + 2Q^{-4}}
\]

\[
Q = \sqrt[3]{3N} = \sqrt[3]{3 \times 7} = \sqrt[3]{21} = 2.6
\]

\[
N = 7, \quad Q = 2.6 \quad \text{is the worst case signal to interference ratio}
\]

\[
S/I \approx 49.56
\]
Trunking and Grade of Service:

The 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 busy hours for cellular radio system typically occur during rush hours by 4 PM to 6 PM on a Thursday or Friday evening.

Common terms used in trunking theory:

(i) Setup Time: The time required to allocate a trunked radio channel to a requesting user.

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

(iii) Traffic Intensity: Measure of channel time utilization, which is the average channel occupancy measured in Erlangs denoted by \( A \).

(iv) Request Rate: The average number of call requests/unit time denoted by \( \lambda/sec \) the traffic intensity \( A = \lambda H \)

\( \lambda \) - average no. of call request/time for each user

\( H \) - average duration of a call

\( U \) - No. of users

For a system containing \( U \) users & an unspecified no. of channels, the total offered traffic intensity \( A \) is given as

\[ A = UA_0 \]
This is determined by the Erlang formula, which is given by

$$P_r (\text{delay} > 0) = \frac{A^c}{A^c + c! \left(1 - \frac{A}{c}\right) \sum_{k=0}^{c} \frac{A^k}{k!}}$$

If no channels are immediately available, the cell is delayed and the probability that the delayed call is forced to wait more than "t" is:

The GOS of a trunked system where blocked calls are delayed is given by

$$P_r (\text{delay} > t) = P_r (\text{delay} > 0) P_r (\text{delay} > t | \text{delay} > 0)$$

$$= P_r (\text{delay} > 0) \exp \left(-\left(C - A\right)t/H\right)$$

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

$$D = P_r (\text{delay} > 0) \cdot \frac{H}{c - A}$$

$$\frac{H}{c - A}$$ is the average delay for those calls which are queued.

Trunking Efficiency:

It is a measure of the number of users which can be offered a particular GOS with a particular configuration of fixed channels.

Load: Traffic Intensity across the entire trunked radio system, measured in Erlangs.
$P_1$ (at old cell boundary) $\propto Pt_1 R^n$

$P_2$ (at new cell boundary) $\propto Pt_2 (R/2)^n$

$n$ is the path loss exponent.

If $n = 4$, $Pt_2 = Pt_1/16$

If the cells are split then the transmitter power will be reduced, so that handoff occurs less frequently.

**Cell Sectoring**

- Sectoring is one way to increase the capacity of the system.
- Sectorization is improved due to usage of directional antennas.
- Directional antennas are used to radiate power in one particular direction.
- The area covered by each directional antenna is called a sector. This method is called as cell sectoring.
- By using directional antennas a given cell will receive interference & transmit with only a fraction of the available co-channel cells.
- The factor by which the co-channel interference is reduced depends on the amount of sectoring used. A cell is normally partitioned into 120° sectors or 60° sectors.
- When sectoring is employed, the channels used in particular cell are broken down into sectors and are used only within a particular sector. From that interference also increases capacity.

![Diagram showing hexagonal sectors]

- Consider the interference experienced by a mobile located in the rightmost sector of the central cell labelled “5”. It will experience interference on the forward link from only two sectors out of six.

**Microcell Zone Approach**

- The number of handoffs required when sectoring is employed results in an increased load on the switching and control links elements of the mobile system.

- In order to avoid the above problem, microcell zone approach is used.
- In this method cells are divided into no. of zones as each no. of zones consists of individual Transceiver.
- so that interference also reduced and capacity is ↑ because ↓ co-channel interference improves the signal quality & also leads to an ↑ in capacity without degradation in tracking efficiency caused by selecting.

Microwave or Fiberoptic link

- when the mobile station moves from one zone to next zone then the base station switches the channel to the new zone site. A given channel is active in only one zone. The channels are distributed in time & space are also reused in co-channel cells. This technique is particularly useful in highways or urban traffic corridors.

Advantages:
- The co-channel interference in the cellular system is reduced
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- The co-channel interference in the cellular system is reduced
Transmitters on the edge of the cell.

2. The signal quality is ↑ due to reduction in co-channel interferents.

3. Channel capacity is ↑ without the degradation in Framing efficiency caused by sectering.