Multiplexing & Demultiplexing of Signals

By

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Introduction

- Bandwidth is one of the most precious resources we have in a communication system.
  - In real life, we have links with limited bandwidths.
  - If the bandwidth of a link is greater than the bandwidth needs of the devices connected to it, the bandwidth is wasted. So, the wise use of these bandwidths is a main challenge in communication.
- Under the simplest conditions, a medium can carry only one signal at any moment in time.
  - For multiple signals to share one medium, the medium must somehow be divided, giving each signal a portion of the total bandwidth.
- Bandwidth utilization is the wise use of available bandwidth to achieve specific goals.
- Efficiency can be achieved by multiplexing.

What is Multiplexing?

- Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared.
- Multiplexing is a form of signal transmission in which multiple data signals coming from different sources are combined and then transmitted over a single shared communication channel at the same time.
- In multiplexing, message signals derived from independent sources are combined into a composite signal suitable for transmission over a common channel. The aim is to share an expensive resource.
  - For example, in a telephone system, multiplexing is used to transmit multiple conversations over a single long-distance line. The signals associated with different speakers are combined in such a way as to not interfere with each other during transmission and so that they can be separated at the receiving end of the system.

What is Multiplexing?

- As data and telecommunication use increases, so does traffic. Using multiplexing technique,
  - Two or more simultaneous transmissions on a single circuit are possible, which is transparent to end user.
  - Multiplexing costs less.
- In multiplexing technique, multiple low data rate signals are multiplexed over a single high data rate link, then demultiplexed at the other end.
- In a multiplexed system, n lines share the bandwidth of one link.
- Figure below shows the basic format of a multiplexed system.

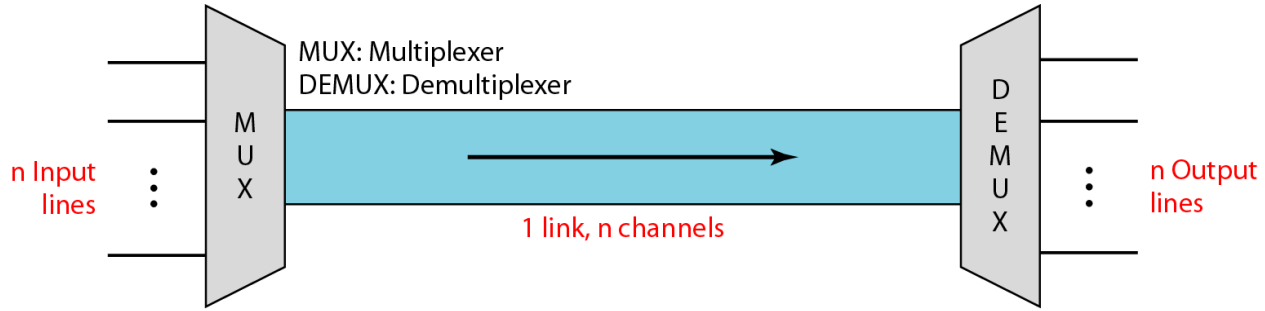


Figure: Dividing a link into channels

What is Multiplexing?

- The lines on the left direct their transmission streams to a multiplexer (MUX), which combines them into a single stream (many-to- one).
- At the receiving end, that stream is fed into a demultiplexer (DEMUX), which separates the stream back into its component transmissions (one-to-many) and directs them to their corresponding lines.
- In the figure, the word link refers to the physical path. The word channel refers to the portion of a link that carries a transmission between a given pair of lines. One link can have many (n) channels.

Multiplexer (MUX) and Demultiplexer (DEMUX):

- Multiplexing is done by an equipment called multiplexer (MUX). It is placed at the transmitting end of the communication link.
- At the receiving end, the composite signal is separated by an equipment called demultiplexer (DEMUX). Demultiplexer performs the reverse process of multiplexing and routes the separated signals to their corresponding receivers or destinations.

Categories of Multiplexing

- Multiplexing can be accomplished by separating the different message signals either in frequency or in time, or through the use of coding techniques.
- Thus we have three basic types of multiplexing:
  1. Frequency-division multiplexing (FDM)
  2. Time-division multiplexing (TDM)
  3. Code-division multiplexing (CDM)
- Another type of multiplexing used in optical communication is wavelength-division multiplexing (WDM).

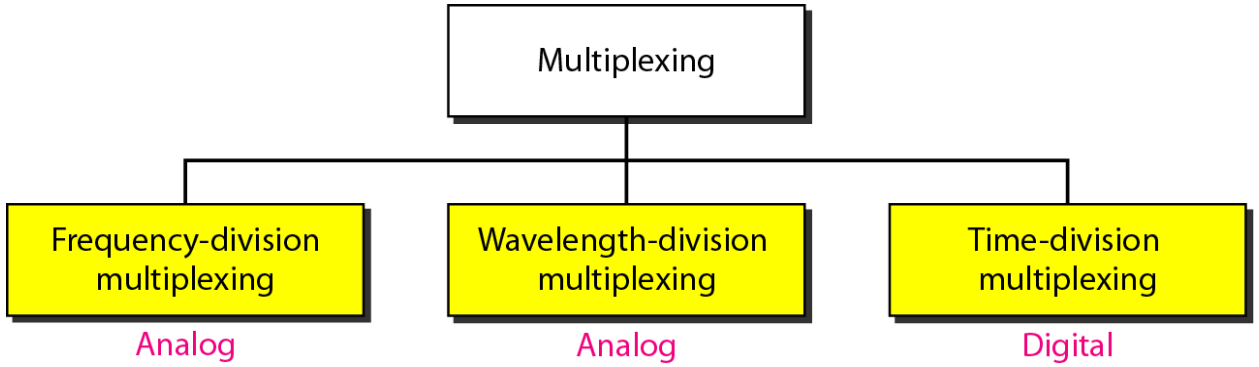


Figure: Basic types of multiplexing

Analogy for Multiplexing

- Before describing each of the multiplexing techniques, let us consider an analogy with an airport lounge with many pairs of people conversing.
  - TDM is comparable to all the people being in the middle in the room but taking turns speaking.
  - FDM is comparable to the people being in widely separated clumps\groups, each clump holding its own conversation at the same time as, but still independent of, others.
  - CDM is comparable to everybody being in the middle of the room talking at once, but with each pair in a different language. The French-speaking couple just hones in on the French, rejecting everything that is not French as noise. Thus, the key to CDM is to be able to extract the desired signal while rejecting everything else as random noise.

Frequency-Division Multiplexing (FDM)

- If multiple users concurrently transmitted their baseband signals over a shared medium, it would be difficult for their intended receivers to extract the signals reliably because of interference.
  - One approach to reduce this interference, known as frequency-division multiplexing, allocates different carrier frequencies to different users (or for different uses, e.g., one might separate out the frequencies at which police radios or emergency responders communicate from the frequencies at which you make calls on your mobile phone.)
- FDM is an analog multiplexing technique that combines data signals coming from different sources and then carries the combined signals simultaneously on the same transmission medium by allocating to each of them a different frequency band within the bandwidth of the single channel.
  - Here, the carrier bandwidth is divided into subchannels of different frequency widths, each carrying a signal at the same time in parallel. This can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted.

Frequency-Division Multiplexing (FDM)

- In FDM, the signals are separated by allocating them to different frequency bands. Signals generated by each sending device modulate different carrier frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link.
  - Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal. These bandwidth ranges are the channels through which the various signals travel.
  - Channels can be separated by strips of unused bandwidth guard bands to prevent signals from overlapping. In addition, carrier frequencies must not interfere with the original data frequencies.
- One of the most common applications of FDM is the cable TV system in which only one cable reaches a customer's residential area, but the service provider can send multiple television channels or signals simultaneously over that cable to all subscribers without interference. Receivers must tune to the appropriate frequency (channel) to access the desired signal.
- Other applications of FDM are in broadcast radio and television, and the AMPS (Advanced Mobile Phone System) cellular phone systems.

Frequency-Division Multiplexing (FDM)

- Figure (A and B) below gives a conceptual view of FDM.

Figure: A

- In the figure we see that the transmission path (common channel) is divided into three parts, each representing a channel that carries one transmission.

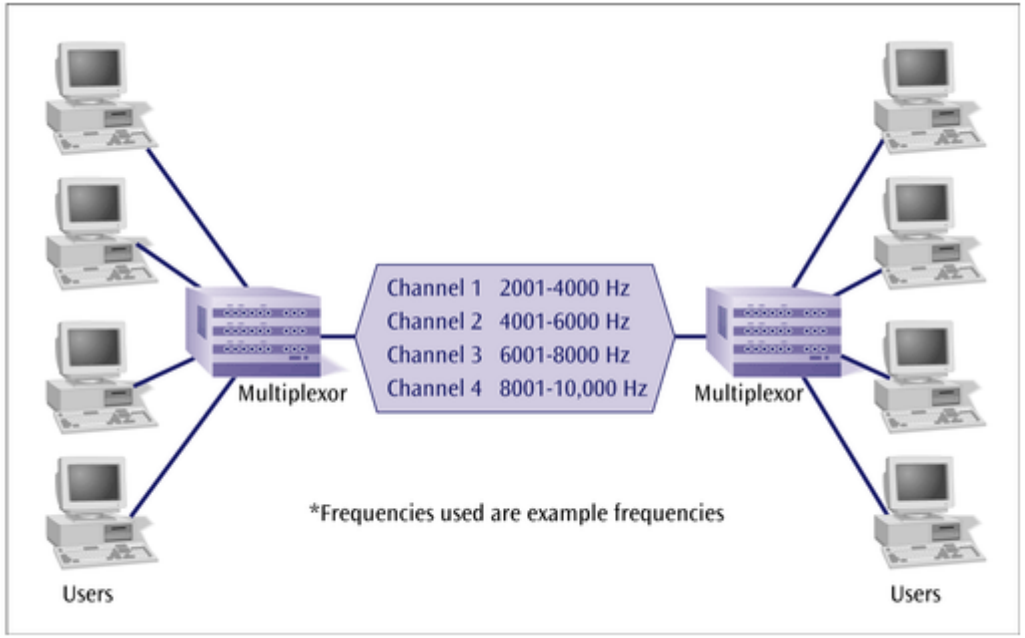


Figure: B

Figure: Conceptual view of FDM

Multiplexing Process in FDM

- Figure below shows the conceptual illustration of FDM process.

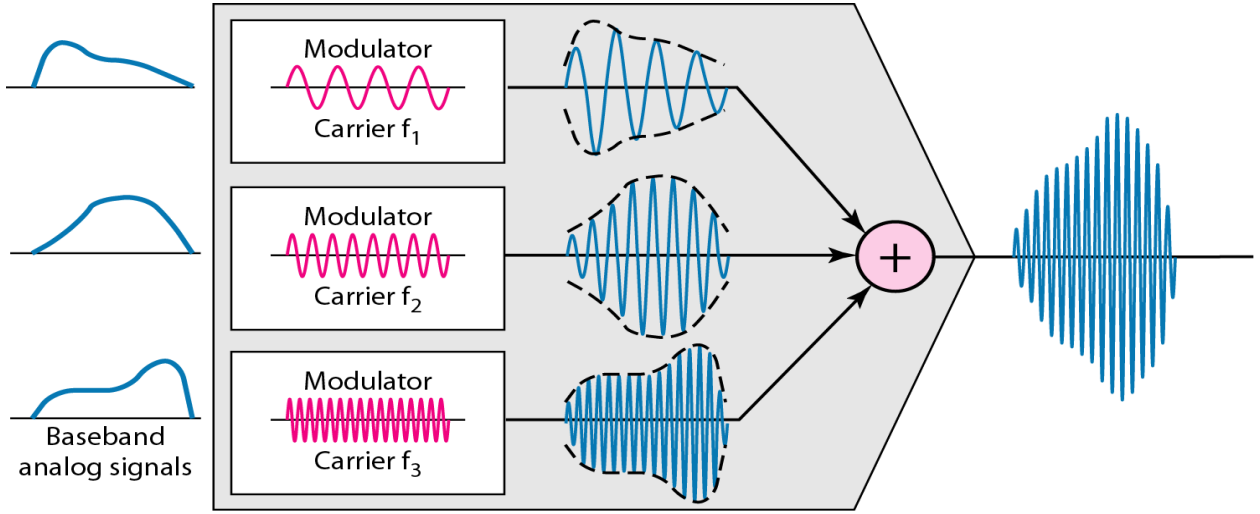


Figure: Multiplexing process

- Each source generates a signal of a similar frequency range.
- Inside the multiplexer, these similar signals modulates different carrier frequencies (f_1, f_2, and f_3).
- The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it.

Demultiplexing Process in FDM

- The demultiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals. Each filter select the frequency for one channel and suppresses other frequencies.
- The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines.
- Figure below is a conceptual illustration of demultiplexing process.

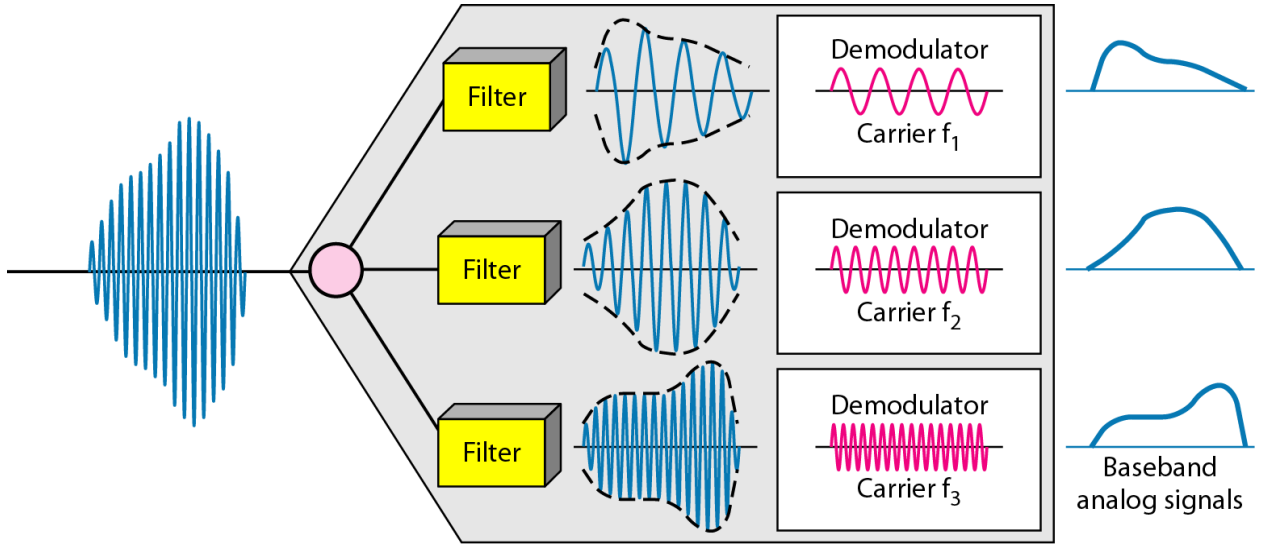


Figure: Demultiplexing process

Merits & Demerits of FDM

Advantages of FDM:

- Here user can be added to the system by simply adding another pair of transmitter modulator and receiver demodulator.
- FDM system support full duplex information flow which is required by most of application.
- Noise problem for analog communication has lesser effect.
- FDM has lower channel bit rate (than TDM) means it is less susceptible to multi path ISI (intersymbol interference).

Disadvantages of FDM:

- In-efficient use of bandwidth if the traffic is distributed unevenly
- FDM requires guard band between channels.
- It cannot readily support variable user data rates, fixed channel width means fixed bit rate.
- In FDM system, the initial cost is high. This may include the cable between the two ends and the associated connectors for the cable.
- In FDM system, a problem for one user can sometimes affect others.
- In FDM system, each user requires a precise carrier frequency.
    - This technique is the oldest multiplexing technique.
    - Since it involves analog signaling, it is more susceptible to noise

Time-Division Multiplexing

- Time-division multiplexing (TDM) is a digital signal (or in rare cases, analog) transmission technology which uses time, instead of space or frequency to separate the different data streams that allows several connections to share the high bandwidth of a link.
  - In TDM, multiple signals are carried over the same channel in alternating time slots.
  - Transmission time on a single channel is divided into non-overlapped time slots.
  - Data signals coming from different sources are divided into units with same size and interleaved successively into the time slots.
- Instead of sharing a portion of the bandwidth as in FDM, time is shared. Each user of the channel is allotted a small time interval during which he may transmit a message. Thus the total time available in the channel is divided and each user is allocated a time slice.

Time-Division Multiplexing

- Figure below gives a conceptual view of TDM. Note that the same link is used as in FDM; here, however, the link is shown sectioned by time rather than by frequency. In the figure, portions of signals 1, 2, 3, and 4 occupy the link sequentially.
  - In TDM, user send message sequentially one after another. Each user can, however, use the full channel bandwidth during the period he has control over the channel. The channel capacity is fully utilized in TDM. This message sent through the physical channel must be separated at the receiving end.

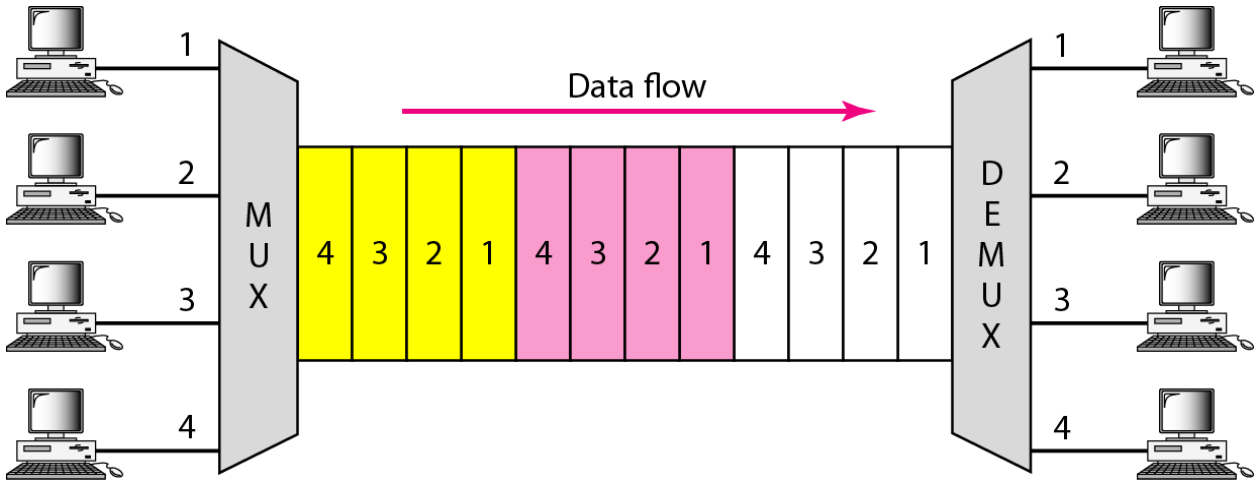


Figure: Conceptual view of TDM

Merits & Demerits of TDM

Advantages of TDM:

- It uses a single links.
- It does not require precise carrier matching at both end of the links.
- Use of capacity is high.
- Ease to expand the number of users on a system at a low cost.
- There is no need to include identification of the traffic stream on each packet.

Disadvantages of TDM:

- The sensitivity to other user problem is high.
- Initial cost is high.
- Technical complexity is more.
- The noise problem for analog communication has greater effect.

Code-Division Multiplexing (CDM)

- This type of multiplexing relies on the assignment of different codes to the individual users of the channel.
- In CDM, several channels simultaneously share the same frequency spectrum, and this spectral bandwidth is much higher than the bit rate or symbol rate.
  - One form is frequency hopping, another is direct sequence spread spectrum.
  - Frequency-hopping spread spectrum is a method of transmitting radio signals by rapidly changing the carrier frequency among many distinct frequencies occupying a large spectral band. The changes are controlled by a code known to both transmitter and receiver.
  - In the latter case, each channel transmits its bits as a coded channel-specific sequence of pulses called chips. Number of chips per bit, or chips per symbol, is the spreading factor. This coded transmission typically is accomplished by transmitting a unique time-dependent series of short pulses, which are placed within chip times within the larger bit time. All channels, each with a different code, can be transmitted on the same fiber or radio channel or other medium, and asynchronously demultiplexed.

Merits & Demerits of CDM

Advantages of CDM:

- Bandwidth efficient and good power control.
- No need for coordination and synchronization.
- Good protection against interference and tapping.

Disadvantages of CDM:

- Lower user data rates.
- It requires more complex signal regeneration.

Wavelength-Division Multiplexing (WDM)

- WDM is an analog multiplexing technique to combine optical signals.
  - It is conceptually the same as FDM, except that the multiplexing and demultiplexing involve optical signals transmitted through fiber-optic channels.
  - The idea is the same: Different signals with different frequencies are combined and carried together as separate wavelengths of light.
- Figure below gives a conceptual view of a WDM multiplexer and demultiplexer.
- Very narrow bands of light from different sources are combined to make a wider band of light. At the receiver, the signals are separated by the demultiplexer.

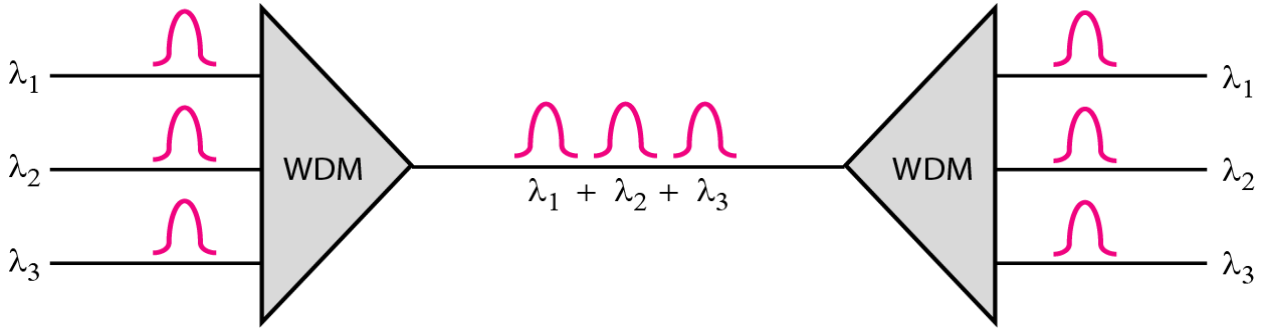


Figure: Conceptual view of WDM

Wavelength-Division Multiplexing (WDM)

- Although WDM technology is very complex, the basic idea is very simple. We want to combine multiple light sources into one single light at the multiplexer and do the reverse at the demultiplexer.
  - The combining and splitting of light sources are easily handled by a prism. Recall from basic physics that a prism bends a beam of light based on the angle of incidence and the frequency.
  - Using this technique, a multiplexer can be made to combine several input beams of light, each containing a narrow band of frequencies, into one output beam of a wider band of frequencies. A demultiplexer can also be made to reverse the process.
- Figure below shows the concept.

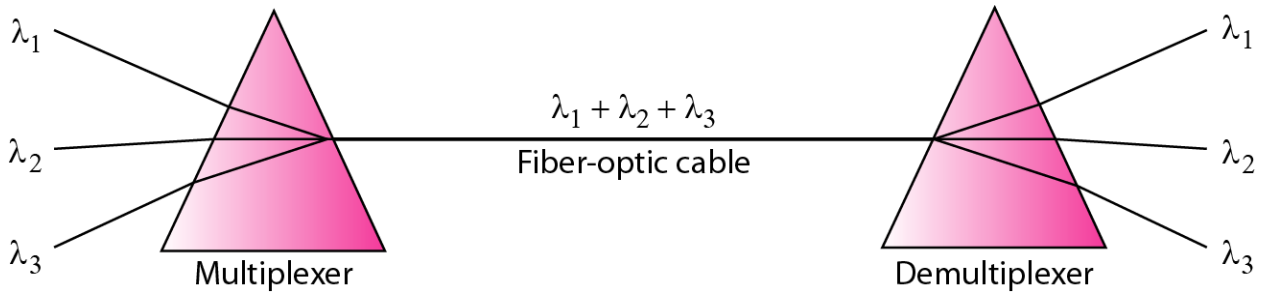


Figure: Prisms in Wavelength-division multiplexing and demultiplexing

Channelization

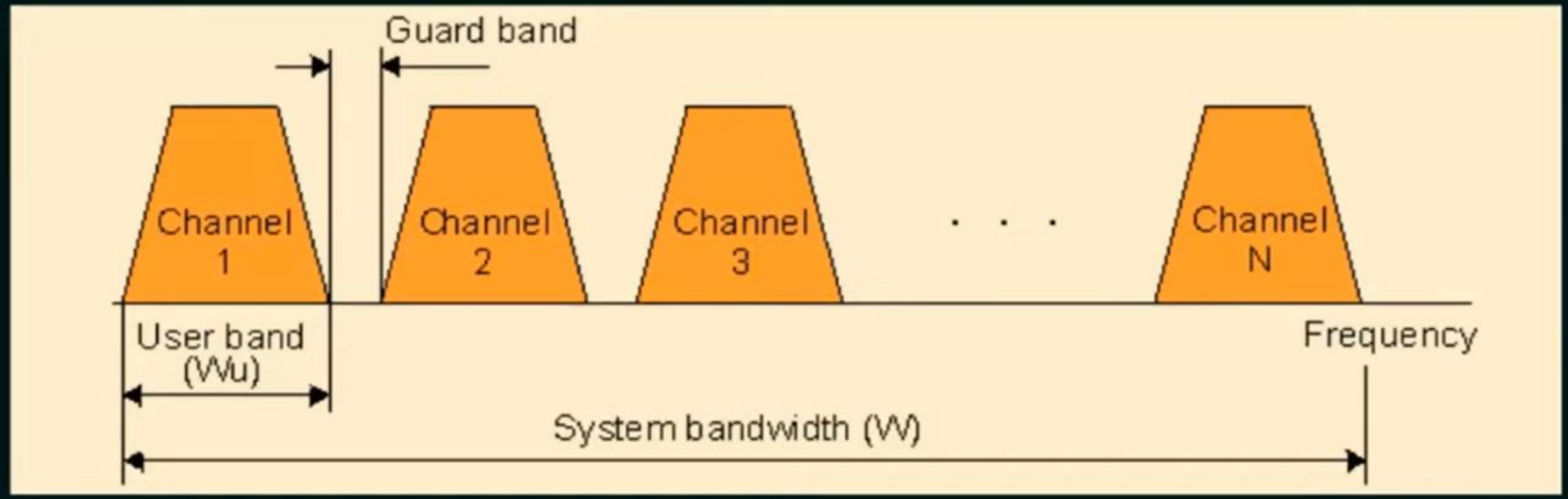
- Channelization is a multiple-access method in which the available bandwidth of a link is shared in time, frequency, or through code, between different stations.

Types of Channelization methods:

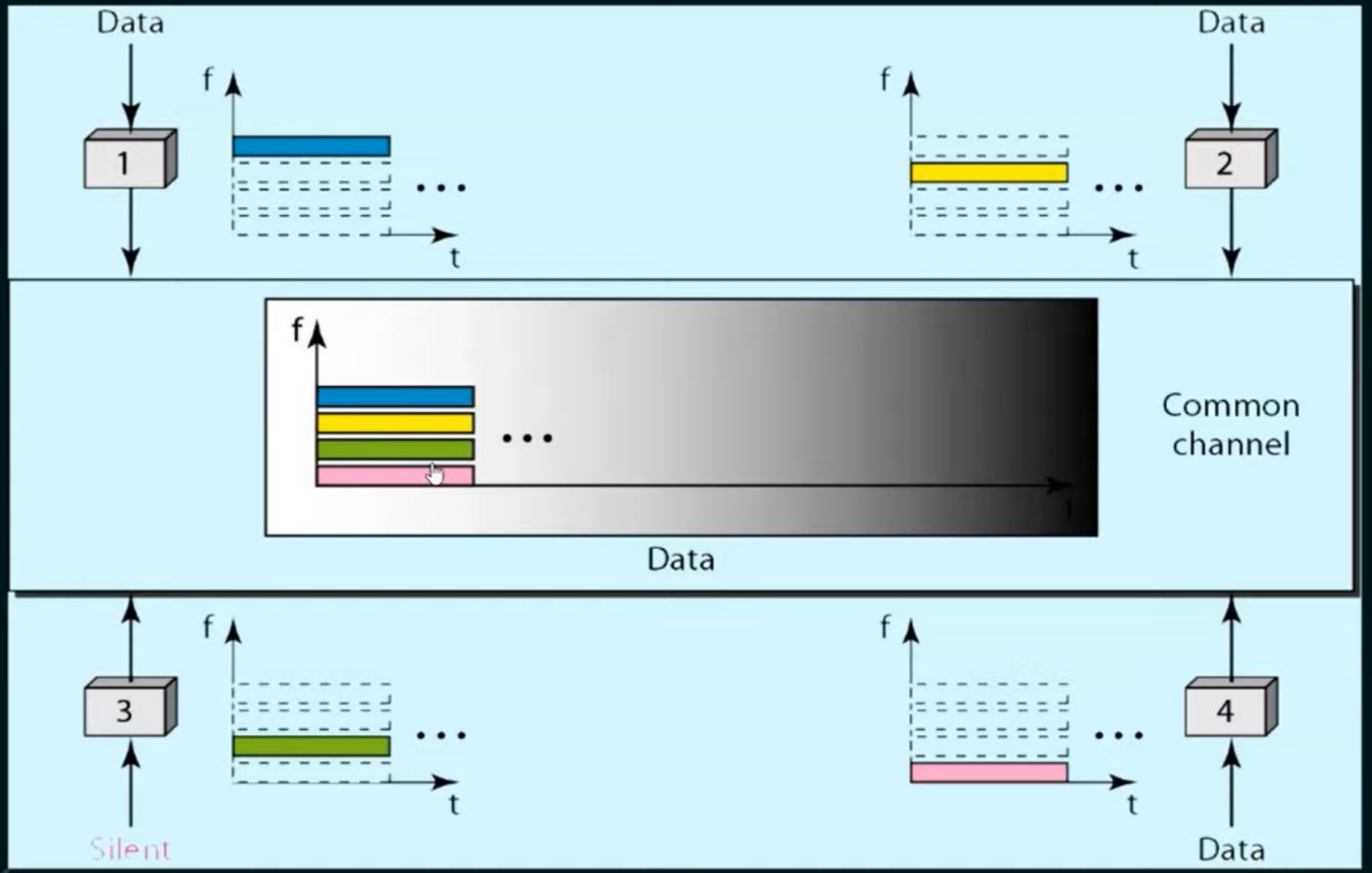
1. Frequency-Division Multiple Access (FDMA)
2. Time-Division Multiple Access (TDMA)
3. Code-Division Multiple Access (CDMA)

FDMA

- ★ In FDMA, the available bandwidth of the common channel is divided into bands that are separated by guard bands.
- ★ The available bandwidth is shared by all stations.
- ★ The FDMA is a data link layer protocol that uses FDM at the physical layer.



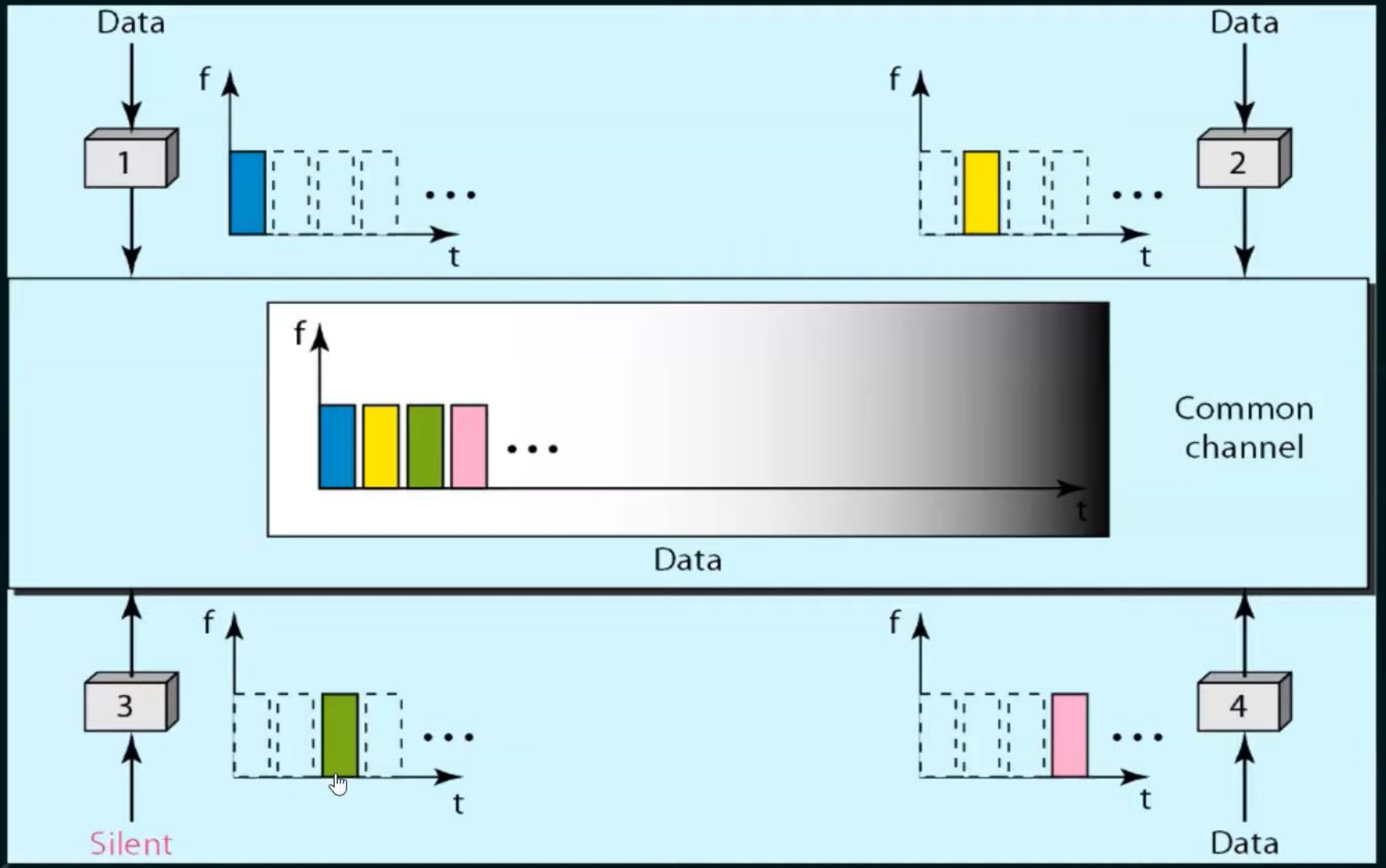
FDMA



TDMA

- ★ In TDMA, the bandwidth is just one channel that is time shared between different stations.
- ★ The entire bandwidth is just one channel.
- ★ Stations share the capacity of the channel in time.

TDMA



Channelization: Code Division Multiple Access (CDMA)

- In CDMA, One channel carries all transmissions simultaneously.
- 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.

Analogy:

Let us first give an analogy.

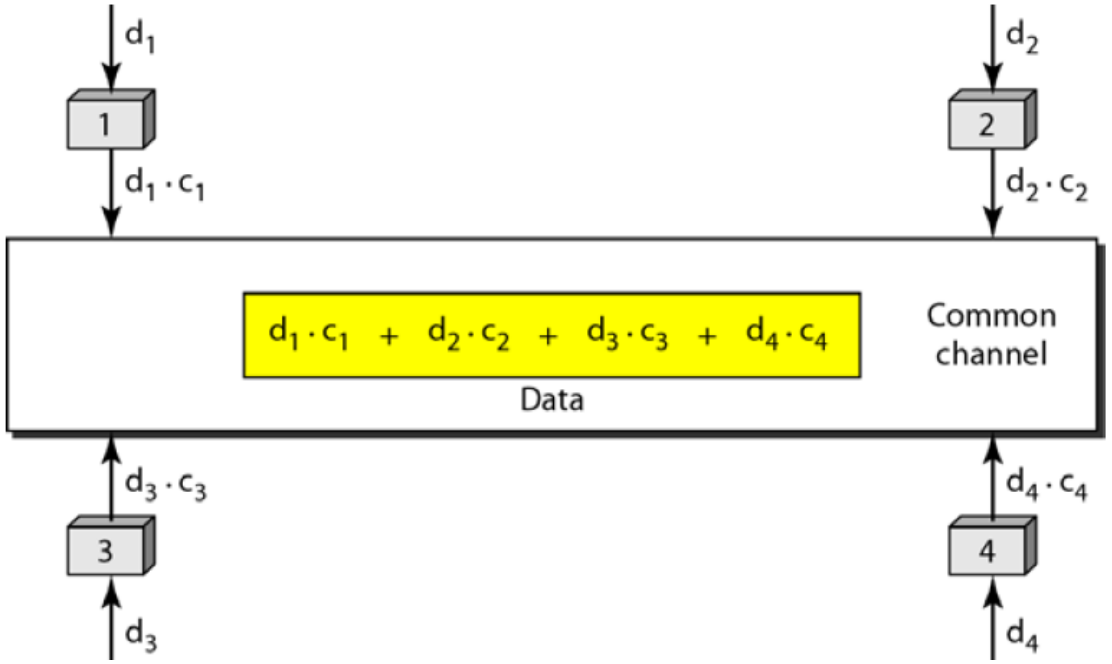
- CDMA simply means communication with different codes.
- For example, in a large room with many people, two people can talk in English if nobody else understands English. Another two people can talk in Chinese if they are the only ones who understand Chinese, and so on.
- In other words, the common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

Channelization: Code Division Multiple Access (CDMA)

Simple idea of communication with CDMA:

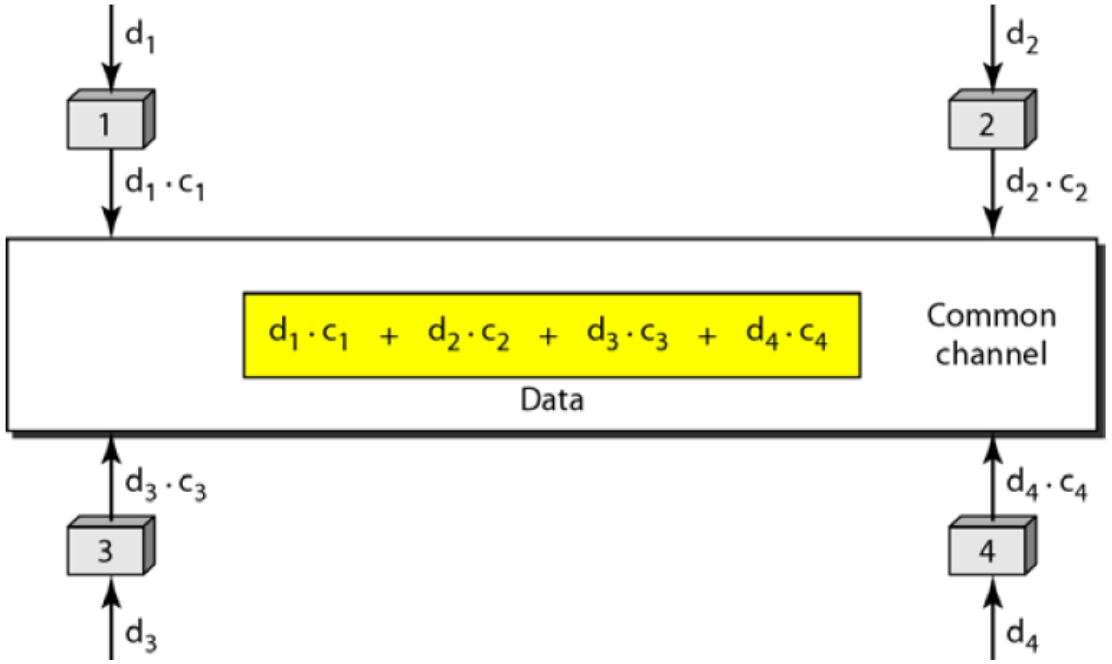
- Let us assume we have four stations 1, 2, 3, and 4 connected to the same channel.
- The data from station 1 are d_1, from station 2 are d_2, and so on.
- The code assigned to the first station is c_1, to the second is c_2, and so on.
- Two properties that the assigned codes have:
  - If we multiply each code by another, we get 0, i.e. $C_1 * C_2 = 0$
  - If we multiply each code by itself, we get number of stations, i.e. $C_1 * C_1 = 4$ in this case.
  - With these two properties in mind, let us see how the above four stations can send data using the same common channel, as shown in the figure below.

Channelization: Code Division Multiple Access (CDMA)



- Station 1 multiplies its data by its code to get $d_1 \cdot c_1$.
- Station 2 multiplies its data by its code to get $d_2 \cdot c_2$. And so on.
- The data that go on the channel are the sum of all these terms, as shown in the box above.
- Any station that wants to receive data from one of the other three multiplies the common data on the channel by the code of the sender. For example, 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.

Channelization: Code Division Multiple Access (CDMA)



data= $(d_1*c_1+d_2*c_2+d_3*c_3+d_4*c_4)*c_1$
$= d_1*c_1*c_1+d_2*c_2*c_1+d_3*c_3*c_1+d_4*c_4*c_1$
$= 4xd_1$

Simple idea of communication with CDMA:

- The code assigned to the first station is c_1, to the second is c_2, and so on.

Thank You