Multiple Access Techniques

Multiple access techniques are used to allow a large number of mobile users to share the allocated spectrum in the most efficient manner. As the spectrum is limited, so the sharing is required to increase the capacity of cell or over a geographical area by allowing the available bandwidth to be used at the same time by different users. And this must be done in a way such that the quality of service doesn't degrade within the existing users.

1   Multiple Access Techniques for Wireless Communication

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

A cellular system divides any given area into cells where a mobile unit in each cell communicates with a base station. The main aim in the cellular system design is to be able to increase the capacity of the channel i.e. to handle as many calls as possible in a given bandwidth with a sufficient level of quality of service. There are several different ways to allow access to the channel. These includes mainly the following:

1) Frequency division multiple-access (FDMA)

2) Time division multiple-access (TDMA)

3) Code division multiple-access (CDMA)

Table 8.1: MA techniques in different wireless communication systems

Advanced Mobile Phone Systems:	FDMA/FDD
Global System for Mobile:	TDMA/FDD
U.S. Digital Cellular:	TDMA/FDD
Japanese Digital Cellular:	TDMA/FDD
CT2 Cordless Telephone:	FDMA/TDD
Digital European Cordless Telephone:	FDMA/TDD
U.S. Narrowband Spread Spectrum (IS-95):	CDMA/FDD

4) Space Division Multiple access (SDMA)

FDMA,TDMA and CDMA are the three major multiple access techniques that are used to share the available bandwidth in a wireless communication system. Depending on how the available bandwidth is allocated to the users these techniques can be classified as narrowband and wideband systems.

1.1 Narrowband Systems

The term narrowband is used to relate the bandwidth of the single channel to the expected coherence bandwidth of the channel. The available spectrum is divided in to a large number of narrowband channels. The channels are operated using FDD. In narrow band FDMA, a user is assigned a particular channel which is not shared by other users in the vicinity and if FDD is used then the system is called FDMA/FDD. Narrow band TDMA allows users to use the same channel but allocated a unique time slot to each user on the channel, thus separating a small number of users in time on a single channel. For narrow band TDMA, there generally are a large number of channels allocated using either FDD or TDD, each channel is shared using TDMA. Such systems are called TDMA/FDD and TDMA/TDD access systems.

1.2 Wideband Systems

In wideband systems, the transmission bandwidth of a single channel is much larger than the coherence bandwidth of the channel. Thus, multipath fading doesnt greatly affect the received signal within a wideband channel, and frequency selective fades occur only in a small fraction of the signal bandwidth
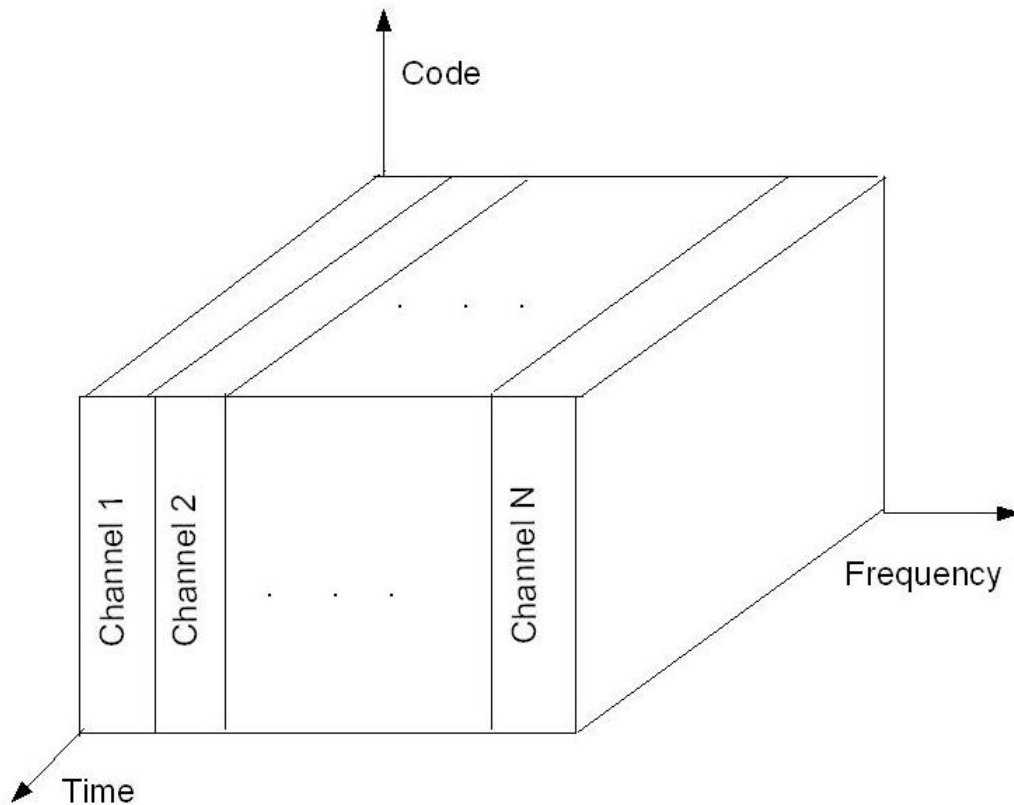
Figure 1:   The basic concept of FDMA.

2   Frequency Division Multiple Access

This was the initial multiple-access technique for cellular systems in which each individual user is assigned a pair of frequencies while making or receiving a call as shown in Figure 1.   One frequency is used for downlink and one pair for uplink. This is called frequency division duplexing (FDD). That allocated frequency pair is not used in the same cell or adjacent cells during the call so as to reduce the co channel interference. Even though the user may not be talking, the spectrum cannot be reassigned as long as a call is in place. Different users can use the same frequency in the same cell except that they must transmit at different times.

The features of FDMA are as follows: The FDMA channel carries only one phone circuit at a time.   If an FDMA channel is not in use, then it sits idle and it cannot be used by other users to increase share capacity.   After the assignment of the voice channel the BS and the MS transmit simultaneously and continuously. The bandwidths of FDMA systems are generally narrow i.e.   FDMA is usually

implemented in a narrow band system The symbol time is large compared to the average delay spread. The complexity of the FDMA mobile systems is lower than that of TDMA mobile systems.   FDMA requires tight filtering to minimize the adjacent channel interference.

2.1   FDMA/FDD in AMPS

The first U.S. analog cellular system, AMPS (Advanced Mobile Phone System) is based on FDMA/FDD. A single user occupies a single channel while the call is in progress, and the single channel is actually two simplex channels which are frequency duplexed with a 45 MHz split. When a call is completed or when a handoff occurs the channel is vacated so that another mobile subscriber may use it. Multiple or simultaneous users are accommodated in AMPS by giving each user a unique signal. Voice signals are sent on the forward channel from the base station to the mobile unit, and on the reverse channel from the mobile unit to the base station. In AMPS, analog narrowband frequency modulation (NBFM) is used to modulate the carrier.

2.2   FDMA/TDD in CT2

Using FDMA, CT2 system splits the available bandwidth into radio channels in the assigned frequency domain. In the initial call setup, the handset scans the available channels and locks on to an unoccupied channel for the duration of the call. Using TDD(Time Division Duplexing), the call is split into time blocks that alternate between transmitting and receiving.

2.3   FDMA and Near-Far Problem

The near-far problem is one of detecting or filtering out a weaker signal amongst stronger signals. The near-far problem is particularly difficult in CDMA systems where transmitters share transmission frequencies and transmission time. In contrast, FDMA and TDMA systems are less vulnerable. FDMA systems offer different kinds of solutions to near-far challenge. Here, the worst case to consider is recovery of a weak signal in a frequency slot next to strong signal. Since both signals are present simultaneously as a composite at the input of a gain stage, the gain is set according to the level of the stronger signal; the weak signal could be lost in the

noise floor. Even if subsequent stages have a low enough noise floor to provide

3   Time Division Multiple Access

In digital systems, continuous transmission is not required because users do not use the allotted bandwidth all the time. In such cases, TDMA is a complimentary access technique to FDMA. Global Systems for Mobile communications (GSM) uses the TDMA technique. In TDMA, the entire bandwidth is available to the user but only for a finite period of time. In most cases the available bandwidth is divided into fewer channels compared to FDMA and the users are allotted time slots during which they have the entire channel bandwidth at their disposal, as shown in Figure 8.2.

TDMA requires careful time synchronization since users share the bandwidth in the frequency domain. The number of channels are less, inter channel interference is almost negligible. TDMA uses different time slots for transmission and reception. This type of duplexing is referred to as Time division duplexing(TDD).

The features of TDMA includes the following: TDMA shares a single carrier frequency with several users where each users makes use of non overlapping time slots. The number of time slots per frame depends on several factors such as modulation technique, available bandwidth etc. Data transmission in TDMA is not continuous but occurs in bursts. This results in low battery consumption since the subscriber transmitter can be turned OFF when not in use. Because of a discontinuous transmission in TDMA the handoff process is much simpler for a subscriber unit, since it is able to listen to other base stations during idle time slots. TDMA uses different time slots for transmission and reception thus duplexers are not required. TDMA has an advantage that is possible to allocate different numbers of time slots per frame to different users. Thus bandwidth can be supplied on demand to different users by concatenating or reassigning time slot based on priority.

3.1   TDMA/FDD in GSM

As discussed earlier, GSM is widely used in Europe and other parts of the world. GSM uses a variation of TDMA along with FDD. GSM digitizes and compresses data, then sends it down a channel with two other streams of user data, each in its
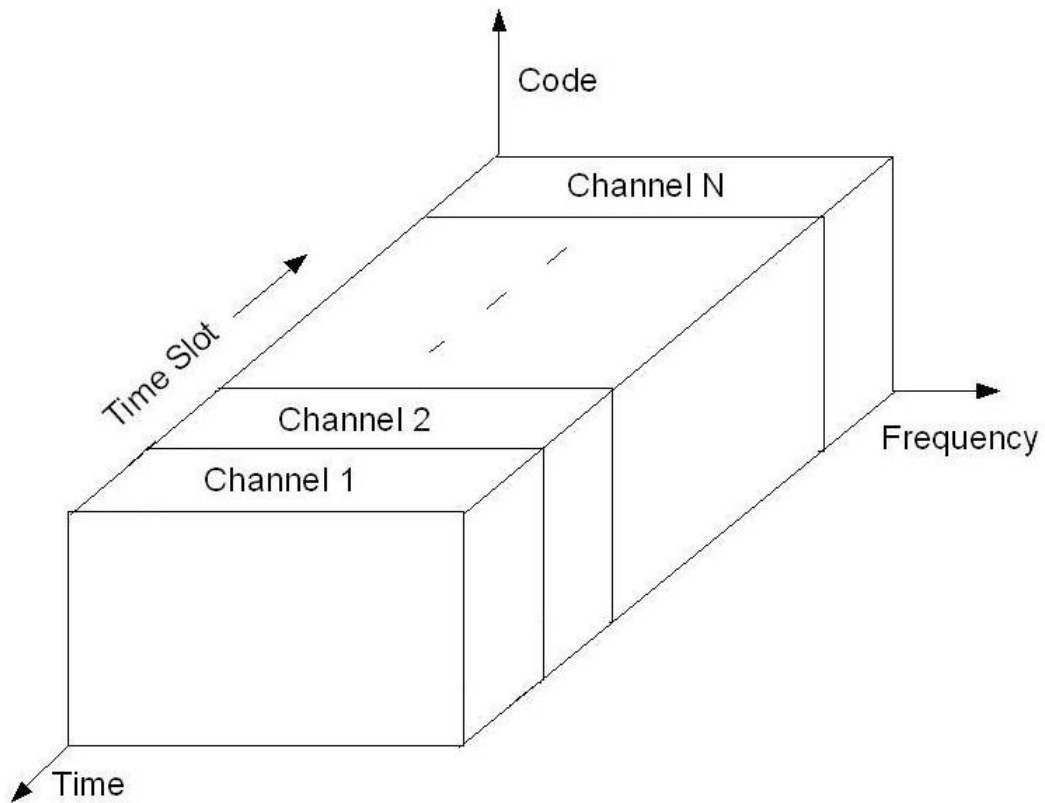
Figure 2:   The basic concept of TDMA.

own time slot. It operates at either the 900 MHz or 1800 MHz frequency band. Since many GSM network operators have roaming agreements with foreign operators, users can often continue to use their mobile phones when they travel to other countries.

3.2   TDMA/TDD in DECT

DECT is a pan European standard for the digitally enhanced cordless telephony using TDMA/TDD. DECT provides 10 FDM channels in the band 1880-1990 Mhz. Each channel supports 12 users through TDMA for a total system load of 120 users. DECT supports handover, users can roam over from cell to cell as long as they remain within the range of the system. DECT antenna can be equipped with optional spatial diversity to deal with multipath fading.

4   Spread Spectrum Multiple Access

Spread spectrum multiple access (SSMA) uses signals which have a transmission bandwidth whose magnitude is greater than the minimum required RF bandwidth. A pseudo noise (PN) sequence converts a narrowband signal to a wideband noise like signal before transmission. SSMA is not very bandwidth efficient when used by a single user. However since many users can share the same spread spectrum bandwidth without interfering with one another, spread spectrum systems become bandwidth efficient in a multiple user environment.

There are two main types of spread spectrum multiple access techniques: Frequency hopped multiple access (FHMA)

Direct sequence multiple access (DSMA) or

Code division multiple access (CDMA).

4.1   Frequency Hopped Multiple Access (FHMA)

This is a digital multiple access system in which the carrier frequencies of the individual users are varied in a pseudo random fashion within a wideband channel. The digital data is broken into uniform sized bursts which is then transmitted on different carrier frequencies.

4.2   Code Division Multiple Access

In CDMA, the same bandwidth is occupied by all the users, however they are all assigned separate codes, which differentiates them from each other (shown in Figure 3). CDMA utilize a spread spectrum technique in which a spreading signal (which is uncorrelated to the signal and has a large bandwidth) is used to spread the narrow band message signal.

Direct Sequence Spread Spectrum (DS-SS)

This is the most commonly used technology for CDMA. In DS-SS, the message signal is multiplied by a Pseudo Random Noise Code. Each user is given his own codeword which is orthogonal to the codes of other users and in order to detect the user, the receiver must know the codeword used by the transmitter. There are, however, two problems in such systems which are discussed in the sequel.
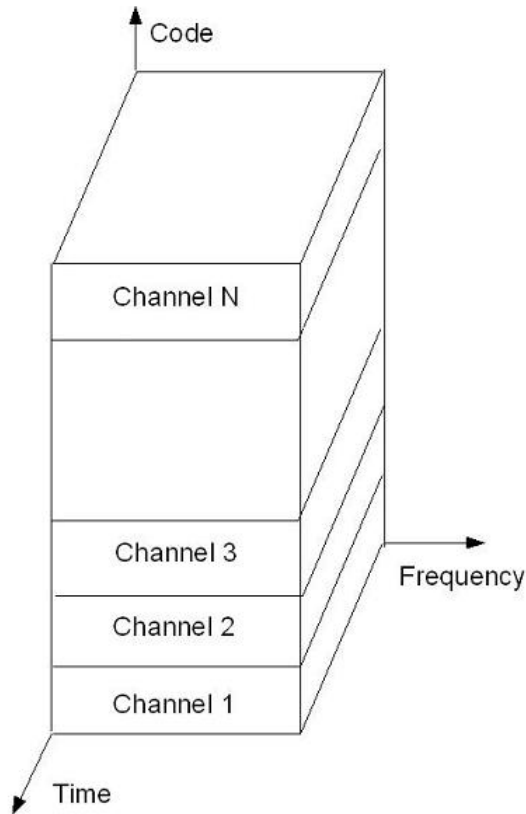
Figure 3:   The basic concept of CDMA.

CDMA/FDD in IS-95

In this standard, the frequency range is: 869-894 MHz (for Rx) and 824-849 MHz (for Tx). In such a system, there are a total of 20 channels and 798 users per channel. For each channel, the bit rate is 1.2288 Mbps. For orthogonality, it usually combines 64 Walsh-Hadamard codes and a m-sequence.

4.3   CDMA and Self-interference Problem

In CDMA, self-interference arises from the presence of delayed replicas of signal due to multipath. The delays cause the spreading sequences of the different users to lose their orthogonality, as by design they are orthogonal only at zero phase offset. Hence in despreading a given user's waveform, nonzero contributions to that user's signal arise from the transmissions of the other users in the network. This is distinct from both TDMA and FDMA, wherein for reasonable time or frequency guardbands, respectively, orthogonality of the received signals can be preserved.

4.4   CDMA and Near-Far Problem

The near-far problem is a serious one in CDMA. This problem arises from the fact that signals closer to the receiver of interest are received with smaller attenuation than are signals located further away. Therefore the strong signal from the nearby transmitter will mask the weak signal from the remote transmitter. In TDMA and FDMA, this is not a problem since mutual interference can be filtered. In CDMA, however, the near-far effect combined with imperfect orthogonality between codes (e.g. due to different time sifts), leads to substantial interference. Accurate and fast power control appears essential to ensure reliable operation of multiuser DS-CDMA systems.

4.5   Hybrid Spread Spectrum Techniques

The hybrid combinations of FHMA, CDMA and SSMA result in hybrid spread spectrum techniques that provide certain advantages. These hybrid techniques are explained below,

Hybrid FDMA/CDMA (FCDMA):

An alternative to the CDMA technique in which the available wideband spectrum is divided into a smaller number of sub spectra with smaller bandwidths. The smaller sub channels become narrow band CDMA systems with processing gain lower than the original CDMA system. In this scheme the required bandwidth need not be contiguous and different user can be allotted different sub spectrum bandwidths depending on their requirements. The capacity of this hybrid FCDMA technique is given by the sum of the capacities of a system operating in the sub spectra.

Hybrid Direct Sequence/Frequency Hopped Multiple Access Techniques (DS/FHMA):

A direct sequence modulated signal whose center frequency is made to hop periodically in a pseudo random fashion is used in this technique. One of the advantages using this technique is they avoid near-far effect. However, frequency hopped CDMA systems are not adaptable to the soft handoff process since it is difficult to synchronize the frequency hopped base station receiver to the multiple hopped signals. Time and Code Division Multiple Access (TCDMA):

In this TCDMA method different cells are allocated different spreading codes. In each cell, only one user per cell is allotted a particular time slot. Thus at any

time only one user is transmitting in each cell. When a handoff takes place the spreading code of that user is changed to the code of the new cell. TCDMA also avoids near-far effect as the number of users transmitting per cell is one.

Time Division Frequency Hopping (TDFH):

This technique has been adopted for the GSM standard, where the hopping sequence is predefined and the subscriber is allowed to hop only on certain frequencies which are assigned to a cell. The subscriber can hop to a new frequency at the start of a new TDMA frame, thus avoiding a severe fade or erasure event on a particular channel. This technique has the advantage in severe multipath or when severe channel interference occurs.

5   Space Division Multiple Access

SDMA utilizes the spatial separation of the users in order to optimize the use of the frequency spectrum. A primitive form of SDMA is when the same frequency is re-used in different cells in a cellular wireless network. The radiated power of each user is controlled by Space division multiple access. SDMA serves different users by using spot beam antenna. These areas may be served by the same frequency or different frequencies. However for limited co-channel interference it is required that the cells be sufficiently separated. This limits the number of cells a region can be divided into and hence limits the frequency re-use factor. A more advanced approach can further increase the capacity of the network. This technique would enable frequency re-use within the cell. In a practical cellular environment it is improbable to have just one transmitter fall within the receiver beam width. Therefore it becomes imperative to use other multiple access techniques in conjunction with SDMA. When different areas are covered by the antenna beam, frequency can be re-used, in which case TDMA or CDMA is employed, for different frequencies FDMA can be used.

7   References

1. T. S. Rappaport, *Wireless Communications: Principles and Practice*, 2nd ed. Singapore: Pearson Education, Inc., 2002.

2. K. Feher, *Wireless Digital Communications: Modulation and Spread Spectrum Applications.* Upper Saddle River, NJ: Prentice Hall, 1995.

3. J. G. Proakis, *Digital Communications*, 4th ed. NY: McGraw Hill, 2000.

4. G. R. Cooper and C. D. McGillem, *Modern Communications and Spread Spectrum*, NY: McGraw Hill, 1986.