Subject Name: Mobile Computing and Wireless Communication
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CHAPTER NO -3: Multiple Access in Wireless System:

TOPIC 1. Multiple access scheme

DESCRIPTIVE QUESTIONS

1. Explain the following Multiple Access Techniques used to access the channel by mobile subscriber. **(June-2012)[L.J.I.E.T]** 7
   - Frequency Division Multiple access.
   - Space Division Multiple access.

ANS:

Multiple Access System:

→ In this kind of system multiple users can transmit by single channel.
→ The multiple access technique is used in the multiuser environment for applications such as satellite communication and wireless mobile communication.
→ Multiple access techniques are classified below:
1. Frequency Division Multiple Access (FDMA)
2. Time Division Multiple Access (TDMA)
3. Space Division Multiple Access (SDMA)
4. Code Division Multiple Access (CDMA)

➢ **Space Division Multiple access [SDMA]:**

→ It is used for allocating a separated space to users in wireless network.
→ It offers service to different users by using different spot beam antennas.
→ The antenna beam covers different areas that offers service at the same frequency.
→ The mobile phone may receive several base stations with different quality.
→ A MAC algorithm could now decide which base station is best, taking into account which frequencies (FDM), time slots (TDM) or code (CDM) are still available (depending on the technology).
→ Typically, SDMA is never used in isolation but always in combination with one or more other schemes.
→ For SDMA, sectorized antenna are preferred to be used.
→ The basis for the SDMA algorithm is formed by cells and sectorized antennas which constitute the infrastructure implementing Space Division Multiplexing (SDM).
→ The spectral efficiency is increased in SDMA. The system capacity is expressed as:

$$C_{SDMA} = N_{SDMA} \ C$$

Where,
C_{SDMA} = Capacity of SDMA system
N_{SDMA} = Average number of simultaneous spatial channel per RF channel.

2. Explain the following Multiple Access Techniques used to access the channel by mobile subscriber. **(June-2012)[L.J.I.E.T]** 7
   - Time Division Multiple access.
   - Code Division Multiple access.

3. Explain FDMA with example of Frequency division duplex. **[L.J.I.E.T]** 4

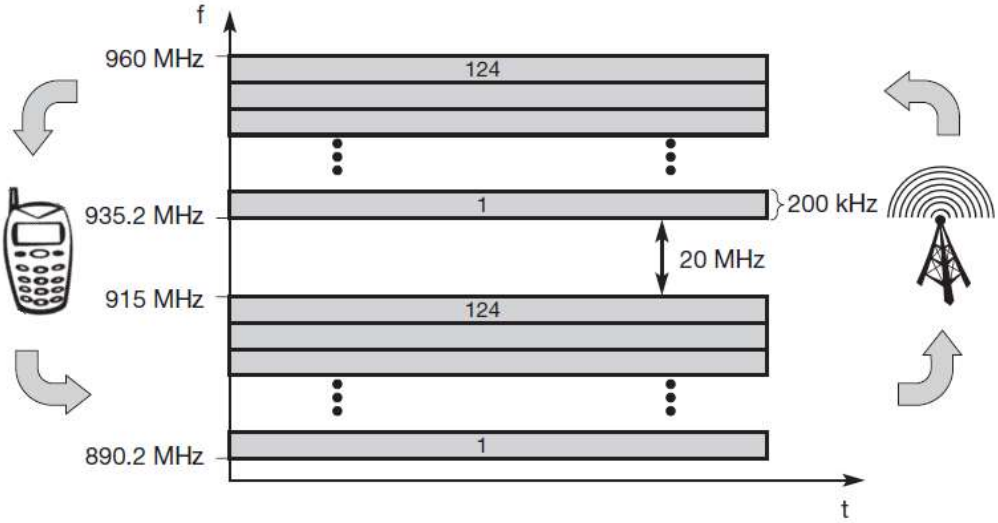
➢ **Frequency division multiple access (FDMA)**

→ In wireless communication, the individual users are allocated individual channels. The

channels or the frequency band is unique for each subscriber.
- → The entire allowed radio spectrum is divided into many slices of the frequency bands and each band or channel is allocated to users.

Features of FDMA:
- → It comprises all algorithms allocating frequencies to transmission channels according to the frequency division multiplexing (FDM).
- → Allocation can either be fixed (as for radio stations or the general planning and regulation of frequencies) or dynamic (i.e., demand driven).
- → Complexity of FDMA is less
- → It have narrow bandwidth as each channel supports only one circuit per carrier.
- → The symbol time is large in comparison to the delay spread
- → ISI (Inter symbol Interference) is low.
- → Cost of cell site is higher in comparison to the TDMA system.
- → It is a continuous transmission method. So few bits are required for overhead purpose.
- → FDM is often used for simultaneous access to the medium by base station and mobile station in cellular network.
- → Channels can be assigned to the same frequency at all times, i.e., pure FDMA, or change frequencies according to a certain pattern, i.e., FDMA combined with TDMA.
- → The latter example is the common practice for many wireless systems to circumvent narrowband interference at certain frequencies, known as frequency hopping.
- → Sender and receiver have to agree on a hopping pattern, otherwise the receiver could not tune to the right frequency.
- → Hopping patterns are typically fixed, at least for a longer period. The fact that it is not possible to arbitrarily jump in the frequency space (i.e., the receiver must be able to tune to the right frequency) is one of the main differences between FDM schemes and TDM schemes.
- → Furthermore, FDM is often used for simultaneous access to the medium by base station and mobile station in cellular networks.

FDD:
- → Here the two partners typically establish a duplex channel, i.e., a channel that allows for simultaneous transmission in both directions. The two directions, mobile station to base station and vice versa are now separated using different frequencies.
- → This scheme is then called frequency division duplex (FDD).
- → Again, both partners have to know the frequencies in advance; they cannot just listen into the medium. The two frequencies are also known as uplink, i.e., from mobile station to base station or from ground control to satellite, and as downlink, i.e., from base station to mobile station or from satellite to ground control.
- → As for example FDM and FDD, Figure shows the situation in a mobile phone network based on the GSM standard for 900 MHz.
- → The basic frequency allocation scheme for GSM is fixed and regulated by national authorities. (Certain variations exist regarding the frequencies mentioned in the examples.) All uplinks use the band between 890.2 and 915 MHz, all downlinks use 935.2 to 960 MHz. According to FDMA, the base station, shown on the right side, allocates a certain frequency for up- and downlink to establish a duplex channel with a mobile phone. Up- and downlink have a fixed relation.
- → If the uplink frequency is $f_u = 890$ MHz + $n \cdot 0.2$ MHz, the downlink frequency is $f_d = f_u + 45$ MHz, i.e., $f_d = 935$ MHz + $n \cdot 0.2$ MHz for a certain channel n. The base station selects the channel.
- → Each channel (uplink and downlink) has a bandwidth of 200 kHz.



→ This illustrates the use of FDM for multiple access (124 channels per direction are available at 900 MHz) and duplex according to a predetermined scheme.

→ Similar FDM schemes for FDD are implemented in AMPS, IS-54, IS-95, IS-136, PACS, and UMTS (FDD mode). Chapter 4 presents some more details regarding the combination of this scheme with TDM as implemented in GSM.

Advantages of FDMA:

1. All stations can operate continuously all 24 hours without having to wait for their turn to come.
2. No synchronization is necessary
3. The complexity of system is low.

Disadvantages of FDMA:

1. Intermodulation frequencies can cause adjacent channel interference.
2. As result of non linearities, intermodulation product are generated.
3. Cell site cost is high
4. Bandwidth is narrow.
5. Carrier only one circuit at a time.

4. Explain TDMA with example of Time division duplex. **[L.J.I.E.T]** 4

TDMA:

→ Compared to FDMA, time division multiple access (TDMA) offers a much more flexible scheme, which comprises all technologies that allocate certain time slots for communication, i.e., controlling TDM. Now tuning in to a certain frequency is not necessary, i.e., the receiver can stay at the same frequency the whole time.

→ Each user to allocate a time slot in which the user can access the channel.

→ In each slot only one user is allowed to transmit or receive.

→ Using only one frequency, and thus very simple receivers and transmitters, many different algorithms exist to control medium access. Listening to different frequencies at the same time is quite difficult, but listening to many channels separated in time at the same frequency is simple.

→ Almost all MAC schemes for wired networks work according to this principle, e.g., Ethernet, Token Ring, ATM etc. Now synchronization between sender and receiver has to be achieved in the time domain. Again this can be done by using a fixed pattern similar to FDMA techniques, i.e., allocating a certain time slot for a channel, or by using a dynamic allocation scheme.

→ Dynamic allocation schemes require an identification for each transmission as this is the case for typical wired MAC schemes (e.g., sender address) or the transmission has to be announced beforehand.

→ MAC addresses are quite often used as identification. This enables a receiver in a broadcast medium to recognize if it really is the intended receiver of a message.

→ Fixed schemes do not need identification, but are not as flexible considering varying bandwidth requirements.

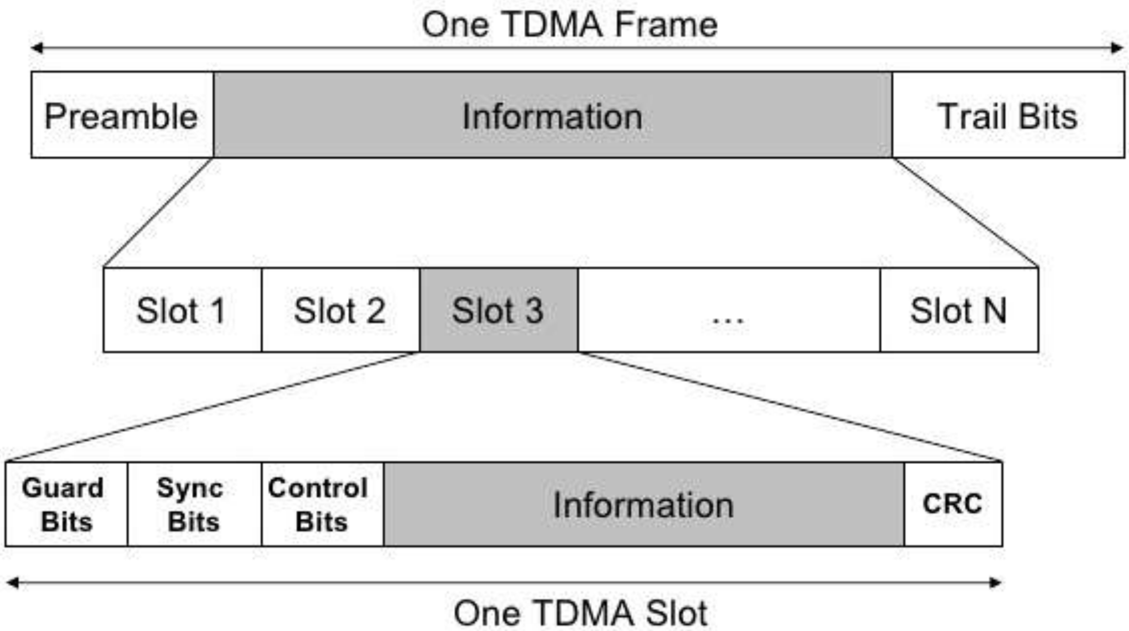
→ Typically, those schemes can be combined with FDMA to achieve even greater flexibility and transmission capacity. The simplest algorithm for using TDM is allocating time slots for channels in a fixed pattern.

→ This results in a fixed bandwidth and is the typical solution for wireless phone systems. MAC is quite simple, as the only crucial factor is accessing the reserved time slot at the right moment. If this synchronization is assured, each mobile station knows its turn and no interference will happen.

→ The fixed pattern can be assigned by the base station, where competition between different mobile stations that want to access the medium is solved.

→ Fixed access patterns (at least fixed for some period in time) fit perfectly well for connections with a fixed bandwidth.

→ Furthermore, these patterns guarantee a fixed delay – one can transmit, e.g., every 10 ms as this is the case for standard DECT systems. TDMA schemes with fixed access patterns are used for many digital mobile phone systems like IS-54, IS-136, GSM, DECT, PHS, and PACS.



→ The TDMA system transmit data in burst and buffer method. Means, the transmission from different users in interfaced into a repeating frame structure.

→ A frame consists of a number of slots. Each frame consists of preamble, an information message and trail bits.

→ Half of the time slots will be used for the forward link channel and the remaining half for reverse link channel.

→ The preamble field comprises the address and synchronization data that both the base stations and subscribers use to identify each other.

→ The guard bits are used to provide synchronization between different time slots and frames.

→ It is assumed that there are "N" number of slots for N users so that each user can access the channel in their allowed time slot.

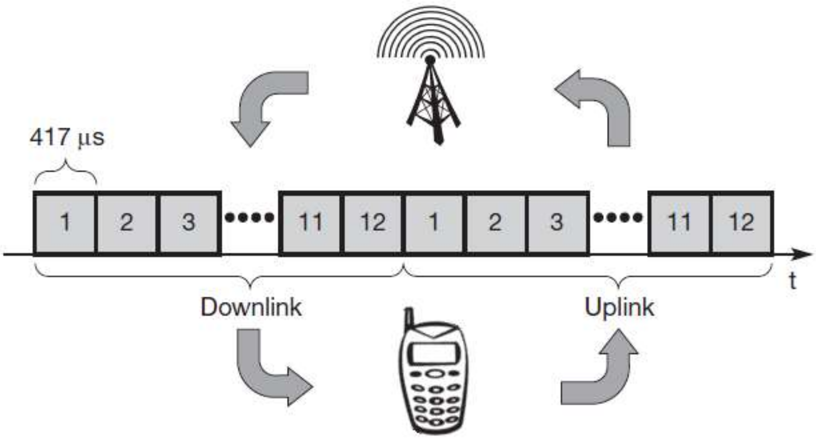
→ The TDMA/FDD system have identical frame structure that can be used for forward or reverse transmission, but the carrier frequencies will be different for both the links.

Features of TDMA:

→ TDMA uses different time slots for transmission and reception. So duplexer not required.
→ As the transmission rates are high adaptive equalization is necessary.
→ TDMA shares a single carrier frequency with several users where each user makes use of non-overlapping time slots.
→ The number of time slots depends on parameters like bandwidth, modulation method etc.
→ Bandwidth is supplied on demand to different users by assigned priority.
→ It can be turned off when not in use.
→ Guard time needs to be minimized.
→ Handoff process is simple.
→ Due to burst transmission high synchronization over head is needed in TDMA systems.

TDD:

→ Figure shows how these fixed TDM patterns are used to implement multiple access and a duplex channel between a base station and mobile station.
→ Assigning different slots for uplink and downlink using the same frequency is called time division duplex (TDD). As shown in the figure, the base station uses one out of 12 slots for the downlink, whereas the mobile station uses one out of 12 different slots for the uplink.
→ Uplink and downlink are separated in time. Up to 12 different mobile stations can use the same frequency without interference using this scheme. Each connection is allotted its own up- and downlink pair.



→ In the example below, which is the standard case for the DECT cordless phone system, the pattern is repeated every 10 ms, i.e., each slot has a duration of 417 μs. This repetition guarantees access to the medium every 10 ms, independent of any other connections.
→ While the fixed access patterns, as shown for DECT, are perfectly apt for connections with a constant data rate (e.g., classical voice transmission with 32 or 64 kbit/s duplex), they are very inefficient for bursty data or asymmetric connections.
→ If temporary bursts in data are sent from the base station to the mobile station often or vice versa (as in the case of web browsing, where no data transmission occurs while reading a page, whereas clicking on a hyperlink triggers a data transfer from the mobile station, often to the base station, often followed by huge amounts of data returned from the web server).
→ While DECT can at least allocate asymmetric bandwidth (see section 4.2), this general scheme still wastes a lot of bandwidth. It is too static, too inflexible for data communication.

5. What is CDMA? Explain the orthogonal codes for it. **[New] (Dec-2015)[L.J.I.E.T]** 7

CDMA:

→ Codes with certain characteristics can be applied to the transmission to enable the use of code division multiplexing (CDM).

→ Code division multiple access (CDMA) systems use exactly these codes to separate different users in code space and to enable access to a shared medium without interference.

→ The main problem is how to find "good" codes and how to separate the signal from noise generated by other signals and the environment.

→ The code directly controls the chipping sequence. But what is a good code for CDMA? A code for a certain user should have a good autocorre-lation2 and should be orthogonal to other codes. Orthogonal in code space has the same meaning as in standard space (i.e., the three dimensional space).

→ Think of a system of coordinates and vectors starting at the origin, i.e., in (0, 0, 0).3 Two vectors are called orthogonal if their inner product is 0, as is the case for the two vectors (2, 5, 0) and (0, 0, 17): (2, 5, 0)*(0, 0, 17) = 0 + 0 + 0 = 0.

→ But also vectors like (3, –2, 4) and (–2, 3, 3) are orthogonal: (3, –2, 4)*(–2, 3, 3) = –6 – 6 + 12 = 0.

→ By contrast, the vectors (1,2,3) and (4,2, –6) are not orthogonal (the inner product is –10), and (1, 2, 3) and (4, 2, –3) are "almost" orthogonal, with their inner product being –1 (which is "close" to zero).

→ This description is not precise in a mathematical sense. However, it is useful to remember these simplified definitions when looking at the following examples where the original code sequences may be distorted due to noise.

→ Orthogonality cannot be guaranteed for initially orthogonal codes.

→ Now let us translate this into code space and explain what we mean by a good autocorrelation. The Barker code (+1, –1, +1, +1, –1, +1, +1, +1, –1, –1, –1),

Features:

→ Soft handoff is done.

→ CDMA uses co channel cells

→ CDMA system users share the same frequency.

→ CDMA has a soft capacity limit.

→ Multipath fading can be reduced.

→ In CDMA more than one user is allowed to share a channel or sub channel with the help of DS-SS.

→ Each user is assigned a unique code.

→ At receiver the signal is recovered by using the same code sequence.

→ In CDMA the user access the channel in random manner. Hence overlap possible (near, far, hidden, exposed)

Encoding Rules for CDMA:

In CDMA each station is assigned a code which is simply a sequence of numbers called chips.

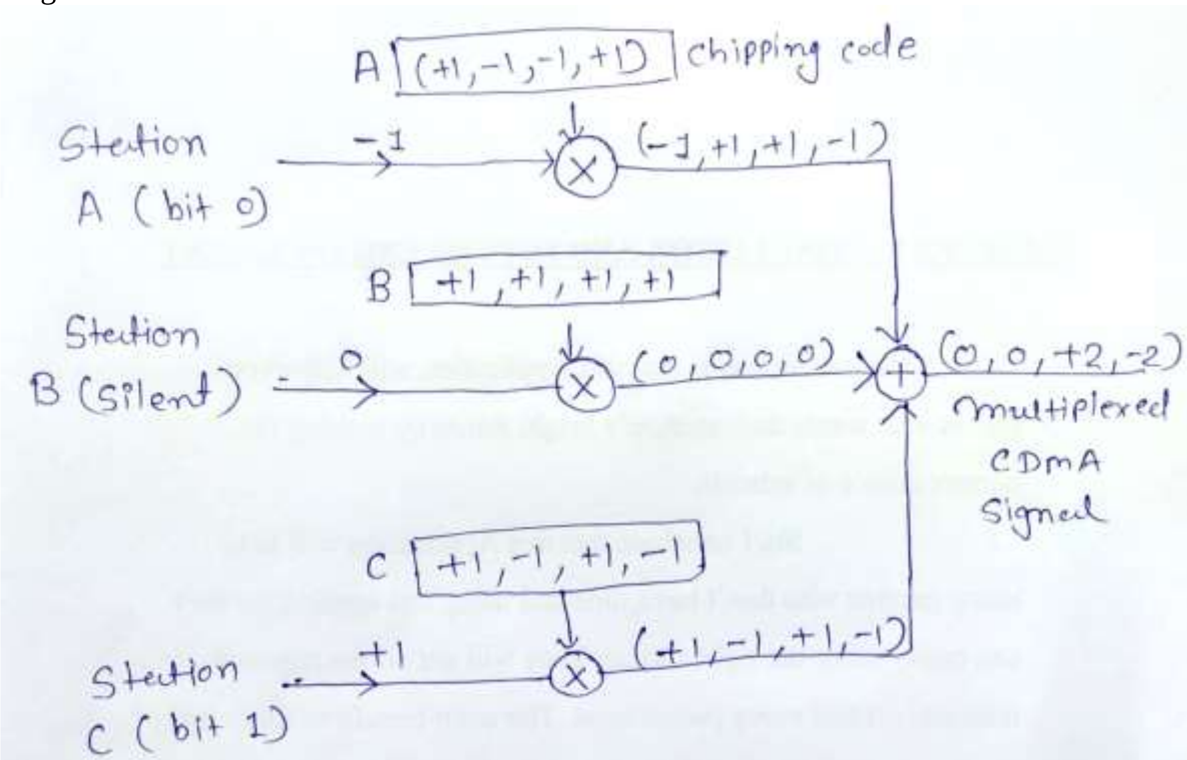
1. If station wants to send bit 0 then sends -1
2. If station want to send bit 1 then sends +1
3. If station does not want to transmit and want to remain idle, it is represented by 0.

CDMA Multiplexer:

→ Assume that we are having 3 stations with their chipping code say,

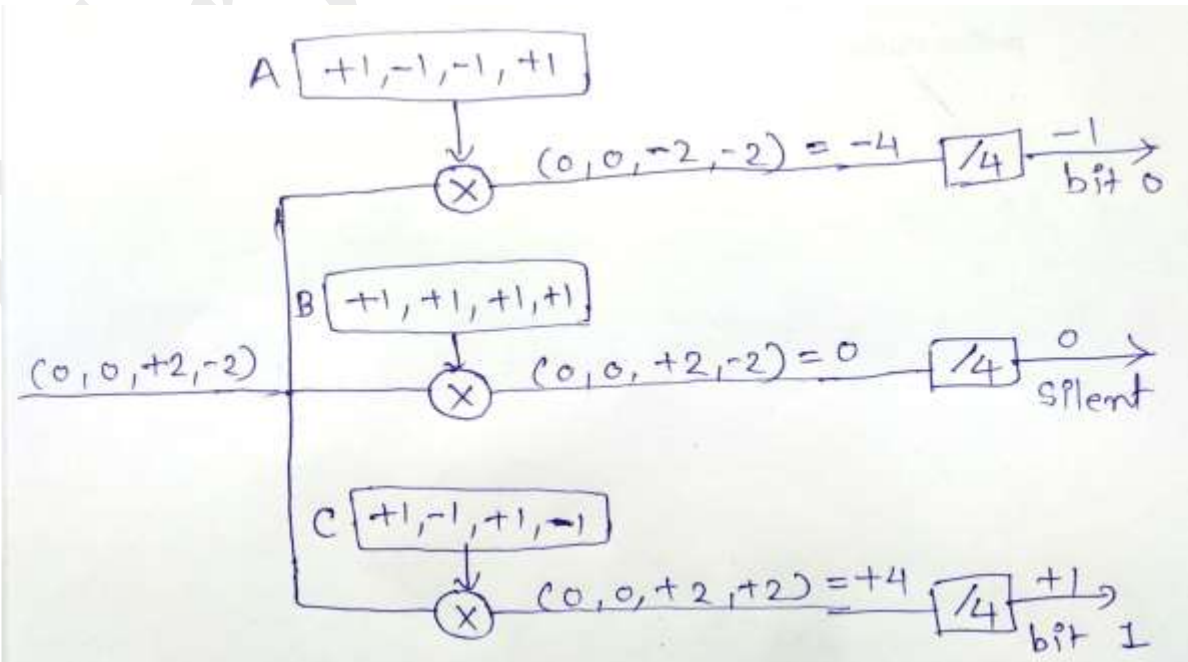
→ **A (+1, -1, -1, +1), B (+1, +1, +1, +1), C (+1, -1, +1, -1)**

- → Assume that A wants to transmit a bit 0, B wants to remain silent and C wants to transmit bit 1.
- → In this multiplexer receives one encoded no from each station (+1, -1, 0)
- → Each bit is multiplied with code no of corresponding station.
- → The output of multipliers are added to obtain the multiplexed CDMA signal.
- → Signal transmitted to link.



CDMA Demultiplexer:

- → CDMA signal is applied to all the multipliers.
- → It is multiplied with the code number assigned to each station A, B and C
- → The bits available at the output of each compiler are added together. This condition will always be either -4, 0, +4.
- → The result of addition at the output of each multiplier is divided by 4 to obtain the original transmitted bit.



Advantages of CDMA:

1. Biggest advantage over TDMA/FDMA provide secure communication.
2. In CDMA Multiplexer the frequency hopping phenomenon can be used.

Disadvantages of CDMA:

1. A problem of self-jamming can be occur.
2. Near and far problem occur in CDMA receiver if an unwanted user uses a high transmitted power.

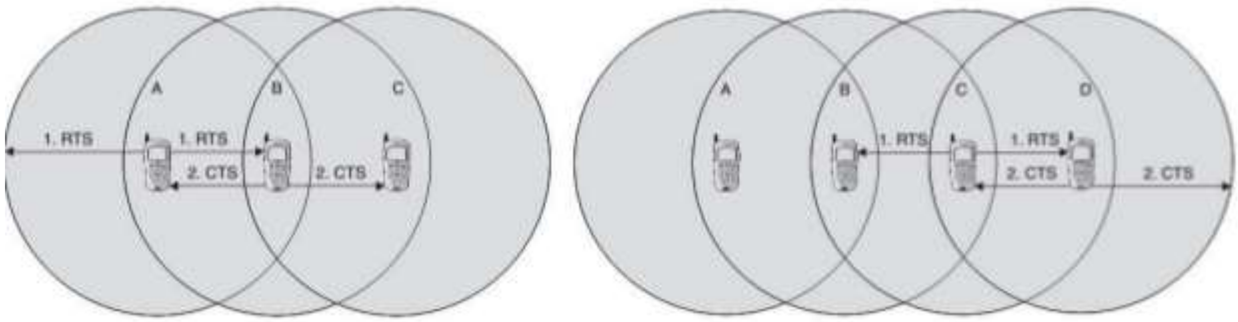
6. Why medium access control (MAC) is required in wireless networks? Explain with hidden and Exposed terminals & near and far terminals. **[L.J.I.E.T]** 7

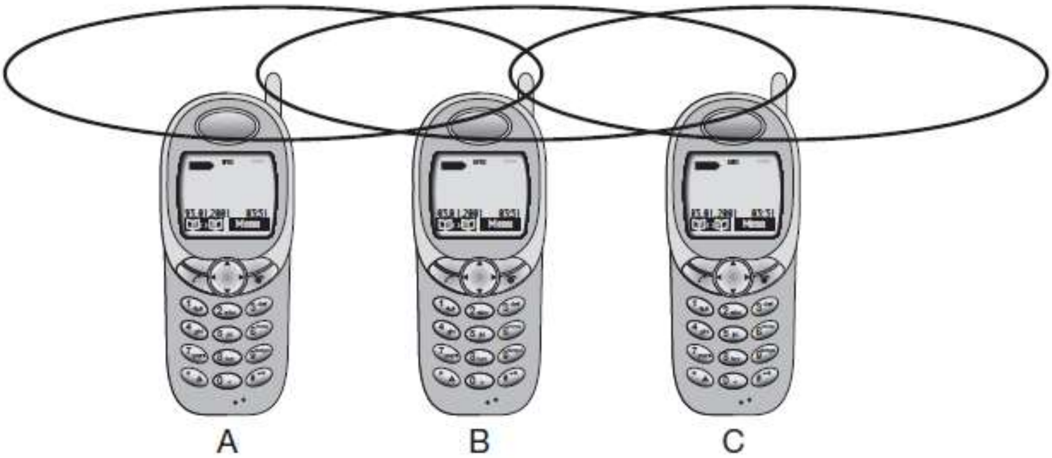
Hidden Terminal and Exposed Terminal:

→ The basic access mechanism, called Distributed Coordination Function in carrier sense Multiple Access with Collision Avoidance mechanism (CSMA/CA).

→ CSMA protocols are well known, the most popular being the Ethernet, which is CSMA/CD protocol.

→ In a Wired environment every station connected to the wire can sense the signal in the wire. In a wired LAN, if there is no activity or a collision of messages, every station connected to the LAN will be able to sense collection almost instantly. This is not true in the case of wireless media.





→ In the case of wireless LANs, a Carrier Sense Multiple Access/ Collision Avoidance (CSMA/CA) protocol is used, as it is not possible to detect a collision of data packets in mid-air.

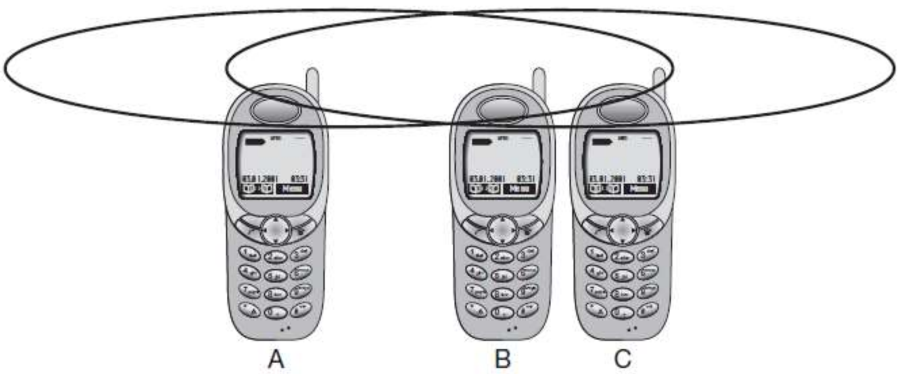
→ Consider the scenario with three mobile nodes shown in figure (a). The transmission of A reaches B, but not C. The transmission of C reaches B, but not A.

→ However, the radio signal of B reaches both A and C making both in the range of B. The net effect is A cannot detect C and vice versa.

→ A start sending to B, C does not receive this transmission. C also wants to send to B and sense the medium. To C the medium appears to be free. Thus C starts sending causing collision at B. But now A cannot detect the collision and continues with its transmission. A is 'Hidden' for C and vice versa.
→ In another case as shown in figure (b). The radio transmission signal of A reaches C and B.
→ The radio signal of C reaches both A and D. A wants to communicate to B, A starts sending signal to B. C wants to communicate to D, C sense the carrier and finds that A is talking to B.
→ C has to wait till the time A finishes with B. However, D is outside the range of A, therefore waiting is not necessary.
→ In fact A, B and C, D can communicate to each other in parallel without any collision, but according to the protocol that is not possible.
→ A and C are 'Exposed' terminals.

Near and Far Terminal

→ Consider the situation as shown in Figure 2. A and B are both sending with the same transmission power. As the signal strength decreases proportionally to the square of the distance, B's signal drowns out A's signal. As a result, C cannot receive A's transmission.
→ Now think of C as being an arbiter for sending rights (e.g., C acts as a base station coordinating media access).



→ In this case, terminal B would already drown out terminal A on the physical layer. C in return would have no chance of applying a fair scheme as it would only hear B.
→ The near/far effect is a severe problem of wireless networks using CDM. All signals should arrive at the receiver with more or less the same strength.
→ Otherwise (referring again to the party example of chapter 2) a person standing closer to somebody could always speak louder than a person further away.
→ Even if the senders were separated by code, the closest one would simply drown out the others.
→ Precise power control is needed to receive all senders with the same strength at a receiver. For example, the UMTS system adapts power 1,500 times per second.

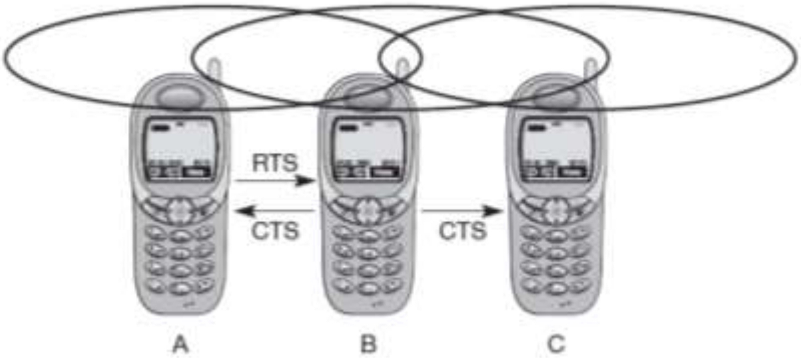
7.	What is hidden terminal problem? How it can be avoided? **(Nov-2017)[L.J.I.E.T]**	3
8.	Explain in brief Multiple access with collision avoidance (MACA). Justify how MACA can avoid hidden terminal problem. **[L.J.I.E.T]**	7
9.	Explain in brief Multiple access with collision avoidance (MACA). Justify how MACA can avoid exposed terminal problem. **[L.J.I.E.T]**	7
10	Why do MAC scheme in wired network fail in wireless networks. Explain how the multiple access with collision avoidance (MACA) scheme work does. **(Dec-2012)[L.J.I.E.T]**	7

Hidden terminal:

→ To all schemes with central base stations assigning TDM patterns, the problem of hidden terminals is unknown. If the terminal is hidden for the base station it cannot communicate anyway. But, more or less fixed access patterns are not as flexible as Aloha schemes.

→ What happens when no base station exists at all? This is the case in so-called ad-hoc networks.

→ Multiple access with collision avoidance (MACA) presents a simple scheme that solves the hidden terminal problem, does not need a base station, and is still a random access Aloha scheme – but with dynamic reservation.



→ Figure shows the hidden terminals. Remember, A and C both want to send to B. A has already started the transmission, but is hidden for C, C also starts with its transmission, thereby causing a collision at B. N mini-slots N * k data-slots e.g. N=6, k=2.

→ Other stations can use free data-slots based on a round-robin scheme Reservations for data-slots Figure 3.9 Reservation TDMA access scheme With MACA, A does not start its transmission at once, but sends a request to send (RTS) first. B receives the RTS that contains the name of sender and receiver, as well as the length of the future transmission.

→ This RTS is not heard by C, but triggers an acknowledgement from B, called clear to send (CTS). The CTS again contains the names of sender (A) and receiver (B) of the user data, and the length of the future transmission.

→ This CTS is now heard by C and the medium for future use by A is now reserved for the duration of the transmission. After receiving a CTS, C is not allowed to send anything for the duration indicated in the CTS toward B. A collision cannot occur at B during data transmission, and the hidden terminal problem is solved – provided that the transmission conditions remain the same. (Another station could move into the transmission range of B after the transmission of CTS.)

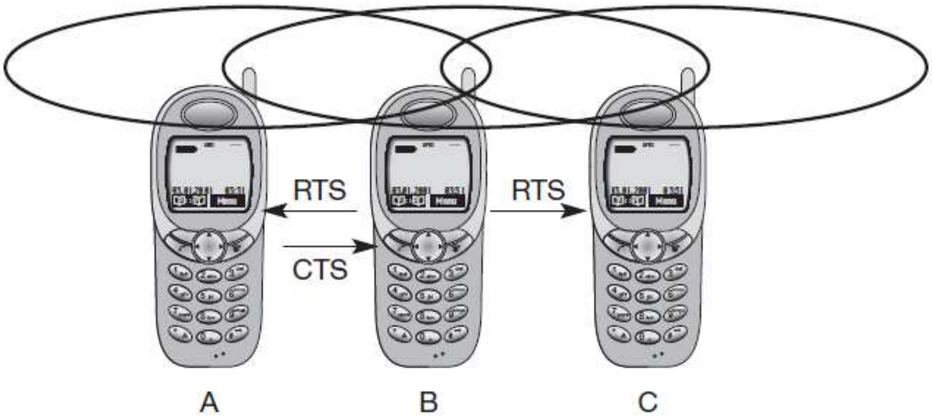
→ Still, collisions can occur during the sending of an RTS. Both A and C could send an RTS that collides at B. RTS is very small compared to the data transmission, so the probability of a collision is much lower.

→ B resolves this contention and acknowledges only one station in the CTS (if it was able to recover the RTS at all). No transmission is allowed without an appropriate CTS. This is one of the medium access schemes that is optionally used in the standard IEEE 802.11 Can MACA also help to solve the 'exposed terminal' problem?

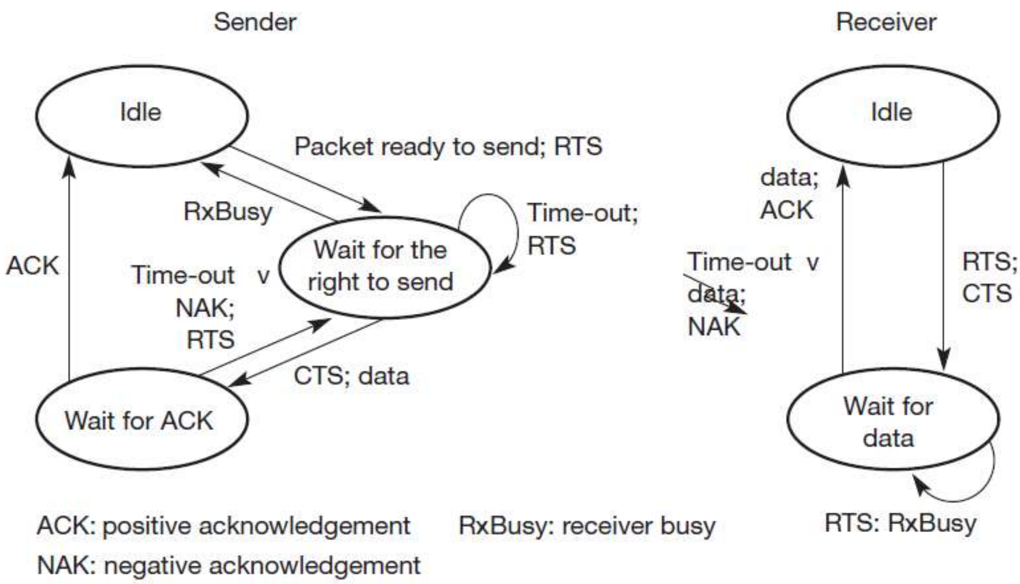
Exposed Terminal

→ B wants to send data to A, C to someone else. But C is polite enough to sense the medium before transmitting, sensing a busy medium caused by the transmission from B. C defers, although C could never cause a collision at A.

→ With MACA, B has to transmit an RTS first (as shown in Figure) containing the name of the receiver (A) and the sender (B). C does not react to this message as it is not the receiver, but A acknowledges using a CTS which identifies B as the sender and A as the receiver of the following data transmission. C does not receive this CTS and concludes that A is outside the detection range.



→ C can start its transmission assuming it will not cause a collision at A. The problem with exposed terminals is solved without fixed access patterns or a base station.
→ One problem of MACA is clearly the overheads associated with the RTS and CTS transmissions – for short and time-critical data packets, this is not negligible.
→ MACA also assumes symmetrical transmission and reception conditions. Otherwise, a strong sender, directed antennas etc. could counteract the above scheme.



→ Figure shows simplified state machines for a sender and receiver. The sender is idle until a user requests the transmission of a data packet. The sender then issues an RTS and waits for the right to send. If the receiver gets an RTS and is in an idle state, it sends back a CTS and waits for data. The sender receives the CTS and sends the data. Otherwise, the sender would send an RTS again after a time-out (e.g., the RTS could be lost or collided).
→ After transmission of the data, the sender waits for a positive acknowledgement to return into an idle state. The receiver sends back a positive acknowledgement if the received data was correct. If not, or if the waiting time for data is too long, the receiver returns into idle state. If the sender does not receive any acknowledgement or a negative acknowledgement, it sends an RTS and again waits for the right to send.
→ Alternatively, a receiver could indicate that it is currently busy via a separate RxBusy. Real implementations have to add more states and transitions, e.g., to limit the number of retries.

	NUMERICALS	
1.	A cellular system uses FDMA with spectrum allocation of 12.5 MHz in each direction, a guard band at the edge of the allocated spectrum of 10 KHz, and a channel bandwidth of 30 KHz. Find out number of channels available. **(Nov-2017) [L.J.I.E.T]**	4
2.	Consider Global System for Mobile, which is TDMA/FDD system that uses 25 MHz for the forward link, which is broken in to 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 no of simultaneous users that can be accommodated in GSM. **(Nov-2017) [L.J.I.E.T]**	4