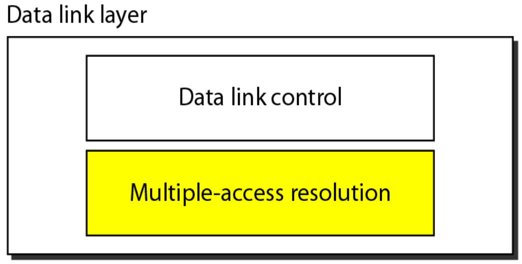
MULTIPLE ACCESS

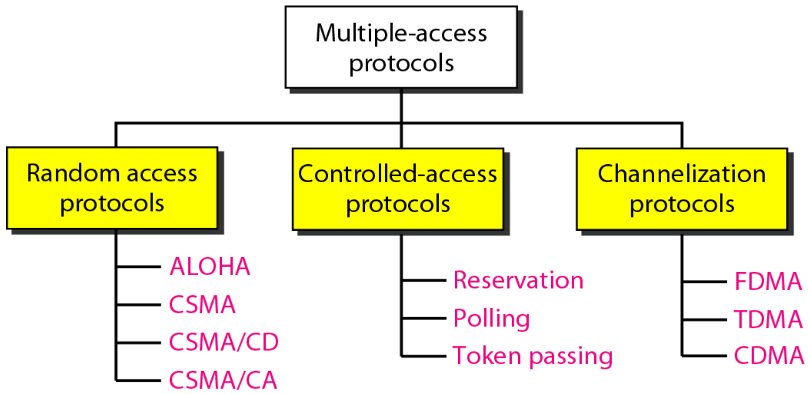
--Data link layer is divided into two sublayers. The upper sublayer is responsible for data link control, and the lower sublayer is responsible for resolving access to the shared media.
--If the channel is dedicated, we do not need the lower sublayer.
--When nodes or stations are connected and use a common link, called a multipoint or broadcast link, a multiple-access protocol is needed to coordinate access to the link.

Fig: 12.19 *Data link layer divided into two functionality-oriented sublayers*



Many formal protocols have been devised to handle access to a shared link. They are divided into three groups.

Fig 12.20 *Types of multiple-access protocols*



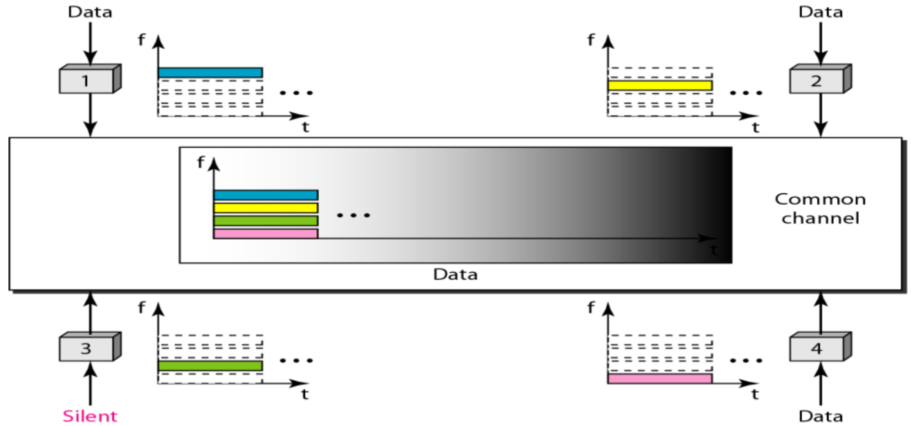
CHANNELIZATION

--Channelization is a multiple-access method in which the available bandwidth of a link is shared in time, frequency, or through code, between different stations.
--There are three channelization protocols: FDMA, TDMA, and CDMA.

Frequency-Division Multiple Access (FDMA)

--In frequency-division multiple access (FDMA), the available bandwidth is divided into frequency bands. Each station is allocated a band to send its data.
--Each band is reserved for a specific station, and it belongs to the station all the time.
--Each station also uses a band pass filter to confine the transmitter frequencies.
--To prevent station interferences, the allocated bands are separated from one another by small *guard bands.*

Figure 12.21 *Frequency-division multiple access (FDMA)*



--FDMA specifies a predetermined frequency band for the entire period of communication. This means that stream data (a continuous flow of data that may not be packetized) can easily be used with FDMA.

--FDMA and FDM conceptually seem similar, but there are differences between them.

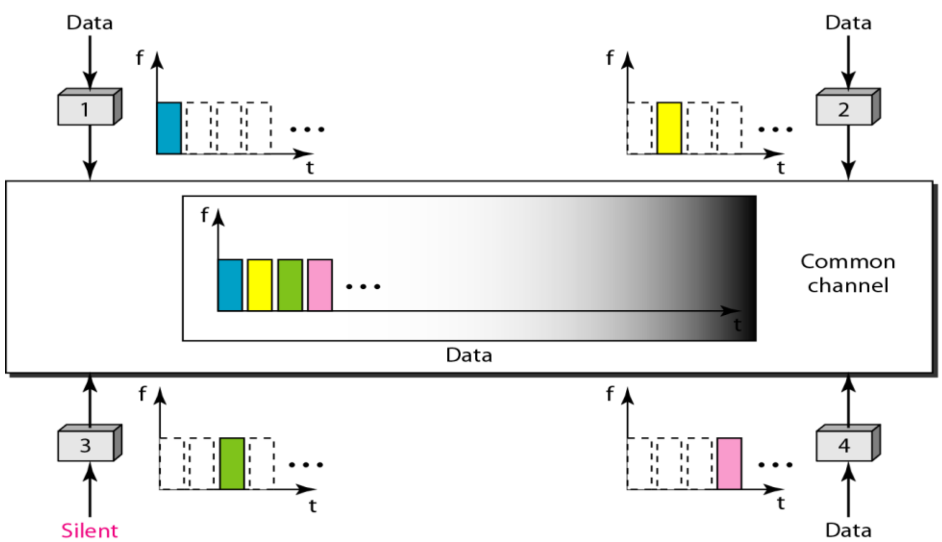
--FDM is a physical layer technique that combines the loads from low-bandwidth channels and transmits them by using a high-bandwidth channel. The multiplexer modulates the signals, combines them, and creates a band pass signal. The bandwidth of each channel is shifted by the multiplexer.

--FDMA, is an access method in the data link layer. The data link layer in each station tells its physical layer to make a band pass signal from the data passed to it. The signal must be created in the allocated band. There is no physical multiplexer at the physical layer. The signals created at each station are automatically band pass-filtered. They are mixed when they are sent to the common channel.

Time-Division Multiple Access (TDMA)

--In TDMA, the stations share the bandwidth of the channel in time. Each station is allocated a time slot during which it can send data. Each station transmits its data in is assigned time slot.

Figure 12.22 *Time-division multiple access (TDMA)*



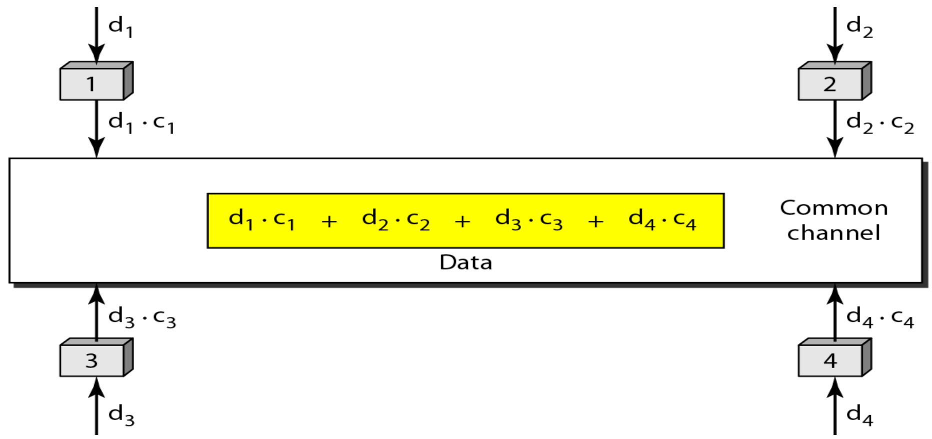
--The main problem with TDMA lies in achieving synchronization between the different stations. Each station needs to know the beginning of its slot and the location of its slot.
--This may be difficult because of propagation delays introduced in the system if the stations are spread over a large area. To compensate for the delays, *guard times* can be inserted.
--Synchronization is normally accomplished by having some synchronization bits (normally referred to as preamble bits) at the beginning of each slot.
--In TDMA, the bandwidth is just one channel that is timeshared between different stations.
--TDMA and TDM conceptually seem the same, there are differences between them.
--TDM is a physical layer technique that combines the data from slower channels and transmits them by using a faster channel. The process uses a physical multiplexer that interleaves data units from each channel.
--TDMA, is an access method in the data link layer. The data link layer in each station tells its physical layer to use the allocated time slot. There is no physical multiplexer at the physical layer.

Code-Division Multiple Access (CDMA)
--Code-division multiple access (CDMA) was conceived several decades ago.
–Recent advances in electronic technology have finally made its implementation possible.
--CDMA differs from FDMA because only one channel occupies the entire bandwidth of the link. It differs from TDMA because all stations can send data simultaneously; there is no timesharing.
--In CDMA, one channel carries all transmissions simultaneously.

Analogy
--CDMA simply means communication with different codes.
--**For eg:** in a large room with many people, two people can talk in English if nobody else understands English. Another two people can talk in Chinese if they are the only ones who understand Chinese, and so on.
--In other words, the common channel, the space of the room in this case, can easily allow communication between several couples, but in different languages (codes).

Idea
--Let us assume there are four stations 1, 2, 3, and 4 connected to the same channel. The data from station 1 are d_1, from station 2 are d_2, and so on.
--The code assigned to the first station is c_1, to the second is c_2, and so on. The assigned codes have two properties.
1. If we multiply each code by another, we get 0.
2. If we multiply each code by itself, we get 4 (the number of stations).
--With these two properties in mind, the four stations can send data using the same common channel.

Figure 12.23 *Simple idea of communication with code*



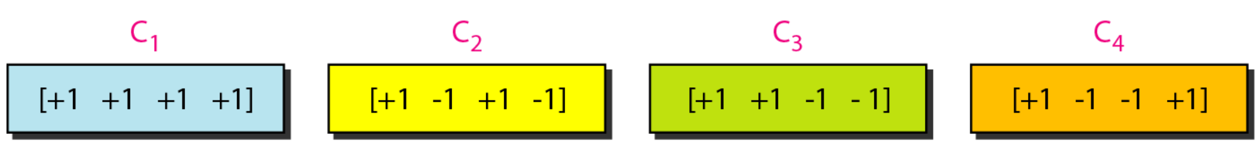
--Station 1 multiplies (a special kind of multiplication) its data by its code to get $d_1 .c_1$. Station 2 multiplies its data by its code to get $d_2 .c_2$ *and* so on.
--The data that go on the channel are the sum of all these terms, as shown in the box.
--Any station that wants to receive data from one of the other three multiplies the data on the channel by the code of the sender.
--For eg, suppose stations 1 and 2 are talking to each other. Station 2 wants to hear what station 1 is saying. It multiplies the data on the channel by c_1 the code of station 1.
--Because (c_1. c_1) is 4, but (c_2. C_1), *(*c_3 .c_1), and (c_4 .c_1) are all 0s, station 2 divides the result by 4 to get the data from station 1.

Data = $(d_1.C_1 + d_2.C_2 + d_3.C_3 + d_4.C_4) . C_1$
$= d_1.C_1.C_1 + d_2.C_2.C_1 + d_3.C_3.C_1 + d_4.C_4.C_1 = 4 \text{ X } d_1$

Chips

--CDMA is based on coding theory. Each station is assigned a code, which is a sequence of numbers called chips.

Figure 12.24 *Chip sequences*



--The codes are for the previous example.
--Sequences are not chosen randomly; they were carefully selected. They are called orthogonal sequences and have the following properties:

1. Each sequence is made of *N* elements, where *N* is the number of stations.
2. If we multiply a sequence by a number, every element in the sequence is multiplied by that element. This is called multiplication of a sequence by a scalar. For example,
   [+1 +1-1-1] = [+2+2-2-2]

3. If two equal sequences are multiplied, element by element, and add the results, N is obtained, where N is the number of elements in the each sequence. This is called the inner product of two equal sequences. For example,

$$[+1\ +1 -1\ -1] \cdot [+1\ +1\ -1\ -1] = 1 + 1 + 1 + 1 = 4$$

4. If we multiply two different sequences, element by element, and add the results, we get 0. This is called inner product of two different sequences. For example,

$$[+1\ +1\ -1\ -1] \bullet [+1\ +1\ +1\ +1] = 1 + 1 - 1 - 1 = 0$$

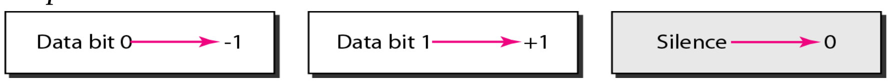
5. Adding two sequences means adding the corresponding elements. The result is another sequence. For example,

$$[+1 +1 -1 -1] + [+1 +1 +1 +1] = [+2 +2\ 0\ 0]$$

Data Representation

--We follow these rules for encoding: If a station needs to send a 0 bit, it encodes it as -1; if it needs to send a 1 bit, it encodes it as +1. When a station is idle, it sends no signal, which is interpreted as a 0.

Figure 12.25 *Data representation in CDMA*



Encoding and Decoding

--As a simple example, we show how four stations share the link during a 1-bit interval.

--The procedure can easily be repeated for additional intervals. We assume that stations 1 and 2 are sending a 0 bit and channel 4 is sending a 1 bit. Station 3 is silent.

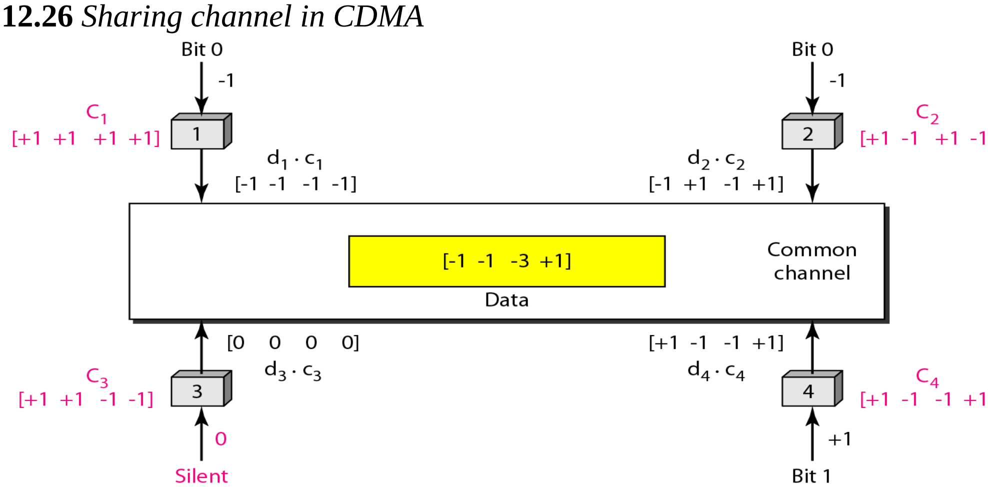
--The data at the sender site are translated to -1, -1, 0, and +1.

--Each station multiplies the corresponding number by its chip (its orthogonal sequence), which is unique for each station.

--The result is a new sequence which is sent to the channel. For simplicity, we assume that all stations send the resulting sequences at the same time.

--The sequence on the channel is the sum of all four sequences as defined before.

Figure 12.26 *Sharing channel in CDMA*



--Now imagine station 3, which we said is silent, is listening to station 2. Station 3 multiplies the total data on the channel by the code for station 2, which is [+1 -1 +1-1], to get

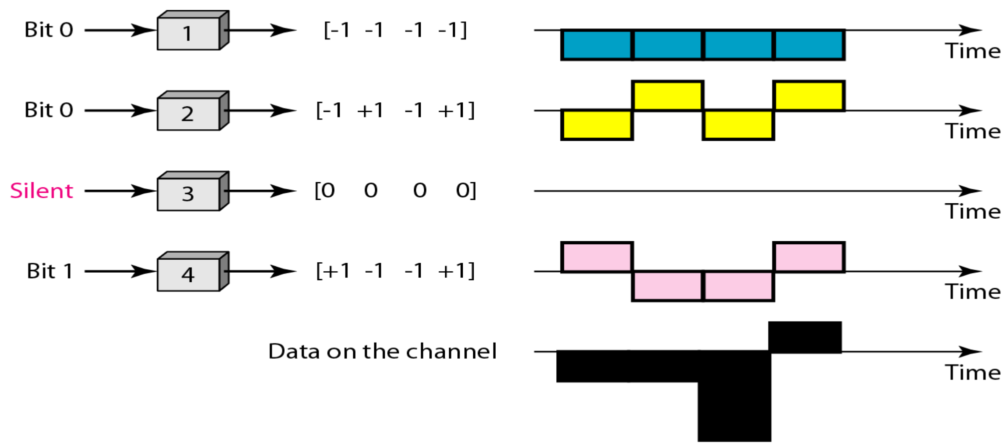
$$[-1 -1 -3 +1] \cdot [+1 -1 +1 -1] = -4/4 = -1 \rightarrow \text{bit } 1$$

Signal Level

--The process can be better understood if we show the digital signal produced by each station and the data recovered at the destination.

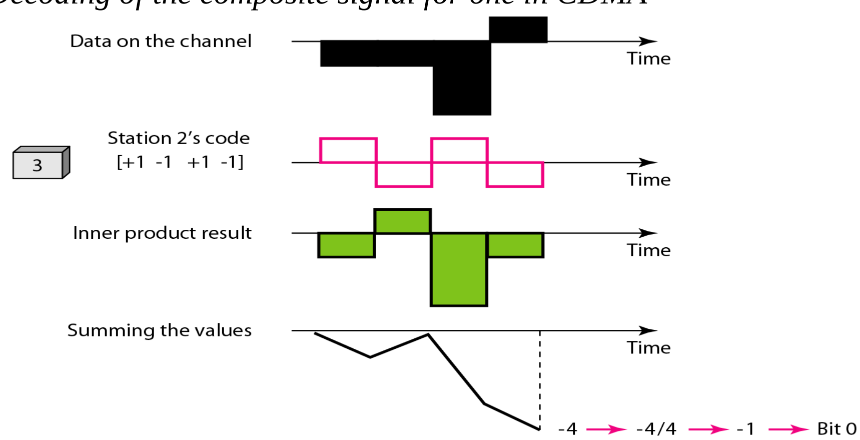
--The figure shows the corresponding signals for each station and the signal that is on the common channel.

Figure 12.27 *Digital signal created by four stations in CDMA*



--Figure 12.28 shows how station 3 can detect the data sent by station 2 by using the code for station 2. The total data on the channel are multiplied (inner product operation) by the signal representing station 2 chip code to get a new signal. The station then integrates and adds the area under the signal, to get the value -4, which is divided by 4 and interpreted as bit 0.

Figure 12.28 *Decoding of the composite signal for one in CDMA*



Sequence Generation

To generate chip sequences, we use a Walsh table, which is a two-dimensional table with an equal number of rows and columns, as shown in Figure 12.29.

Figure 12.29 *General rule and examples of creating Walsh tables*

$$W_1 = \begin{bmatrix} +1 \end{bmatrix} \qquad W_{2N} = \begin{bmatrix} W_N & W_N \\ W_N & \overline{W_N} \end{bmatrix}$$

a. Two basic rules

$$W_1 = \begin{bmatrix} +1 \end{bmatrix} \qquad W_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \qquad W_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}$$

b. Generation of W_1, W_2, and W_4

--The number of sequences in a Walsh table needs to be $N = 2^m$

Que: Find the chips for a network with
a. Two stations b. Four stations
Solution

We can use the rows of W_2 and W_4 in Figure 12.29:

a. For a two-station network, we have

[+1 +1] and [+1 −1].

b. For a four-station network we have

[+1 +1 +1 +1], [+1 −1 +1 −1], [+1 +1 −1 −1], and [+1 −1 −1 +1].

Que: What is the number of sequences if we have 90 stations in our network?
Solution

The number of sequences needs to be 2^m. We need to choose m = 7 and $N = 2^7$ or 128. We can then use 90 of the sequences as the chips.

Que: Prove that a receiving station can get the data sent by a specific sender if it multiplies the entire data on the channel by the sender's chip code and then divides it by the number of stations.
Solution

Let us prove this for the first station, using our previous four-station example. We can say that the data on the channel $D = (d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4)$.
The receiver which wants to get the data sent by station 1 multiplies these data by c_1.

$$\begin{aligned} D \cdot c_1 &= (d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4) \cdot c_1 \\ &= d_1 \cdot c_1 \cdot c_1 + d_2 \cdot c_2 \cdot c_1 + d_3 \cdot c_3 \cdot c_1 + d_4 \cdot c_4 \cdot c_1 \\ &= d_1 \times N + d_2 \times 0 + d_3 \times 0 + d_4 \times 0 \\ &= d_1 \times N \end{aligned}$$

When we divide the result by N, we get d_1 .