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Comparative Analysis of MAC Protocols in Wireless Cellular Networks

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I. Introduction

A cellular network is a radio network distributed over land through cells where each cell includes a fixed location transceiver known as base station. These cells together provide radio coverage over large geographical areas. User equipment such as mobile phones is therefore able to communicate even if the equipment is moving through cells during transmission.

The term cellular refers that the certain geographical area is divided into small areas called **cells**. Each cell contains a **base station** (BS). The BS transmits and receives the signals to and from the **mobile stations** (MS) in its cell. The coverage area of a cell depends on transmitting power of BS, the transmitting power of MS, buildings and mountains in a cell etc. Each base station is connected to **mobile switching center** (MSC) as shown in the Figure 1.1. The MSC is then connected to Public Switched Telephone Network (PSTN) which serves the functionalities as done by conventional telephone switching center.

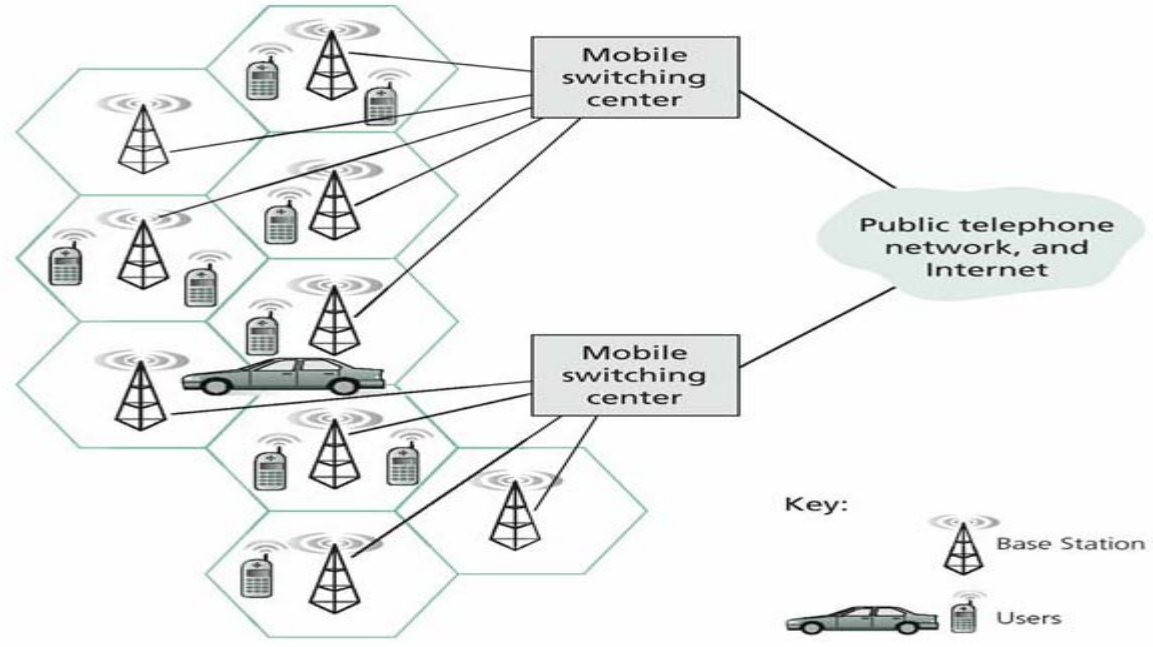

Figure 1.1 : Cellular Network Architecture

As cellular network is a type of telecommunication network, so it requires the communication like in ordinary telephone system; talking and listening simultaneously. This mechanism is called Duplexing. In cellular network the Duplexing can be done by using either frequency or time division duplexing.

- *Frequency Division Duplexing (FDD): FDD* provides two different frequencies bands to each user; one is for uplink channel and other for downlink. The uplink channel is responsible for data flow from mobile station to base station, and downlink channel is from base to mobile station. In FDD, actually a

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duplex channel is consists of two simplex channels (forward and reverse) at the same time.

- *Time Division Duplexing (TDD):* TDD uses time in order to provide uplink and downlink. In TDD, multiple users utilize a single radio channel by taking turns in different time-slots. Each duplex channel has both uplink time-slot and a downlink timeslot for bidirectional communication. Thus, TDD provides two simplex time-slots on same frequency.

II. MAC Protocols In Cellular Networks

The cellular network has different requirements for sharing a common medium. Its network and users are spread over the cities, a country or even more than one country. The users must be allowed to use their mobile phones calls at their own will. It should not be case that they remain busy in sensing the carries or exchanging the control packets like in WLANs. Thus, the sharing of medium access in cellular network can be achieved by allocating each user a different frequency or time-slot in order to access the channel at any time as same as in conventional telephone system. Particularly in cellular networks, sharing a common medium by several users is dependent to four basic dimensions: space, time, frequency and code.

a) FDMA

The frequency division multiple access (FDMA) divides the whole frequency available into several frequency bands or channels depends on the number of users. These bands are non-overlapping and unique in nature. A user is assigned a unique frequency band as soon as new mobile phone connection is established. Sender can use a certain frequency continuously at any time. Each channel in FDMA is a pair of frequencies by using FDD; one frequency is for uplink, while other is used for downlink. Since it uses duplexing, so both caller and receiver can communicate at the same time. Overall it is a less complex system. The Figure 1.2 is describing the protocol clearly if there are six users than whole frequency available is sub-divided into six sub-channels each having different frequency. They are unlikely to interference each other.

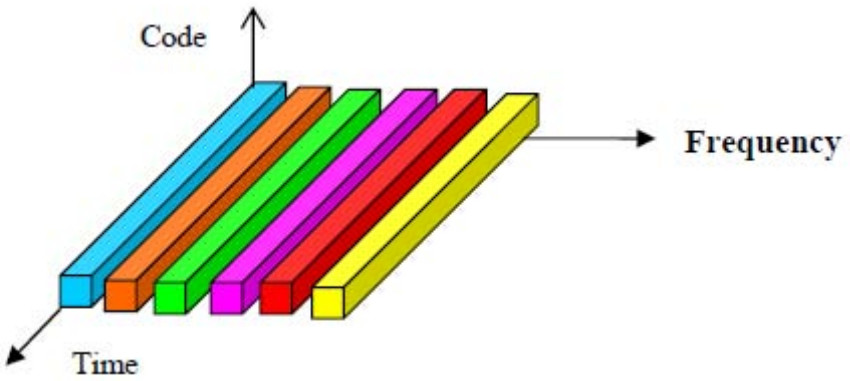


Figure 1.2 : Frequency Division

b) TDMA

It is much more flexible scheme as compared to FDMA. In time division multiple accesses (TDMA) the channel is divided into time-slots. Each time slot allows one user to either transmit or receive data. The frequency remains same for all users but separation is achieved through division of time i.e. time-slots, as in the Figure 1.3 the frequency is same for all 6 channels but total time is divided into 6 slots.

Two or more time periods can interfere each other, and to avoid this precise synchronization is necessary. This is done by base station which reserves the time slot at right moment for different callers. In TDMA system the data is transmitted in a buffer and burst method. During one time-slot only the part of whole data is buffered and burst to destination and remaining data is buffered in the next time-slots accordingly. Thus, the transmission is not continuous for all users. But time difference between two time-slots is so small (in micro-seconds) that it is not felt by a user e.g., GSM system based on TDMA and a caller using GSM, does not feel any delay due to time-slots. The data of different users is buffered into repeating frames. The frame consists of number of slots. The receivers are also required to be synchronized for each data burst. TDMA/TDD separates the time-slots for uplink and downlink procedure by using different frames. But if TDMA/FDD is the system, then similar frame would be used for uplink/downlink transmission, but carrier frequency would be different for both links.

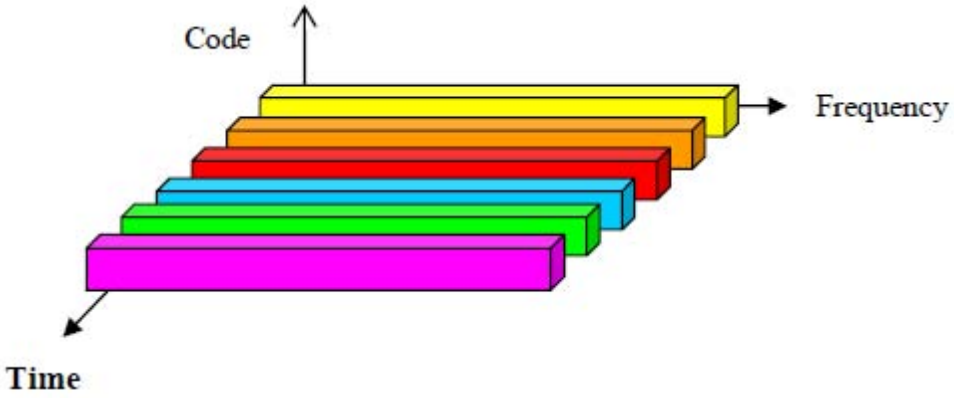


Figure 1.3 : Time Division

c) SDMA

The task of space division multiple accesses (SDMA) is to allocate a separate space to each user for wireless communication with a minimum of interference and a maximum of channel utilization. SDMA assigns space, time, frequency and code to each communication channel. Actually, it is never used alone but always works together with any other technique like time, frequency or code division etc. The space division implies the interference range of each channel. For example, the range of FM radio station is limited to certain region. The FM 100 channel is running in both Sweden and Pakistan with same frequency but different spaces which are limited to their respective countries.

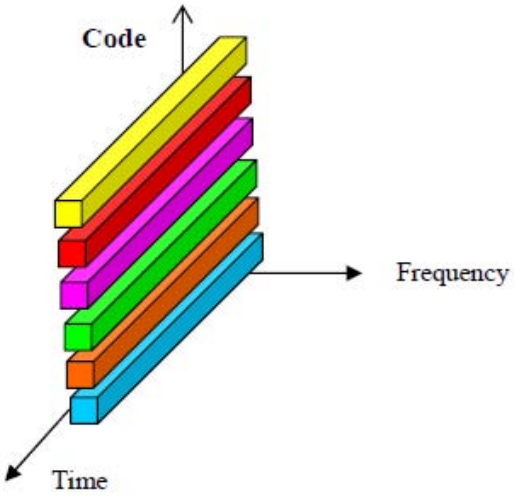
In cellular networks using SDMA, each mobile phone is assigned an appropriate base station. The Mobile phone may receive signals from several base stations. But the (SDMA) MAC algorithm chooses the required one among all signals considering the time, frequency or code. The down link procedure is strong as base station has entire control over the power of all transmitted signals. In case of uplink, the transmitted power is dynamically controlled to avoid interference with other signals. The transmitted power is limited in mobile phones due to the use of small batteries.

d) DSMA

The digital sense multiple access (DSMA) algorithm is used for packet data transmission service: Cellular Digital packet Data (CDPD). It is a type of slotted p-persistent CSMA mechanism. There is only one Uplink/Downlink pair available per slot for data transmission in each CDPD cell. The downlink channel is easy to manage because base station is the only sender per cell. On the contrary, the uplink channel is critical as there are number of mobile stations (MSs) trying to send data at same time. When MS wants to send packet it senses the downlink for a flag bit indicating whether the uplink is busy or idle at the moment. If it is free then data is sent and acknowledgment from base station is received. But if uplink is busy then MS does not wait for next slot rather it skips the random number of slots and tries again.

e) CDMA

Code division multiple access (CDMA) is relatively the new and advance medium access algorithm for wireless networks. Initially it has been used in military applications, now this system is a part of commercial cellular networks as well. In CDMA transmission all channels use same frequency at the same time, but separation is achieved by assigning each channel a unique '**code**' e.g., orthogonal codes. These unique codes provide better security against interference and tapping. The critical tasks like how to find suitable codes, performing encoding and decoding are all done by **spread spectrum** technique shall be explained after issues.



III. Spread Spectrum

The narrowband signal of CDMA is multiplied by a very large bandwidth signal; resulting signal is called the spread spectrum. The spread spectrum is a pseudo-noise or pseudorandom code sequence. Each user has its own pseudorandom code which is orthogonal to all other codes. These codes are basically random binary sequence. There are two ways of spreading the spectrum;

a) Direct Sequence Spread Spectrum

The Direct Sequence Spread Spectrum (DSSS) system uses chipping sequence for spreading the spectrum. The chipping sequence is a binary code which is usually called pseudo-noise sequence; generated as a unique code each time when user has to send the signal. While using DSSS, the user data (bit stream) is taken and then performed an XOR with the chipping sequence. Each bit of user is XOR with whole sequence code periodically. For example the user data is 01, and the chipping sequence is 0110101. The result of XOR (resulting signal/spread spectrum) would be: 0110101 1001010. The resulting signal is then modulated and finally transmitted to the receiver. The receiver side is more complex than sender particularly in spread spectrum systems. The receiver has to perform demodulation first in order to get original spread spectrum signal. Next is the critical part to know the original chipping sequence to perform XOR with receiving spread spectrum signal. Actually the transmitter and the receiver are synchronized with the same chipping code. The receiver calculates the code from receiving signal. After having the required code, the XOR is performed and got the original message. The spreading signal was 0110101 1001010, code is 0110101 and the result of XOR = 0000000 1111111. Each seven resulting bits representing the one original bit, hence the data is 01. In this way, the DSSS works nicely depending on the codes.

b) Frequency Hopping Spread Spectrum

The Frequency Hopping Spread Spectrum (FHSS) system splits the total available bandwidth into several sub-channels with smaller bandwidth each. While communication the transmitter and the receiver stay on one of these sub-channels with a certain frequency for small amount of time and then hop to another sub-channel. This implies that, the signal hops from sub-channel to sub-channel and transmitting short bursts of data on each channel for a certain period of time. The pattern of changing the channels is called the **hopping sequence**, and time spent on each channel is called **dwell time**. The system has implemented both FDM and TDM. The sender and the receiver must be synchronized to the hopping sequence. FHSS can work in either of two ways; slow hopping and fast hopping. In slow hopping the transmitter uses one frequency (one sub-channel) for several bits, e.g., the transmitter sends first three bits of data by using frequency f2. For fast hopping the transmitter changes the frequency several times to transmit a single bit, e.g., the transmitter uses three frequencies f1, f2, f3 (hops three sub channels) during one bit. Fast hopping has been implemented in Bluetooth, whereas slow hopping in GSM.

IV. Comparison of MAC Protocols

The different techniques and mechanisms have been deployed in domain of cellular network. The protocols used here are more versatile in nature. There is no one basic mechanism that belongs to all protocols, rather all have distinct features. TDMA makes time-slots for better sharing of medium, FDMA splits the total bandwidth into sub-channels of different frequency each, CDMA produces unique codes for each user with help of spread spectrum technique, SDMA is applied in separate spaces and DSMA senses the carrier before transmitting the uplink data etc. Furthermore, the protocols are most famous GSM network, and both SDMA and DSMA are the combination of two or more

schemes as well. The CDMA has an edge that it can add number of users without any upper limit, because it uses single channel (same frequency and time) but with different codes which has abundant capacity. On the other hand, TDMA and FDMA divide total available time and frequency respectively. The number of users is confined to either total number of time-slots or number of sub-channels with different frequencies each. If all time-slots or sub-channels are allocated to users then a new user cannot be added in the network. The table below is representing some more comparisons of protocols.

Table 1.2 : Comparison of MAC protocols in Wireless Cellular Networks

Algorithms	Basic concept	Multiple sub-channels	Single channel	Combination with more schemes	Limited no. of users	Network system
TDMA	Total time of channel divided into time-slots	Yes , multiple sub-channels as many as time-slots	No	No	Yes, limited to no. of time-slots	GSM
FDMA	Total frequency of channel divided into sub-bands	Yes, multiple sub-channels as many as sub-frequency bands	No	No	Yes, limited to no. of sub-frequency bands	AMPS
SDMA	Separate space is allocated to each user	No	Yes	Yes, with TDMA/FDMA or CDMA	No	----
DSMA	Type of slotted p-persistent CSMA	Yes , multiple channels as many as time-slots	No	Yes, with TDMA / CSMA	Yes	CDPD
CDMA	Orthogonal codes using spread spectrum	No	Yes	No	No limit	IS-95
WCDMA	CDMA technique with larger bandwidth	No	Yes	No	No limit	UMTS (3 G)

V. Conclusion

We have gone through a detailed explanation with many comparisons of MAC protocols in wireless sensor networks. Each network type has its own demand for its medium access control technique. It has been superb learning and exposure of different types of wireless networks as well as their requirements particularly for MAC schemes. So, it was nice opportunity to learn in-depth about various MAC schemes or mechanisms. In addition to all, the upcoming feature is integration of technologies. Hence, different types of wireless technologies are going to communicate with each other in near future. The newly proposed MAC schemes are mostly focusing on CDMA and spread spectrum technologies.

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