BACHELOR OF COMPUTER APPLICATIONS

SEMESTER 3

DCA2104

BASICS OF DATA COMMUNICATION

Unit 10

Spread Spectrum

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1. INTRODUCTION

This unit introduces the concept of spread spectrum. Spread spectrum is an important form of encoding for wireless communications. The basic idea of spread spectrum is to modulate the signal to increase significantly the bandwidth (spread the spectrum) of the signal to be transmitted. We have discussed in unit 9, in multiplexing signals from several sources combines to achieve bandwidth efficiency and the available bandwidth of a link is divided between the sources. In spread spectrum also, we combine signals from different sources to fit into a larger bandwidth.

In this unit, we are going to discuss concept of spread spectrum. In the next section we will be see what is 'frequency hopping spread spectrum' and 'direct sequence spread spectrum' and how they function. In the last section, we will discuss code division multiple access.

1.1 Learning Objectives

After studying this unit, you should be able to:

- *Describe concept of spread spectrum*
- *Explain frequency hopping spread spectrum*
- *Describe direct sequence spread spectrum*
- *Explain code division multiple access*

2. CONCEPT OF SPREAD SPECTRUM

As we discussed, spread spectrum is designed to use in wireless applications. In wireless application, all stations must be able to share the medium without any malicious attacks. To achieve this goal, spread spectrum technique add redundancy. They spread the original spectrum needed for each station. Suppose the required bandwidth for each station is B, spread spectrum expands it to Bss, such that Bss >>B. Figure 1 shows the key characteristics of any spread spectrum system.

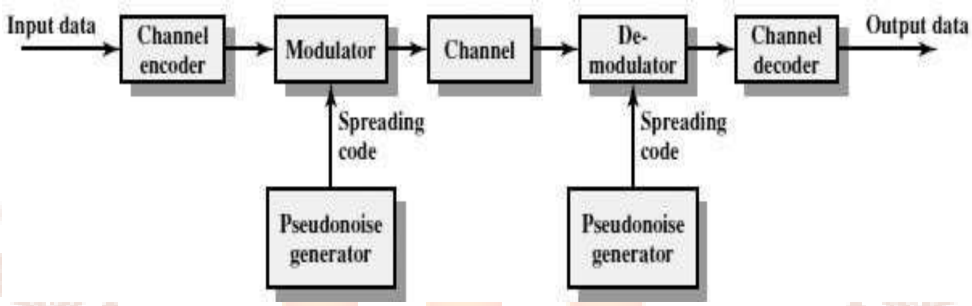

Figure 1: General model of spread spectrum digital communication system

Input is fed into a channel encoder that produces an analog signal with a relatively narrow bandwidth around some centre frequency. This signal is further modulated using a sequence of digits known as a spreading code or spreading sequence. Generally, the spreading code is generated by a pseudonoise, or pseudorandom number generator. The effect of this modulation is to increase significantly the bandwidth (spread the spectrum) of the signal to be transmitted. On the receiving end, the same digit sequence is used to demodulate the spread spectrum signal. Finally, the signal is fed into a channel decoder to recover the data.

This spreading technique helps the signals to gain immunity from various kinds of noise and multipath distortion. The earliest applications of spread spectrum were military where it was used for its immunity to jamming. It can also be used for hiding and encrypting signals. Only a recipient who knows the spreading code can recover the encoded information. Multiple users can independently use the same higher bandwidth with very little interference. This property is used in cellular telephony applications, with a technique known as code division multiplexing (CDM) or code division multiple access (CDMA).

Pseudorandom numbers are generated by an algorithm using some initial value called the seed. The algorithm is deterministic and therefore produces sequences of numbers that are not statistically random. However, if the algorithm is good, the resulting sequences will pass many reasonable tests of randomness. Such numbers are often referred to as pseudorandom numbers. The important point is that unless you know the algorithm and the seed, it is impractical to predict the sequence. Hence, only a receiver that shares this information with a transmitter will be able to decode the signal successfully.

Self-Assessment Questions - 1

1. Which of the following area uses spread spectrum encoding?
   a) Wired communication
   b) Wireless communication
   c) Analog to analog conversion
   d) Analog to digital conversion
2. In order to make all stations share the medium without any malicious attacks, spread spectrum technique add ____________ .
3. The analog signal produced by channel encoder is further modulated using a sequence of digits known as ________________.
4. The spreading code is generated by_______________.
5. Spreading technique is used in cellular telephony applications, with a technique known as __________________.
6. Pseudorandom numbers are generated by an algorithm using some initial value called __________________.

3. FREQUENCY HOPPING SPREAD SPECTRUM

Frequency-hopping spread spectrum is a form of spread spectrum in which the signal is broadcast over a seemingly random series of radio frequencies, hopping from frequency to frequency at fixed intervals. A receiver, hopping between frequencies in synchronization with the transmitter, picks up the message.

The frequency hopping spread spectrum (FHSS) technique uses M different carrier frequencies that are modulated by the source signal. At one moment, the signal modulates one carrier frequency. At the next moment, the signal modulates another carrier frequency. Although the modulation is done using one carrier frequency at a time, M frequencies are used in the long run. The bandwidth occupied by a source after spreading is $B_{FHSS} >> B$.

Figure 2 depicts the general layout for frequency hopping spread spectrum. A pseudorandom code generator called pseudorandom noise (PN) creates a k-bit pattern for every hopping period Th. The frequency table uses the pattern to find the frequency to be used for this hopping period and passes it to the frequency synthesizer. The frequency synthesizer creates a carrier signal of that frequency, and the source signal modulates the carrier signal.

Suppose we have decided to have eight hopping frequencies. For real applications it will be more. In this case, M is 8 and k is 3. The pseudorandom code generator will create eight different 3-bit patterns. These are mapped to eight different frequencies in the frequency table.

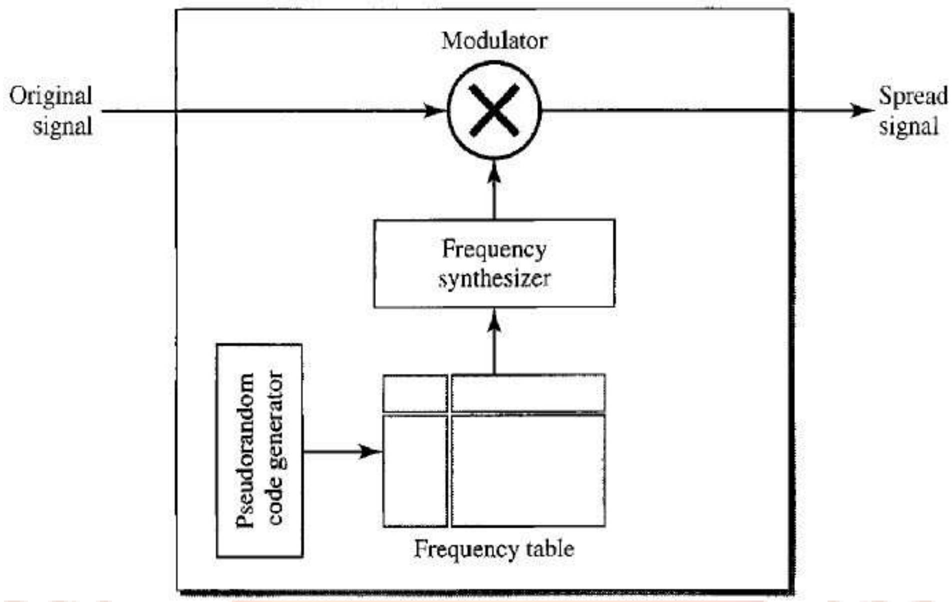

Figure 2: Frequency hopping spread spectrum (FHSS)

Figure 3 shows the frequency selection in FHSS. The pattern for this station is 101, 111, 001, 000, 010, 011, 100. The pattern is pseudorandom, it is repeated after eight hoppings. This means that at hopping period 1, the pattern is 101.

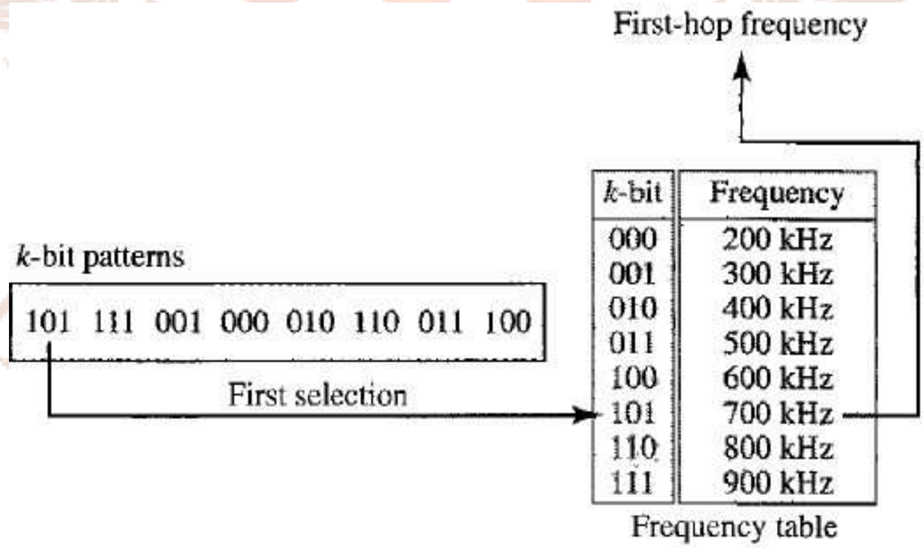

Figure 3: Frequency selection in FHSS

The frequency selected is 700 kHz. The source signal modulates this carrier frequency. The second k bit pattern selected is 111, which selects the 900 kHz carrier. The eighth pattern is 100, the frequency is 600 kHz. After eight hoping the pattern repeats, starting from 101 again. Figure 4 shows how the signal hops around from carrier to carrier. We assume the required bandwidth of the original signal is 100 kHz.

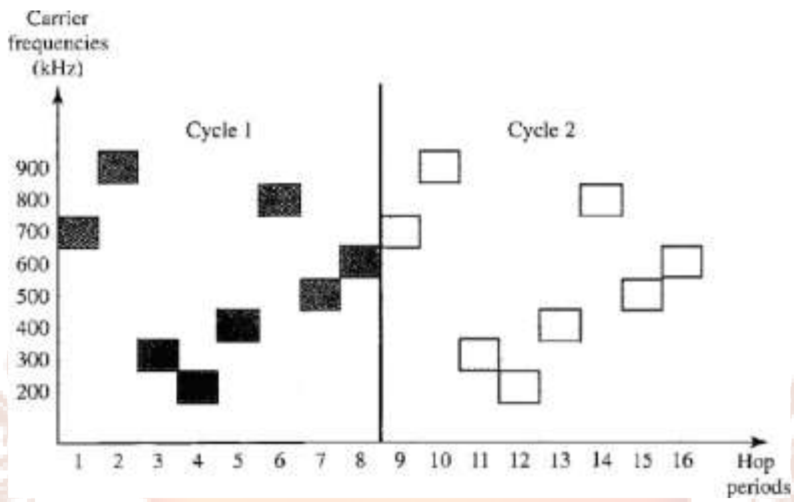

Figure 4: FHSS cycles

If there are many k-bit patterns and the hopping period is short, a sender and receiver can have privacy. If an intruder tries to intercept the transmitted signal, he can only access a small piece of data because she does not know the spreading sequence to quickly adapt herself to the next hop. The scheme has also an antijamming effect. A malicious sender may be able to send noise to jam the signal for one hopping period but not for the whole period.

Bandwidth Sharing

If the number of hopping frequencies is M, we can multiplex M channels into one by using the same B_{ss} bandwidth. This is possible because a station uses just one frequency in each hopping period; M-1 other frequencies can be used by other M-1 stations. That is M different stations can use the same B_{ss} if an appropriate modulation technique such as multiple FSK (MFSK) is used. FHSS is similar to FDM. Figure 5 shows an example of four channels using FDM and four channels using FHSS.

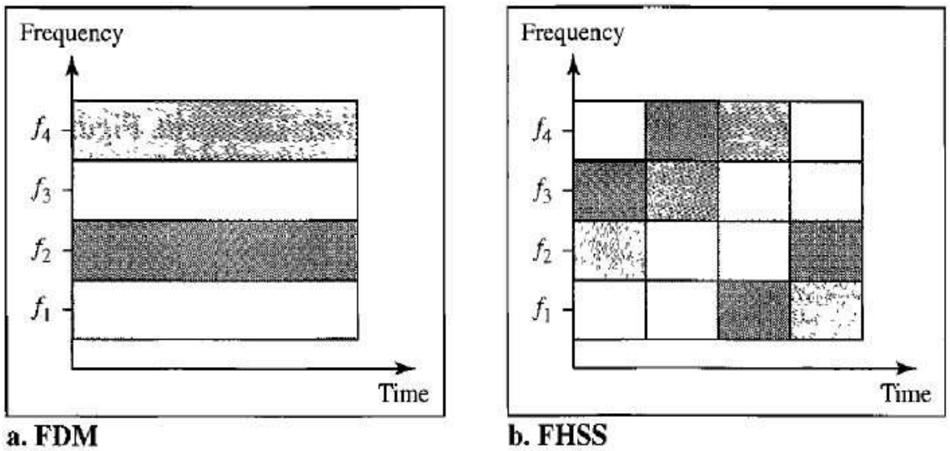

Figure 5: Bandwidth sharing

In FDM, each station uses 1/M of the bandwidth, but the allocation is fixed. In FHSS, each station uses 1/M of the bandwidth but the allocation changes hop to hop.

Self-Assessment Questions - 2

7. In___spread spectrum, the signal is broadcast over a seemingly random series of radio frequencies, hopping from frequency to frequency at fixed intervals.

8. The frequency table uses the pattern to find the frequency to be usedfor hopping period and passes it to________________________________.

4. DIRECT SEQUENCE SPREAD SPECTRUM

Direct sequence spread spectrum (DSSS) is a form of spread spectrum in which each bit in the original signal is represented by multiple bits in the transmitted signal, using a spreading code. The direct sequence spread spectrum also expands the bandwidth of the original signal, but the process is different. In DSSS, we replace each data bit with n bits using a spreading code. That is, each bit is assigned a code of n bits called chips, where chip rate is n times that of the data bit. Figure 6 shows the concept of direct sequence spread spectrum.

As an example, consider the sequence used in a wireless LAN which is known as the famous barker sequence where n is 11. We assume that the original signal and the chips in the chip generator use polar NRZ encoding.

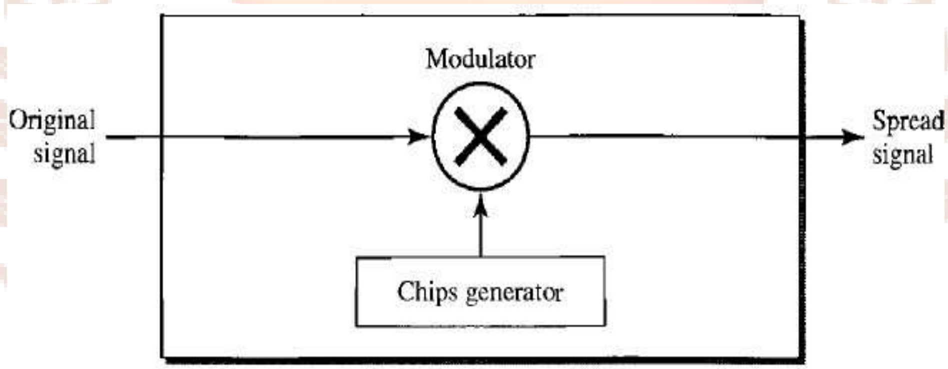

Figure 6: Concept of direct sequence spread spectrum

Figure 7 shows the chips and the result of multiplying the original data by the chips to get the spread signal. In Figure 7, the spreading code is 11 chips having the pattern 10110111000. If the original signal rate is N, the rate of the spread signal is 11N. This means that the required bandwidth for the spread signal is 11 times larger than the bandwidth of the original signal. The spread signal can provide privacy if the intruder does not know the code. It can also provide immunity against interference if each station uses a different code.

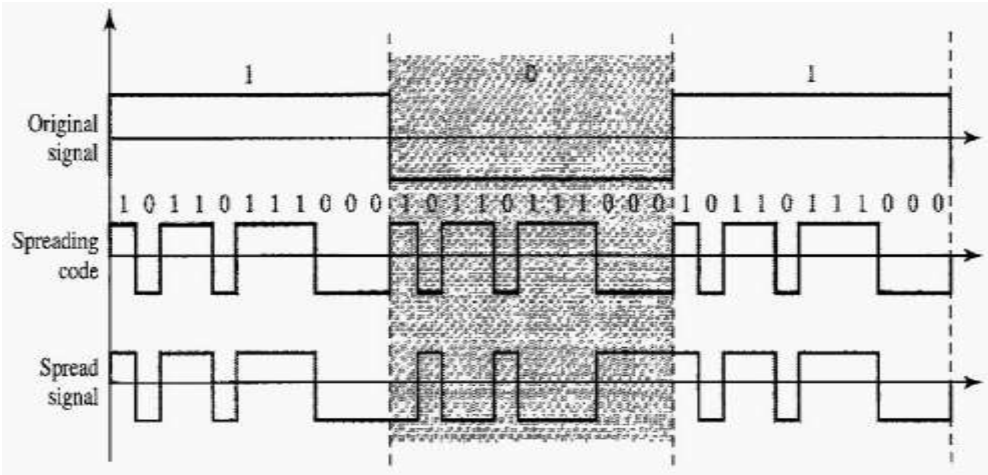

Figure 7: Direct sequence spread spectrum example

Bandwidth sharing

If we use a spreading code that spread signals that cannot be combined and separated, we cannot share a bandwidth. But, if we use a special type of sequence code that allows the combining and separating of spread signals, we can share the bandwidth. A special spreading code allows us to use DSSS in cellular telephony and share a bandwidth between several users.

Self-Assessment Questions - 3

9. In ________________ spread spectrum, each bit in the original signal is represented by multiple bits in the transmitted signal, using a spreading code.
10. In direct sequence spread spectrum, each bit is assigned a code of n bits called ______________.

5. CODE DIVISION MULTIPLE ACCESS

Code division multiple access exploits the nature of spread spectrum transmission to enable multiple users to independently use the same bandwidth with very little interference. CDMA (Code-Division Multiple Access) is a channel access method used by various radio communication technologies. It is a form of multiplexing, which allows numerous signals to occupy a single transmission channel, optimizing the use of available bandwidth. The technology is used in ultra-high-frequency (UHF) cellular telephone systems in the 800-MHz and 1.9-GHz bands.

CDMA employs analog-to-digital conversion (ADC) in combination with spread spectrum technology. Audio input is first digitized into binary elements. The frequency of the transmitted signal is then made to vary according to a defined pattern (code), so it can be intercepted only by a receiver whose frequency response is programmed with the same code, so it follows exactly along with the transmitter frequency. There are trillions of possible frequency-sequencing codes, which enhance privacy.

Basic principles

CDMA is a multiplexing technique used with spread spectrum. The scheme works in the following manner. We start with a data signal with rate D, which we call the bit data rate. We break each bit into k chips according to a fixed pattern that is specific to each user, called the user's code. The new channel has a chip data rate of kD chips per second. We consider a simple example with k=6. It is simplest to characterize a code as a sequence of 1s and -1s.

Figure 8 shows the code for three users A, B and C each of which is communicating with the same base station receiver R. Thus, the code for user A is C_A = <1, -1, -1, 1, -1, 1>. Similarly, user B has code C_B = <1, 1, -1, -1, 1 1>and user C has C_C = <1, 1, -1, 1, 1, -1>.

We now consider the case of user A communicating with the base station. The base station is assumed to know A's code. For simplicity, we assume that communication is already synchronized so that the base station knows when to look for codes. If A wants to send a 1 bit, A transmits its code as a chip pattern <1, -1, -1, 1, -1, 1>. If a 0 bit is to be sent, A transmits the complement (1s and -1s reversed) of its code, <-1, 1, 1,-1, 1,-1>. At the base station the receiver decodes the chip patterns. In our simple version, if the receiver R receives a chip pattern d = <d1, d2, d3, d4, d5, d6>, and the receiver is seeking to communicate with a user u so that it has at hand u's code, <c1, c2, c3, c4, c5, c6>, the receiver performs electronically the following decoding function:

$$S_u(d) = d1\times c1 + d2\times c2 + d3\times c3 + d4\times c4 + d5\times c5 + d6\times c6$$

The subscript u on S simply indicates that u is the user that we are interested in.

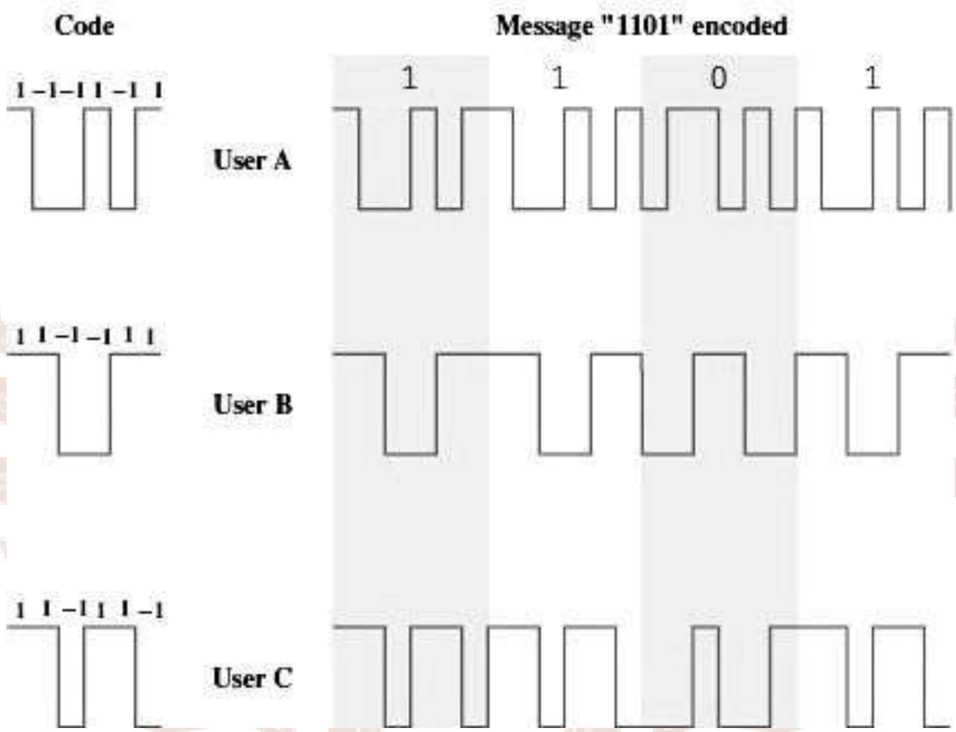

Figure 8: CDMA Example

Suppose user u is actually A, then if A sends a 1bit, then d is <1, -1, -1, 1, - 1, 1> and the preceding computations using S_A becomes

$S_A(1, -1, -1, 1, -1, 1) = 1\times1 + (-1)\times (-1) + (-1)\times (-1) + 1\times1 + (-1)\times (-1) + 1\times1 =6$

If A sends a 0 bit that corresponds to d= <-1, 1,1, -1,1,-1>, we get

$S_A(-1,1, 1, -1, 1,-1) = -1\times1 + 1\times (-1) + 1\times(-1) + (-1) \times 1 + 1 \times (-1) + (-1) \times1 = -6$

This is always the case that $-6 \leq S_A(d) \leq 6$, no matter what sequence of -1s and 1s that *d* is, and that the only *d*'s resulting in the extreme values of 6 and -6 are A's code and its complement, respectively. So if S_A produces a+6, we say that we have received a 1 bit from A; if S_A produces a -6, we say that we have received a 0 bit from user A; otherwise, we assume that someone else is sending information or there is an error. Now let's see what happens if user B is sending and we try to receive it with S_A, that is, we are decoding with the wrong code, A's. If B sends a 1 bit, then d= <1,1,-1,- 1,1,1>. Then

$SA(1,1,-1,-1,1,1) = 1\times1 + 1\times (-1) + (-1)\times (-1) + (-1)\times 1 + 1 \times (-1) + 1\times1 =0$

Thus, the unwanted signal (from B) does not show up at all. We can easily verify that if B had sent a 0 bit, the decoder would produce a value of 0 for S_A again. This means that if the decoder is linear and if A and B transmit signals S_A and S_B, respectively, at the same time, then $S_A(S_A + S_B) = S_A(S_A) + S_A(S_B) = S_A (S_A)$ since the decoder ignores B when it is using A's code. The codes of A and B that have the property that $S_A (C_B) = S_B (C_A) =0$ are called *orthogonal*. Such codes are very nice to have but there are not all that many of them. More common is the case when $S_X(C_y)$ is small in absolute value when $X \neq Y$. Then it is easy to distinguish between the two cases when $X = Y$ and when $X \neq Y$. In our example, $S_A(C_C) = S_C(C_A) =0$, but $S_B(C_C) = S_C (C_B)=2$. In the latter case the C signal would make a small contribution to the decoded signal instead of 0. Using the decoder, Su, the receiver can sort out transmission from u even when there may be other users broadcasting in the same cell. Figure 9 summarizes the example from the preceding discussion.

In practice, the CDMA receiver can filter out the contribution from unwanted users or they appear as low-level noise. However, if there are many users competing for the channel with the user the receiver is trying to listen to, or if the signal power of one or more competing signals is too high, perhaps because it is very near the receiver (near-far problem), the system breaks down.

(a) User's codes

User A	1	−1	−1	1	−1	1
User B	1	1	−1	−1	1	1
User C	1	1	−1	1	1	−1

(b) Transmission from A

Transmit (data bit = 1)	1	−1	−1	1	−1	1	
Receiver codeword	1	−1	−1	1	−1	1	
Multiplication	1	1	1	1	1	1	= 6

Transmit (data bit = 0)	−1	1	1	−1	1	−1	
Receiver codeword	1	−1	−1	1	−1	1	
Multiplication	−1	−1	−1	−1	−1	−1	= −6

(c) Transmission from B, receiver attempts to recover A's transmission

Transmit (data bit = 1)	1	1	−1	−1	1	1	
Receiver codeword	1	−1	−1	1	−1	1	
Multiplication	1	−1	1	−1	−1	1	= 0

(d) Transmission from C, receiver attempts to recover B's transmission

Transmit (data bit = 1)	1	1	−1	1	1	−1	
Receiver codeword	1	1	−1	−1	1	1	
Multiplication	1	1	1	−1	1	−1	= 2

(e) Transmission from B and C, receiver attempts to recover B's transmission

B (data bit = 1)	1	1	−1	−1	1	1	
C (data bit = 1)	1	1	−1	1	1	−1	
Combined signal	2	2	−2	0	2	0	
Receiver codeword	1	1	−1	−1	1	1	
Multiplication	2	2	2	0	2	0	= 8

Figure 9: CDMA Example

Characteristics of CDMA

Spread spectrum techniques use a transmission bandwidth that is several orders of magnitude greater than the minimum required signal bandwidth. CDMA systems were designed using spread spectrum because of its security and resistance to jamming. Since narrow band interference affects only a small portion of the spread spectrum signal, CDMA can effectively reject narrow band interference. CDMA devices use a rake receiver, which exploits multipath delay components to improve the performance of the system. In a CDMA system, the same frequency can be used in every cell, because channelization is done using the pseudo-random codes. Reusing the same frequency in every cell eliminates the need for frequency planning in a CDMA system. CDMA systems use the soft hand off, which is undetectable and provides a more reliable and higher quality signal.

Advantages of CDMA

- Efficient practical utilization of fixed frequency spectrum
- Many users of CDMA use the same frequency, TDD or FDD may be used
- Flexible allocation of resources.
- No absolute limit on the number of users, Easy addition of more users.
- Impossible for hackers to decipher the code sent
- Better signal quality
- No sense of handoff when changing cells. CDMA networks use a scheme called soft handoff, which minimizes signal breakup as a handset passes from one cell to another.
- CDMA is compatible with other cellular technologies; this allows for nationwide roaming.
- The combination of digital and spread-spectrum modes supports several times as many signals per unit bandwidth as analog modes.

Disadvantages of CDMA

As the number of users increases, the overall quality of service decreases. Another problem is self jamming. Near-far problem is another drawback of CDMA.

Uses of CDMA

One of the early applications for code division multiplexing is in GPS (global positioning system). The Qualcomm standard IS-95, marketed as CDMAOne. The Qualcomm standard IS-2000, known as CDMA2000, which is used by several mobile phone companies, including the Globalstar satellite phone network. The UMTS 3G mobile phone standard, which uses W-CDMA. CDMA has been used in the OmniTRACS satellite system for transportation logistics.

Self-Assessment Questions - 4

11. ______________ is a channel access method used by various radio communication technologies.
12. CDMA employs _______________ conversion in combination with spread spectrum technology.
13. The technology used in ultra-high-frequency (UHF) cellular telephone systems is __________________.
14. CDMA systems were designed using ________________ because of its security and resistance to jamming.

6. SUMMARY

Let us recapitulate the important concepts discussed in this unit:

- The basic idea of spread spectrum is to modulate the signal so as to increase significantly the bandwidth of the signal to be transmitted.
- The spread spectrum technique helps the signals to gain immunity from various kinds of noise and multipath distortion.
- Frequency-hopping spread spectrum is a form of spread spectrum in which the signal is broadcast over a seemingly random series of radio frequencies, hopping from frequency to frequency at fixed intervals.
- Direct sequence spread spectrum (DSSS) is a form of spread spectrum in which each bit in the original signal is represented by multiple bits in the transmitted signal, using a spreading code.
- Code division multiple access exploits the nature of spread spectrum transmission to enable multiple users to independently use the same bandwidth with very little interference.
- CDMA employs analog-to-digital conversion (ADC) in combination with spread spectrum technology.
- CDMA is a channel access method used by various radio communication technologies.

7. TERMINAL QUESTIONS

1. Describe the concept of spread spectrum.
2. Differentiate between frequency hopping spread spectrum and direct sequence spread spectrum.
3. Explain CDMA technology.
4. Describe the working principles of CDMA.
5. Explain the advantages and disadvantages of CDMA.

8. ANSWERS

Self-Assessment Questions

1. (b) wireless communication
2. Redundancy
3. Spreading code or spreading sequence
4. Pseudonoise or pseudorandom number generator
5. Code division multiple access (CDMA)
6. Seed
7. Frequency-hopping
8. Frequency synthesizer
9. Direct sequence
10. Chips
11. CDMA
12. Analog to digital conversion
13. CDMA
14. Spread spectrum

Terminal Questions

1. Spread spectrum is designed to use in wireless applications. In wireless application, all stations must be able to share the medium without any malicious attacks. To achieve this goal, spread spectrum technique add redundancy. (Refer section 2 for detail).
2. Frequency-hopping spread spectrum is a form of spread spectrum in which the signal is broadcast over a seemingly random series of radio frequencies, hopping from frequency to frequency at fixed intervals. Direct sequence spread spectrum (DSSS) is a form of spread spectrum in which each bit in the original signal is represented by multiple bits in the transmitted signal, using a spreading code. (Refer section 3 and 4 for detail).
3. Code division multiple access exploits the nature of spread spectrum transmission to enable multiple users to independently use the same bandwidth with very little interference. CDMA (Code-Division Multiple Access) is a channel access method used

by various radio communication technologies. It is a form of multiplexing, which allows numerous signals to occupy a single transmission channel, optimizing the use of available bandwidth. (Refer section 5 for detail).

4. CDMA is a multiplexing technique used with spread spectrum. The scheme works in the following manner. We start with a data signal with rate *D*, which we call the bit data rate. We break each bit into *k* chips according to a fixed pattern that is specific to each user, called the user's code. (Refer section 5 for detail).
5. Advantages of CDMA are efficient practical utilization of fixed frequency spectrum, Flexible allocation of resources...Disadvantages are as the number of users increases, the overall quality of service decreases. Another problem is self-jamming (Refer section 5 for detail)

9. REFERENCES

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