Data Communication
Chapter 2
Data Transmission

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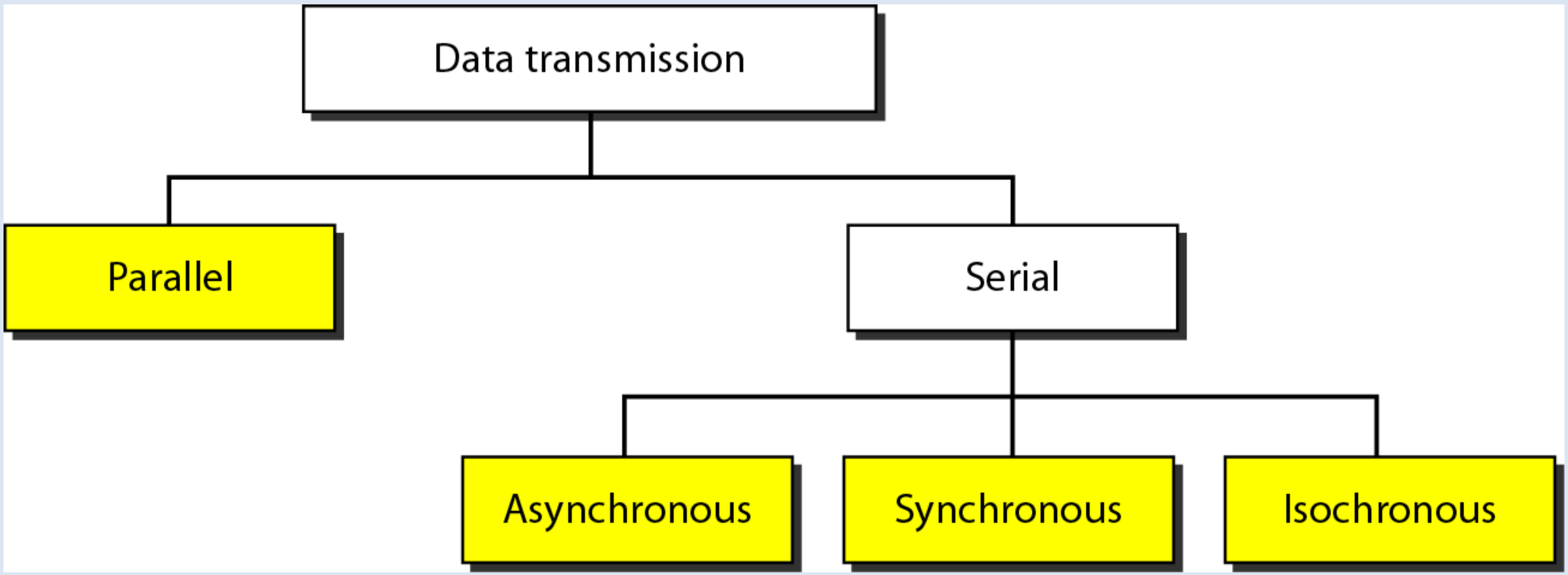
Transmission Modes

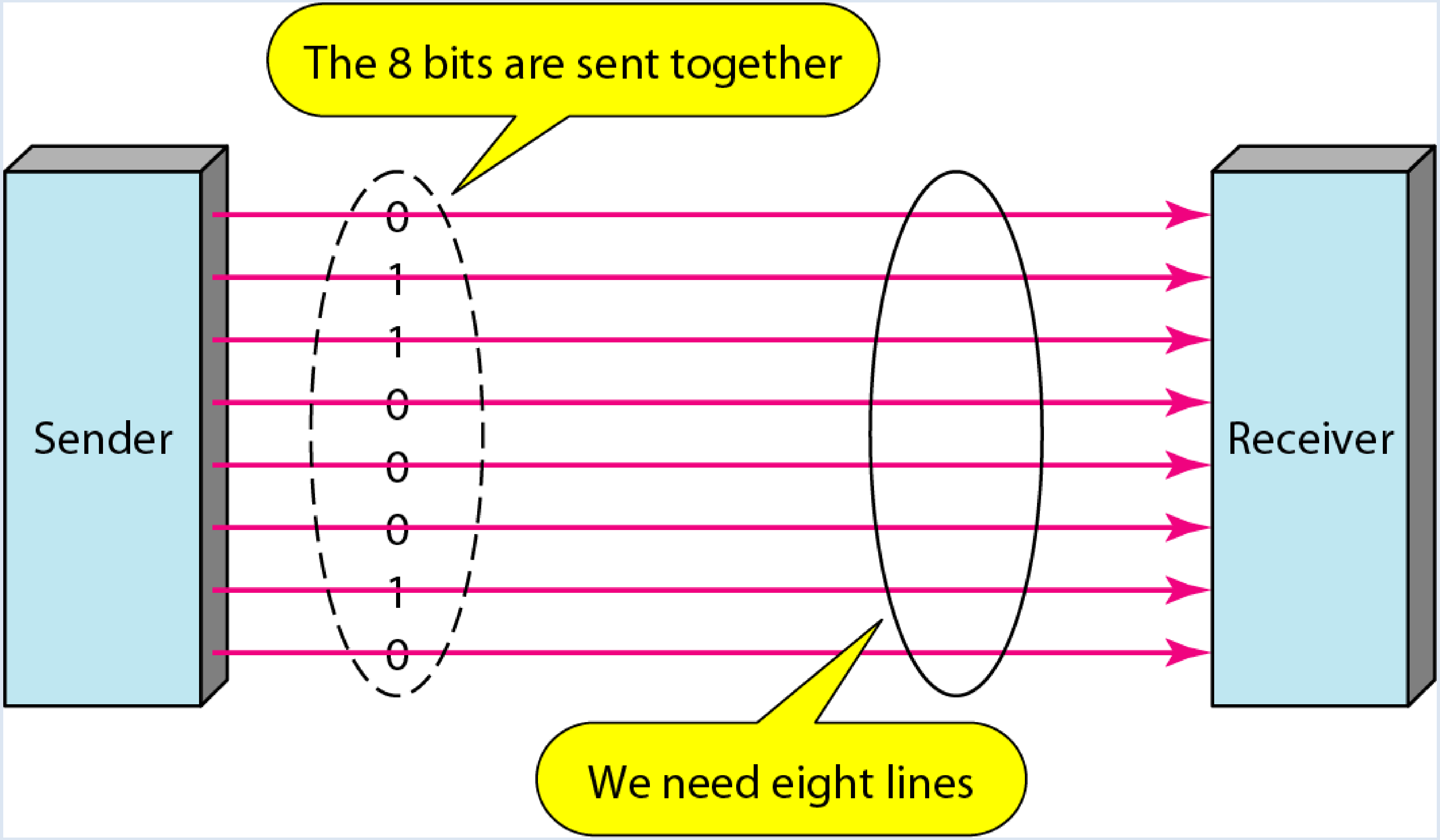
- Of primary concern when we are considering the transmission of data from one device to another is the wiring, and of primary concern when we are considering the wiring is the data stream.

- Do we send 1 bit at a time; or do we group bits into larger groups and if so, how?
  - Either parallel or serial mode
  - In parallel mode, multiple bits are sent with each clock tick.
  - In serial mode, 1 bit is sent with each clock tick.

Figure ***Data transmission and modes***



Parallel Transmission



Parallel Transmission

- In parallel transmission, all the bits of data are transmitted simultaneously on separate communication lines
- In order to transmit n bits, n wires or lines are used. Thus each bit has its own line.
- All n bits of one group are transmitted with each clock pulse from device to another i.e. multiple bits are sent with each clock pulse
- Parallel transmission is used for short distance communication.
- As shown in figure, eight separate wires are used to transmit 8 bit data from sender to receiver.

Advantage

- Speed – Parallel transmission can increase the transfer speed by a factor of n over serial transmission.

Disadvantage

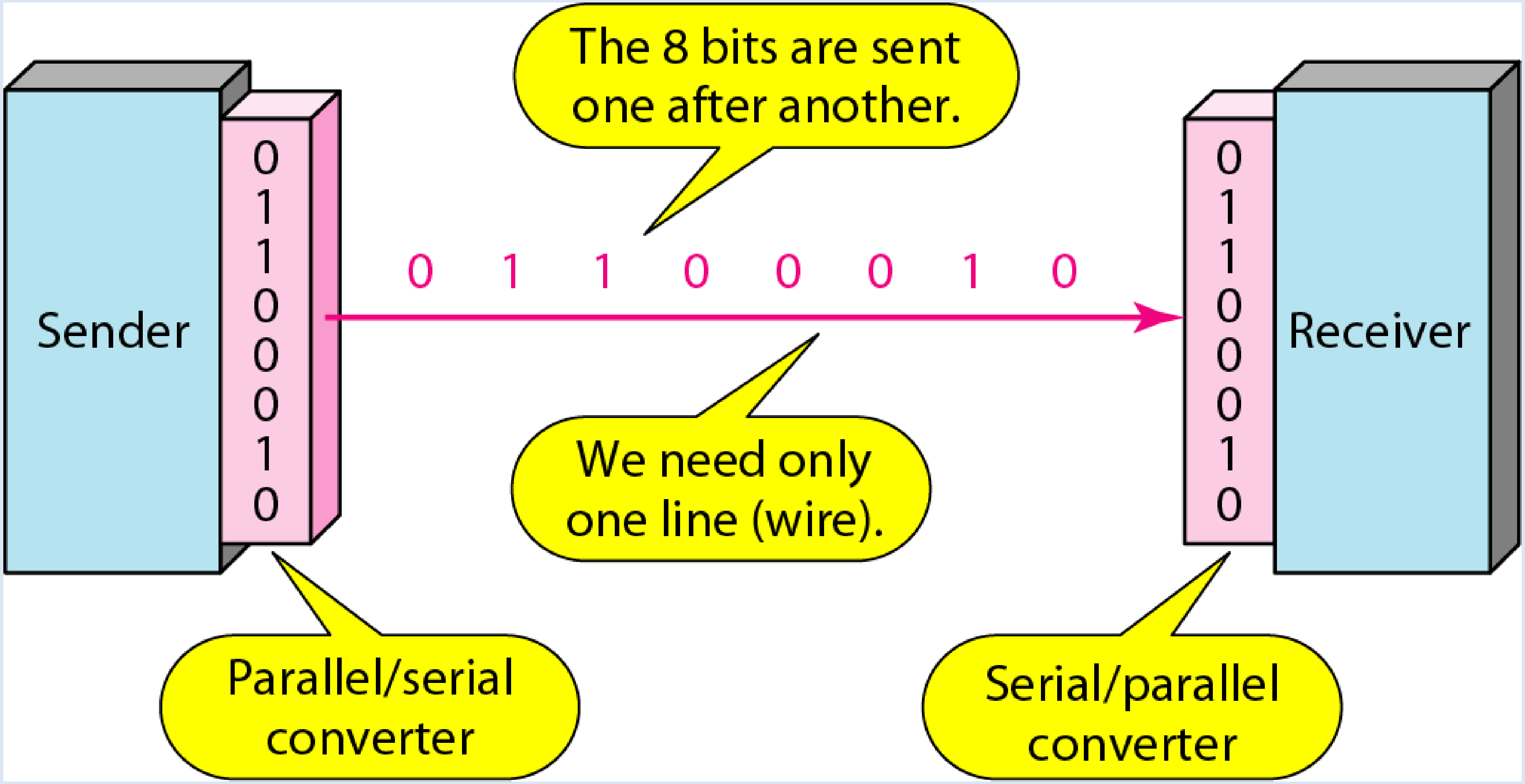
Cost – Parallel transmission requires n communication lines (wires in the example) just to transmit the data stream. Because this is expensive, parallel transmission is usually limited to short distances.

Application

Printers

Data bus -> used to transmit data inside computer system; CPU to memory and vice-versa

Serial Transmission



- In serial transmission, one bit follows another, so we need only one communication channel rather than n to transmit data between communicating devices.

Advantage

The advantage of serial over parallel transmission is that with only one communication channel, serial transmission reduces the cost of transmission over parallel by roughly a factor of n.

Disadvantages of Serial Transmission

- Since communication within devices is parallel , conversion devices are required at the interface between the sender and the line (parallel-to-serial) and between the line and the receiver (serial-to-parallel)

- This method is slower as compared to parallel transmission as bits are transmitted serially one after the other.

Serial transmission occurs in one of three ways: Asynchronous, Synchronous and Isochronous

Asynchronous Transmission

- It can occur at any time with an arbitrary delay between the transmission of two data items.
- Sender and receiver are not synchronized.
  - The sender can start data transmission at any time instant without informing the receiver.
- Data is sent in a group of 8bits , in bytes
- Without synchronization, the receiver cannot use timing to predict when the next group will occur.
- Bit synchronization between two devices is made possible using start bit and stop bit.
- **Start bit indicates the beginning of data i.e. alerts the receiver to arrival of new group bits. A start bit usually 0 is added to the beginning of each byte.**
- **Stop bit indicates the end of data *i.e.* to let the receiver know that byte is finished, one or more additional bits are appended to the end of the byte. These bits, usually 1s are called stop bits.**

Note

In asynchronous transmission, we send 1 start bit (0) at the beginning and 1 or more stop bits (1s) at the end of each byte. There may be a gap between each byte.

Note

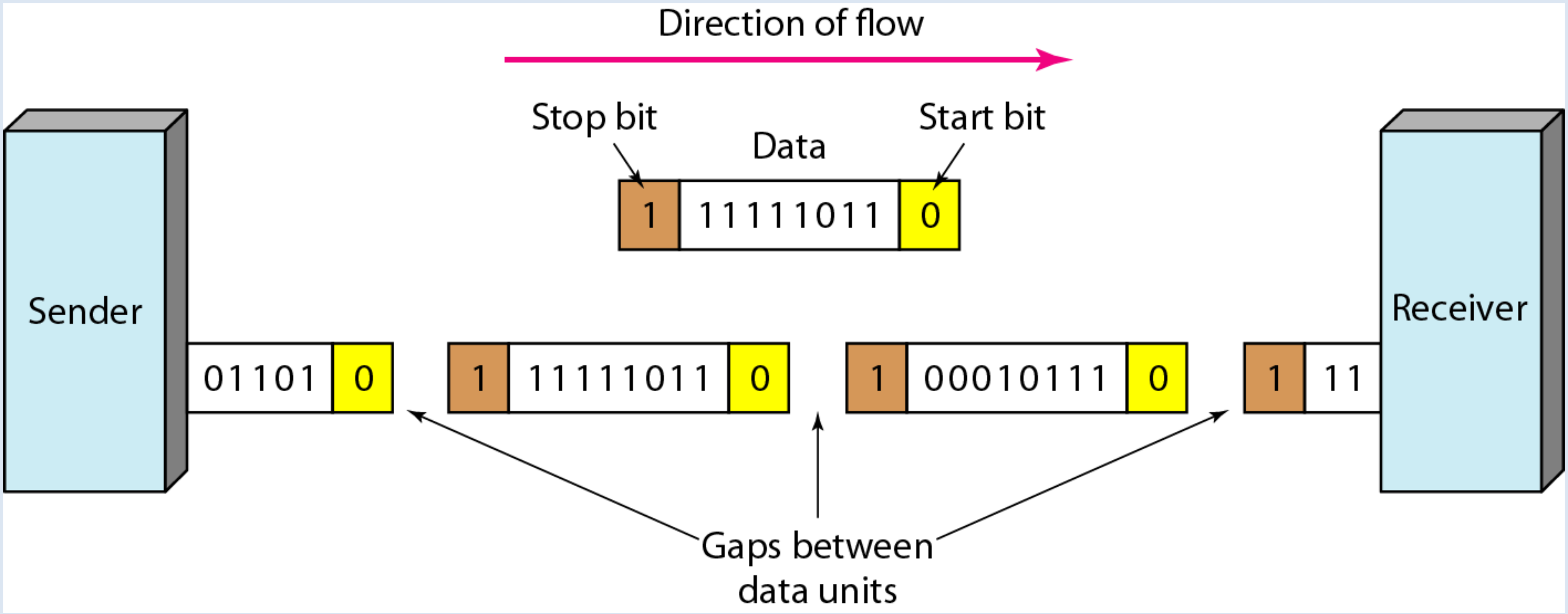
Asynchronous here means "asynchronous at the byte level," but the bits are still synchronized; their durations are the same.

Start	Data	Stop
0	11001010	**1**

- The transmission of each byte may then be followed by a gap of varying duration. This gap can be represented either by an idle channel or by a stream of additional stop bits.

- The receiving device resynchronizes at the onset of each new byte. When the receiver detects a start bit, it sets a timer and begins counting bits as they come in.

- After *n* bits, the receiver looks for a stop bit. As soon it detects the stop bit, it waits until it detects the next start bit.



Direction of flow
Stop bit
Data
Start bit
1
11111011
0
Sender
Receiver
01101
0
1
11111011
0
1
00010111
0
1
11
Gaps between
data units

Advantages

- No synchronization is required between the transmitter and receiver devices.

  - Attractive choice for situations such as low-speed communications as it is cheap and effective.

For example, the connection of a keyboard to a computer is a natural application for asynchronous transmission.
A user types only character at a time, types extremely slowly in data processing terms, and leaves unpredictable gaps of time between characters.

Disadvantage

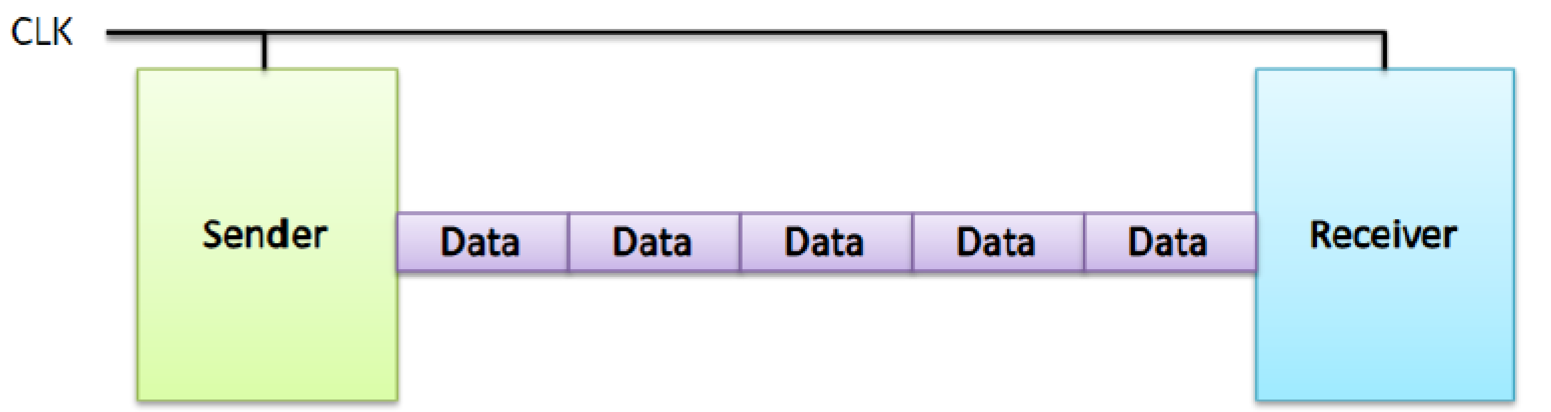
The addition of stop and start bits and the insertion of gaps into the bit stream make asynchronous transmission slower than forms of transmission that can operate without the addition of control information.

Application

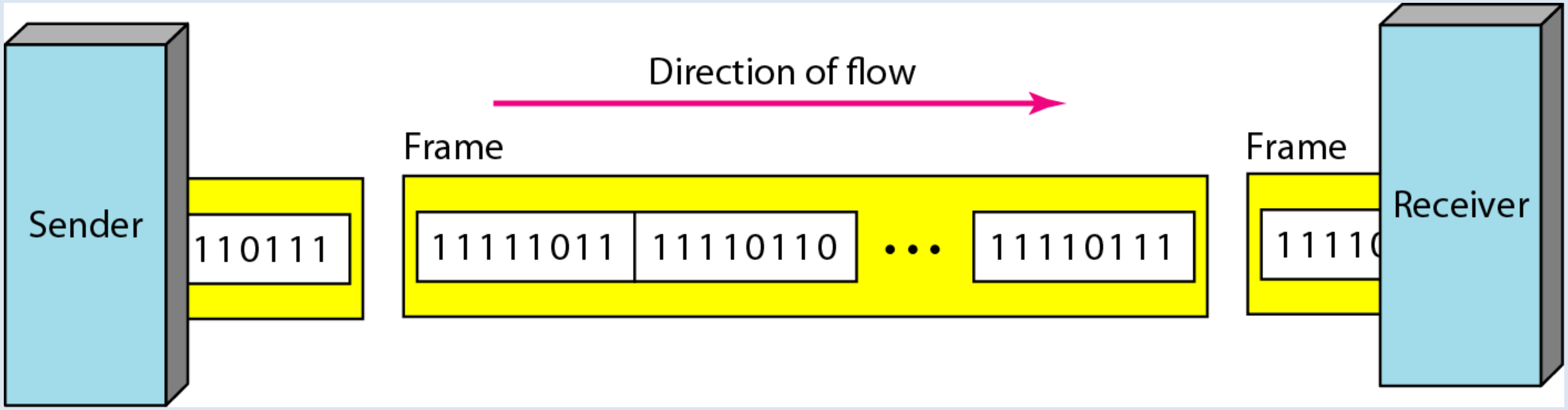
- Best suited for internet traffic in which information is transmitted for short bursts.
- Asynchronous transmission is well suited for keyboard type-terminals.

Synchronous Transmission

- Synchronous transmission does not use start and stop bits.
- In this method bit stream is combined into longer frames that may contain multiple bytes.
- There is no gap between the various bytes in the data stream.
- In the absence of start and stop bits, bit synchronization is established between sender and receiver by ‘timing’ the transmission of each bit.
- Since the various bytes are placed on the link without any gap, it is the responsibility of receiver to separate the bit stream into bytes so as to reconstruct the original information.
- In order to receive the data error free, the receiver and sender operates at the same clock frequency.



Synchronous transmission



Advantages

- Speed: with no extra bits or gaps to introduce at the sending end and remove at the receiving end, and, by extension, with fewer bits to move across the link, synchronous transmission is faster than asynchronous transmission. For this reason, it is more useful for high-speed applications such as the transmission of data from one computer to another.
  - ❖ Byte synchronization is accomplished in the data-link layer.

Disadvantages

- Although there is no gap between characters in synchronous serial transmission, there may be uneven gaps between frames.
- Requires accurately synchronized clocks at both ends
- Costly as compared to asynchronous

Examples:

Telephony, High-speed networks, real-time data transfer

Isochronous Transmission

- In real-time audio and video, in which uneven delays between frames are not acceptable, synchronous transmission fails.
  - For example, TV images are broadcast at the rate of 30 images per second; they must be viewed at the same rate.
  - If each image is sent by using one or more frames, there should be no delays between frames. For this type of application, synchronization between characters is not enough; the entire stream of bits must be synchronized.
- The isochronous transmission guarantees that the data arrive at a fixed rate.

Advantages of Serial Transmission over Parallel Transmission

- Serial Transmission is easy to use and reliable. On the other hand, Parallel Transmission is complex and unreliable
- Serial Transmission is suitable for long-distance transmission. On the other hand, Parallel Transmission is only suitable for short distances.
- Serial transmission is full-duplex because the transmitter can both send and receive data. On the other hand, Parallel Transmission is half-duplex because data is either transmit or received.
- Serial Transmission utilizes a single link, inexpensive. On the other hand, Parallel Transmission necessitates the implementation of many links, making it not cost-efficient.

Assignment :

1. Differences between serial transmission and parallel transmission
2. Compare between synchronous transmission and asynchronous transmission

Qn. On a Tx. Channel, 600 character messages using ASCII 7 bit code is used for sync. Data stream, there are two SYNC character and a single error detection character is added. In async. Data Tx, there are one start-bit and one stop-bit and single error detection character is added. Calculate the efficiency of the transmission in both mode.

Solution:

For sync. TX mode:

Original information character = 600 characters

Total no. of characters transmitted = 600 + 2 SYN char + 1 error detection char

= 600+ 2 + 1 = 603 character

Then, total no. of bits transmitted = 603 * 7 = 4221 bits

& actual data bits =600 * 7 = 4200 bits

Thus efficiency, η = 4200 / 4221 *100 % = 99.73%

For Async.mode

Original information character = 600 characters

Total no. of characters transmitted = 601

Each character is represented by 7 ASCII bits + 1 start bit + 1 stop bit = 9 bits

Then, total no. of bits transmitted = 601 * 9 = 5409 bits

& actual data bits =600 * 7 = 4200 bits

Thus efficiency, η = 4200 / 5409 *100 % = 77.65%

Bit Rate and Baud Rate

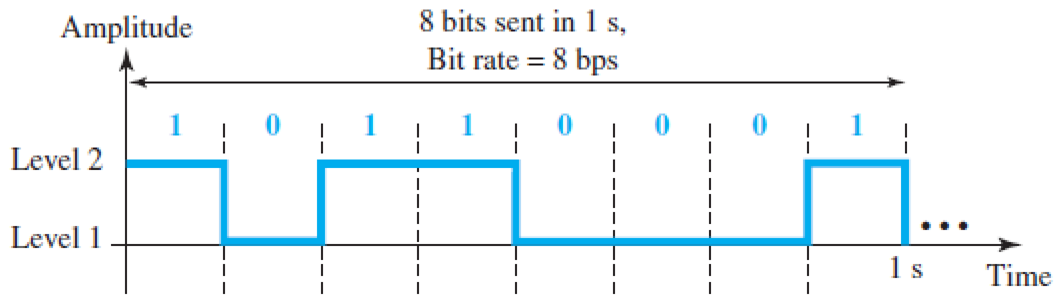
- Bit rate is the number of bits sent per second, expressed in bps
- Date rate is sometimes called the bit rate
- The signal rate is number of signal elements sent in 1s. Unit is baud. The signal rate is sometimes called the pulse rate, the modulation rate, or the baud rate.
- Goal:
  - ❑ Increase the data rate while decreasing the signal rate. Increasing the data rate increases the speed of transmission; decreasing the signal rate decreases the bandwidth requirement.
  - ❑ In our vehicle-people analogy, we need to carry more people in fewer vehicles to prevent traffic jams. We have a limited bandwidth in our transportation system.

- Need to consider the relationship between bit rate *R* and baud rate *S*

$$baud\ rate\ S = \frac{bit\ rate\ R}{r}$$

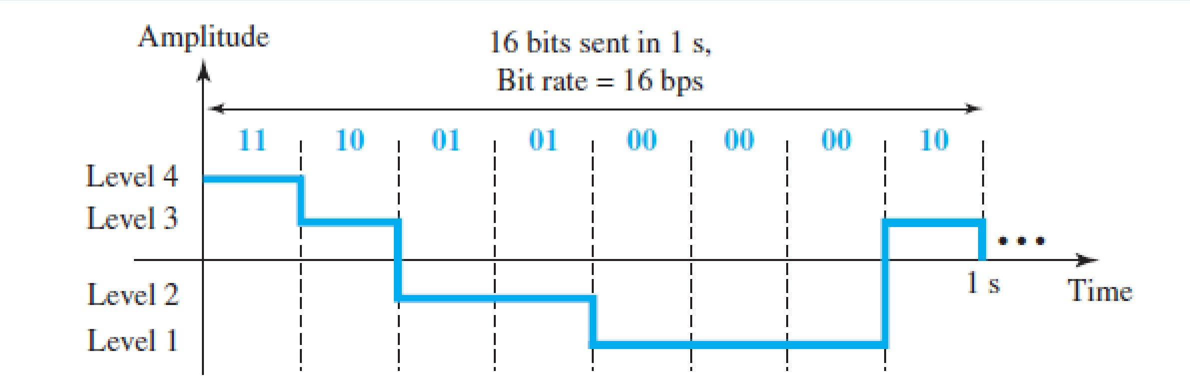
r is the number of data (bit) in signal or symbol.

$$r = \frac{number\ of\ bits}{number\ of\ signal\ elements}\frac{bit}{baud}$$



a. A digital signal with two levels

8 bps
8 baud/sec



b. A digital signal with four levels

- 16 bit/sec , 8 baud/sec

- In general, if a signal has L levels, each level needs log_2L bits.

Example. A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the following formula. Each signal level is represented by 3 bits.

Number of bits per level = $\log_2 8 = 3$

Example. An analog signal carries 4 bits in each signal unit. If 1000 signal units are sent per second, find the baud rate and the bit rate.

$r = 4$, baud rate $S = 1000$, $R = 1000 \times 4 = 4kbps$

A system sends a signal that can assume 8 different voltage levels. It sends 400 of these signals per second. What are the baud and bit rates?

Solution:

L = 8 , Baud Rate S = ? , Bit Rate R = ?

$$r = \log_2 L = 3$$

S = 400 signals/sec

R = r x S = 3 x 400 = 1200 bps

An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How many data elements are carried by each signal element? How many signal elements do we need?

Solution:

Baud Rate S = 1000 , Bit Rate R = 8000

Number of data elements carried by each signal element $r = \frac{8000}{1000} = 8\ bits/baud$

Number of signal elements L = $2^r = 2^8 = 256$

Networks

- A *network* is a set of devices (often referred to as nodes) connected by communication *links*.
- A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network.
- Most networks are *distributed* processes, in which a task is divided among multiple computers.
- <u>Network Criteria</u>: A network must meet certain criteria. Most important of these are:

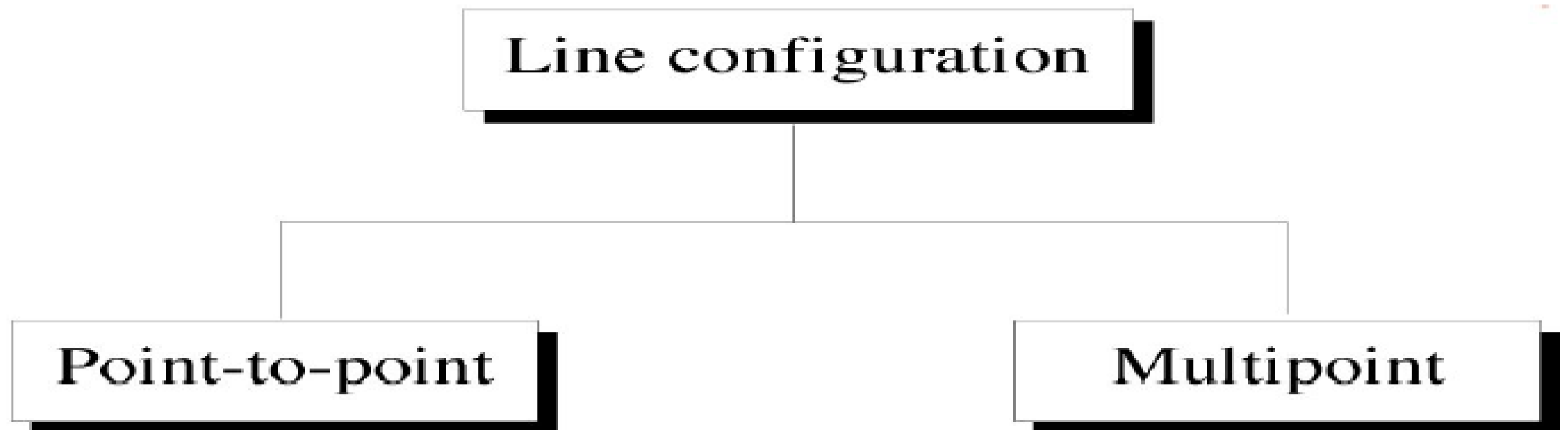
✓ **Performance**: Can be measured in many ways, including transit time and response time. It can depend on number of factors, including the number of users, type of transmission medium, hardware/software.

✓ **Reliability**: Network reliability is measured by the frequency of failure, the time it takes a link to recover from a failure, and network's robustness in a catastrophe.

✓ **Security**: Protecting data from unauthorized access.

Type of Connection

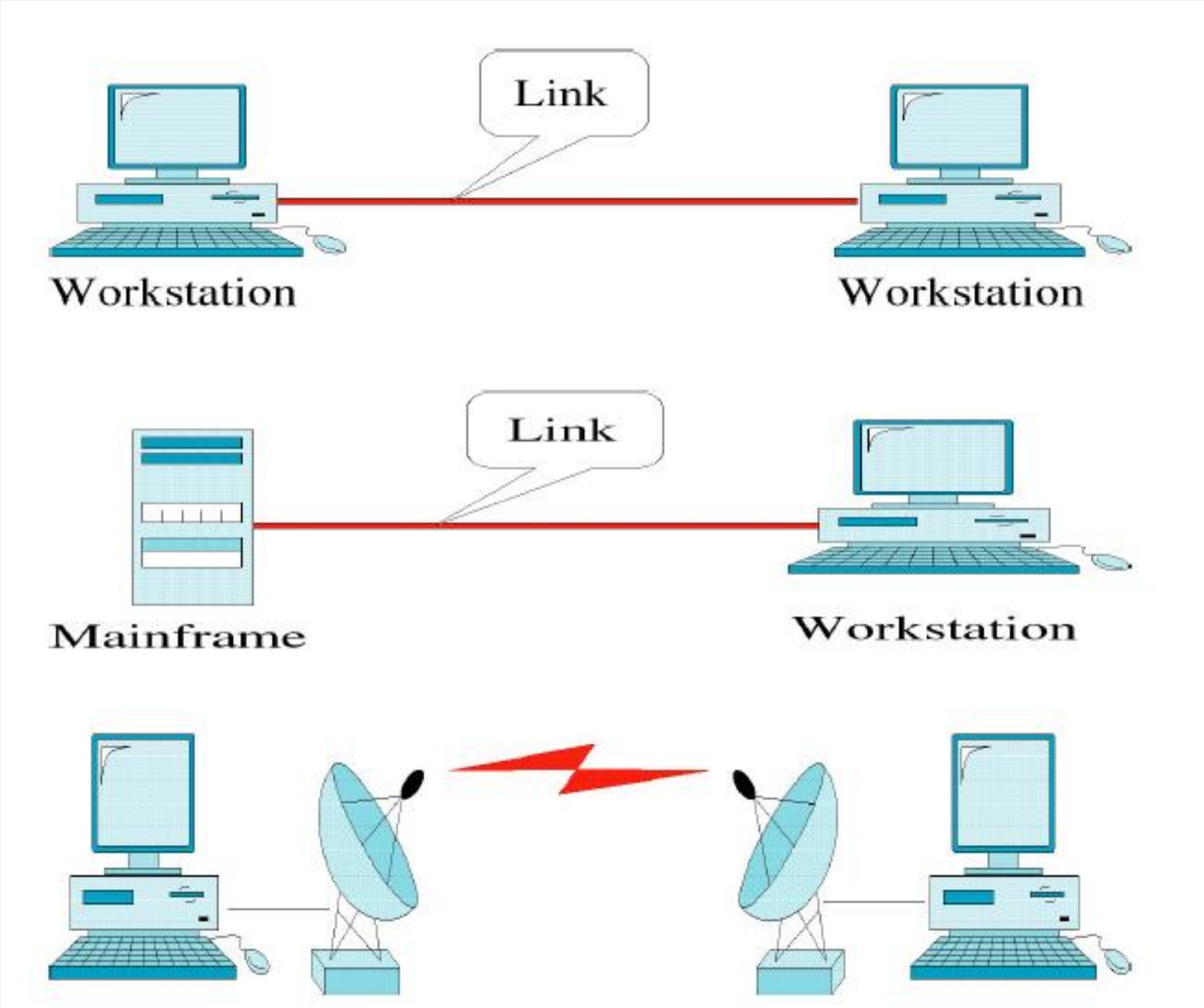
- Refers as connection or link between communication devices to transfer data
- For communication to occur, two devices must be connected in some way to the same link at the same time.
- Two possible way of connections are: Point-to-Point and Multipoint



Point-to-Point Connection

- Provides a dedicated link between two devices via pair of wires or using a microwave or satellite links
  - Connection between two nodes that can be used to communicate back and forth
  - Example: Telephone Call
  - When we change television channels by infrared remote control, we are establishing a point-to-point connection between the remote control and the television's control system

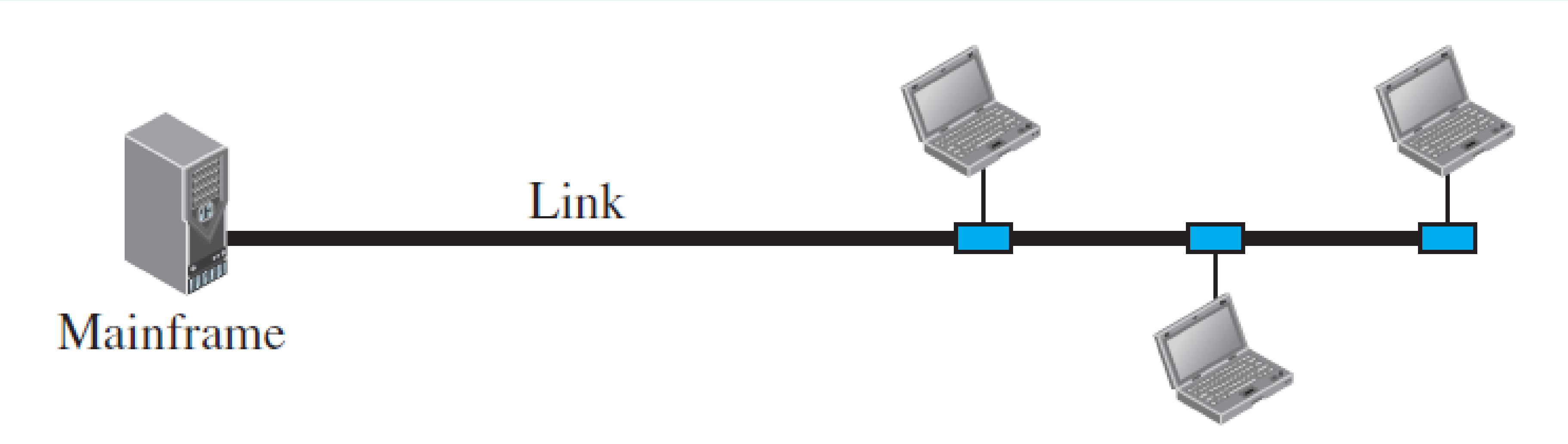
Point-to-Point Connection



Multipoint Connection

- Connection in which more than two devices share a single link
- In a multipoint environment, the capacity is shared, either spatially or temporally.
- **Spatial Sharing: If several devices can share the link simultaneously**
- **Temporal (Time) Sharing: If users must take turns using the link , then its called Temporally shared or Time Shared Line Configuration**

Multipoint Connection



Data Flow

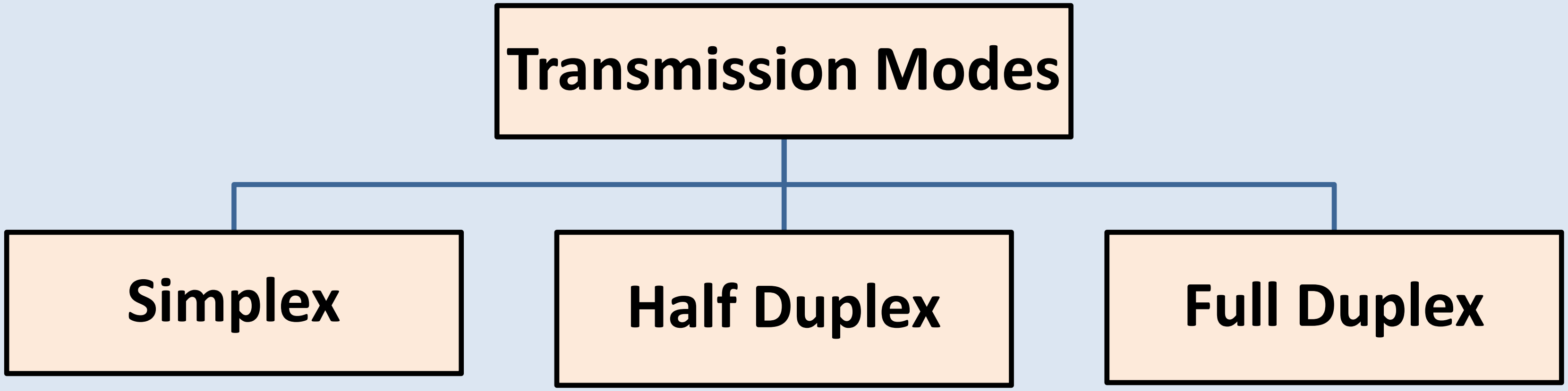
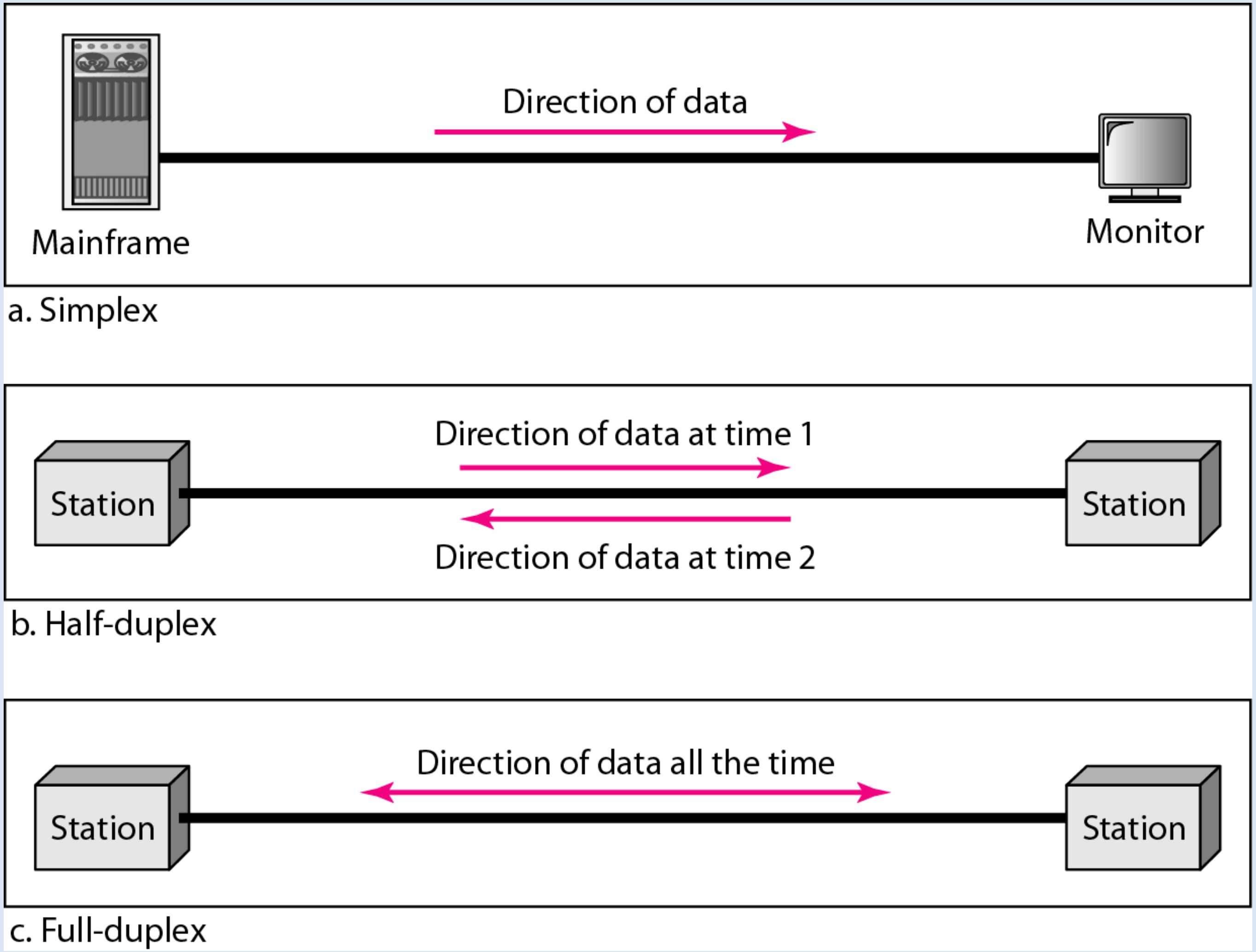


Figure: Transmission mode

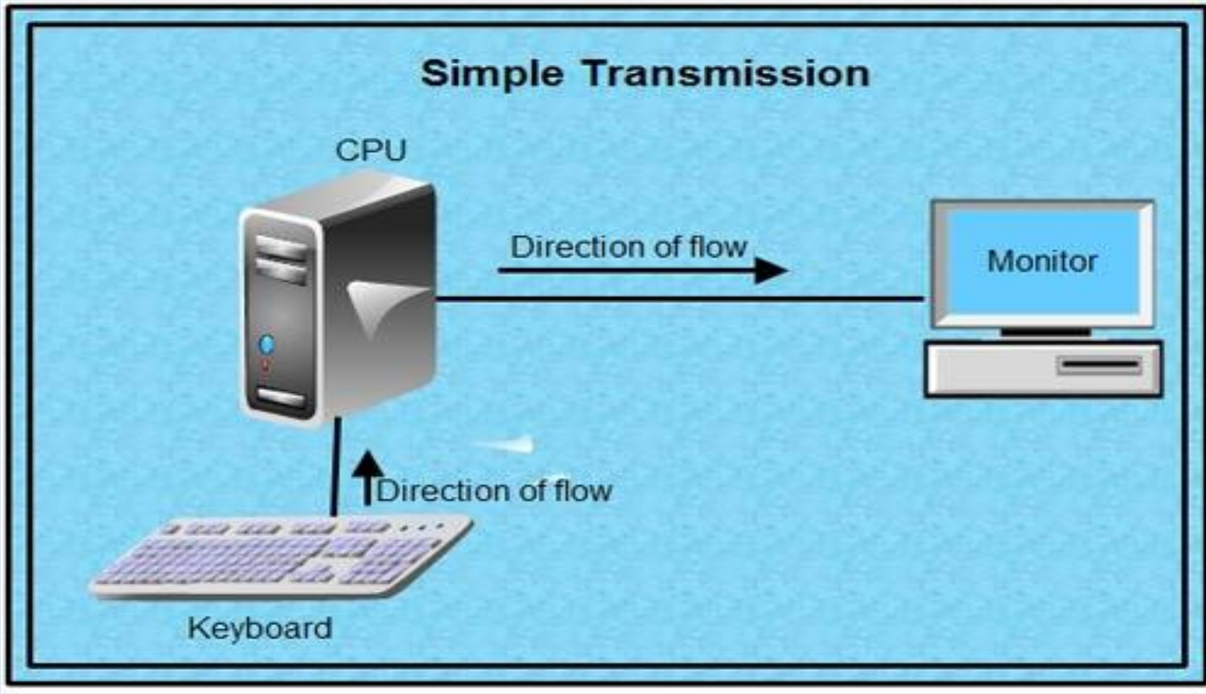
Data flow


Direction of data
Mainframe
Monitor
a. Simplex
Direction of data at time 1
Station
Station
Direction of data at time 2
b. Half-duplex
Direction of data all the time
Station
Station
c. Full-duplex

Data Flow - Simplex

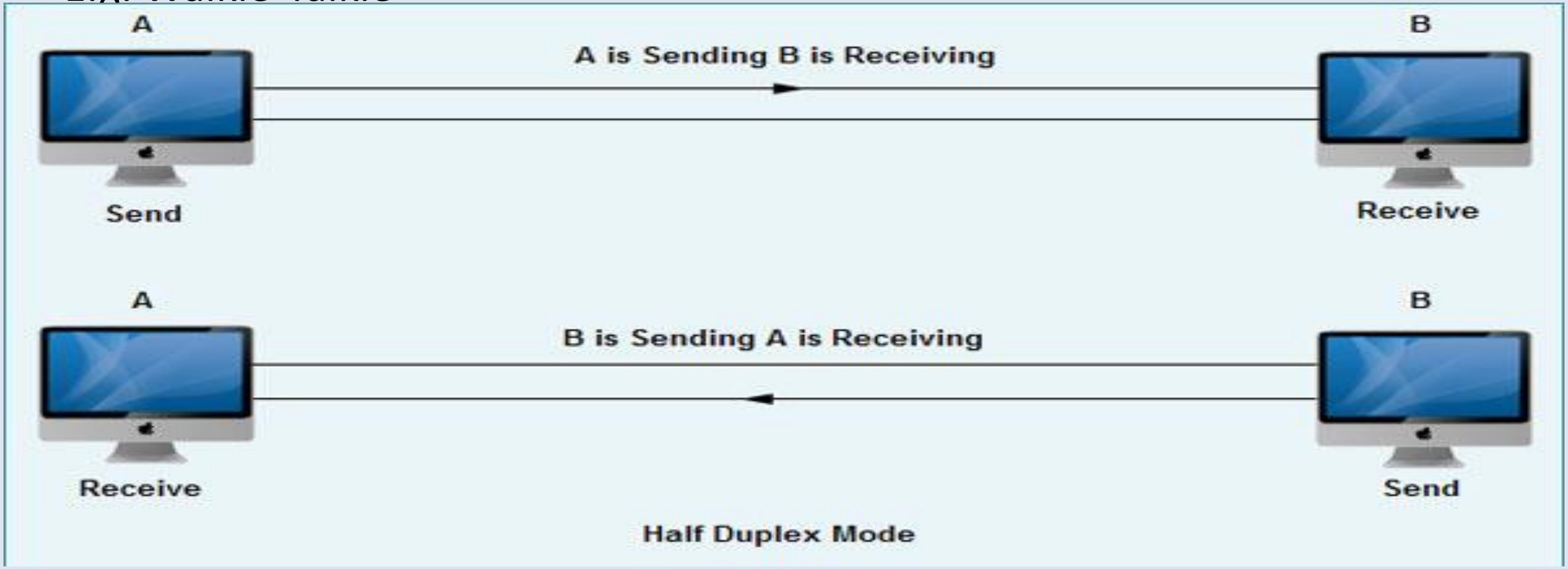
- Communication can take place in one direction connected to such a circuit are either a send only or receive only device.
- Keyboards and traditional monitors are examples of simplex devices.

✓ Keyboard can only introduce input; the monitor can only accept.



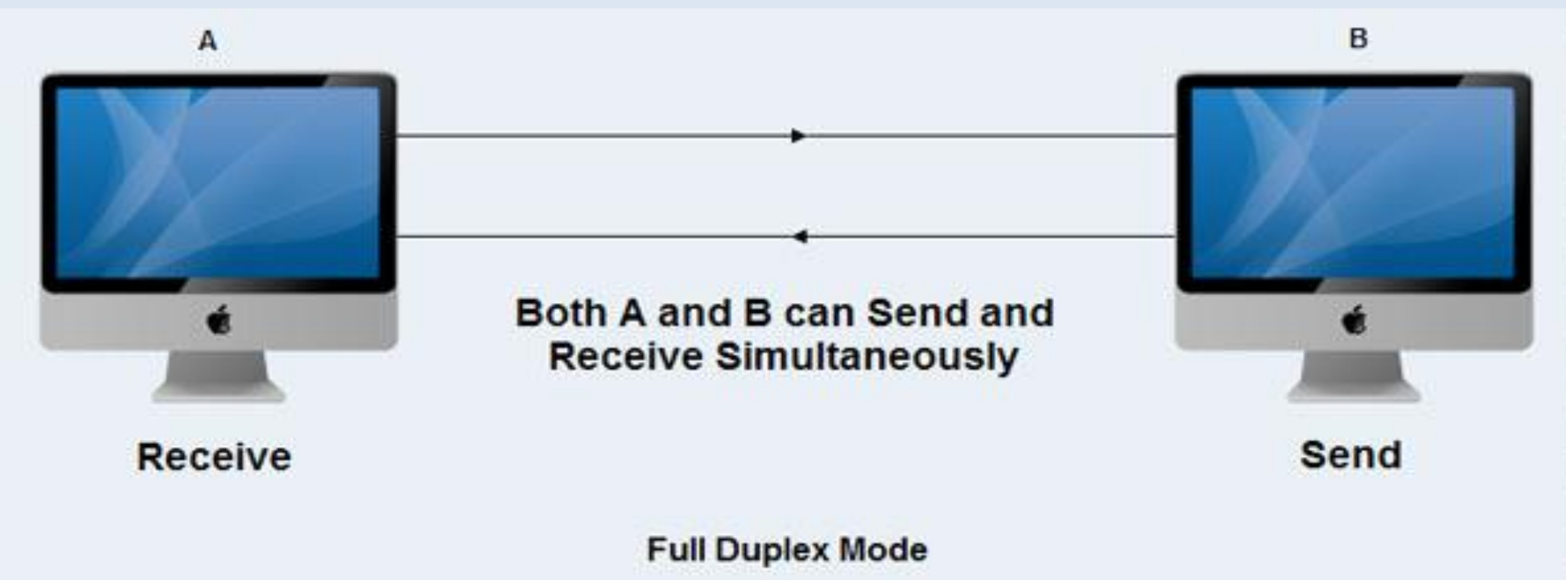
Data Flow – Half duplex

- In half-duplex mode, each station can both transmit and receive, but not at the same time. When one device is sending, the other only can receive, and vice-versa.
- E.g. Walkie-Talkie



Full Duplex

- A full duplex system can transmit data simultaneously in both directions on transmission path.
- Full-duplex method is used to transmit the data over a serial communication link.
- Two wires needed to send data over a serial communication link layer.
- Full-duplex transmission, the channel capacity is shared by both communicating devices at all times.



Data Rate Limits

A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depends on three factors:

1. The Bandwidth available
2. The level of signal we use
3. The quality of the channel (Level of noise)

Topics Discussed:

- Noiseless channel: Nyquist Bit Rate
- Noisy channel: Shannon Capacity
- Using Both Limits

Note

Increasing the levels of a signal increases the probability of an error occurring, in other words it reduces the reliability of the system. Why??

Capacity of a System

- The bit rate of a system increases with increase in the number of signal levels we denote a symbol.
- A symbol can consist of a single bit or “n” bits.
- The number of signal levels = 2^n
- As the number of levels goes up, the spacing between level decreases-> increasing the probability of an error occurring in the presence of transmission impairments.

Noiseless Channel: Nyquist Bit Rate

- Let us consider the case of a channel that is noiseless
  - Limitation on data rate is simply the bandwidth of the signal
  - States that if the rate of signal transmission is *2B* , then a signal with frequencies no greater than *B* is sufficient to carry the signal rate.

Nyquist Theorem

B- Bandwidth of the channel , L – Number of signal levels used to represent data , then the maximum data rate R on this channel is given by

$$R = 2B\ \log_2 L\ \ bps$$

Maximum data rate for reliable transmission , channel capacity

$$C = 2B\ \log_2 L\ \ bps$$

Example

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

$$Bitrate = 2\ X\ 3000\ X\ \log_2 2 = 6000\ bps$$

We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Solution

We can use the Nyquist formula as shown:

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L \longrightarrow \log_2 L = 6.625 \longrightarrow L = 2^{6.625} = 98.7 \text{ levels}$$

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

Noisy Channel: Shannon Capacity

In reality, we cannot have a noiseless channel; the channel is always noisy. In 1944, Claude Shannon introduced a formula, called the **Shannon capacity,** to determine the theoretical highest data rate for a noisy channel

$$\text{Capacity} = \text{Bandwidth} \times \log_2(1 + \text{SNR})$$

SNR is the ratio of the power in a signal to the power contained in the noise that is present at a particular point in the transmission

$$SNR = \frac{Signal\ Power}{Noise\ Power}, \Rightarrow Noise\ power\ (N) = N_0 B\ ;\ N_0 : Noise\ Density$$

$$SNR_{dB} = 10\ \log_{10} \frac{Signal\ power}{Noise\ Power}$$

Example

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel, calculate the capacity C.

$$\boxed{C = B \log_2 (1 + \text{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0}$$

This means that the capacity of this channel is zero regardless of the bandwidth. In other words, we cannot receive any data through this channel.

Example

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

$$C = B \log_2 (1 + \text{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163$$
$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

This means that the highest bit rate for a telephone line is 34.860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

Example

The signal-to-noise ratio is often given in decibels. Assume that SNR_{dB} = 36 and the channel bandwidth is 2 MHz. Calculate The theoretical channel capacity of the channel

$$SNR_{dB} = 10 \log_{10} SNR \quad \rightarrow \quad SNR = 10^{SNR_{dB}/10} \quad \rightarrow \quad SNR = 10^{3.6} = 3981$$

$$C = B \log_2 (1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

Example Using Both Limits

We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?

Solution

First, we use the Shannon formula to find the upper limit.

$$C = B \log_2 (1 + \text{SNR}) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}$$

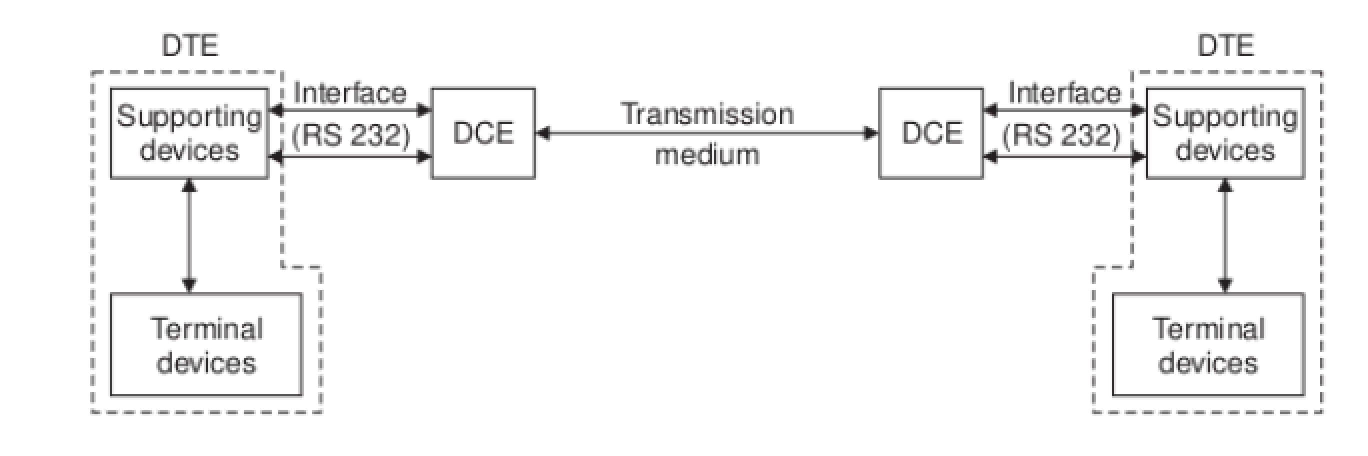
The Shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower, 4 Mbps, for example. Then we use the Nyquist formula to find the number of signal levels.

$$4 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L \quad \longrightarrow \quad L = 4$$

Note

The Shannon capacity gives us the upper limit; the Nyquist formula tells us how many signal levels we need.

Data Communication



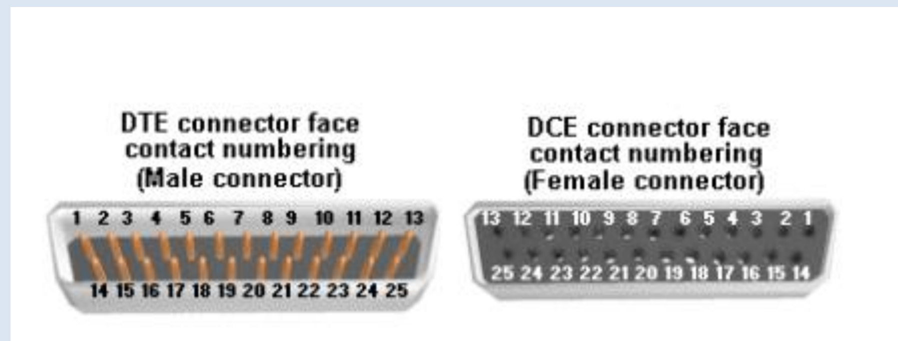
- Transmission medium can be broadly defined as anything that can carry information from a source to a destination.
- Terminal devices/ nodes: Endpoints in a communication link

Examples: Workstation, GPS receivers, Output peripherals – Visual Display Unit, Input Peripherals- Keyboard

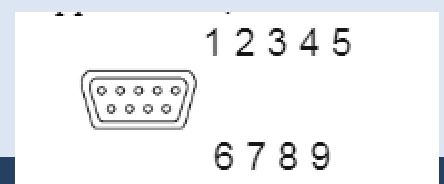
- Data Terminal Equipment (DTE): Equipment as source or destination
    - ❑ Capable of converting information to signals and also reconverting received signals
    - ❑ DTE do not communicate with each other, usually done by DCE
- RS – 232 Interfaces: for serial communication
    - ❖ All modems use RS 232 connections and all PCS have a RS 232 port
- Data communication equipment (DCE): used to convert the serial data stream into a form which is suitable for transmission
    - ➢ At the receiver side, the serial data stream is converted back to digital and sent to DTE
    - ➢ DCE may be a modem or a computer-based node in a data network

RS-232C (Recommended Standard 232) Interface

- RS-232C is a long-established standard that describes the physical interface and protocol for relatively low-speed serial data communication between computer and related devices.
- RS-232C is the interface that the computer uses to talk and exchange data with modem and other serial devices. In this case the computer is referred to as the DTE and the attached device as the DCE.
- Works at the physical layer of the network protocol.



- The communication is done through the serial port of the PC. This is male connector with 25 pins (old) or 9 pins (new PC computer)

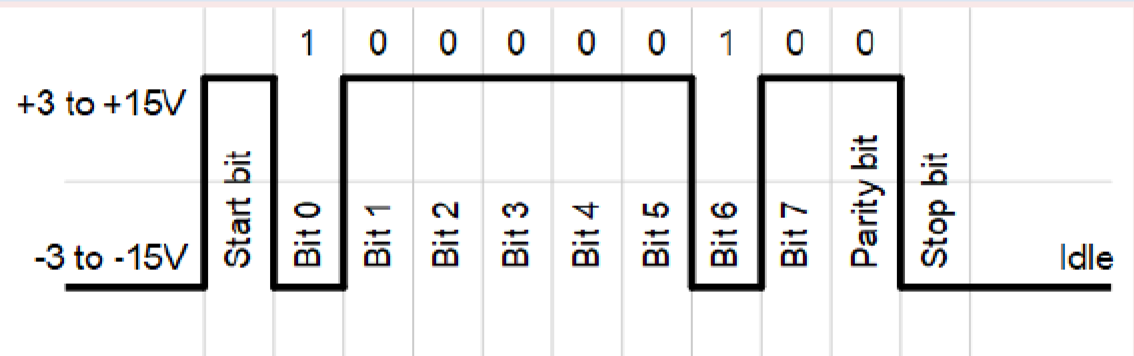


RS-232C

- Short cables of less than 15 metres (50 feet) are recommended.
- Electrical Interface
  - ❑ All circuits carry bi-polar low-voltage signals, measured at the connector with respect to signal ground, and many not exceed $\pm$25 volts. Signals are valid in the range ± 3 volts to ± 25 volts.

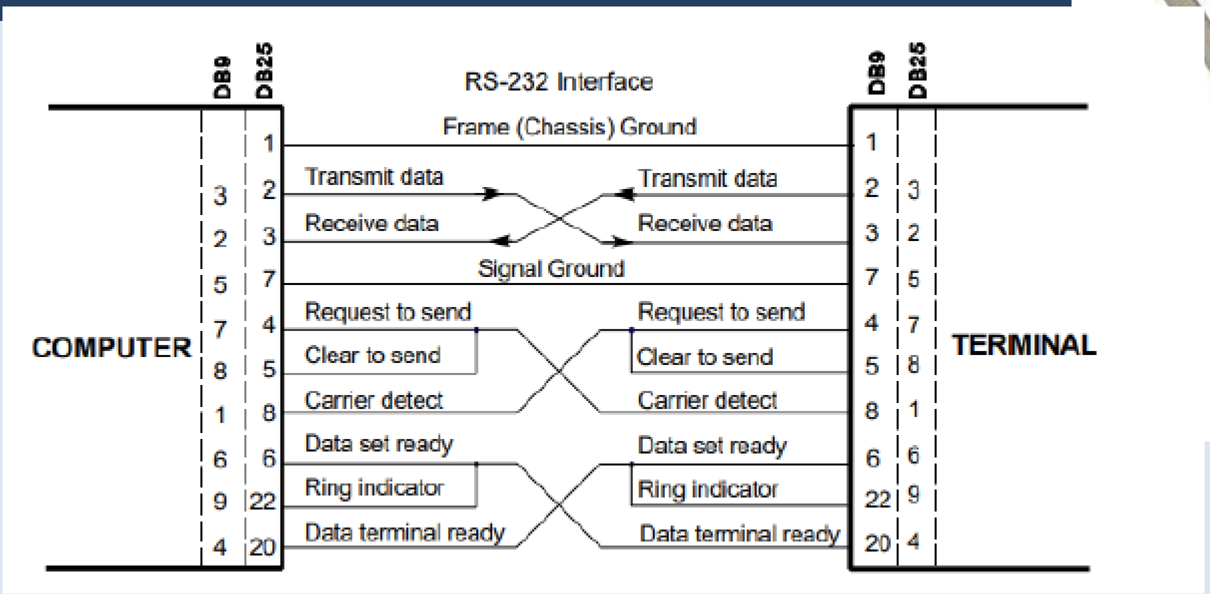
RS232C-to-TTL signal conversion

TTL		RS232C	
Logic	Voltage	Logic	Voltage
High(1)	*2.4 to 5 volts*	*MARK*	*-3 to -25 volts*
Low(0)	*0 to 0.8 volts*	*SPACE*	*+3 to +25 volts*



Data Format:
Start bit: always low (0)
Stop bit: always high (1)
Parity bit
8-data bits: LSB sent first and MSB sent last

RS-232C Interface



- **Data Pins:** Flow of the data occurs through the data pins:
  a) Transmit Data TD: carries data from DTE to DCE
  b) Receive data RD: receives data from DCE and pass to DTE

- **Reference Pin**: Used as reference for all pin voltage pulses
  a) Ground GND
  b) Frame Ground: protect from the metallic conductor (only in DB 25)

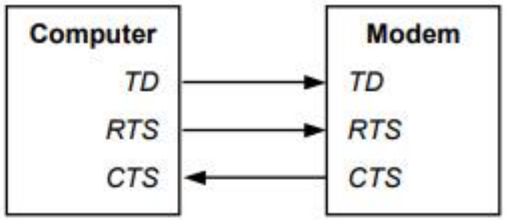
- **Control Pins**: used to establish the interface between the devices for smooth data transmission

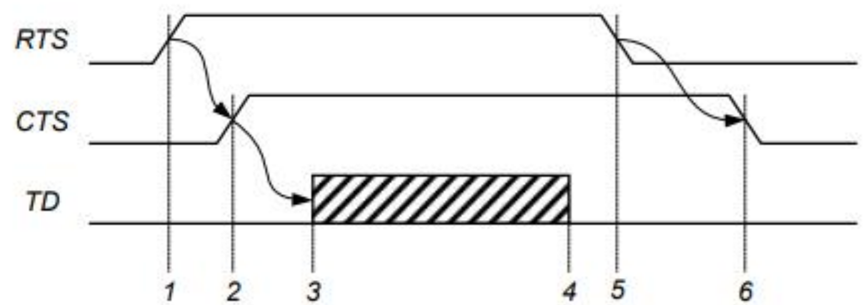
1. Data Carrier Detect DCD: This control line is asserted by the modem, informing the computer that it has established a physical connection to the other modem
2. **Data Terminal Ready** DTR: This signal line is asserted by the computer, and informs the modem that the computer is ready to receive data.
3. **Data Set Ready** DSR: This signal line is asserted by the modem in response to a DTR signal from the computer. The computer will monitor the state of this line after asserting DTR to detect if the modem is turned on.
4. **Request to send** RTS: This signal is asserted by the computer (DTE) to inform the modem (DCE) that it wants to transmit data.
5. **Clear to Send** CTS: Asserted by the modem after receiving a RTS signal, indicating that the computer can now transmit.
6. **Ring Indicator** RI: When an incoming call on the telephone line is detected by DCE (inform to DTE), then the Ring Indicator gets activated.

RS-232C Handshaking

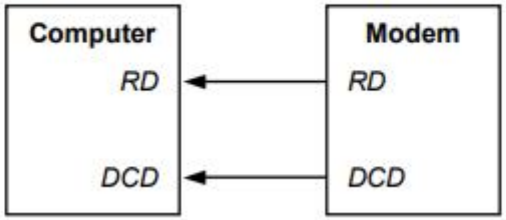
- Handshaking: a process which is used to transfer the signal from DTE to DCE to make connection before the actual transfer of data

- **When the computer wants to transmit data to the modem**
  - RTS is asserted by the DTE (1)
    - to indicate that the DTE wishes to send data
  - CTS is asserted by the DCE (2)
    - to indicate that the DCE is ready to receive data
  - DTE transmits data through TD (3)
  - DTE completes data transmission (4)
  - RTS is negated by the DTE (5)
    - to indicate that the DTE has finished transmitting data
  - CTS is negated by DCE (6)





- **When the modem wants to transmit data to the computer**
  - The DCE asserts DCD
    - To indicate that a data carrier is present and to transmit data
  - The DTE must be prepared to receive data any time DCD is asserted



Null Modem

- The RS-232C interface was designed to connect computers to modems

However, many of today's RS-232C applications are for connecting a computer (DTE) to a peripheral (such a printer, also considered a DTE), rather than to a modem (DCE)

- In order to connect a DTE to a DTE we must cross some of the control signals

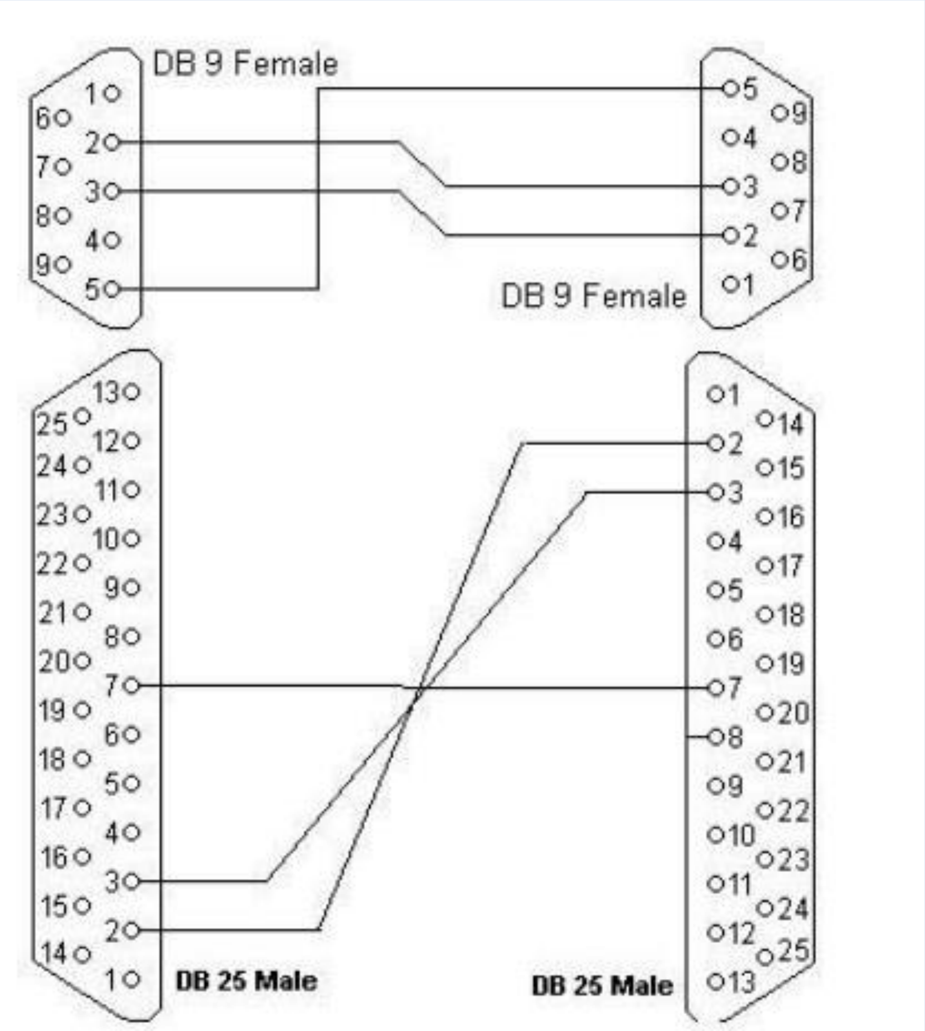
the DTE signals from one computer are swapped over as inputs to supply the DCE expected signals on the other DTE

- This DTE-DTE interface is accomplished with a special connector cable called a null modem

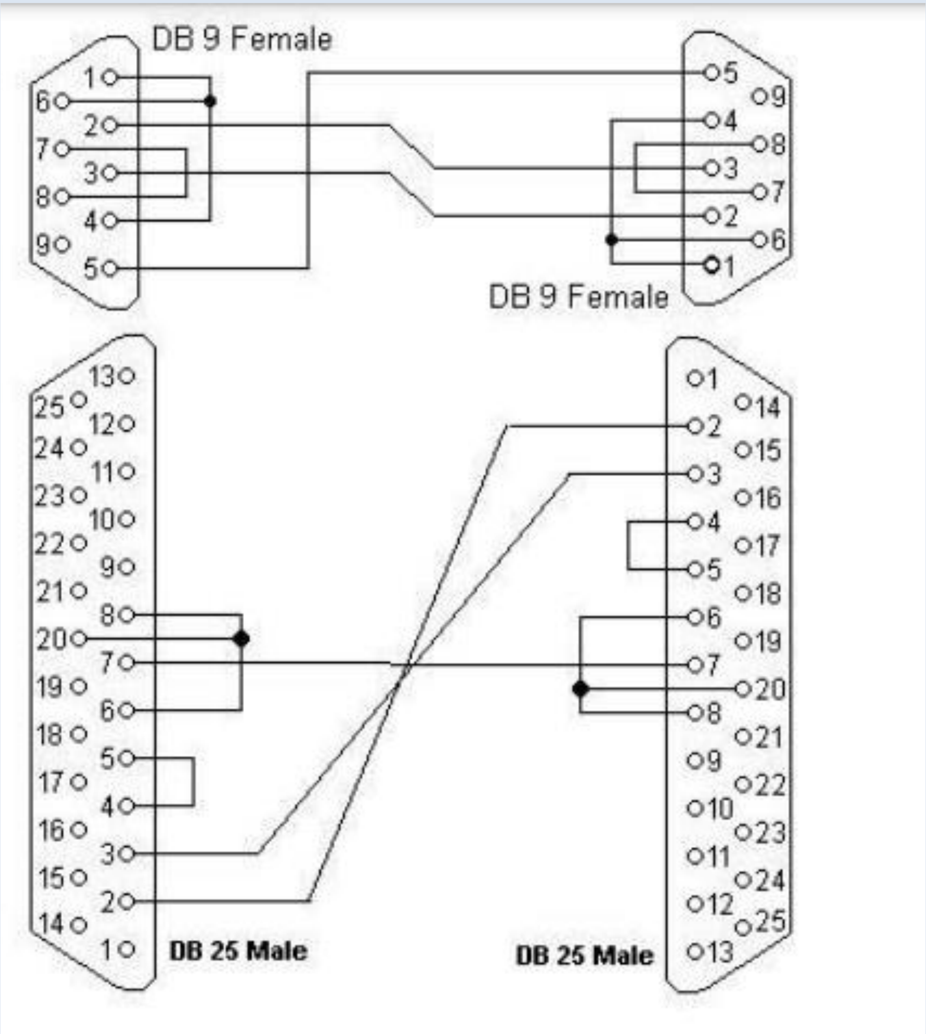
A null modem simulates a DTE-DCE-DCE-DTE circuit:

- Null modem cables with handshaking can be defined in numerous ways, with loop back handshaking to each PC, or complete handshaking between the two systems.

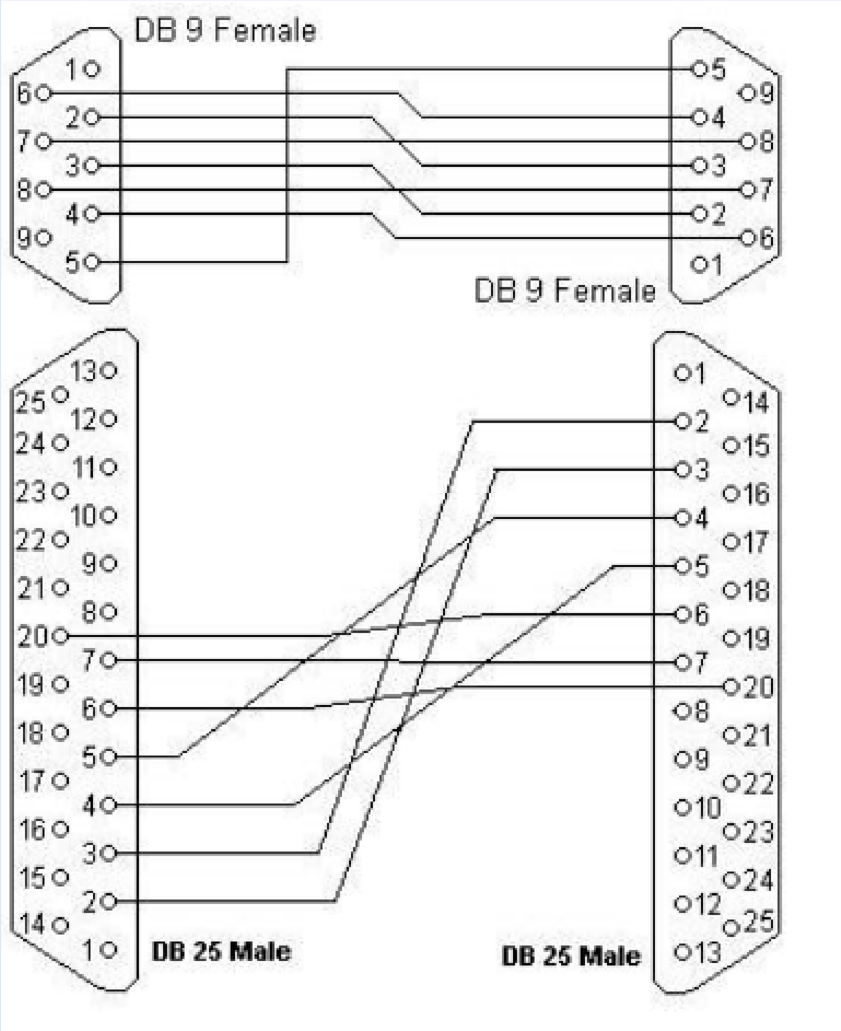
Simple Null modem without handshaking



Null Modem with loop back handshaking



Null modem with full handshaking



Advantages of RS-232C

- Provides a reliable means of communication – Control and handshake signal
- Low-cost interface
- Suitable for low baud rate slow systems typically upto 20,000 bauds
- Standard voltage levels for mark and space to reduce the interference

Disadvantages of RS-232C

- Range of communication is around 50 ft. To increase the range, baud rate has to be reduced
- Multiple users cannot share the same wire: Designed for two users connected directly to each other
- Less flexibility: suitable for system-to-system communication, not suitable for chip-to-chip or chip-to-sensor device communications.