Digital Communications ||

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Lecture No.8

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Multiple Access Techniques for Wireless Communication

Multiple-Access Technologies

Multiple access schemes are used to allow many mobile users to share simultaneously a finite amount of radio spectrum. The sharing of spectrum is required to achieve high capacity by simultaneously allocating the available bandwidth (or the available amount of channels) to multiple users. For high quality communications, this must be done without severe degradation in the performance of the system.

Introduction

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. For example, in conventional telephone systems, it is possible to talk and listen simultaneously, and this effect, called duplexing, is generally required in wireless telephone systems. Duplexing may be done using frequency or time domain techniques. Frequency division duplexing (FDD) provides two distinct bands of frequencies for every user. 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 (a forward and reverse), and a device called a duplexer is used inside each subscriber unit and base station to allow simultaneous bidirectional radio transmission and reception for both the subscriber unit and the base station on the duplex channel pair. The frequency separation between each forward and reverse channel is constant throughout the system, regardless of the particular channel being used.

Time division duplexing (TDD) uses time instead of frequency to provide both a forward and reverse link. In TDD, multiple users share a single radio channel by taking turns in the time domain. Individual users are allowed to access the channel in assigned time slots, and each

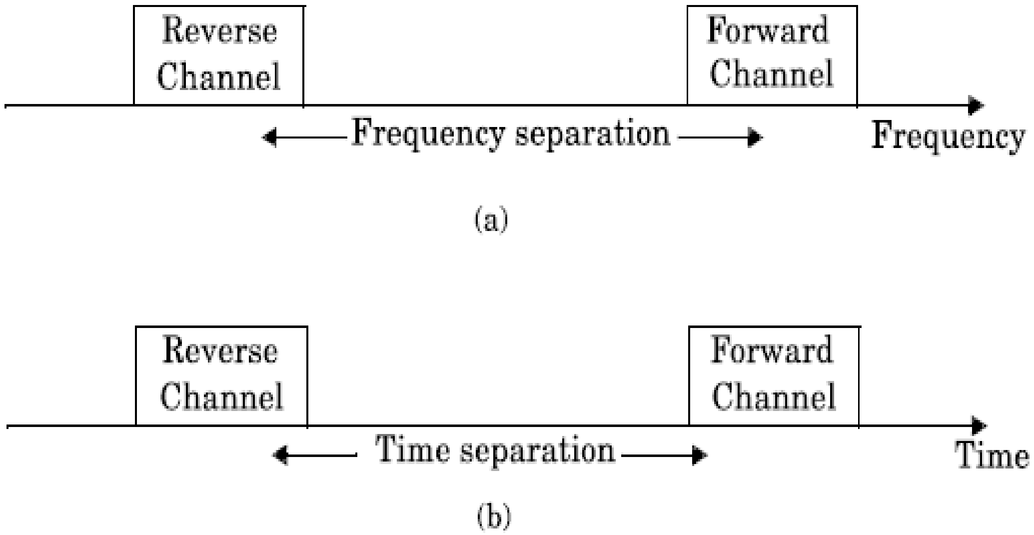


Figure 1: (a) FDD provides two simplex channels at the same time; (b) TDD provides two simplex time slots on the same frequency.

duplex channel has both a forward time slot and a reverse time slot to facilitate bidirectional communication. If the time separation between the forward and reverse time slot is small, then the transmission and reception of data appears simultaneous to the users at both the subscriber unit and on the base station side. Figure 1 illustrates FDD and TDD techniques. TDD allows communication on a single channel (as opposed to requiring two separate simplex or dedicated channels) and simplifies the subscriber equipment since a duplexer is not required.

Introduction to Multiple Access

Frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA) are the three major access techniques used to share the available bandwidth in a wireless communication system. These techniques can be grouped as narrowband and wideband systems, depending upon how the available bandwidth is allocated to the users. The duplexing technique of a multiple access system is usually described along with the particular multiple access scheme, as shown in the examples that follow.

There are subtle differences between multiple access and multiplexing that should be noted:

1. Multiple access refers to the remote sharing of a communications channel such as wireless or satellite channel by users in a highly dispersed location. On the other hand, multiplexing refers to the sharing of a channel such as a telephone channel by users confined to a local site.
2. In a multiplexed system, user requirements are ordinarily fixed. In contrast, in a multiple-access system user requirement can change dynamically with time, in which case provisions

are necessary for dynamic channel allocation.
There are several different ways to allow access to the channel. These include mainly the following:

The way the message channels are arranged depends on the multiple access technique employed which may be:

- Frequency Division Multiple-Access FDMA
- Time Division Multiple-Access TDMA
- Code Division Multiple-Access CDMA
- Space Division Multiple-Access SDMA

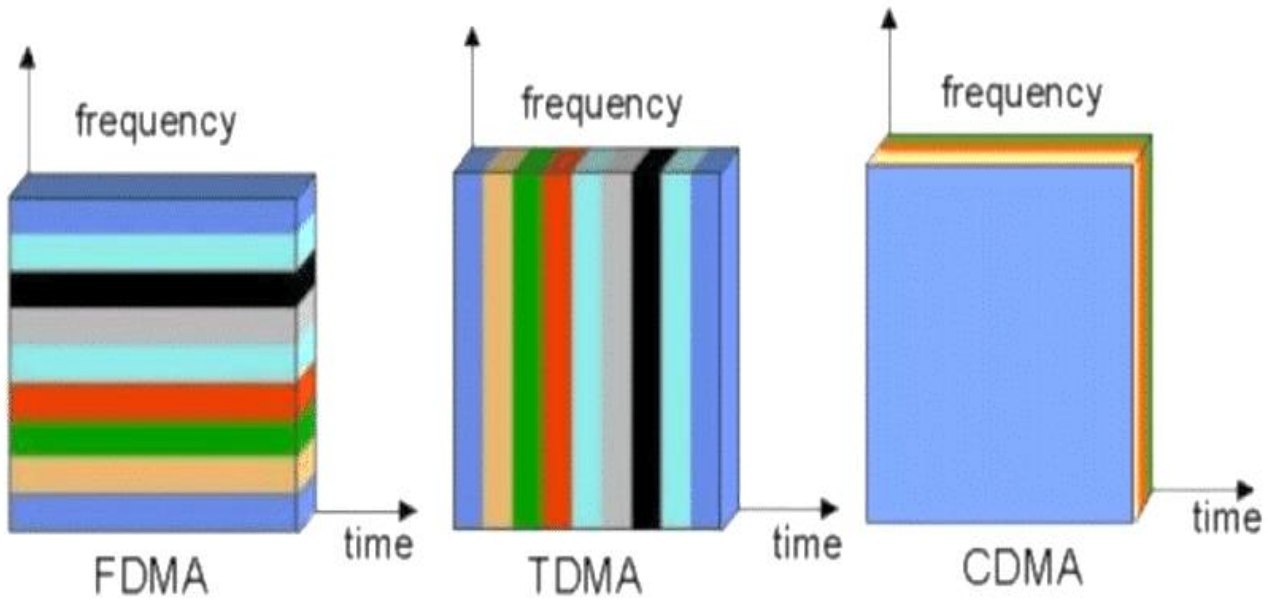


Figure 2: Multiple-Access Technologies

1. Frequency Division Multiple Access FDMA

Frequency division multiple access (FDMA) assigns individual channels to individual users. It can be seen from Figure 3 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 channel. In FDO 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. The features of FDMA are as follows:

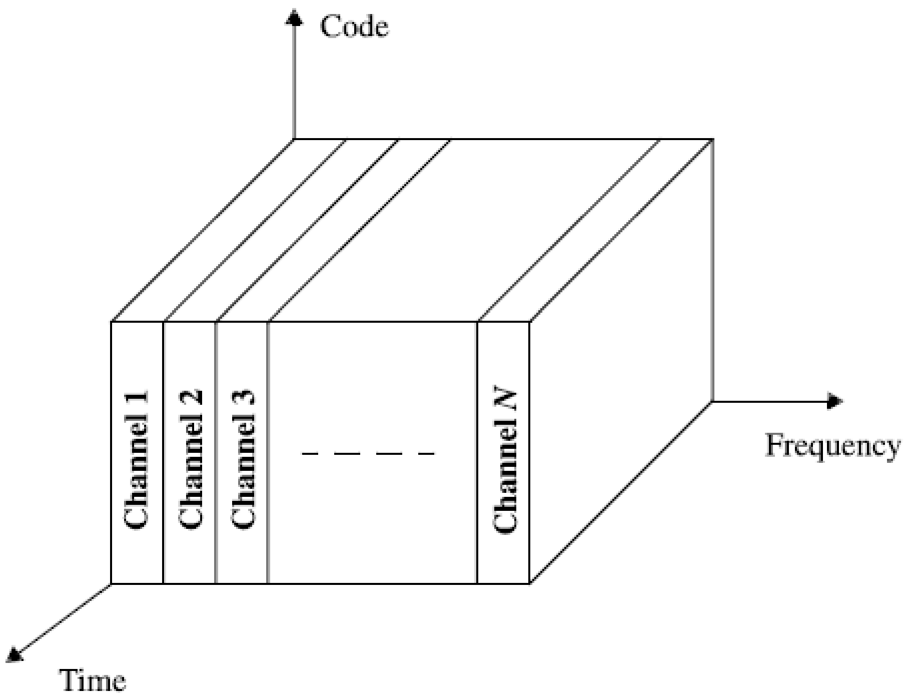


Figure 3: FDMA where different channels are assigned different frequency bands.

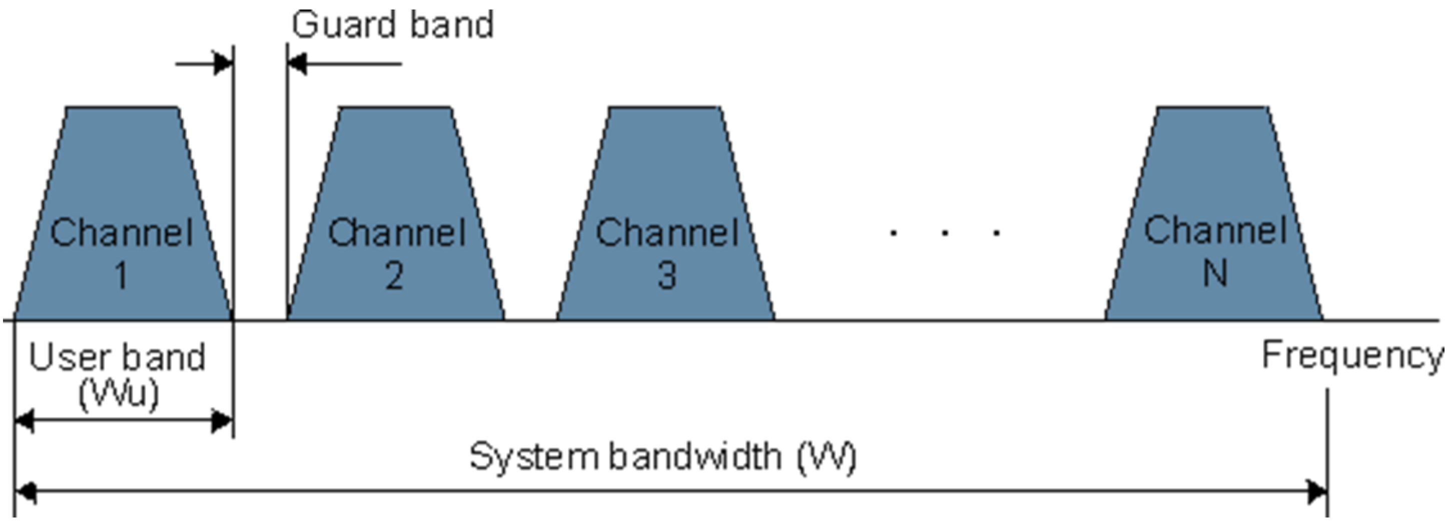


Figure 4: Guard Band of FDMA.

- The FDMA channel carries only one phone circuit at a time.
- If an FDMA channel is not in use, then it sits idle and cannot be used by other users to increase or share capacity. It is essentially a wasted resource.
- After the assignment of a voice channel, the base station and the mobile transmit simultaneously and continuously.

- The bandwidths of FDMA channels are relatively narrow (30kHz in AMPS) as each channel supports only one circuit per carrier. That is, FDMA is usually implemented in narrowband systems.
- The symbol time of a narrowband signal is large as compared to the average delay spread. This implies that the amount of inter symbol interference is low and, thus, little or no equalization is required in FDMA narrowband systems.
- The complexity of FDMA mobile systems is lower when compared to TDMA systems, though this is changing as digital signal processing methods improve for TDMA.
- Since FDMA is a continuous transmission scheme, fewer bits are needed for overhead purposes (such as synchronization and framing bits) as compared to TDMA.
- 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.
- 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 units and base stations.
- FDMA requires tight RF filtering to minimize adjacent channel interference.

FDMA is employed in first-generation cellular technology Advanced Mobile Phone Systems (AMPS)

A total bandwidth of 50 MHz is divided equally into two:

- 25 MHz for forwarding link; and
- 25 MHz for the reverse link.
- 12.5 MHz each is allocated to two competing network operators.
- **Channel bandwidth** of **30 kHz** and a total of **832 channels** are available.
- A **guard band** of **10 kHz** is allowed at the edge to reduce inter-system interference.

FDMA System Capacity

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

Where:

N: Number of channels

B_t: Total spectrum allocation

B_{guard}: Guard band

B_c: Channel bandwidth

Example: What the number of FDMA channels, has 12.5 MHz per simplex band with guard 10KHz and channel bandwidth = 30KHz

$$N = \frac{12.5 * 10^6 - 2 * 10 * 10^3}{30 * 10^3} = 416 \text{ Channels}$$

Applications of FDMA

FDMA has used a variety of applications such as telephone systems, radio systems, TV

Advantages of FDMA

1. Simple to implement
2. Efficient with a small base population

Disadvantages of FDMA

1. Network and spectrum planning are time-consuming
2. Channels are dedicated to the single user.

2. **Time Division Multiple Access (TDMA)**

Time division multiple access (TDMA) systems divide the radio spectrum into time slots, and in each slot only one user is allowed to either transmit or receive. It can be seen from Figure 9.3 that each user occupies a cyclically repeating time slot, so a channel may be thought of as a particular time slot that reoccurs every frame, where N time slots comprise a frame. TDMA systems transmit data in a buffer-and-burst method, thus the transmission for any user is noncontinuous. This implies that, unlike in FDMA systems which accommodate analog FM, digital data and digital modulation must be used with TDMA. The transmission from various users is interlaced into a repeating frame structure as shown in Figure 4. It can be seen that a frame consists of a number of slots. Each frame is made up of a preamble, an information message, and tail bits.

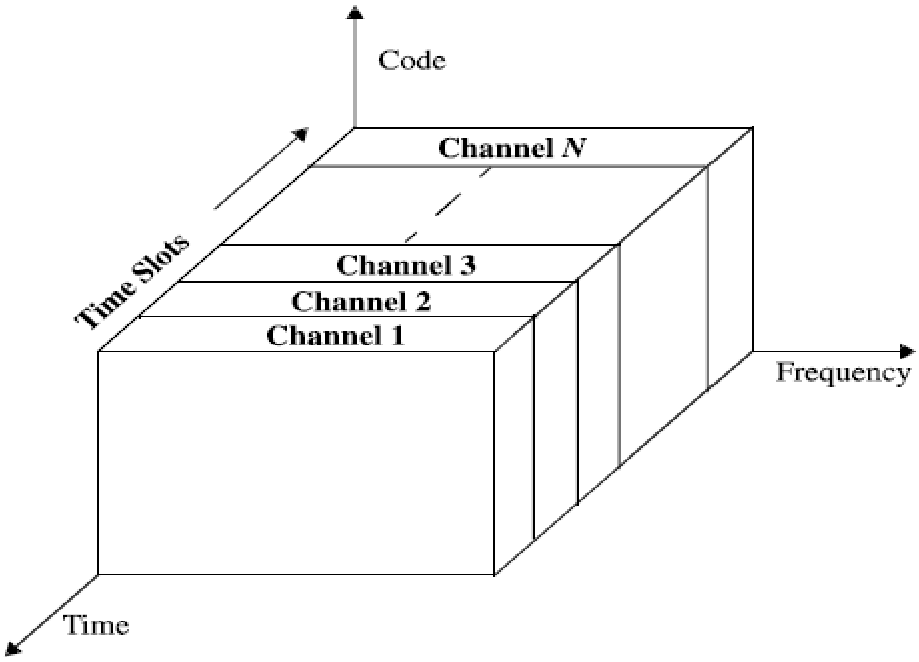


Figure 5: TDMA scheme where each channel occupies a cyclically repeating time slot.

In TDMA/ TDD, half of the time slots in the frame information message would be used for the forward link channels and half would be used for reverse link channels. In TDMA/FDD systems, an identical or similar frame structure would be used solely for either forward or reverse transmission, but the carrier frequencies would be different for the forward and reverse links.

In general, TDMA/FDD systems intentionally induce several time slots of delay between the forward and reverse time slots for a particular user, so that duplexers are not required in the subscriber unit.

In a TDMA frame, the preamble contains the address and synchronization information that both the base station and the subscribers use to identify each other. Guard times are utilized to allow synchronization of the receivers between different slots and frames.

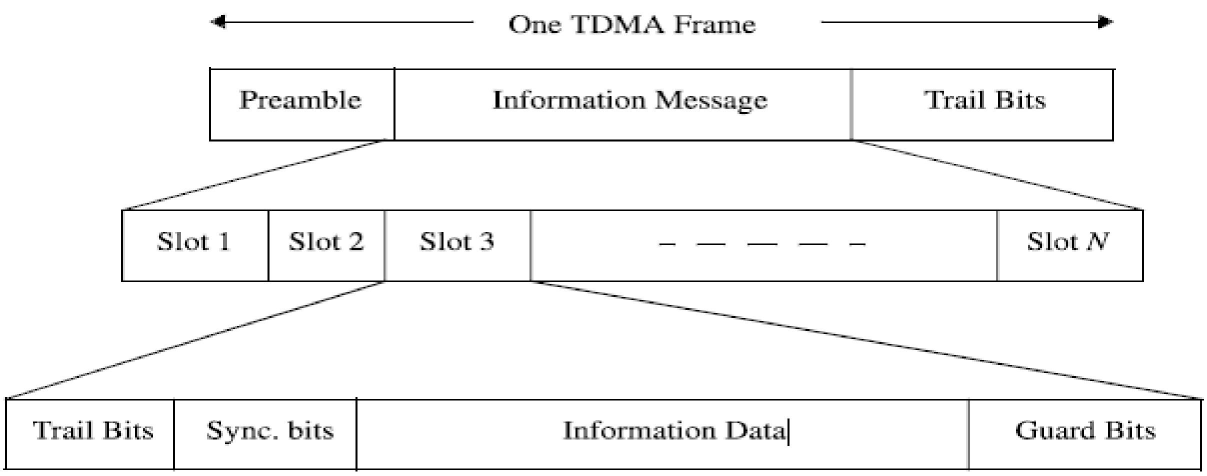


Figure 6: TDMA frame structure. The frame is cyclically repeated over time.

The features of TDMA include the following:

- TDMA shares a single carrier frequency with several users, where each user makes use of nonoverlapping time slots. 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 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 (which is most of the time).
- Because of discontinuous transmissions in TDMA, the handoff process is much simpler for a subscriber unit, since it is able to listen for other base stations during idle time slots. An enhanced link control, such as that provided by mobile assisted handoff (MAHO) can be carried out by a subscriber by listening on an idle slot in the TDMA frame.
- TDMA uses different time slots for transmission and reception, thus duplexers are not required. Even if FDD is used, a switch rather than a duplexer inside the subscriber unit is all that is required to switch between transmitter and receiver using TDMA.
- Adaptive equalization is usually necessary in TDMA systems, since the transmission rates are generally very high as compared to FDMA channels.
- In TDMA, the guard time should be minimized. If the transmitted signal at the edges of a time slot are 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 transmissions are slotted, and this requires the receivers to be synchronized for each data burst. In addition, guard slots are necessary to separate users, and this results in the TDMA systems having larger overheads as compared to FDMA.
- 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 by concatenating or reassigning time slots based on priority.

FDMA System Capacity

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

Where:

- N: Number of channels
- m: Number of TDMA users per radio channel
- B_{tot}: Total spectrum allocation
- B_{guard}: Guard Band
- B_c: Channel bandwidth

Example: What the number of TDMA channels, has forward link at Btot = 25 MHz with radio channels of Bc = 200 kHz if m = 8 speech channels supported, and guard band is 10KHz

$$N = \frac{8 * 25 * 10^6 - 2 * 10 * 10^3}{200 * 10^3} = 1000 \text{ users}$$

TDMA is used in a variety of applications such as 2G cellular systems, GSM

Advantages of TDMA

1. TDMA can easily adapt to the transmission of data as well as voice communication.
2. Ability to carry 64 kbps to 120 Mbps of data rates.
3. Most cost-effective technology to convert an analog system to digital.

Disadvantages of TDMA

1. Dropped calls are possible.
2. Higher costs due to greater equipment

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 for the access scheme. The frame efficiency, 111, is the percentage of bits per frame which contain transmitted data. Note that the transmitted data may include source and channel coding bits, so the raw end-user efficiency of a system is generally less than η_f. The frame efficiency can be found as follows. The number of overhead bits per frame is

$$b_{OH} = N_r b_r + N_t b_p + N_t b_g + N_r b_g$$

where

N_r is the number of reference bursts per frame.

N_t is the number of traffic bursts per frame.

b_r is the number of overhead bits per reference burst.

b_p is the number of overhead bits per preamble in each slot.

b_g is the number of equivalent bits in each guard time interval.

The total number of bits per frame, b_T, is

$$b_T = T_f R$$

where

T_f is the frame duration.

R is the channel bit rate. The frame efficiency η_f is thus given as

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

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

Solution

A time slot has 6 + 8.25 + 26 + 2(58) = 156.25 bits.

A frame has 8 x 156.25 = 1250 bits/frame.

The number of overhead bits per frame is given by

b_{oH} = 8(6) + 8(8.25) + 8(26) = 322 bits

Thus, the frame efficiency $\eta f = \left[1 - \frac{322}{1250}\right] * 100 = 74.24\%$

3. Code Division Multiple Access (COMA)

In code division multiple access (CDMA) systems, the narrowband message signal is multiplied by a very large bandwidth signal called the spreading signal. The spreading signal is a pseudo noise code sequence that has a chip rate which is orders of magnitudes greater than the data rate of the message. All users in a CDMA system, as seen from Figure 7, use the same carrier frequency and may transmit simultaneously. Each user has its own pseudorandom codeword which is approximately orthogonal to all other codewords. The receiver performs a time correlation operation to detect only the specific desired codeword. All other codewords appear as noise due to decorrelation. For detection of the message signal, the receiver needs to know the codeword used by the transmitter. Each user operates independently with no knowledge of the other users.

In CDMA, the power of multiple users at a receiver determines the noise floor after decorrelation. If the power of each user within a cell is not controlled such that they do not appear equal at the base station receiver, then the near-far problem occurs. 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.

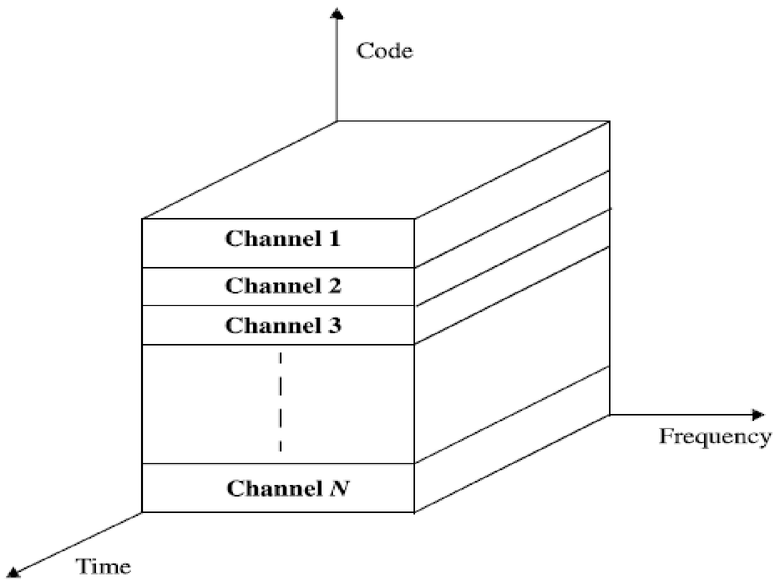


Figure 7: Code Division Multiple Access

In CDMA, stronger received signal levels raise the noise floor at the base station demodulators for the weaker signals, thereby decreasing the probability that weaker signals will be received. To combat the near-far problem, power control is used in most CDMA implementations. The features of COMA including the following:

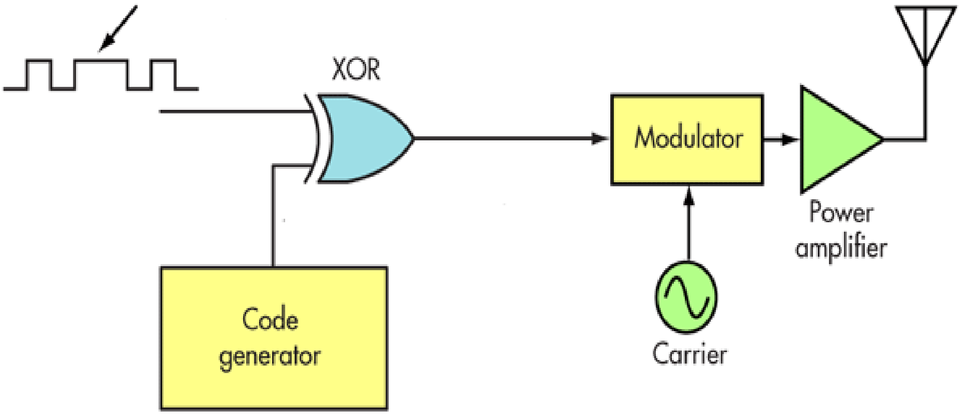
- Many users of a COMA system share the same frequency. Either TDD or FDD may be used.
- Unlike TDMA or FDMA, COMA has a soft capacity limit. Increasing the number of users in a COMA system raises the noise floor in a linear manner. Thus, there is no absolute limit on the number of users in COMA. Rather, the system performance gradually degrades for all users as the number of users is increased, and improves as the number of users is decreased.
- Multipath fading may be substantially reduced because the signal is spread over a large spectrum. If the spread spectrum bandwidth is greater than the coherence bandwidth of the channel, the inherent frequency diversity will mitigate the effects of small-scale fading.
- Channel data rates are very high in COMA systems. Consequently, the symbol (chip) duration is very short and usually much less than the channel delay spread. Since PN sequences have low autocorrelation, multipath which is delayed by more than a chip will appear as noise. A RAKE receiver can be used to improve reception by collecting time delayed versions of the required signal.
- Since COMA uses co-channel cells, it can use macroscopic spatial diversity to provide soft handoff. Soft handoff is performed by the MSC, which can simultaneously monitor a particular

user from two or more base stations. The MSC may choose the best version of the signal at any time without switching frequencies.

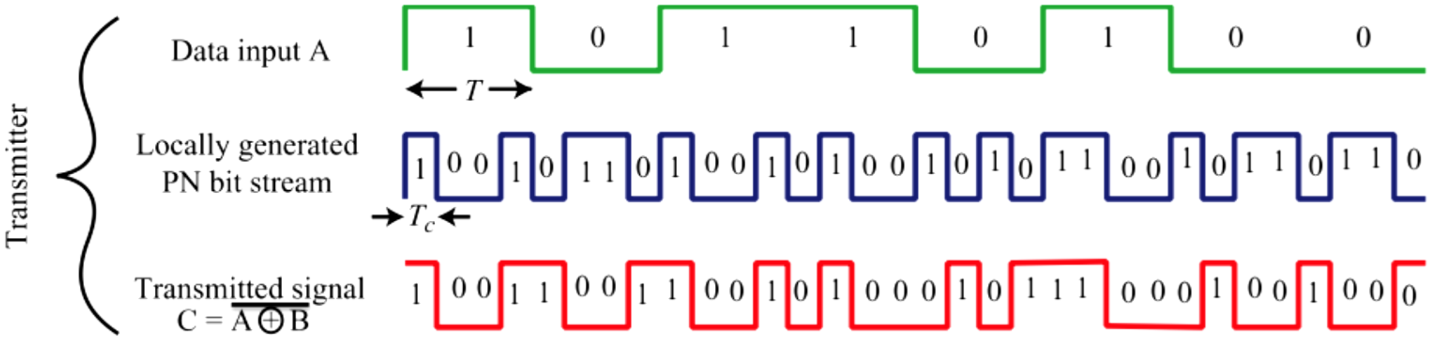
- Self-jamming is a problem in COMA system. Self-jamming arises from the fact that the spreading sequences of different users are not exactly orthogonal, hence in the dispreading of a particular PN code, non-zero contributions to the receiver decision statistic for a desired user arise from the transmissions of other users in the system.
- The near-far problem occurs at a COMA receiver if an undesired user has a high detected power as compared to the desired user.

CDMA is another technique for sharing channel resources by using a hybrid combination of FDMA and TDMA, which represents a specific form of code-division multiple access (CDMA). For example, frequency hopping may be employed to ensure that during each successive time slot, the frequency bands assigned to the users are reordered in an essentially random manner.

To be specific, during time slot 1, user 1 occupies frequency band1, user 2 occupies frequency band 2, user 3 occupies the frequency



band 3, and so on. During time slot 2, user 1 hops to frequency band 3, user 2 hops to frequency band 1, user 3 hops to frequency band 2 and so. The third-generation (3G) cell phone technology used CDMA.



Applications of CDMA

CDMA has used a variety of applications such as 3G cellular system, LTE, Satellite communication, Data security, GPS

Advantages of CDMA

1. Better signal quality
2. High data rates
3. Impossible for hackers to decipher the code sent.

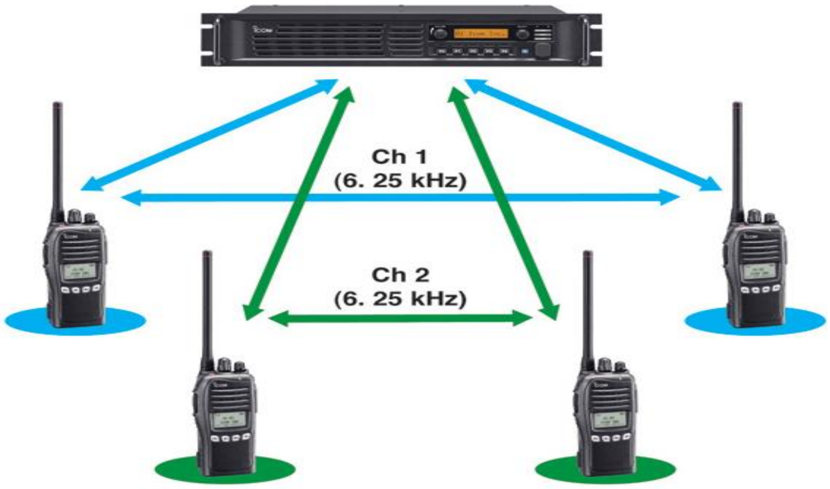
Disadvantages of CDMA

1. Self-jamming (if sync not done b/w users)
2. As the number of users increases, the overall quality of service decreases

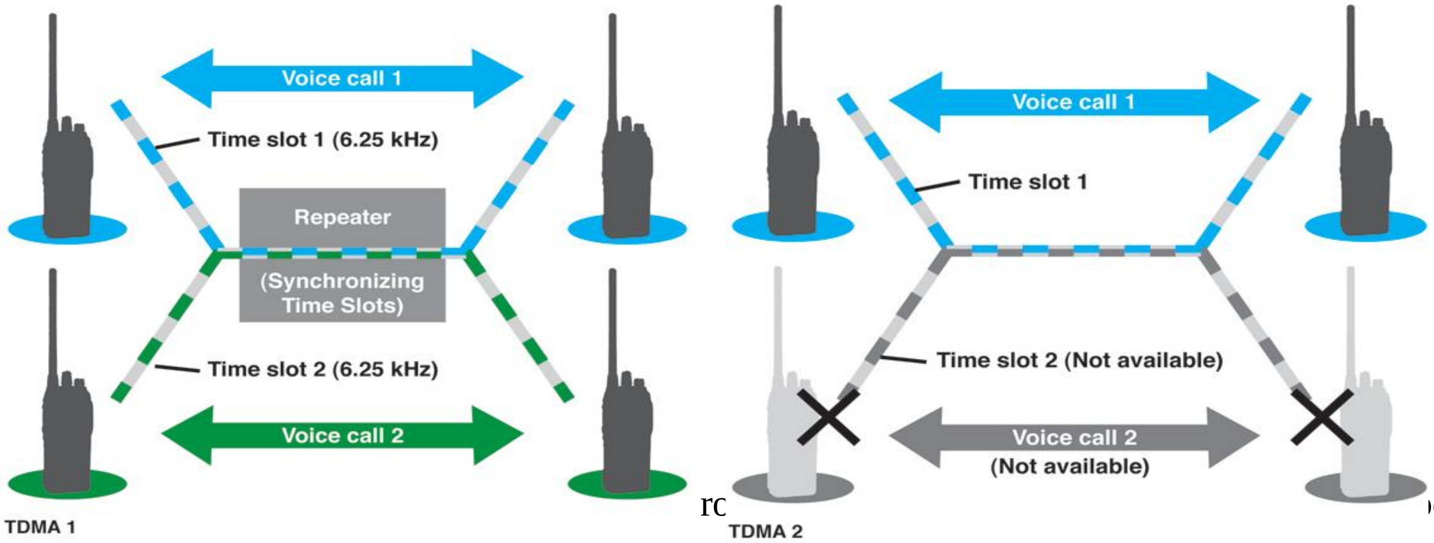
Summary:

There is a large room (spectrum) in which there is a group of people and this group is divided into pairs, each pair makes a call and then it is:

1. FDMA: The large room is divided into small rooms and each pair sits in a room to make the call and be reserved for them until the end call and no one else can enter this room.



2. **TDMA**: Three pairs are entered into each small room (3-time slots) so that each pair speaks within a specified period.



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so the volume control (terminal capacity) can enter a larger number of users.