

MULTIPLE ACCESS

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Introduction

- the simplest kind on communication systems, consists of one pair of users:
 - one transmits and one receives, one-to-one, called point to-point communication.
- In many applications, it is required that several transmitters send information simultaneously through the same channel.

Introduction

- As an example:
 - a cellular telephone system. A base station is placed in the center of each cell to provide the communication services of all mobile phone users over the area covered by the radio waves.
 - several mobile phone users may need to communicate with the same base station at the same time.

Introduction

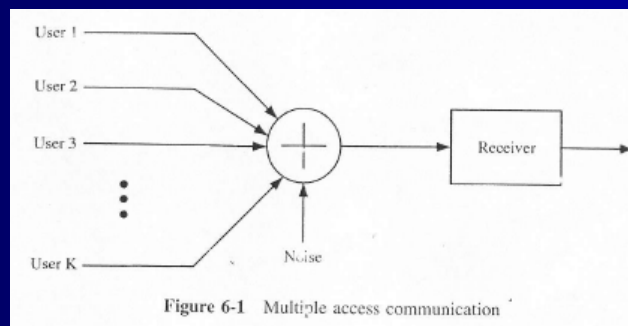
- other examples of multiple access communications:
 - ground stations communicating with a satellite,
 - local-area network,
 - packet-radio network,
 - cable television network,
 - etc

Introduction

- Problem: interference each other.
- For example,
 - in wired telephone systems, it causes crosstalk between different telephone links. In cellular telephony systems, it causes
 - serious interference between users, if the same radio frequency is used simultaneously by distinct users.

Introduction

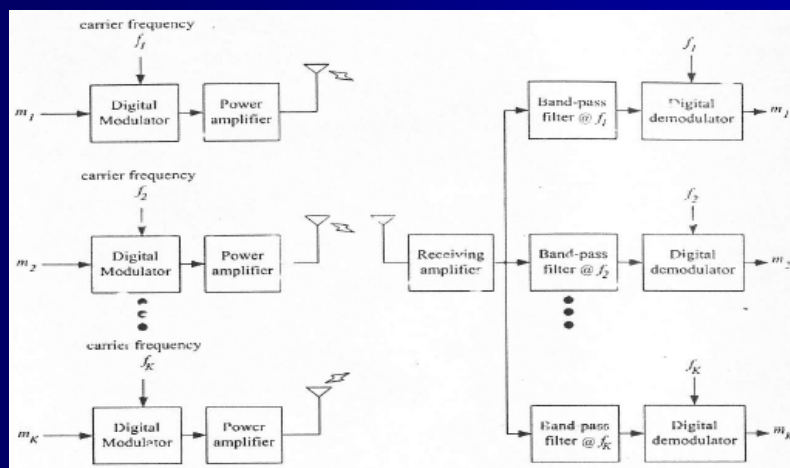
- scenario of multiple access



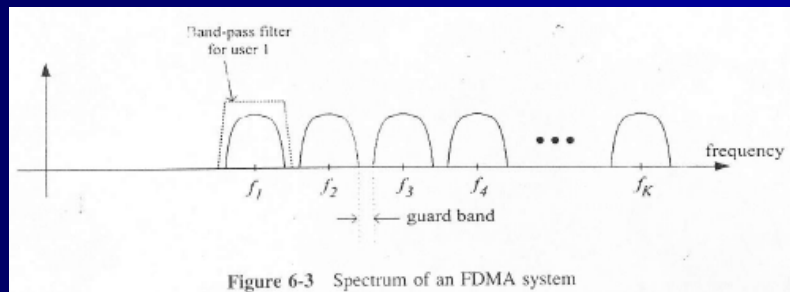
Frequency-division Multiple Access (FDMA)

- Radio-frequency modulation enables several transmissions to coexist in time and space without mutual interference by using different carrier frequencies.
 - Currently information transmitted over most of the radio and television broadcast systems is in analogue form.
 - Digital broadcast systems that provide better quality of audio and video will become popular in the future.

FDMA

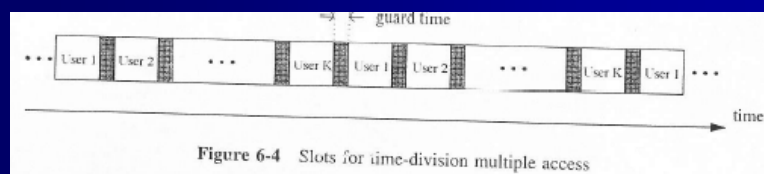


The spectrum

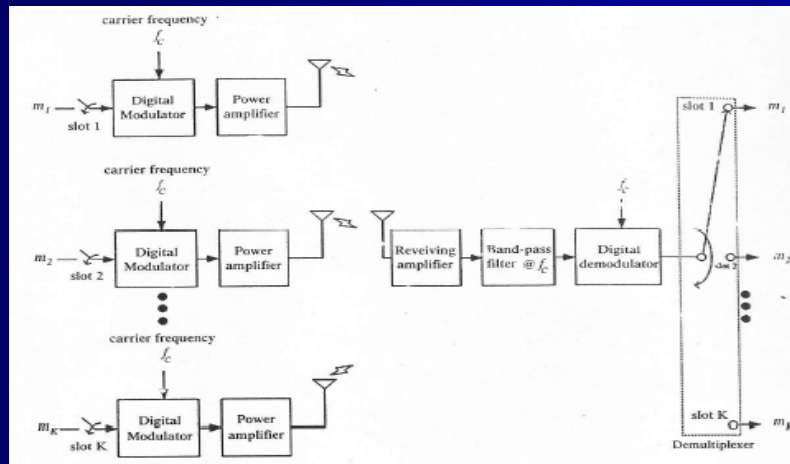


Time-division Multiple Access (TDMA)

- In time-division multiple access (TDMA) systems, all users use the same frequency band, but the time domain is partitioned into slots assigned to each user



TDMA



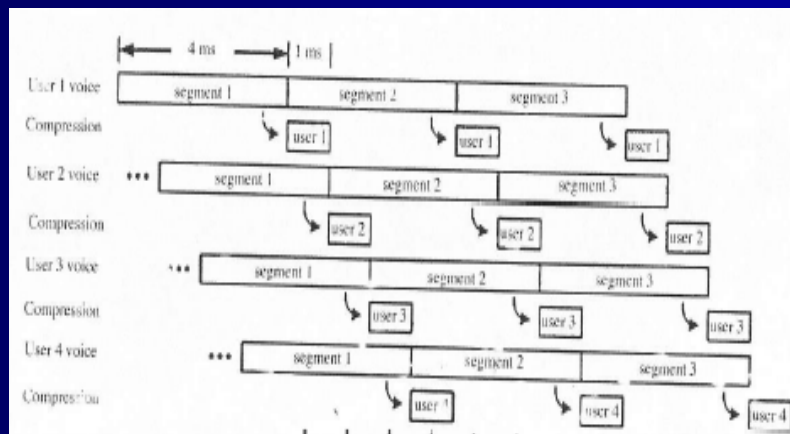
TDMA

- In a TDMA system, user k can transmit data only in the time slots assigned to user k.
- Therefore, each user's data are not transmitted continuously.
- Under this scenario, one may ask why the voice can be transmitted and received continuously in a TDMA system without any feeling of time-sharing. This problem is solved by partitioning the continuous voice signal into small segments.

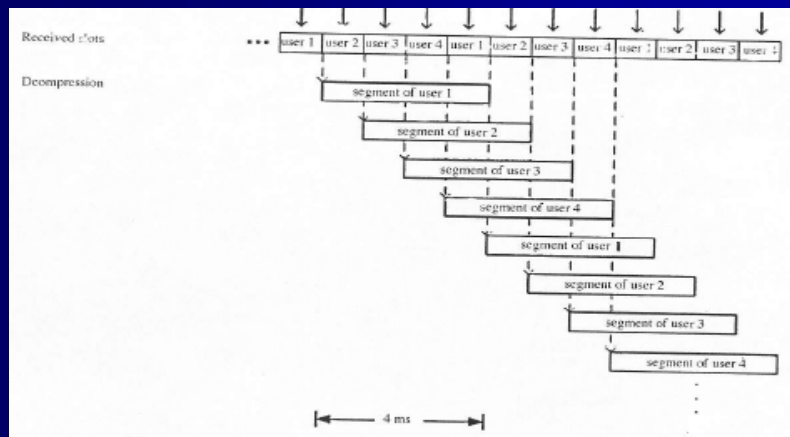
TDMA

- For example, for a four-user TDMA system, assume that each slot occupies 1 ms. Then each user can use one slot every 4ms.
- The voice signal is then each user can use one slot every 4ms. The voice signal is then partitioned into segments of 4 ms each. Each segment is then converted (and compressed) into digital form.
- Assume that a total of B bits of voice data is produced for each segment of voice signal. The transmitter then transmits the B bits during each allowed 1 ms slot,
- The receiver receives each user's data at the corresponding time slot and reconstructs the voice signal in the following 4 ms. All reconstructed voice segments are concatenated in time, resulting in a continuous voice signal.

TDMA



TDMA



TDMA

- Note that the bit rate as well as the bandwidth of a communication system will be increased if the TDMA system is used.

Examples of TDMA and FDMA System

- systems that use these both FDMA and TDMA technologies
 - GSM Mobile Phone System (Both FDMA and TDMA)
 - T1 to T4 Systems (TDMA)
 - Digital Enhanced Cordless Telecommunication (DECT) (FDMA and TDMA)
 - Digital Audio Broadcasting (DAB) (FDMA and TDMA)

GSM Multiple Access

- For the GSM system, RF are in the range of 900, 1800 and 1900MHz.
 - Each RF channel consists of 124 sub channels and each subchannel has a bandwidth 0.2 MHz with eight TDMA systems.
 - Thus, each GSM has a bandwidth around $124 \times 0.2 \approx 25$ MHz.
 - Each carrier frequency is shared by eight users in the TDMA fashion.
 - The total number of users is $124 \times 8 \approx 1000$.
 - So, the GSM system allows maximum 1000 users to access one base station.
 - The GSM system uses Gaussian Minimal-shift Keying (GMSK), that is quite similar to the FSK technique for digital modulation.

T1 –T4 Multiple Access

- The T1 to T4 systems are transmission lines along which data are transmitted by, using the base-band pulse transmission method. There is no carrier frequency involved, so these systems all use the TDMA technique.
 - bit rate for T1 is 1.544Mbps with 24 channels, and each channel transmits data with 64Kbps.
 - The T2 system has 6.312Mbps and is equal to four T1s, and thus 96 channels.
 - The T3 system has 44.13 Mbps and is equivalent to seven T2s and has 672 channels.
 - Finally, T4 has 274.17 Mbps, is equal to six T3s, and has 4032 channels.

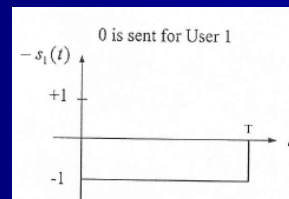
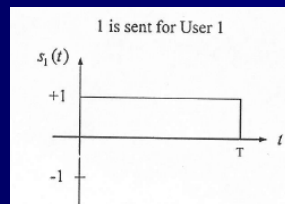
DECT

- In the home we often use cordless phones. Thus, some wireless communication technique must be used. Our present cordless phone system actually allows people in the house to talk to each other.
 - The channel spacing of DECT is 1.728 MHz located in the 1880-1900 MHz.
 - DECT employs the TDMA technology with 24-timeslot per carrier frequency.
 - Thus, a single DECT carrier can support multiple calls over a single RF transceiver. The modulation technique employed in the DECT is the Gaussian Frequency-shift Keying (GFSK) which is also a special form of the FSK

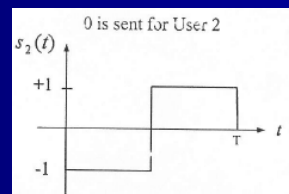
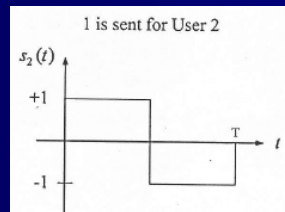
Code-division Multiple Access (CDMA)

- In the code-division multiple access (CDMA) method, each user is given a unique code to represent 1s and 0s.
- All of the signals thus overlap both in time and in frequency.
- The basic requirement is that the codes are orthogonal

Two-user CDMA System

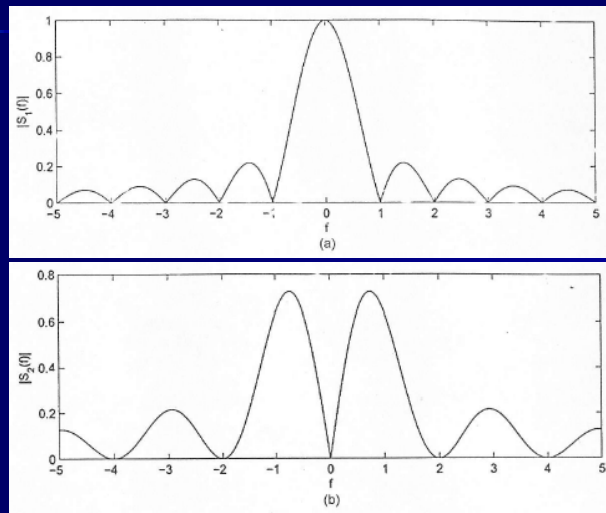


User 1



User 2

Two-user CDMA



User 1

User 2

Two-user CDMA

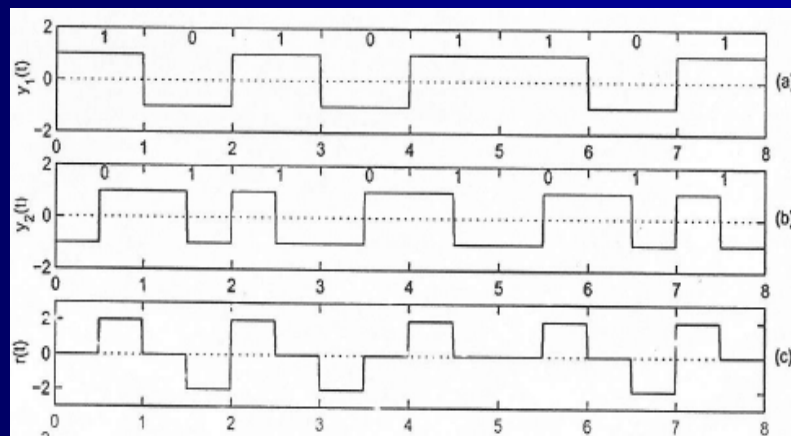
- $s_1(t)$ and $s_2(t)$ also overlap in the frequency domain
- Signals $s_1(t)$ and $s_2(t)$ are mutually orthogonal over $(0, T)$

$$\langle s_1(t), s_2(t) \rangle = \int_0^T s_1(t) s_2(t) dt = 0.$$

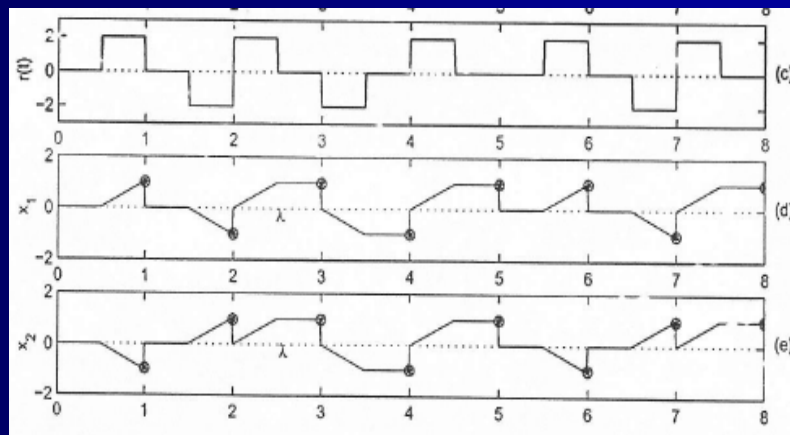
Two-user CDMA

- Figure below show examples of $s_1(t)$ and $s_2(t)$ with the message sequence
 - 1010 1101 for user 1 and
 - 0110 1011 for user 2,
- where the signaling interval T is assumed to
- be one second. Assume that both transmitted signals are received periodically.

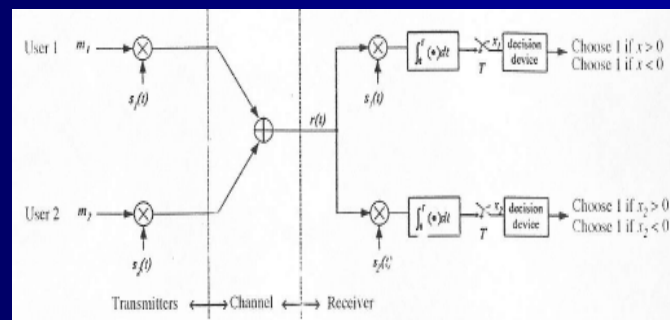
Two-user CDMA



Two-user CDMA



CDMA model of 2 users



K-users CDMA

- For a general K-user CDMA system, each user is assigned a particular signature waveform which corresponds to a sequence of +1 and -1 of length N.
- Let $s_k : (s_{k0}, s_{k1}, \dots, s_{k(N-1)})$ be the sequence of user k, where each s_{kj} equals +1 or -1 for $j=0, 1, \dots, N-1$.

$$s_k(t) = \sum_{j=0}^{N-1} s_{kj} p(t - jT_c),$$

K-users CDMA

$$s_k(t) = \sum_{j=0}^{N-1} s_{kj} p(t - jT_c),$$

- where $T_c = T/N$
- $p(t)$ is a rectangular signal within $(0, T_c)$
 - $p(t)=1$ for $0 < t < T_c$,
 - $p(t)=0$ elsewhere.
- The quantity T_c is called the chip duration and $1/T_c$ is called the chip rate.

K-users CDMA

- For example, a sequence
 $(+1, +1, -1, +1, -1, -1, +1, -1)$
- of length 8 corresponds to the signature signal shown in Figure 6-11.
- It can be proved that the bandwidth of a CDMA signal has a broader spectrum than that of the original base-band signal.
- Therefore, the transmitted signal is expanded in the spectrum, and consequently a CDMA system is also called a spread spectrum system.

K-users CDMA

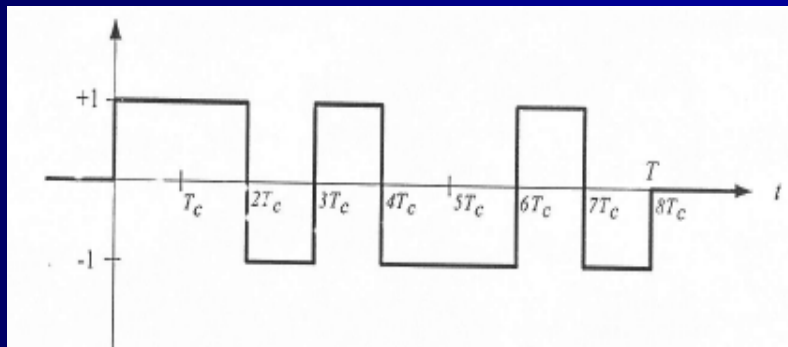


Figure 6-11 Signature waveform for the signature sequence $(+1, +1, -1, +1, -1, -1, +1, -1)$

K-users CDMA

- Let there be K users.
 - In the CDMA system, user k uses his own code sequence $s_k(t)$ to represent binary symbol 1. User k sends $m_k s_k(t)$ where $m_k = \pm 1$.
 - If 1(0) is sent, $m_k = 1(-1)$, we require that the K sequences be mutually orthogonal.
 - These K sequences are mixed together to be sent as the message signal.
- Thus the send signal is,

$$s(t) = \sum_{k=1}^K m_k s_k(t).$$

K-users CDMA

- Since the $s_k(t)$ are orthogonal, m_k can be easily detected by performing an inner product of $s(t)$ and $s_k(t)$. It can be easily seen that

$$\langle s(t), s_k(t) \rangle = NT_c m_k.$$

- If the inner product is positive, then $m_k = +1$, otherwise $m_k = -1$

Hadamard Matrices

- The problem now is how to find a set of k orthogonal signature waveforms so that for

$$k \neq k'$$

$$\langle s_k(t), s_{k'}(t) \rangle = \int_0^T s_k(t) s_{k'}(t) dt = 0.$$

Hadamard Matrices

- From the equation, the inner product of $s_k(t)$ and $s_{k'}(t)$ is zero if and only if the inner product of the two vectors s_k and $s_{k'}$ is zero.
- For example.
 - in the two-user system.
 - $s_1 = (+1, +1)$ and $s_2 = (+1, -1)$.
- It is obvious that the inner product of s_1 and s_2 is zero and therefore
$$\langle s_1(t), s_2(t) \rangle = 0.$$

Hadamard Matrices

- For a set of N-dimensional signature sequences (vectors), there are at most N orthogonal vectors.
- We may generate a set of orthogonal vectors by Walsh functions.
- Walsh functions are generated by special square matrices called Hadamard-matrices

Hadamard Matrices

$$H_1 = [+1]$$

$$H_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix}$$

$$H_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}$$

$$H_{2^m} = \begin{bmatrix} H_{2^{m-1}} & H_{2^{m-1}} \\ H_{2^{m-1}} & -H_{2^{m-1}} \end{bmatrix}$$

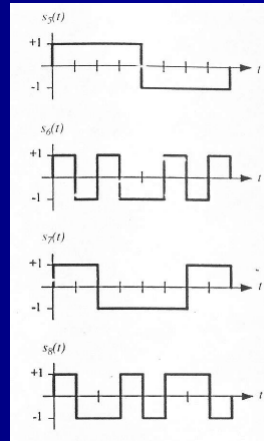
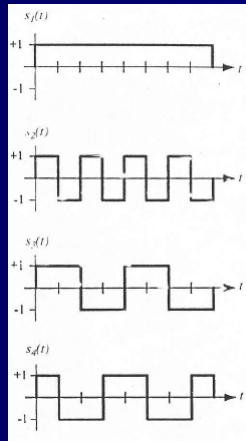
Hadamard Matrices

- It can be shown that the inner product of different rows from H_{2^m} equals zero.
- Therefore, the signature sequence s_k for user k can be assigned as the k^{th} row of H_N with $N = K = 2^m$.
- This method guarantees that two arbitrary different signature signals are orthogonal.

Hadamard Matrices

$$H_8 = \begin{bmatrix} +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 & +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 & +1 & -1 & -1 & +1 \\ +1 & +1 & +1 & +1 & -1 & -1 & -1 & -1 \\ +1 & -1 & +1 & -1 & -1 & +1 & -1 & +1 \\ +1 & +1 & -1 & -1 & -1 & -1 & +1 & +1 \\ +1 & -1 & -1 & +1 & -1 & +1 & +1 & -1 \end{bmatrix}$$

Hadamard Matrices



Hadamard Matrices

- Each user will use one of the rows. That is,
 - when user k sends 1, it sends s_k , the the k^{th} row of H_8 .
 - when user k sends 0, it sends $-s_k$,
- For instance,
 - user 2 will send
 $S_2 = [+1 \ -1 \ +1 \ -1 \ +1 \ -1 \ +1 \ -1]$ if he intends to send 1
 - user 3 will send
 $S_3 = [-1 \ -1 \ +1 \ +1 \ -1 \ -1 \ +1 \ +1]$ if he intends to send 0.

Hadamard Matrices

- Consider the case where users 1,2 and 3 send 1, 0 and 0 respectively.
- That is,
 - $m_1 = +1$, $m_2 = -1$ and $m_3 = -1$.
- The following signals will be sent:

$$\begin{aligned}y_1 &= m_1 s_1 = +s_1 = [+1, +1, +1, +1, +1, +1, +1, +1] \\y_2 &= m_2 s_2 = -s_2 = [-1, +1, -1, +1, -1, +1, -1, +1] \\y_3 &= m_3 s_3 = -s_3 = [-1, -1, +1, +1, -1, -1, +1, +1]\end{aligned}$$

Hadamard Matrices

- The received signal will be

$$z = y_1 + y_2 + y_3 = [-1, +1, +1, +3, -1, +1, +1, +3]$$

- the inner product to recover y_1 , y_2 and y_3 , we compute $z.s_1$, $z.s_2$ and $z.s_3$ as

Hadamard Matrices

$$\begin{aligned}x_1 &= z \cdot s_1 \\&= [-1, +1, +1, +3, -1, +1, +1, +3] \cdot [+1, +1, +1, +1, +1, +1, +1, +1] \\&= -1 + 1 + 1 + 3 - 1 + 1 + 1 + 3 \\&= 8.\end{aligned}$$

Since $x_1 > 0$, then $m_1 = +1$

$$\begin{aligned}x_2 &= z \cdot s_2 \\&= [-1, +1, +1, +3, -1, +1, +1, +3] \cdot [+1, -1, +1, -1, +1, -1, +1, -1] \\&= -1 - 1 + 1 - 3 - 1 - 1 + 1 - 3 \\&= -8.\end{aligned}$$

Since $x_2 < 0$, then $m_2 = -1$

Hadamard Matrices

$$\begin{aligned}x_3 &= z \cdot s_3 \\&= [-1, +1, +1, +3, -1, +1, +1, +3] \cdot [+1, +1, -1, -1, +1, +1, -1, -1] \\&= -1 + 1 - 1 - 3 - 1 + 1 - 1 - 3 \\&= -8\end{aligned}$$

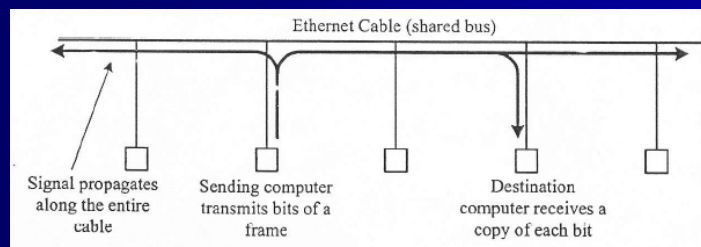
Since $x_3 < 0$, then $m_3 = -1$

Advantages of CDMA

- The bandwidth of the CDMA is larger because each symbol consists of a number of bits and each bit must be of smaller pulse length. And a small pulse length will give us a larger bandwidth.
- What is the advantage of having a larger bandwidth?
- Note that the signal, after it leaves the transmitter, may go into different directions and reflections may occur. Thus, one signal becomes several signals and they will all reach the receiver. This problem is called the multipath problem.
- A larger bandwidth will make us easier to overcome this difficulty. The CDMA technology is used in the third-generation mobile systems because, when we use a mobile phone, we may be moving and the multipath problem can be a serious one.
- In such an environment, CDMA is of course quite desirable.

Carrier-sense Multiple Access (CSMA)

- Carrier-sense multiple access (CSMA) is widely used in a local-area network (LAN) where several host computers are connected. All of the computers will talk to one another.



Carrier-sense Multiple Access (CSMA)

- Ethernet employs a bus. Naturally, only one user can have access to it.
- It is important to note that Ethernet is a computer network.
- Information flowing through it is data, not say voice. Thus there is no requirement that the information has to be received by someone in real time.

Carrier-sense Multiple Access (CSMA)

- Let us assume that there is only one computer, say computer A, which is sending data to computer B.
- Data are in digital form and prepared into frames, or packets. Each frame will contain some control information.
- For instance, we have to let the network know who is sending the frame, who is proposed to receive the frame and so on.
- As the frame propagates from computer A to the Ethernet bus, it fully occupies the bus. Thus all computers connected to the bus can receive the frame.
- Since the control information of the frame tells us that computer B is to receive the frame, all other computers ignore it and only computer B receive it.

Carrier-sense Multiple Access (CSMA)

- Since the Ethernet allows a sender to fully occupy it, each computer must check whether anyone is occupying the bus.
- The computer has to have the ability to sense whether there is any signal transmitted over the bus.
- This is why this kind of checking whether there is a signal occupying the bus is called **'carrier sense'**.

CSMA / CD

- Since a bus allows only one user to occupy it, when two computers simultaneously send signals to the bus, collision occurs and this must be resolved. The Ethernet enables each sender to be able to monitor whether a collision occurs or not.
- If a sender senses a collision, it backs off immediately. That is, it stops sending signals to the bus. It does not send the signal back right away. Instead, it waits for a certain period of time and transmits again.
- A random number generator determines the length of this period of time.
- Thus, if two senders simultaneously back off, the probability that they will send signals back at the same time is very small.
- This kind of CSMA system is called carrier-sense multiple access with collision detection (CSMA/CD).

CSMA / CA

- Another way of solving the collision problem in a CSMA system is to avoid collisions at the very beginning.
- The system requires each user to send an exceedingly short message signal to the bus to reserve the system. If a collision of this reservation occurs, it is solved by the method discussed in the above paragraph.
- Because these reservation messages are very short, the overhead caused by resolving their collision is quite slight.
- After a sender successfully reserves the bus, it can send signals and only it can send signals.
- This kind of system is called a carrier-sense multiple-access with collision avoidance (CSMA/CA).
- IEEE 802.11a WLAN system uses this technology.