Fundamentals of Computer Networks

Course Code: CSE3001

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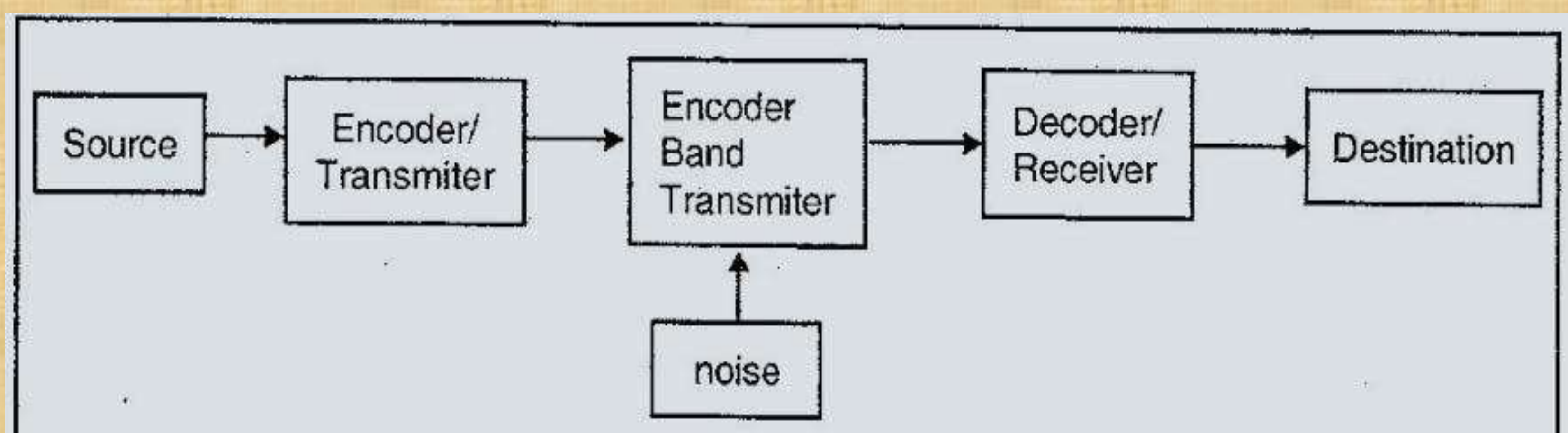
Contents

- Data communication technologies
- Analog and digital communication
- Encoding mechanisms
- Packet Switching
- Circuit Switching

Data Communication

- **Data communication** refers to the exchange of **data** between a source and a receiver via form of **transmission** media such as a wire cable.

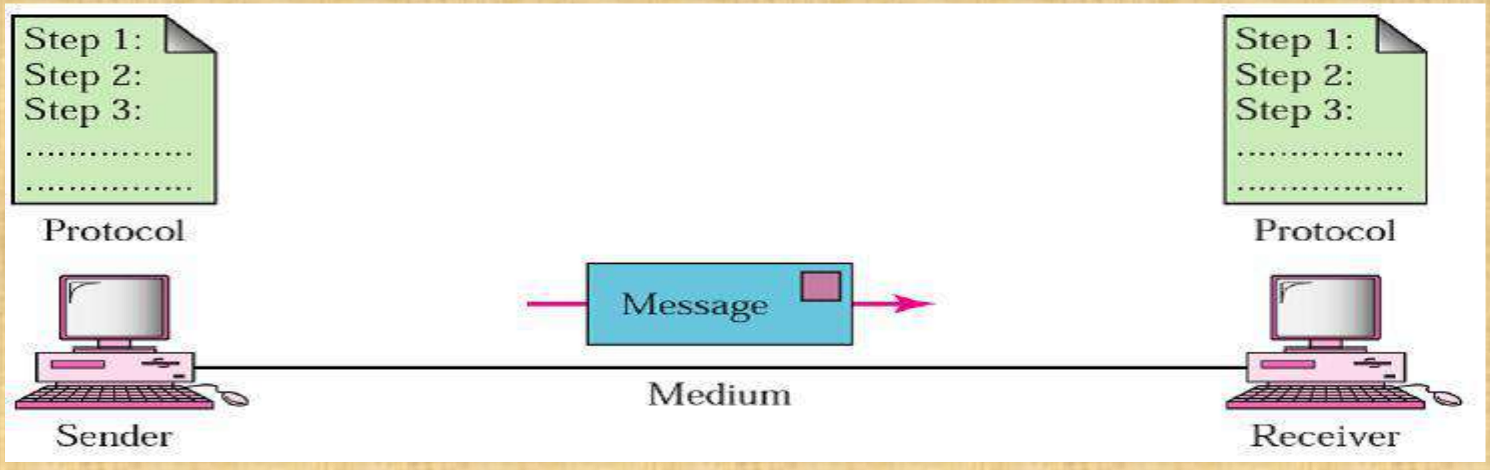
- Components of data communication



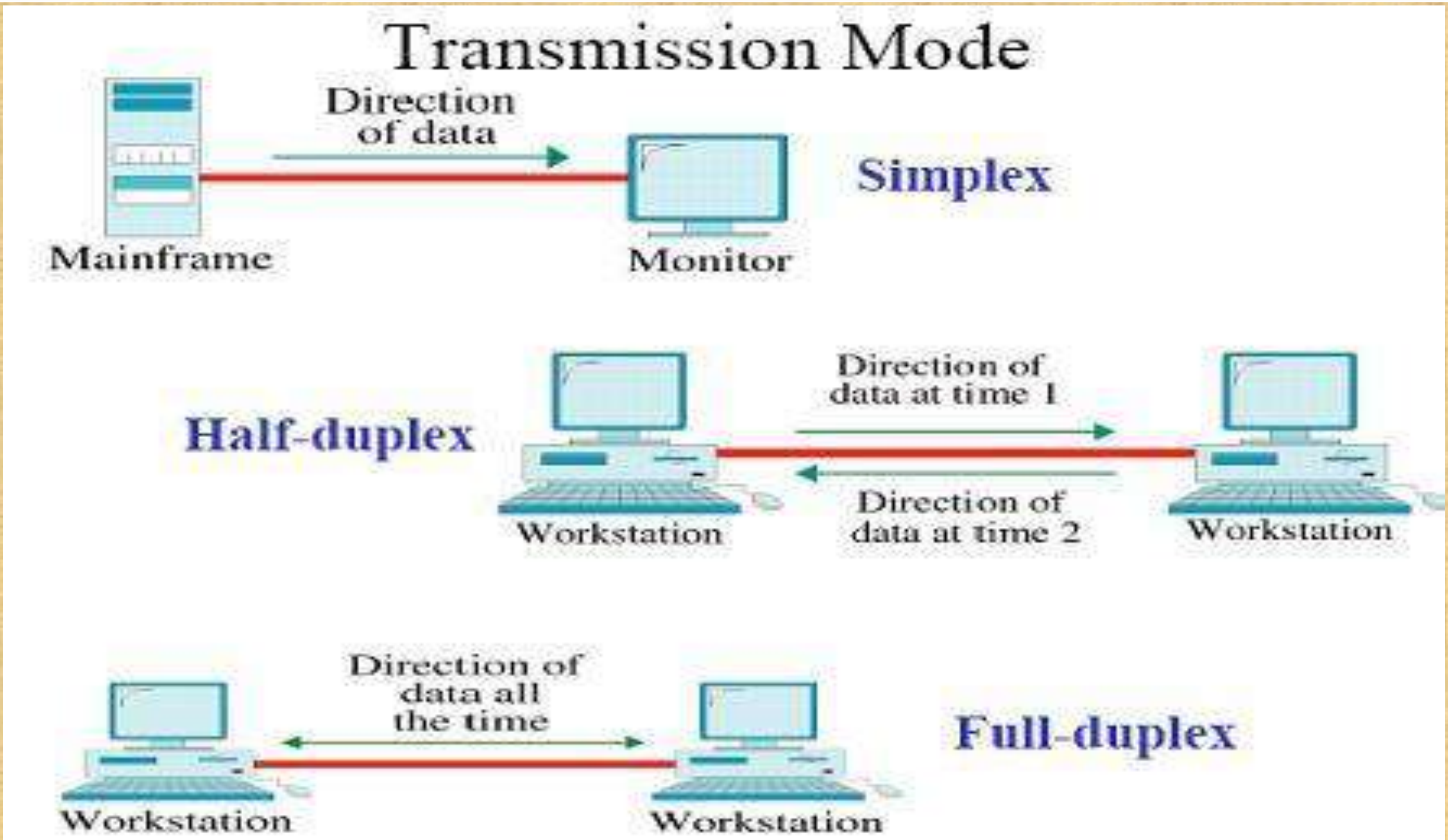
A Simple Communication System

Components of Data Communication

- Transmitter
- Receiver
- Medium
  - Guided medium
    - e.g. twisted pair, optical fiber
  - Unguided medium
    - e.g. air, water, vacuum



Transmission Mode



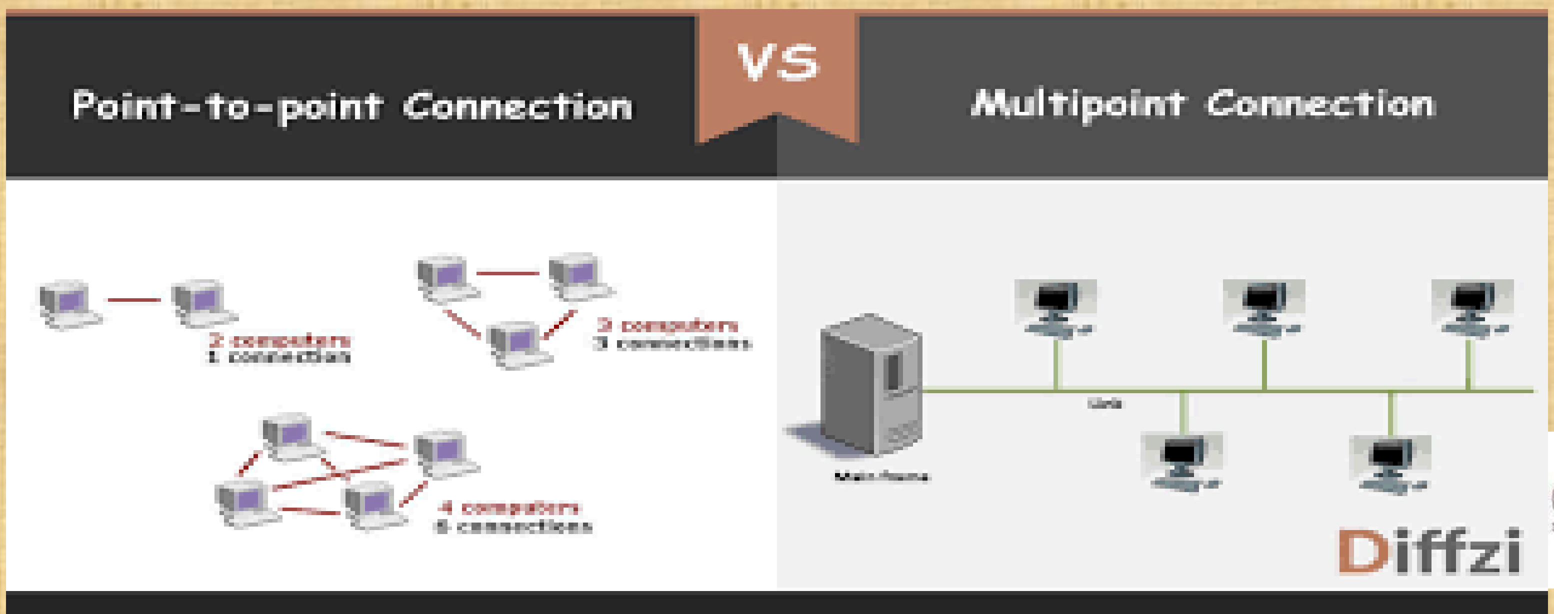
Transmission Mode

- Simplex
  - One direction
    e.g. Television
- Half duplex
  - Either direction, but only one way at a time
    e.g. police radio
- Full duplex
  - Both directions at the same time
    e.g. telephone

Types of Connection

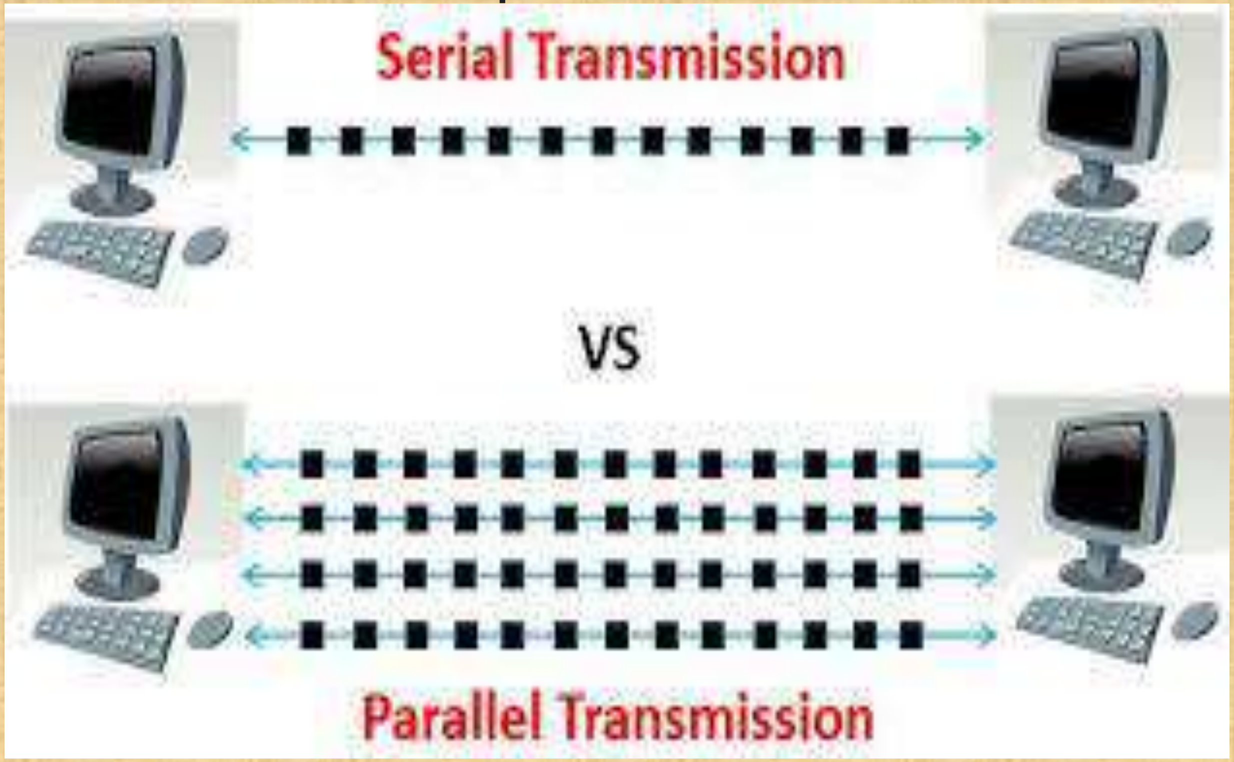
- Point-to-point
  - Direct link
  - Only 2 devices share link

- Multi-point
  - More than two devices share the link



Methods to Transmit data

- **Serial** data transmission sends data bits one after another over a single channel.
- **Parallel** data transmission sends multiple data bits at the same time over multiple channels.



Synchronous and Asynchronous Transmission

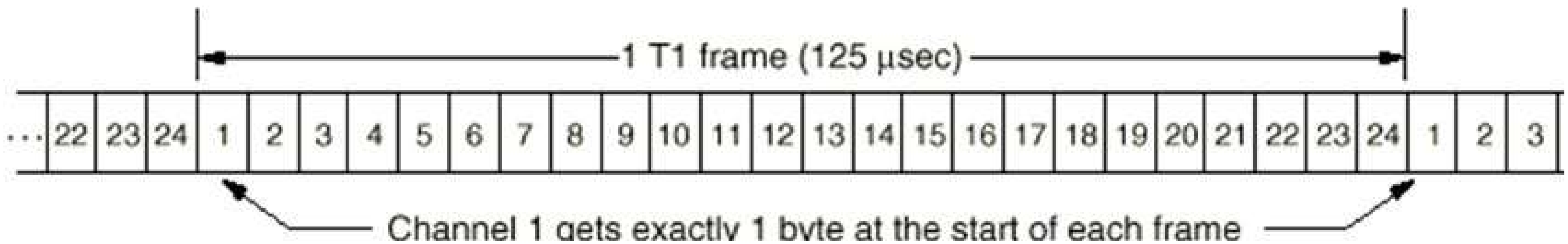
- **Synchronous transmissions** are **synchronized** by an external clock.

  e. g. realtime streaming media, for example IP telephony, IP-TV and video conferencing.

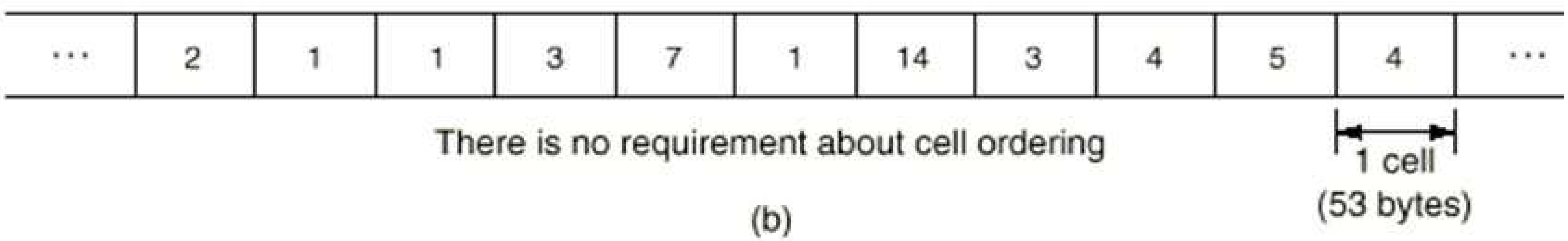
- A**synchronous transmissions** are **synchronized** by special signals along the **transmission** medium.

  e. g. file **transfer**, email and the World Wide Web.

Synchronous Vs. Asynchronous Data Transmission



Synchronous Transmission in a T1 Line



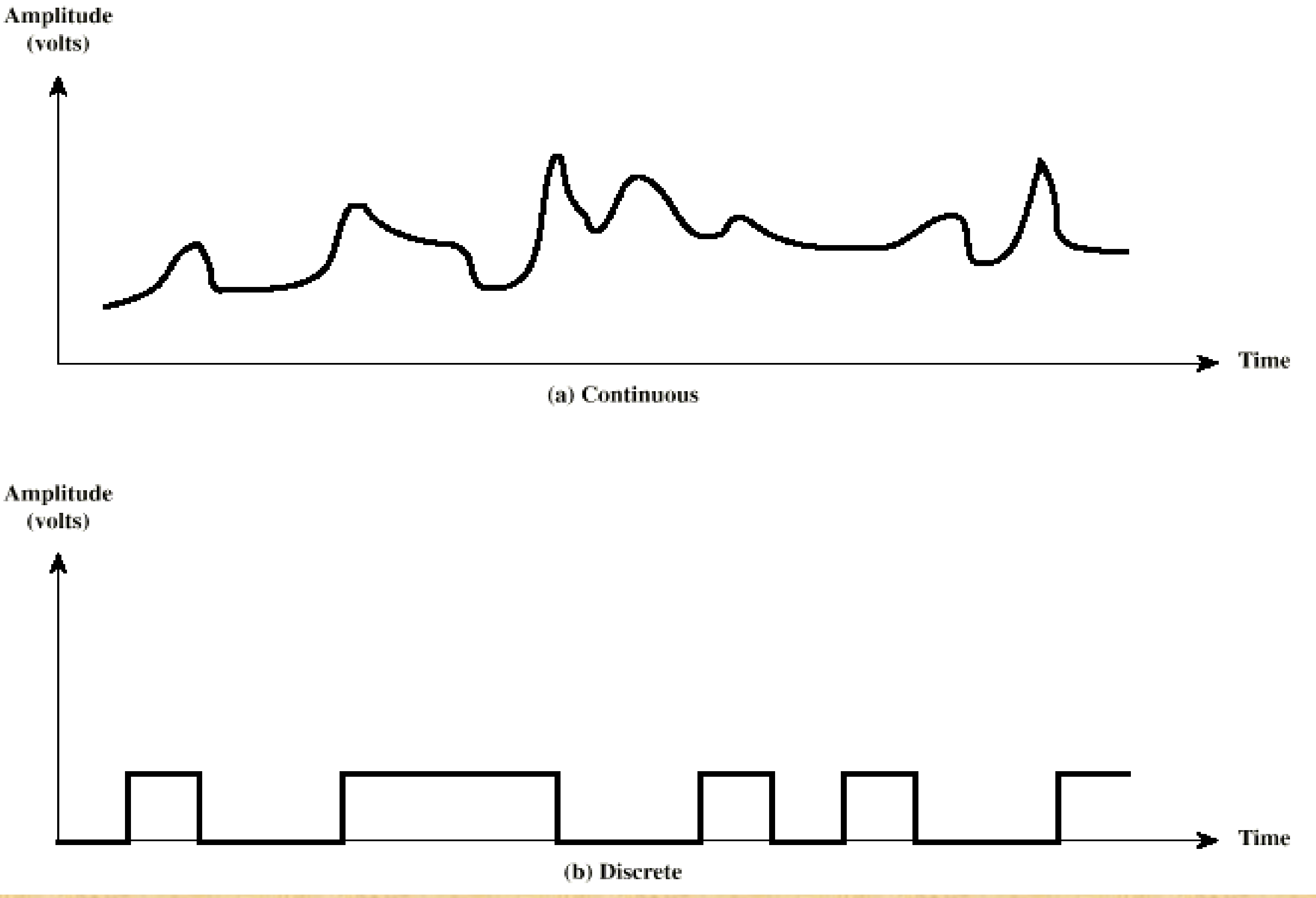
Asynchronous Transmission in an ATM Line

Frequency, Spectrum and Bandwidth

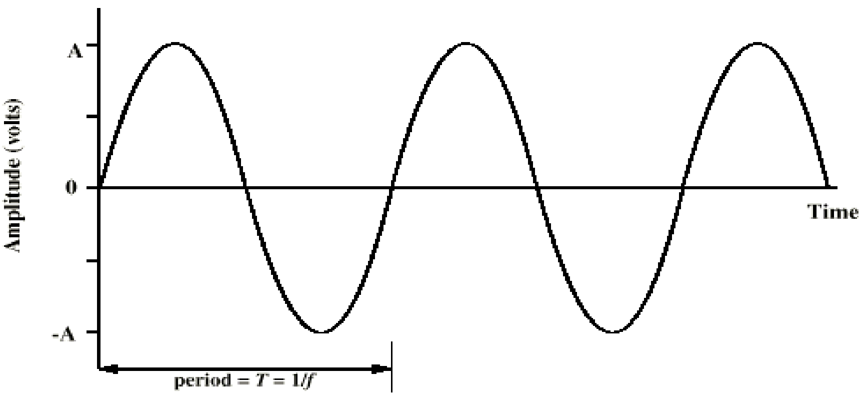
Time domain concepts

- Continuous signal
  - Various in a smooth way over time
- Discrete signal
  - Maintains a constant level then changes to another constant level
- Periodic signal
  - Pattern repeated over time
- Aperiodic signal
  - Pattern not repeated over time

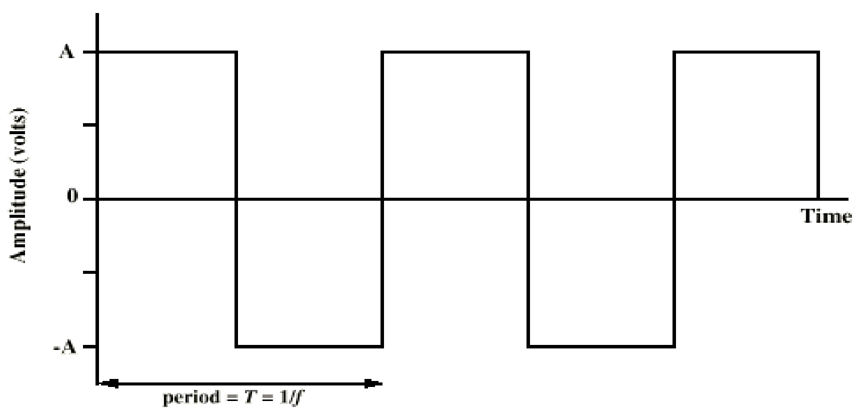
Continuous & Discrete Signals



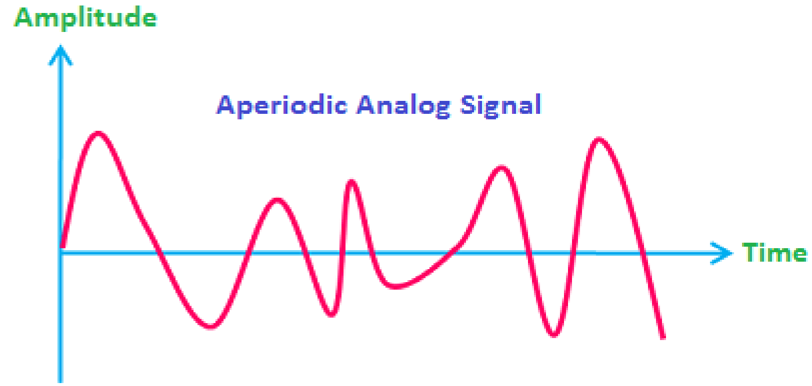
Periodic & Aperiodic Signals

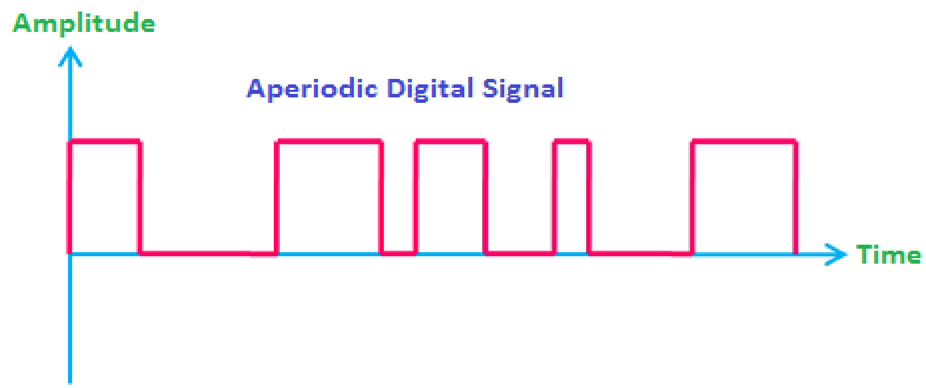


(a) Sine wave



(b) Square wave

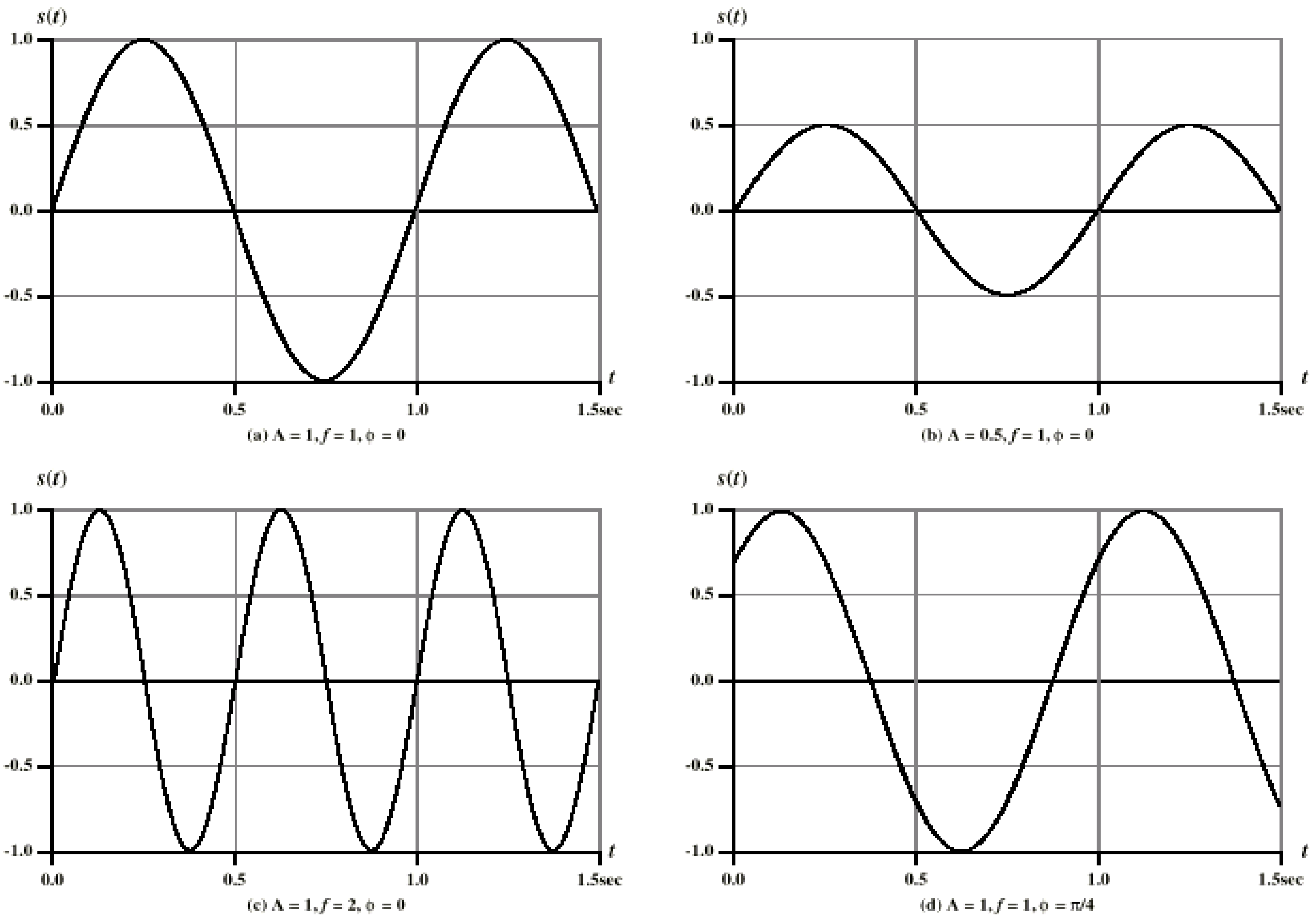




Sine Wave

- Peak Amplitude (A)
  - maximum strength of signal
  - volts
- Frequency (f)
  - Rate of change of signal
  - Hertz (Hz) or cycles per second
  - Period = time for one repetition (T)
  - $T = 1/f$
- Phase (ϕ)
  - Relative position in time

Varying Sine Waves



Wavelength

- Distance occupied by one cycle
- Distance between two points of corresponding phase in two consecutive cycles
- λ
- Assuming signal velocity v
  - $\lambda = vT$
  - $\lambda f = v$
  - $c = 3*10^8\ ms^{-1}$ (speed of light in free space)

Frequency Domain Concepts

- Spectrum
  - range of frequencies contained in signal
- Absolute bandwidth
  - width of spectrum
- Effective bandwidth
  - Often just *bandwidth*
  - Narrow band of frequencies containing most of the energy
- DC Component : Component of zero frequency

When the voltage level in a digital signal is constant for a while, the spectrum creates very low frequencies, called **DC components**, that present **problems** for a system that cannot pass low frequencies.

Bandwidth, Throughput and Data Rate

- **What is Bandwidth?**
  Bandwidth is the measurement of the ability of an electronic communications device or system to send and receive information.

- **What is Throughput?**
  Throughput is the amount of data that enters and goes through a system.

- **What is Data Rate?**
  Data rate is the speed at which data is transferred between two devices, measured in mega bits per second (Mbps or mbps).

Analog and Digital Data Transmission

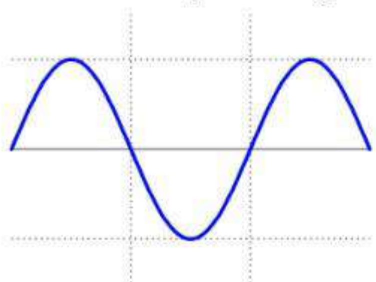
- Data
  - Entities that convey meaning
- Signals
  - Electric or electromagnetic representations of data
- Transmission
  - Communication of data by propagation and processing of signals

Data

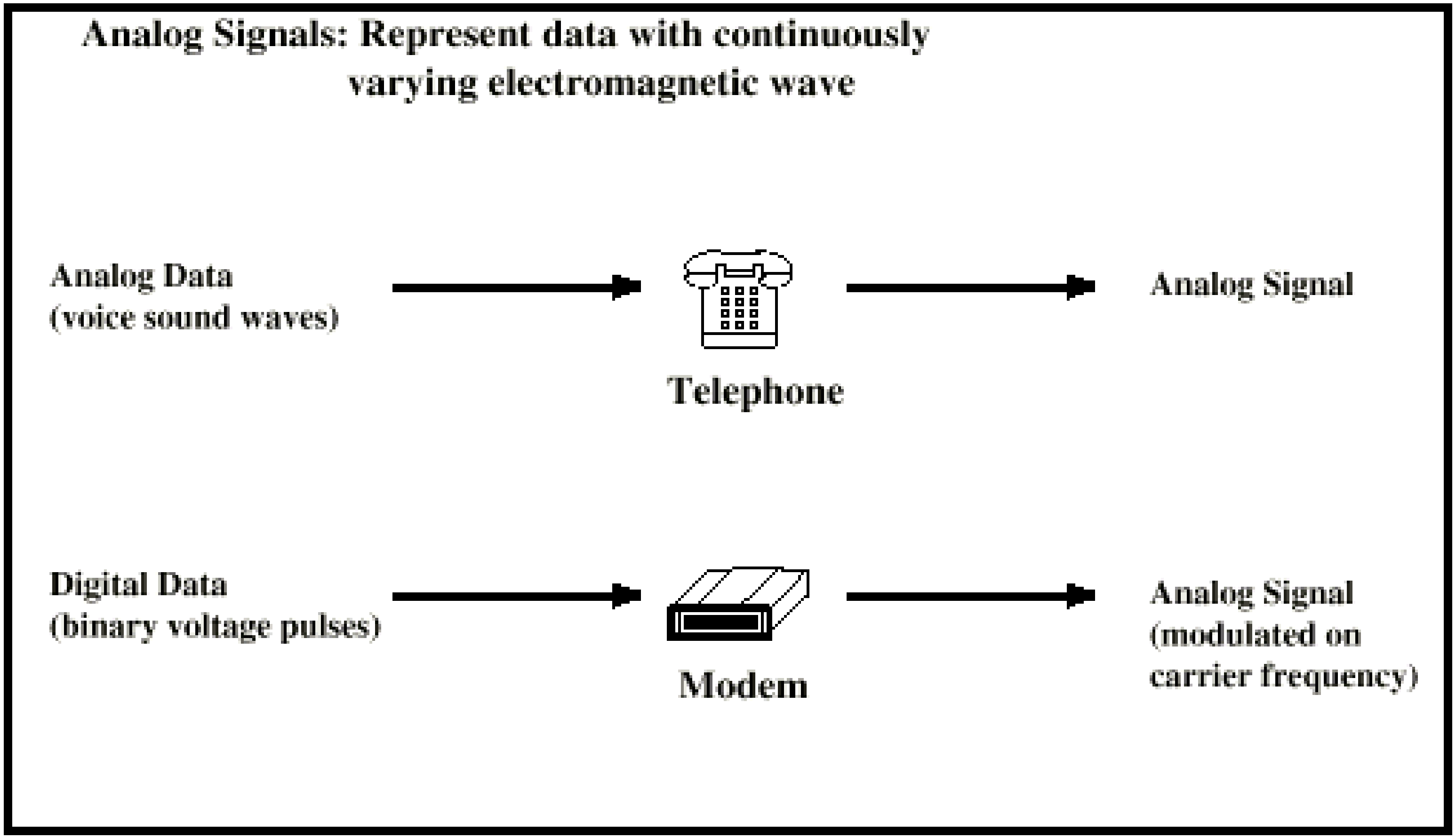
- Analog
  - Continuous values within some interval
  - e.g. sound, video
- Digital
  - Discrete values
  - e.g. text, integers

Analog and Digital Signals

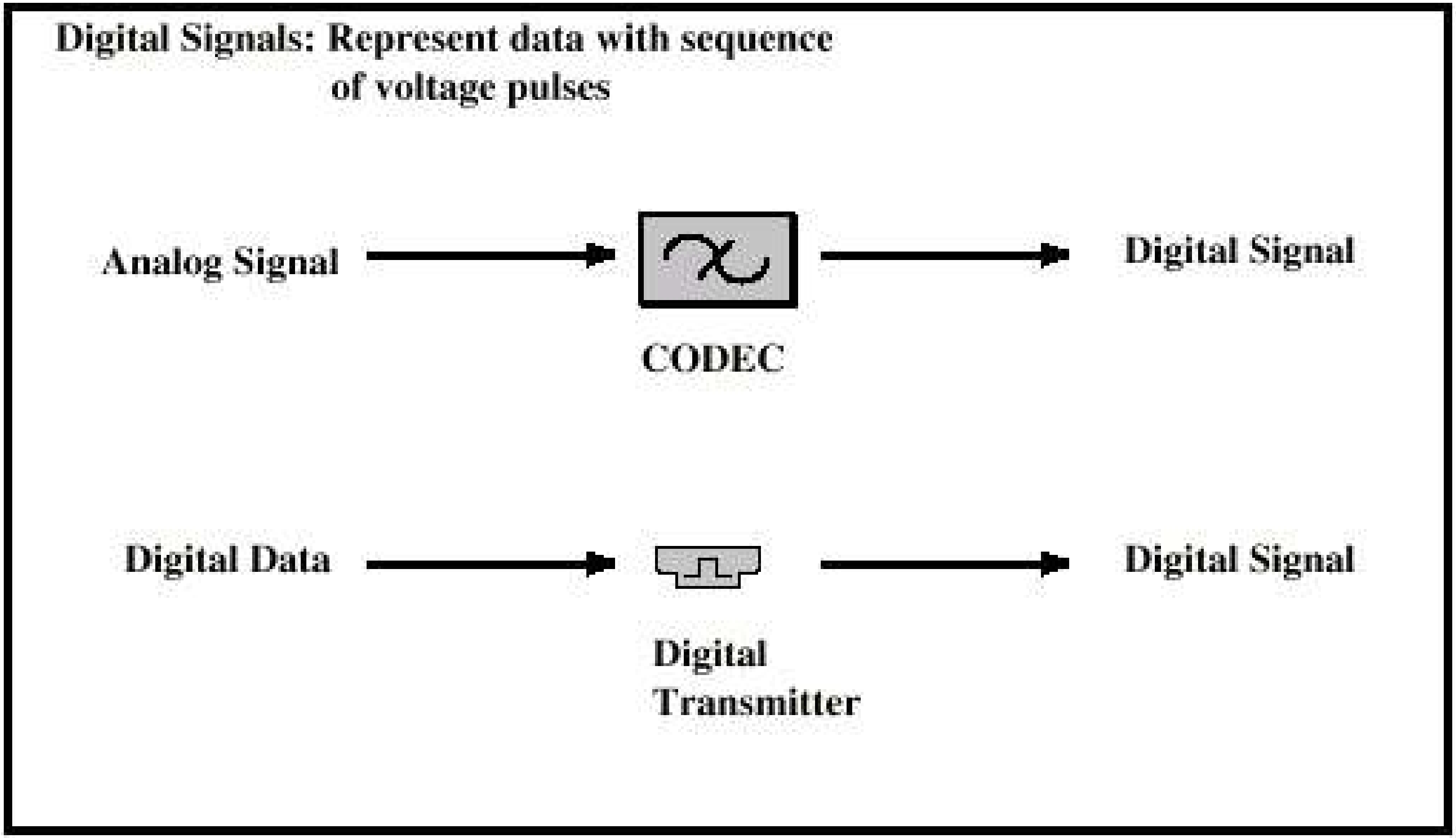
Table 1: Analog vs. Digital Waves Structure and Function

	Analog	Digital
Signal	Analog signals are continuous signals	Digital signals are discrete (binary) signals
Waves	Denoted by sine (curvy) waves 	Denoted by square (block) waves 
Examples	Human voice in air, record player, cassette tape, VHS tapes	Computers, CDs, DVDs, mP3s, digital photos, and cell phones
Uses	Can be used in analog devices only	Used in computing and digital electronics

Analog Signals Carrying Analog and Digital Data



Digital Signals Carrying Analog and Digital Data



Analog Transmission

- Analog signal transmitted without regard to content
- May be analog or digital data
- Attenuated over distance
- Use amplifiers to boost signal
- Also amplifies noise

Digital Transmission

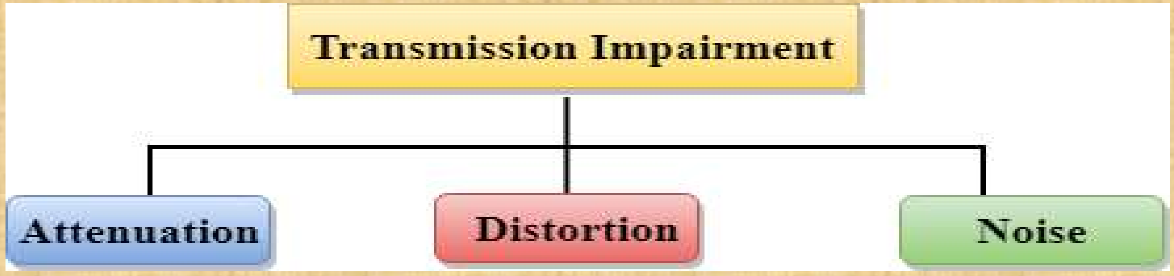
- Concerned with content
- Integrity endangered by noise, attenuation etc.
- Repeaters used
- Repeater receives signal
- Extracts bit pattern
- Retransmits
- Attenuation is overcome
- Noise is not amplified

Advantages of Digital Transmission

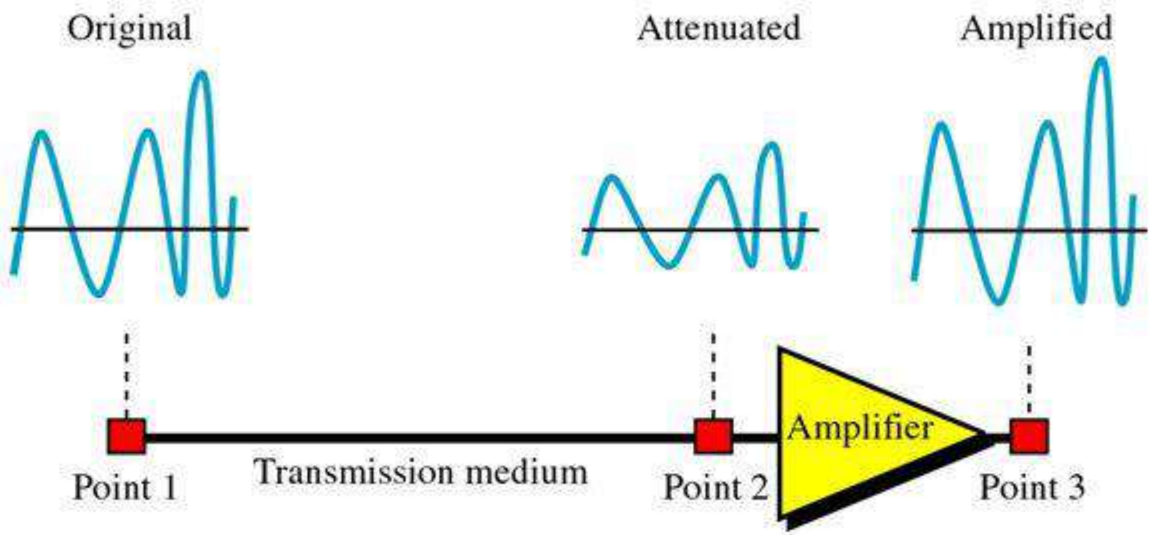
- Digital technology
  - Low cost LSI/VLSI technology
- Data integrity
  - Longer distances over lower quality lines
- Capacity utilization
  - High bandwidth links economical
  - High degree of multiplexing easier with digital techniques
- Security & Privacy
  - Encryption
- Integration
  - Can treat analog and digital data similarly

Transmission Impairments

- Signal received may differ from signal transmitted
- Analog - degradation of signal quality
- Digital - bit errors
- Caused by
  - Attenuation
  - Delay distortion
  - Noise

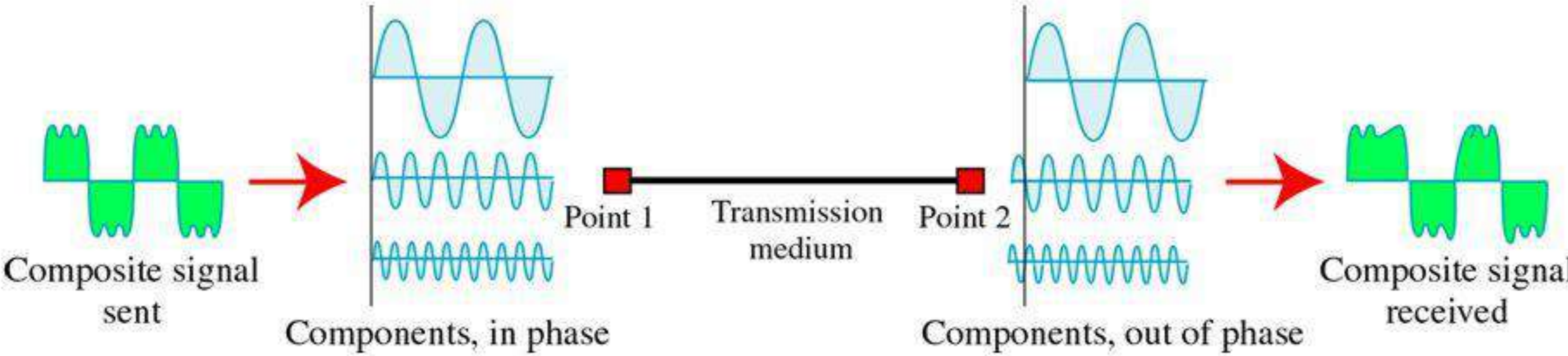


Attenuation



- Attenuation:
  - Signal strength falls off with distance
  - Depends on medium
  - Received signal strength:
    - must be enough to be detected
    - must be sufficiently higher than noise to be received without error
  - Attenuation is an increasing function of frequency

Delay Distortion

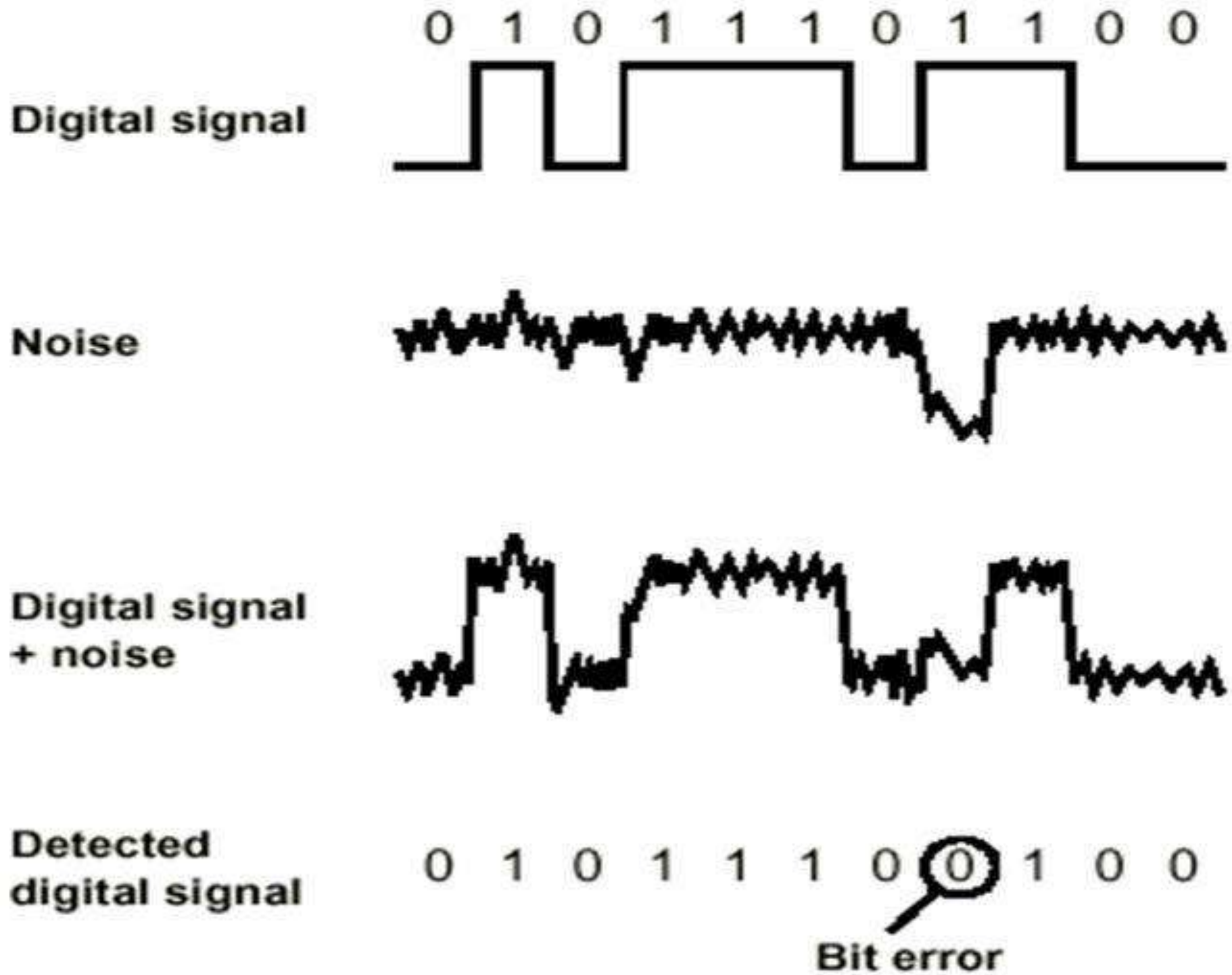


- Delay Distortion:
  - Only in guided media
  - Propagation velocity varies with frequency
  - Called also "Intersymbol Interference". Due to delay distortions, some of the signal components of one bit position will spill over into other bit positions.

Noise

- Additional signals inserted between transmitter and receiver
- Thermal
  - Due to thermal agitation of electrons
  - Uniformly distributed
  - White noise
- Intermodulation
  - Signals that are the sum and difference of original frequencies sharing a medium
- Crosstalk : A signal from one line is picked up by another
- Impulse : Irregular pulses or spikes
  - e.g. External electromagnetic interference
  - Short duration
  - High amplitude

Noise in Digital transmission



Various Encoding Techniques

- **Encoding** is the conversion of streams of bits into a signal (digital or analog).

- **Categories of Encoding techniques:**
  - Digital data, digital signal
  - Analogue data, digital signal

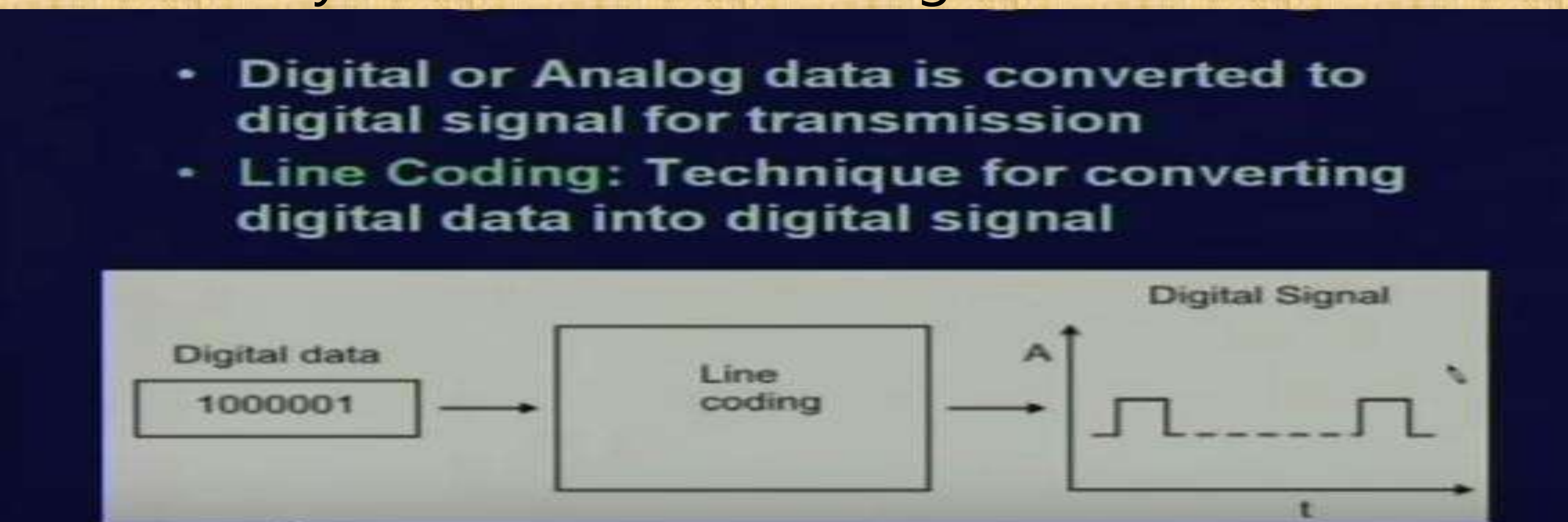
  Digital transmission

  - Digital data, analog signal
  - Analogue data, analog signal

  Analog transmission

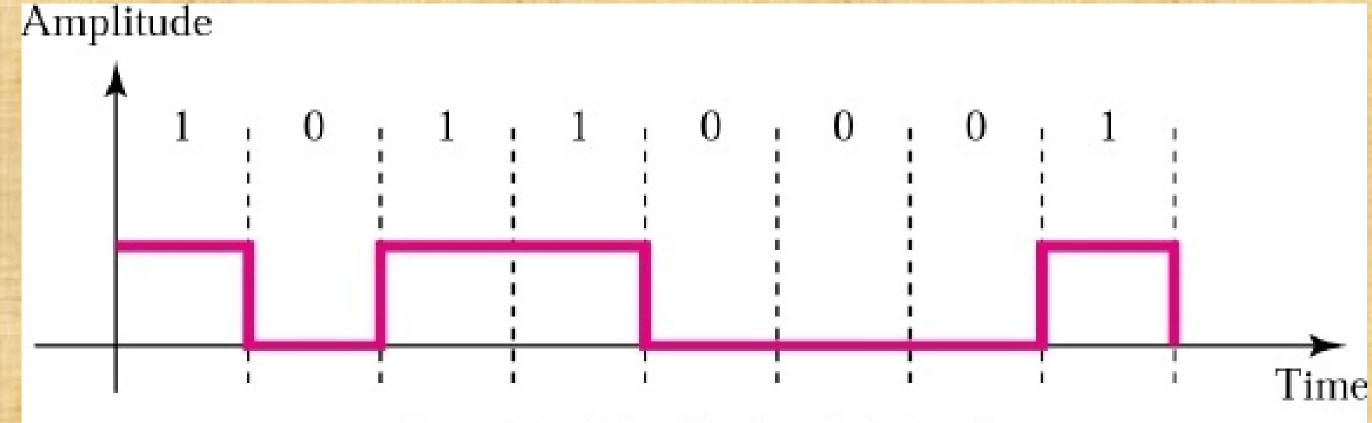
Digital Data, Digital Signal

- Digital signal
  - Discrete, discontinuous voltage pulses
  - Each pulse is a signal element
  - Binary data encoded into signal elements

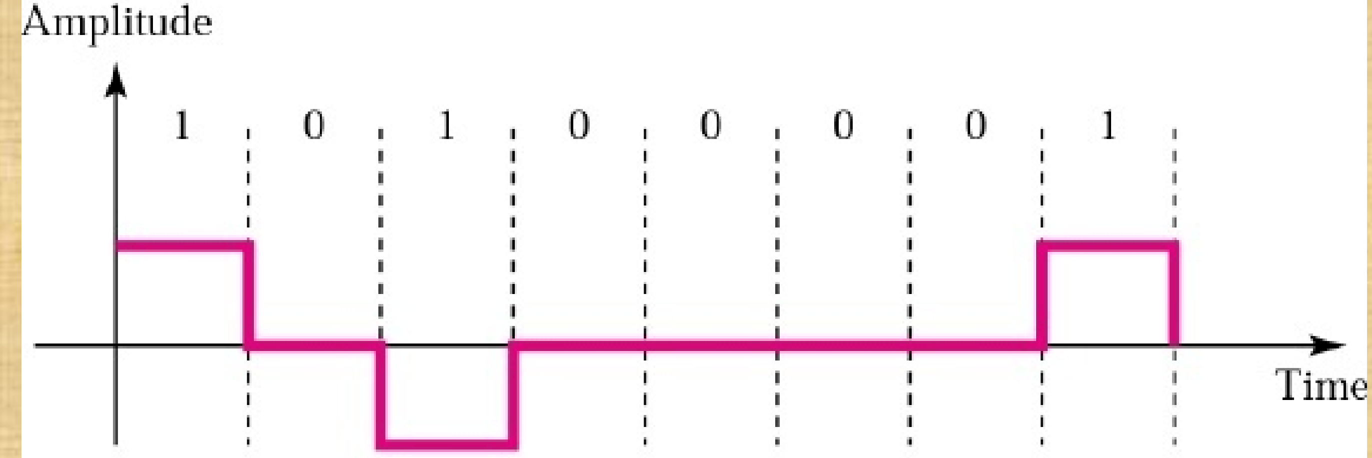


Important Characterstics

- No. of Signal levels
- Bit rate v/s Baud rate
- DC Components
- Signal Spectrum
- Noise Immunity
- Error detection
- Synchronization
- Cost of Implementation



a. Two signal levels, two data levels

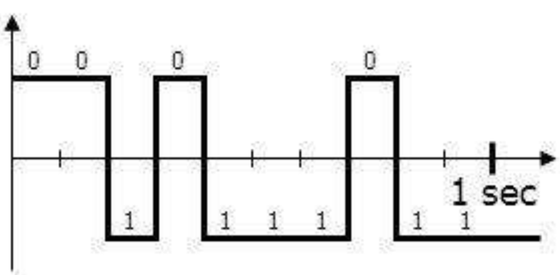


b. Three signal levels, three data levels

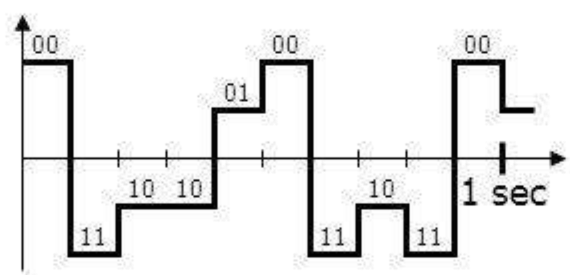
I=2BlogM

Baud and Bit Rate

- **Baud** → How many times a signal changes per second
- **Bit rate** → How many bits can be sent per time unit (usually per second)
- Bit rate is controlled by baud and number of signal levels

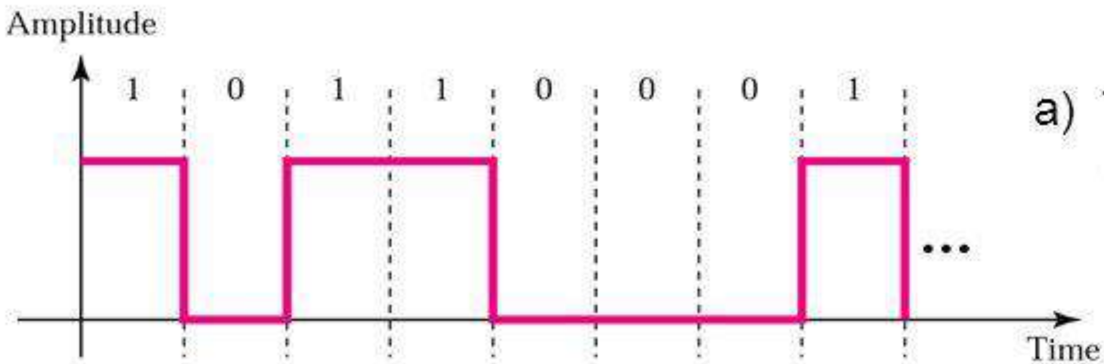


Baud = 10
Bit rate = 10 bps



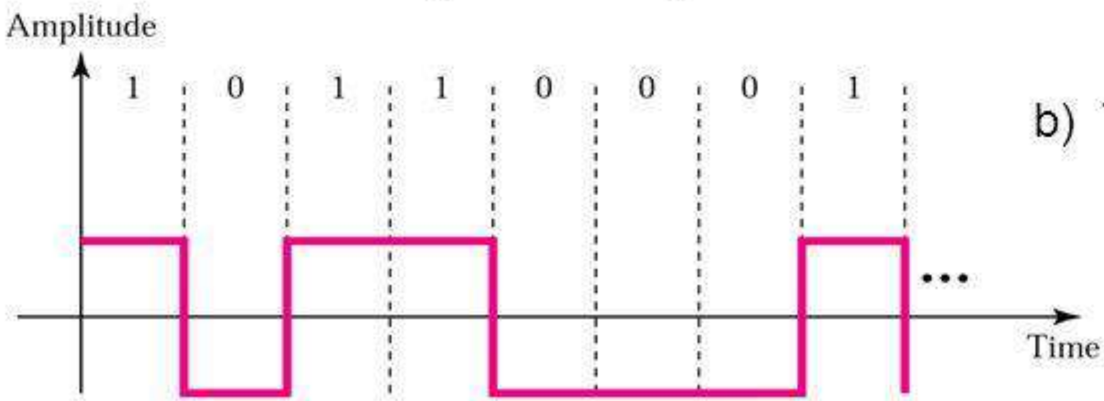
Baud = 10
Bit rate = 20 bps

- Some line coding scheme leaves a residual direct-current (DC) component (zero frequency).
- This component is undesirable for 2 reason:
  1. Some system does not allow the passage of DC component, the signal is distorted and may create errors in the output.
  2. Create extra energy residing on the line and is useless.



a. A signal with dc component

a) The positive voltage are not canceled by the negative voltages.



b. A signal without dc component

b) The positive voltages are canceled by any negative voltage.

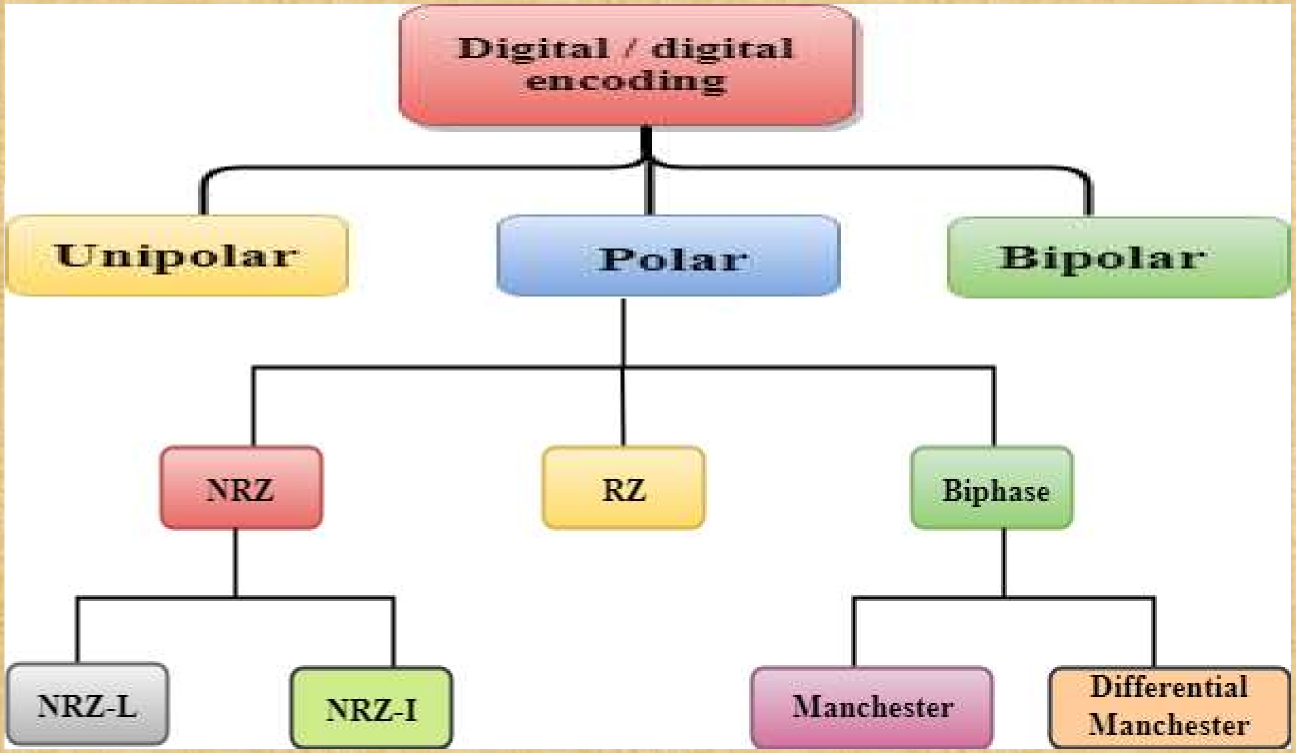
Comparison of Encoding Schemes (1)

- Signal Spectrum
  - Lack of high frequencies reduces required bandwidth
  - Lack of dc component allows ac coupling via transformer, providing isolation
  - Concentrate power in the middle of the bandwidth
- Clocking
  - Synchronizing transmitter and receiver
  - External clock
  - Sync mechanism based on signal

Comparison of Encoding Schemes (2)

- Error detection
  - Can be built in to signal encoding
- Signal interference and noise immunity
  - Some codes are better than others
- Cost and complexity
  - Higher signal rate (& thus data rate) lead to higher costs
  - Some codes require signal rate greater than data rate

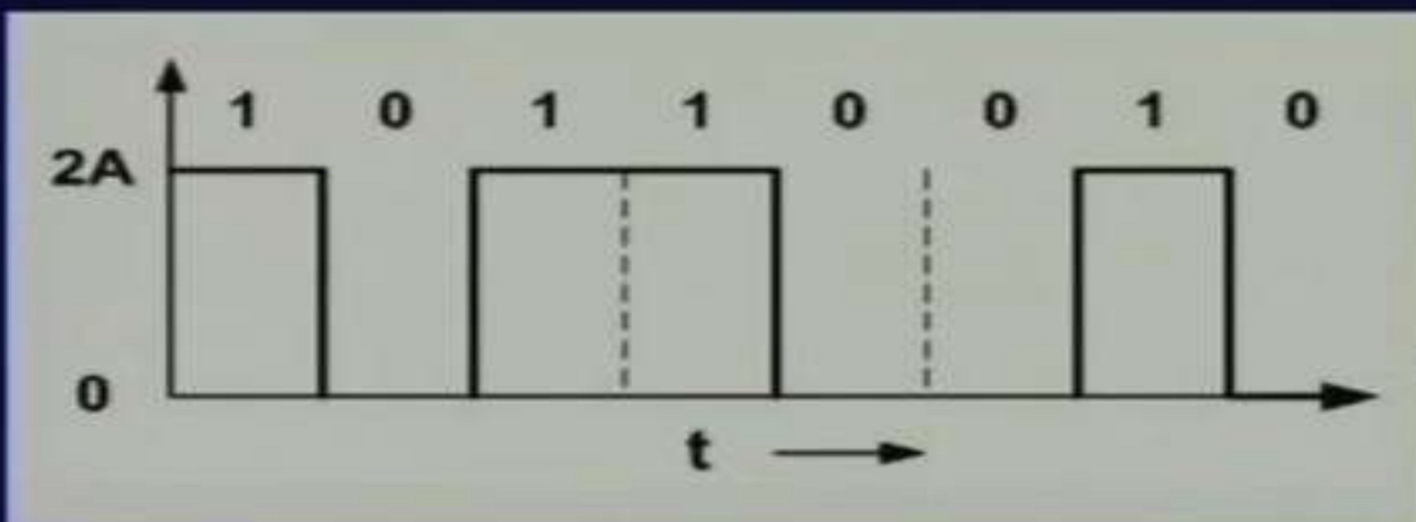
Encoding Schemes



Unipolar Encoding Schemes

Unipolar

- Only two voltage levels are used



Unipolar Characteristics

Characteristics of Unipolar Signal:

- It uses only one polarity of voltage level
- Bit rate same as data rate
- DC component present
- Loss of synchronization for long sequences of 0's and 1's.
- Simple but obsolete

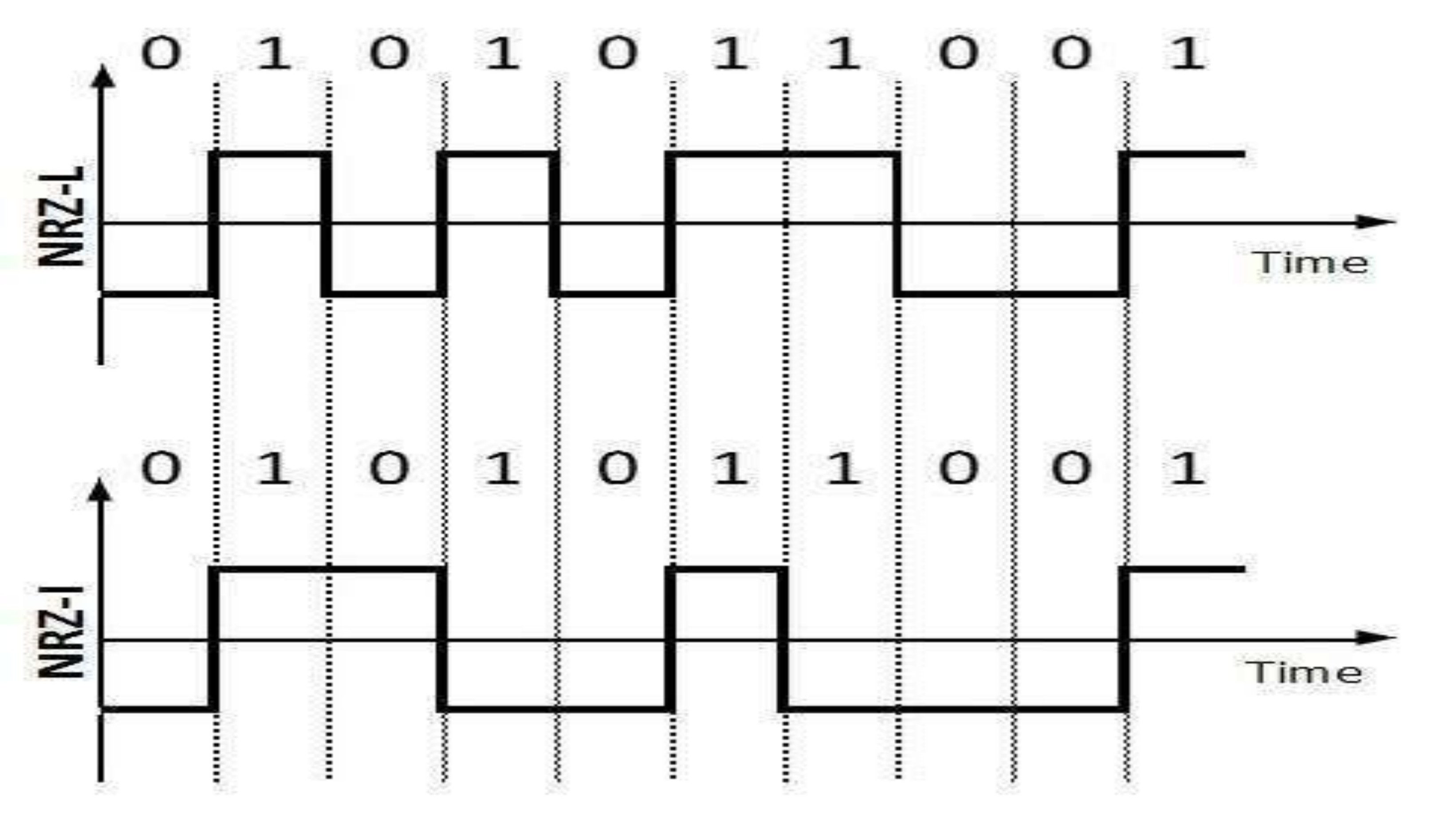
Nonreturn to Zero-Level (NRZ-L)

- Two different voltages for 0 and 1 bits
- Voltage constant during bit interval
  - no transition I.e. no return to zero voltage
- e.g. Absence of voltage for zero, constant positive voltage for one
- More often, negative voltage for one value and positive for the other
- This is NRZ-L

Nonreturn to Zero Inverted (NRZ-I)

- Nonreturn to zero inverted on ones
- Constant voltage pulse for duration of bit
- Data encoded as presence or absence of signal transition at beginning of bit time
- Transition (low to high or high to low) denotes a binary 1
- No transition denotes binary 0
- An example of differential encoding

NRZ

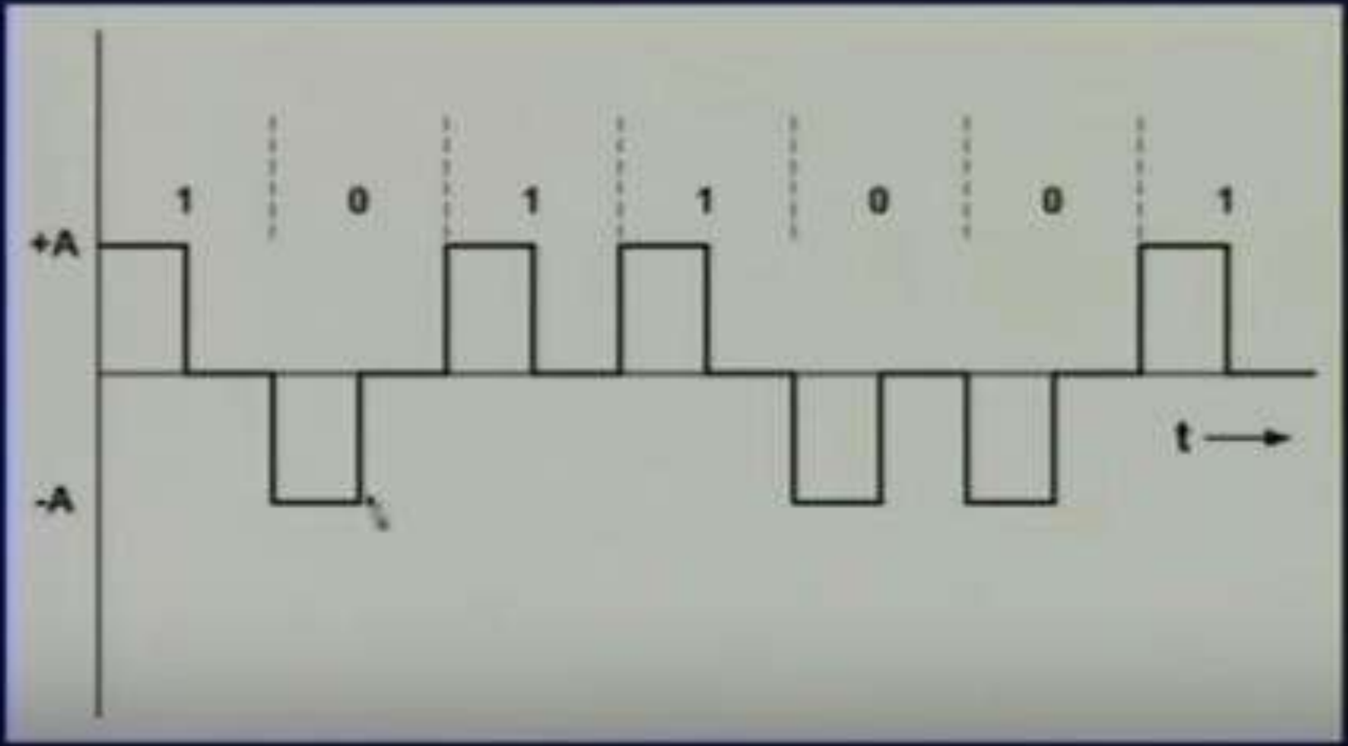


NRZ pros and cons

- Pros
  - Two level
  - Make good use of bandwidth
- Cons
  - dc component
  - Lack of synchronization capability
- Used for magnetic recording
- Not often used for signal transmission

RZ Encoding Scheme

- Return to Zero: To ensure synchronization, there must be a signal transition in each bit

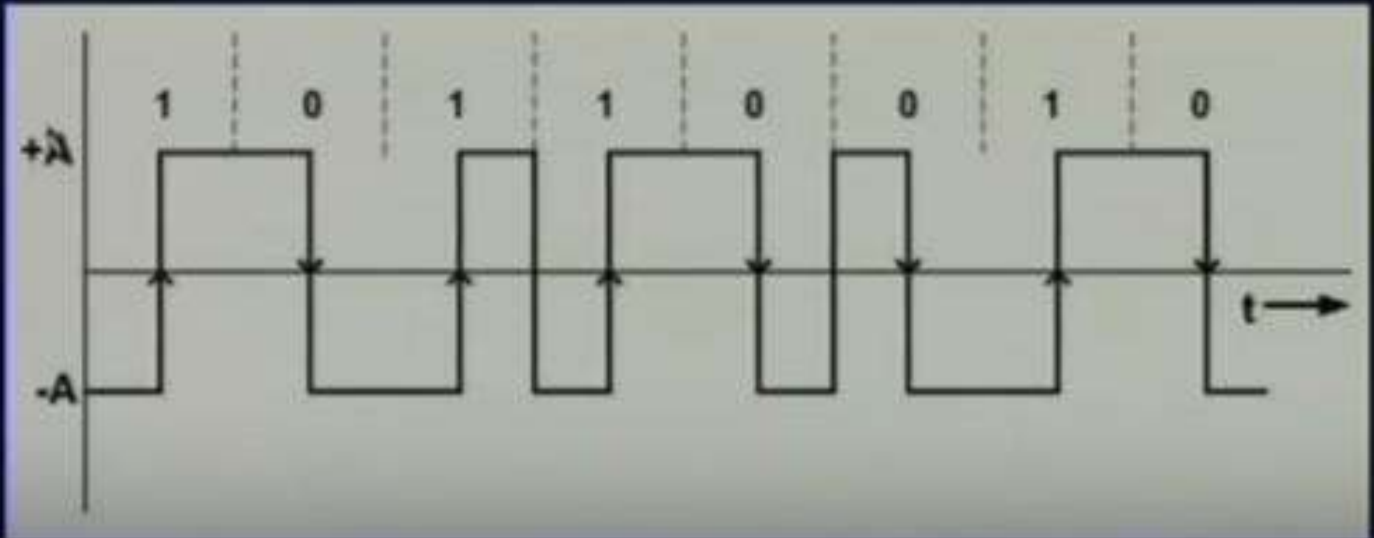


RZ Characterstics

- Three levels
- Bit rate is double that of data rate
- No dc component
- Good synchronization
- Increase in bandwidth is the main limitation

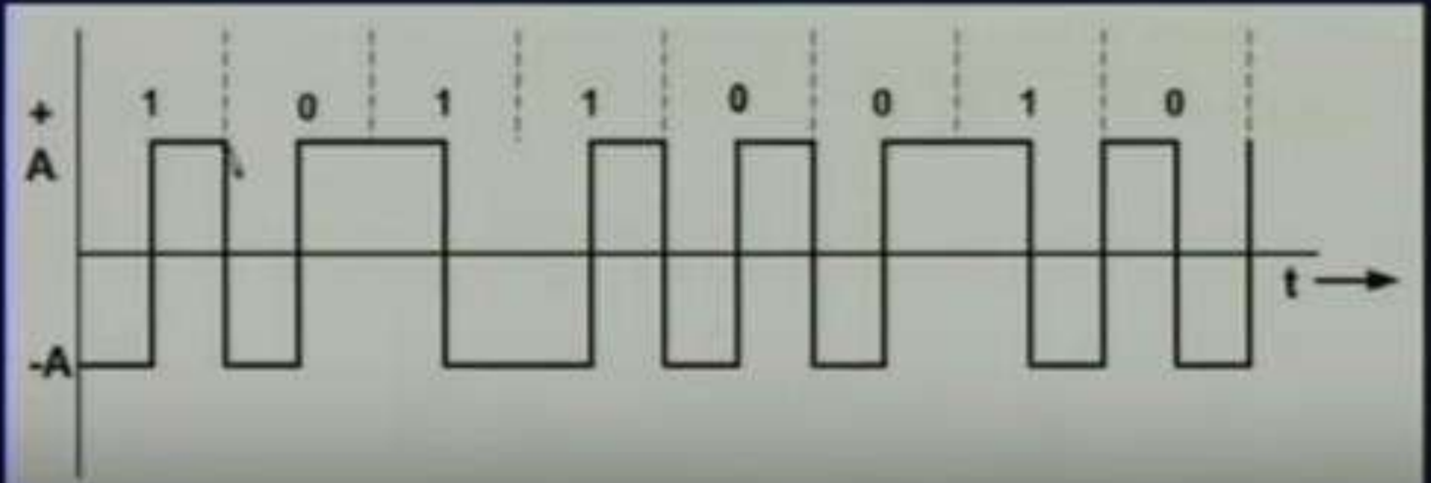
Manchester(Biphase) Encoding

- In Manchester code the mid-bit transition serves as a clocking mechanism and also as data.
- Low-to-high represents a 1 and high-to-low represents a 0



Differential Manchester (Biphase) Encoding

- Presence of transition in the beginning of a bit represents a 0
- Uses inversion in the middle of each bit for synchronization



Characteristic of Biphase Encoding

- Two levels
- No DC component
- Good synchronization
- Higher bandwidth due to doubling of bit rate with respect to data rate

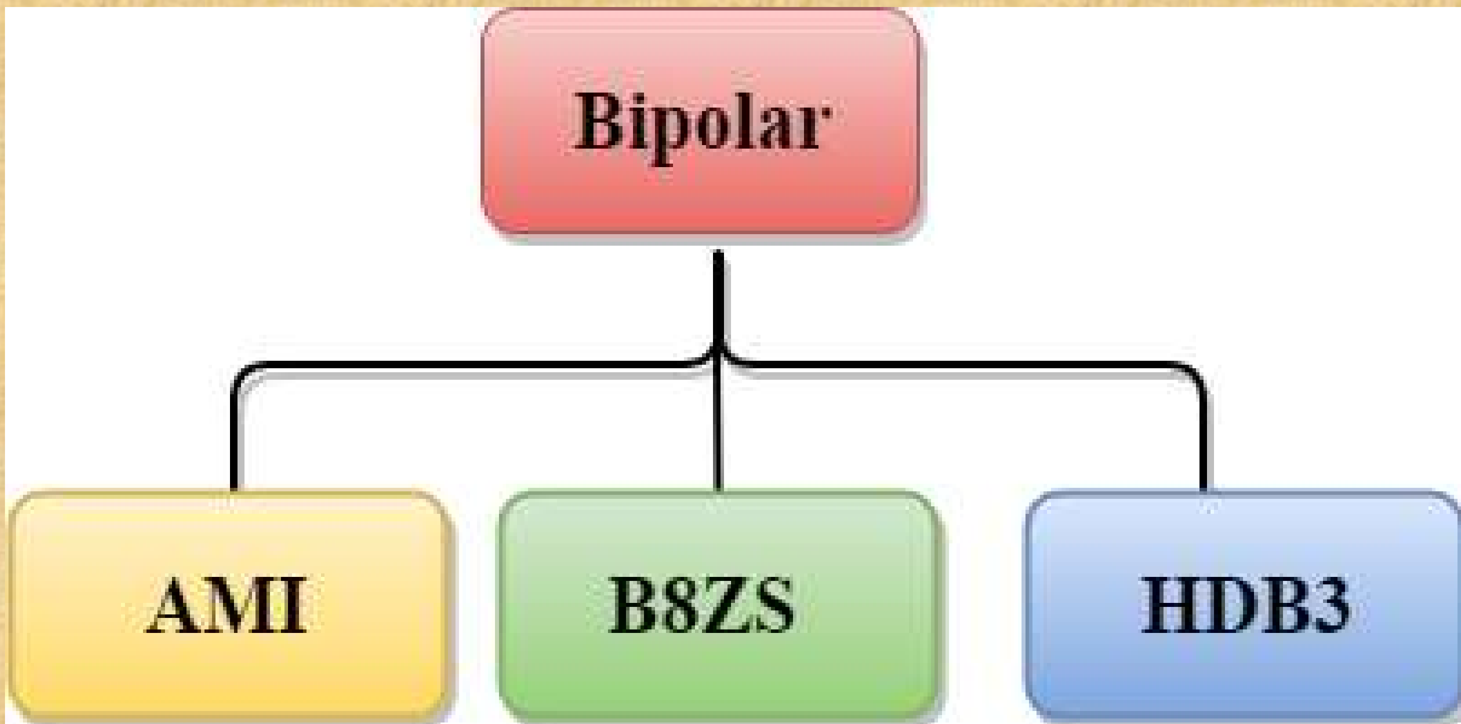
Biphase

- Manchester
  - Transition in middle of each bit period
  - Transition serves as clock and data
  - Low to high represents one
  - High to low represents zero
  - Used by IEEE 802.3
- Differential Manchester
  - Midbit transition is clocking only
  - Transition at start of a bit period represents zero
  - No transition at start of a bit period represents one
  - Note: this is a differential encoding scheme
  - Used by IEEE 802.5

Biphase Pros and Cons

- Cons
  - At least one transition per bit time and possibly two
  - Maximum modulation rate is twice NRZ
  - Requires more bandwidth
- Pros
  - Synchronization on mid bit transition (self clocking)
  - No dc component
  - Error detection
    - Absence of expected transition

Types of Bipolar encoding



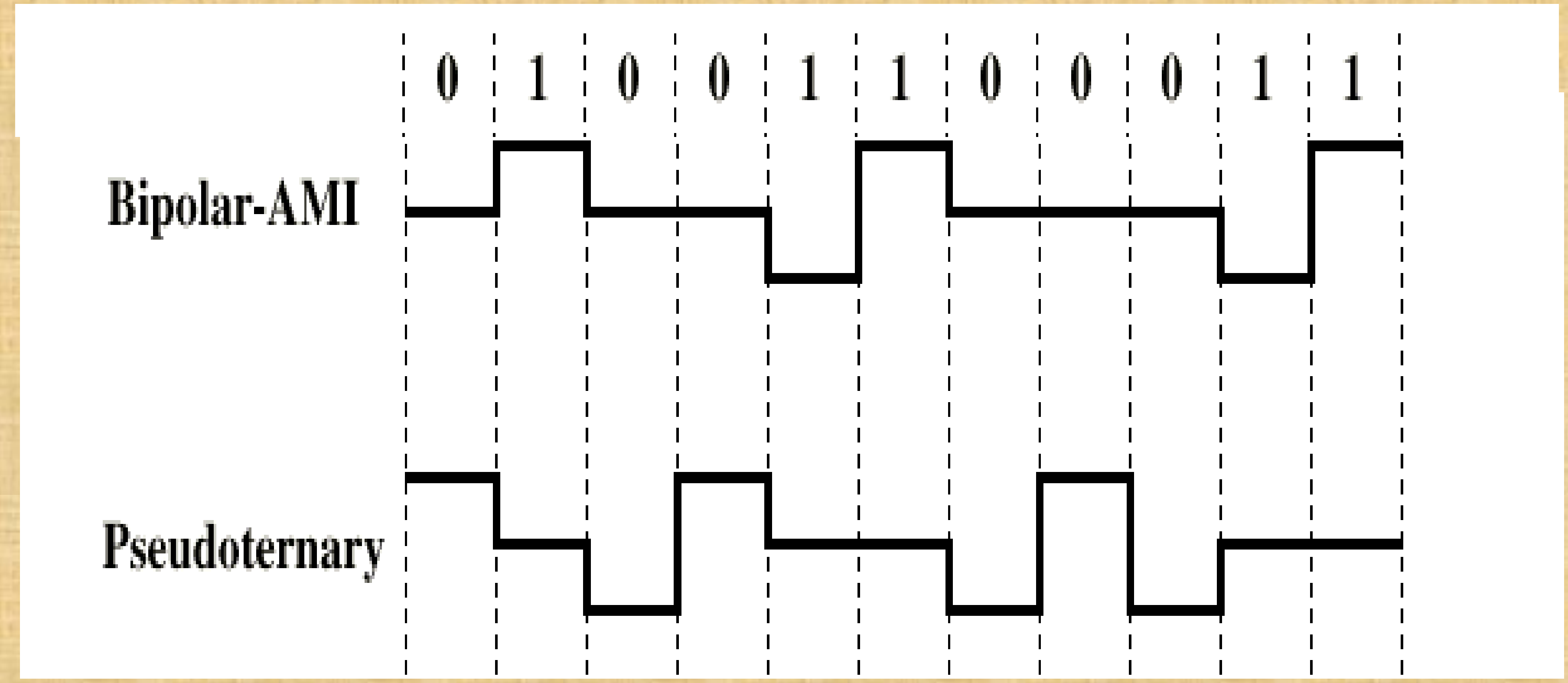
Multilevel Binary

- Use more than two levels
- Bipolar-AMI (Amplitude Mark Inversion)
  - zero represented by no line signal
  - one represented by positive or negative pulse
  - one pulses alternate in polarity
  - No loss of sync if a long string of ones (zeros still a problem)
  - No net dc component
  - Lower bandwidth
  - Easy error detection

Pseudoternary

- One represented by absence of line signal
- Zero represented by alternating positive and negative
- No advantage or disadvantage over bipolar-AMI

Bipolar-AMI and Pseudoternary

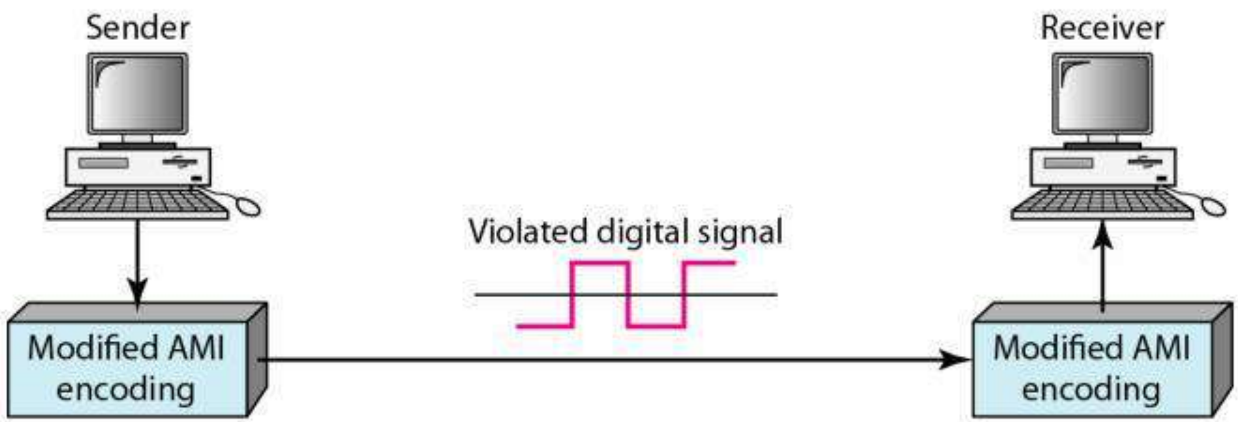


Trade Off for Multilevel Binary

- Not as efficient as NRZ
  - Each signal element only represents one bit
  - In a 3 level system could represent $\log_2 3 = 1.58$ bits
  - Receiver must distinguish between three levels (+A, -A, 0)
  - Requires approx. 3dB more signal power for same probability of bit error

Scrambling

- Biphase : not suitable for long distance communication due to its wide bandwidth requirement
- Combination of block coding and NRZ: not suitable for long distance encoding due to its DC component problem
- Bipolar AMI: synchronization problem → Scrambling



Two cases of B8ZS scrambling technique

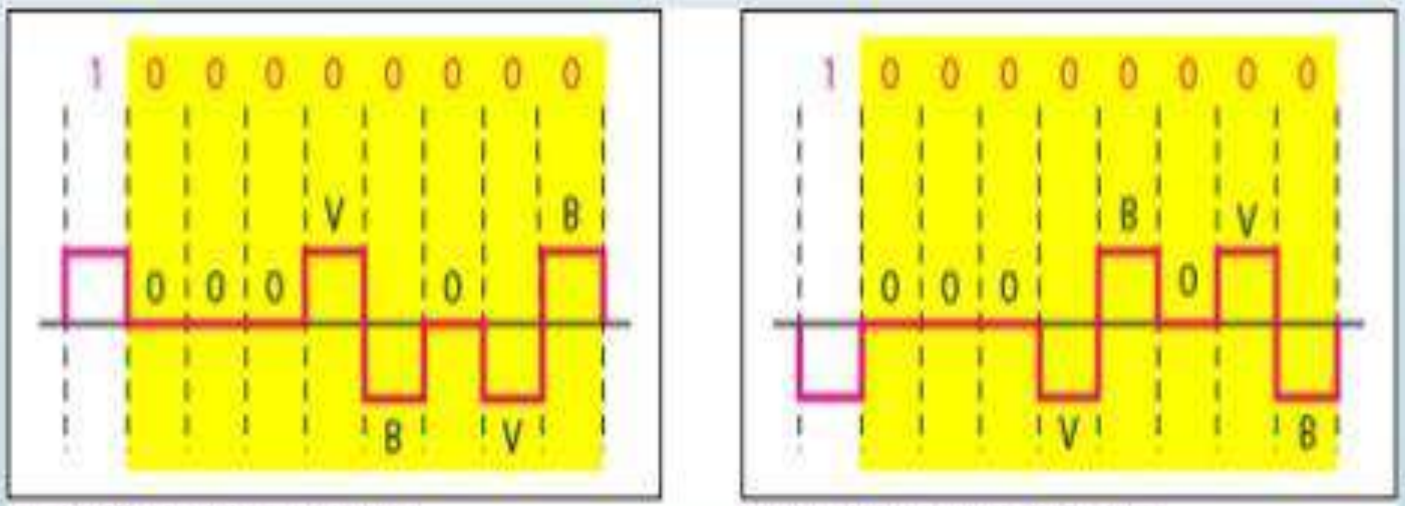
- The main formula for B8ZS is 000VB0VB

Where V

- stands for "violation bit"
- Follows the polarity of previous non-zero bit

B

- stands for "bipolar bit" or "balance bit"
- Inverses the polarity of previous non-zero bit

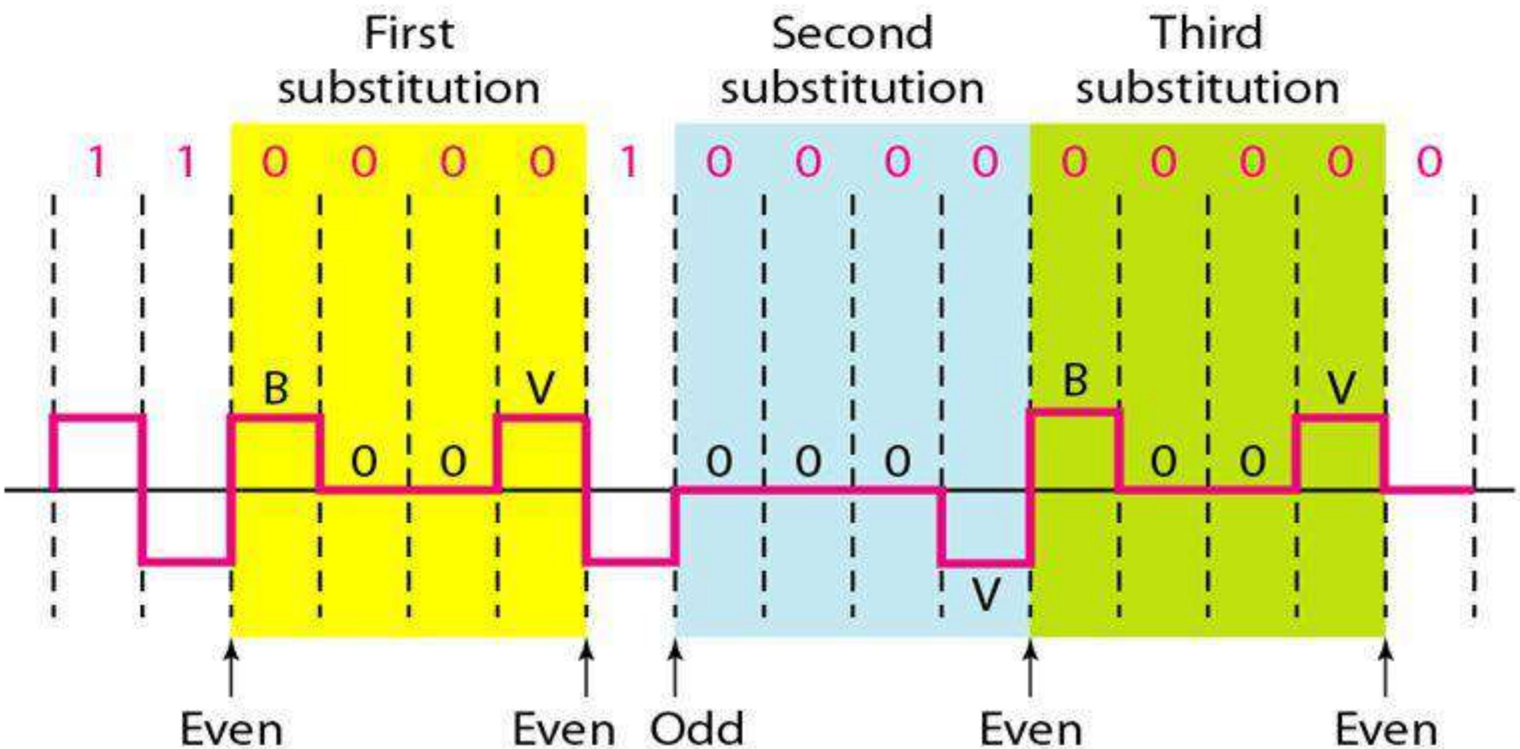


a. Previous level is positive.

b. Previous level is negative.

HDB3 Substitution Rules (Europe)

	Number of Bipolar Pulses (ones) since Last Substitution	
Polarity of Preceding Pulse	**Odd**	**Even**
−	000−	+00+
+	000+	−00−



Example-1

HDB 3 coding of 0000_2

Number of marks after last substitution	Pattern	Previous pulse	Coded
Odd	000V	+	000+
		−	000−
Even	B00V	+	−00−
		−	+00+

The pattern of bits (initially consider odd 1s after last substitution):

101 **0000** 1**0000** 1 1**0000**1 1 1**0000**1 1 1 1**0000** 10 1**0000**$_2$

Encoded in HDB3 considering odd parity at the starting is:

+0−000V+000V−+B00V+−+000V−+−+ B00V+0− B00V

which is:

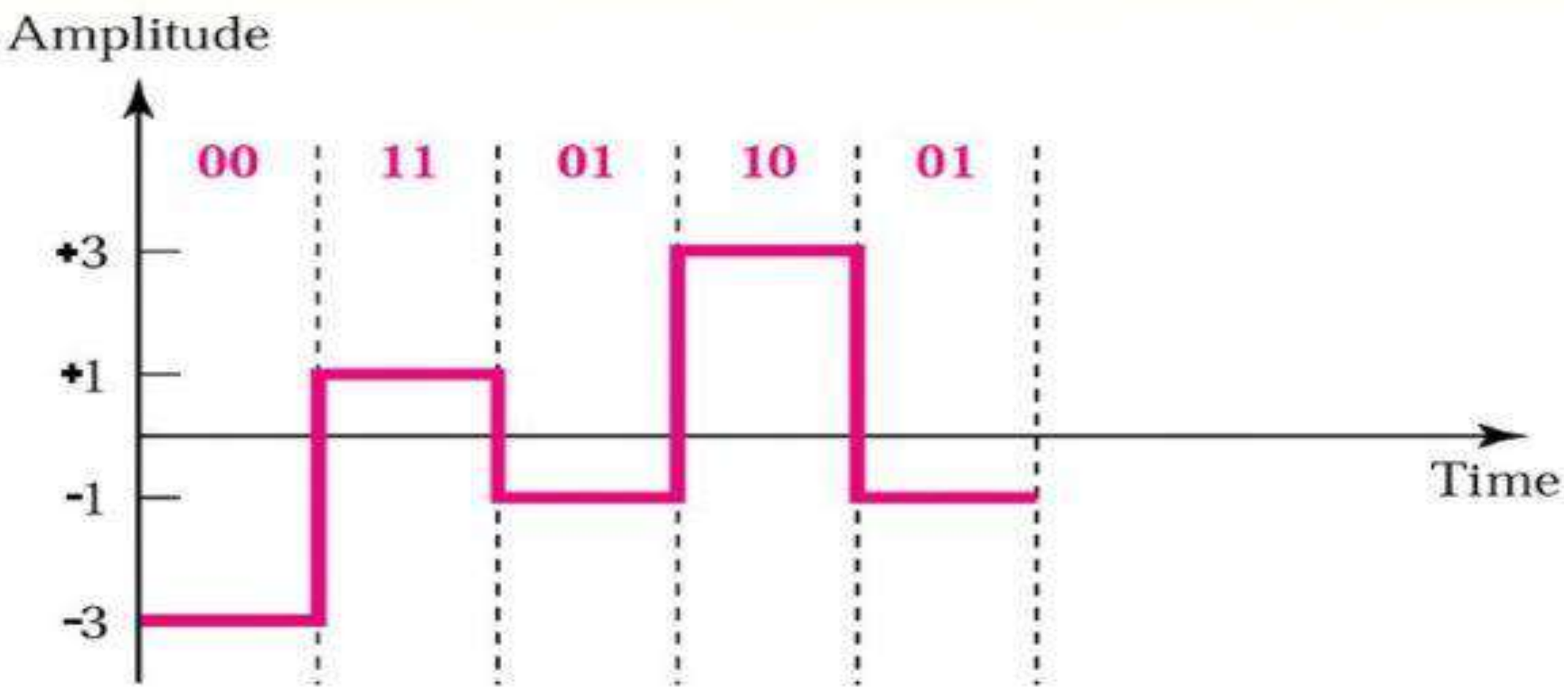
+0− 000− +000+ −+−00− +−+000+− +−+−00−+ 0− +00+

Corresponding encoding using AMI is

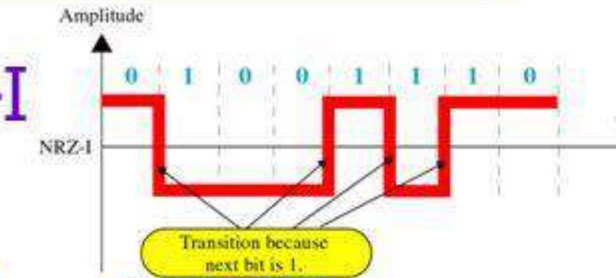
+0−0000+0000−+0000−+− 0000+−+ −0000+0−0000

2B1Q Multilevel Encoding

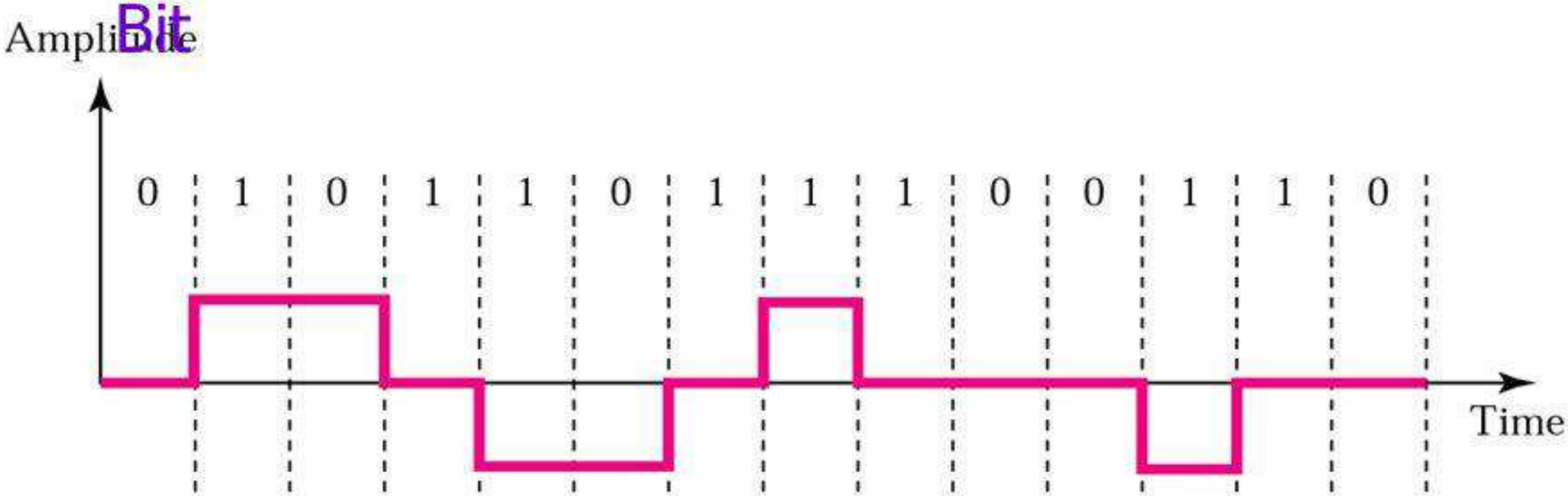
- The first mBnL scheme, two binary, one quaternary (2B1Q), uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal.
- In this type of encoding m =2, n =1, and L =4 (quaternary).
- Figure below shows an example of a 2B1Q signal.



MLT-3 Encoding



- **MLT-3 Encoding** Similar to NRZ-I
- Uses 3 Levels Of Signal +1, 0, -1
- The Signal Transitions From One Level To The Next At The Beginning Of A 1 Bit
- There Is No Transition At The Beginning Of A 0 Bit



Digital-to-Digital Encoding Schemes

- 3 Broad Categories: Unipolar, Polar, and Bipolar

-Nonreturn to Zero-Level (NRZ-L)
-Nonreturn to Zero Inverted (NRZI)
Magnetic Recording

-Manchester
-Differential Manchester
LAN

-Bipolar -AMI
-B8ZS
-HDB3
WAN

Switching

- Long distance transmission between stations (called "end devices") is typically done over a network of **switching nodes**.
- Switching nodes do not concern with content of data. Their purpose is to provide a switching facility that will move the data from node to node until they reach their destination (the end device).
- A collection of nodes and connections forms a communications network.
- In a switched communications network, data entering the network from a station are **routed** to the destination by being switched from node to node.

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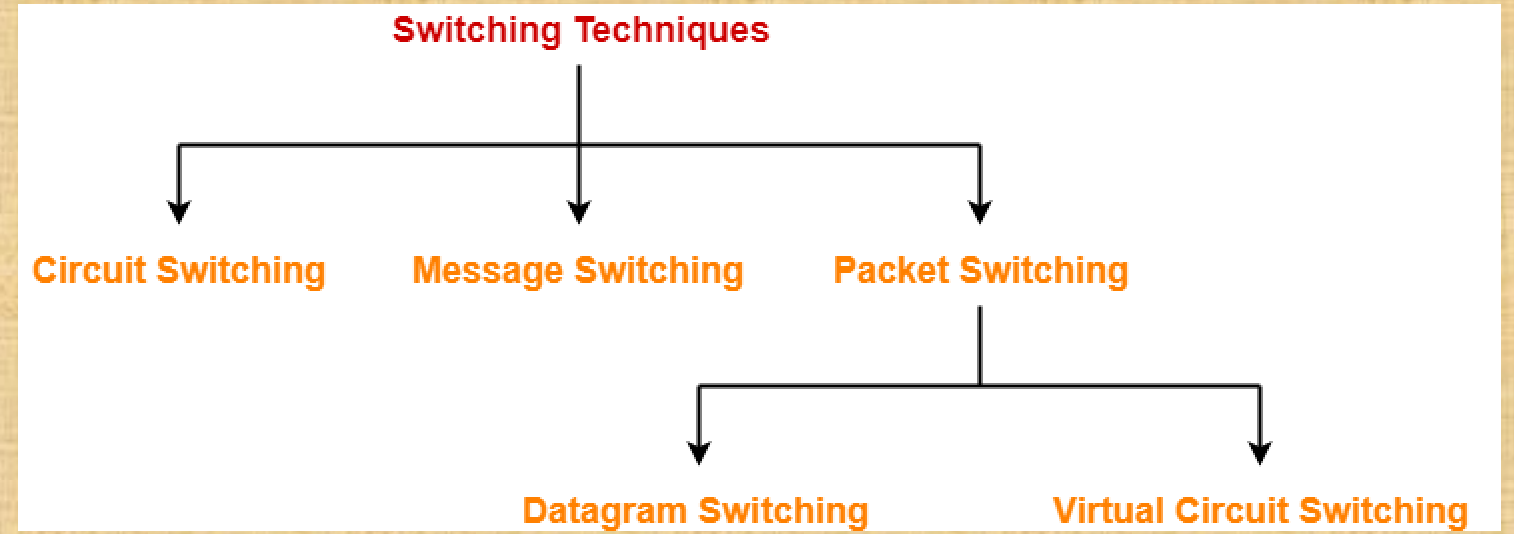
Types of Switching



Overview

- Networks are used to interconnect many devices.
- We have checked with Local Area Networks.
- Now, wide area networks
  - Since the invention of the telephone, **circuit switching** has been the dominant technology for voice communications.
  - Since 1970, **packet switching** has evolved substantially for digital data communications. It was designed to provide a more efficient facility than circuit switching for bursty data traffic.
    - Two types of packet switching:
      - Datagram (such as today's Internet)
      - Virtual circuit (such as Frame Relay, ATM)

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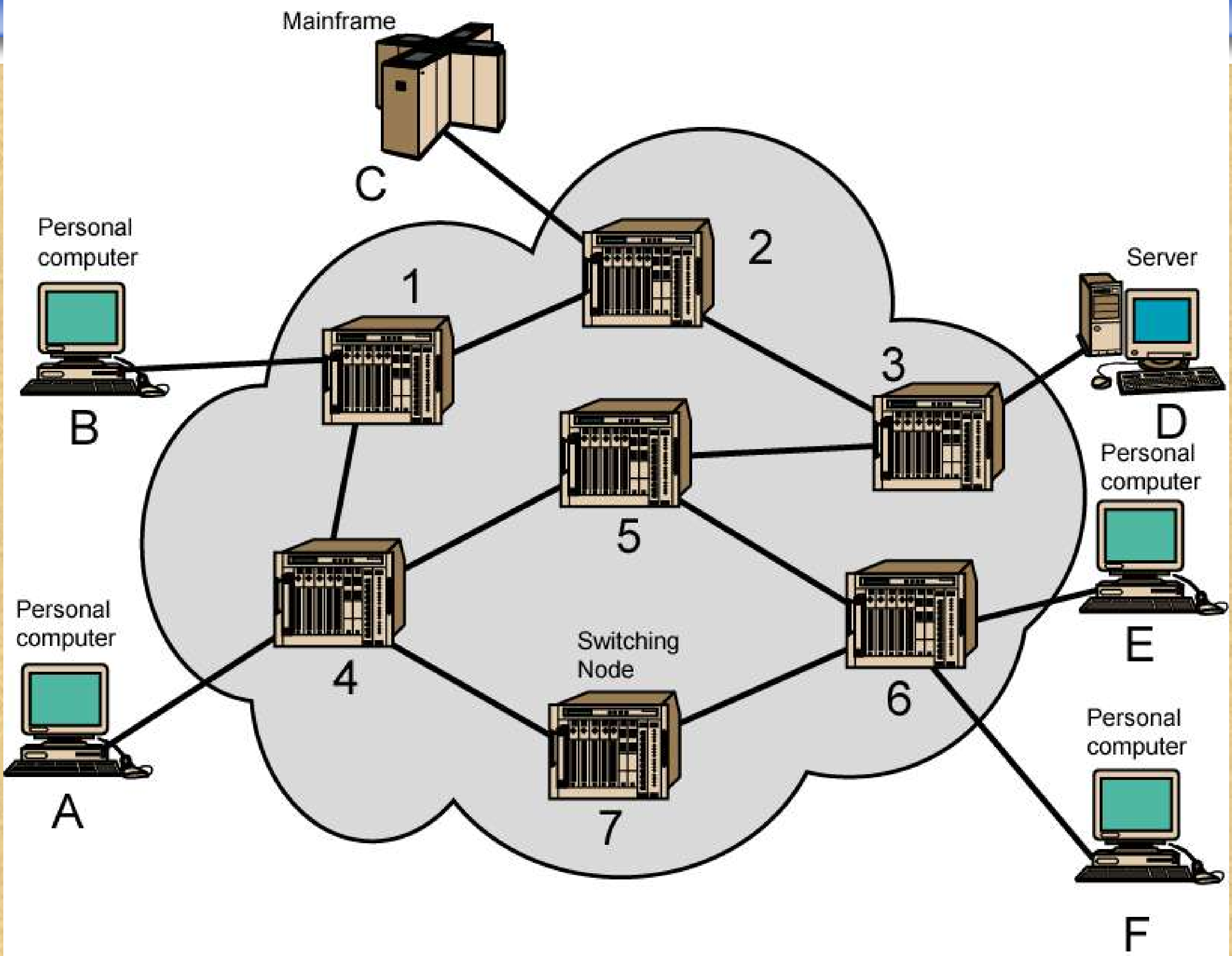
Simple Switching Network



Switching Nodes

- Nodes may connect to other nodes, or to some stations.
- Network is usually partially connected
  - However, some redundant connections are desirable for reliability
- Two different switching technologies
  - Circuit switching
  - Packet switching

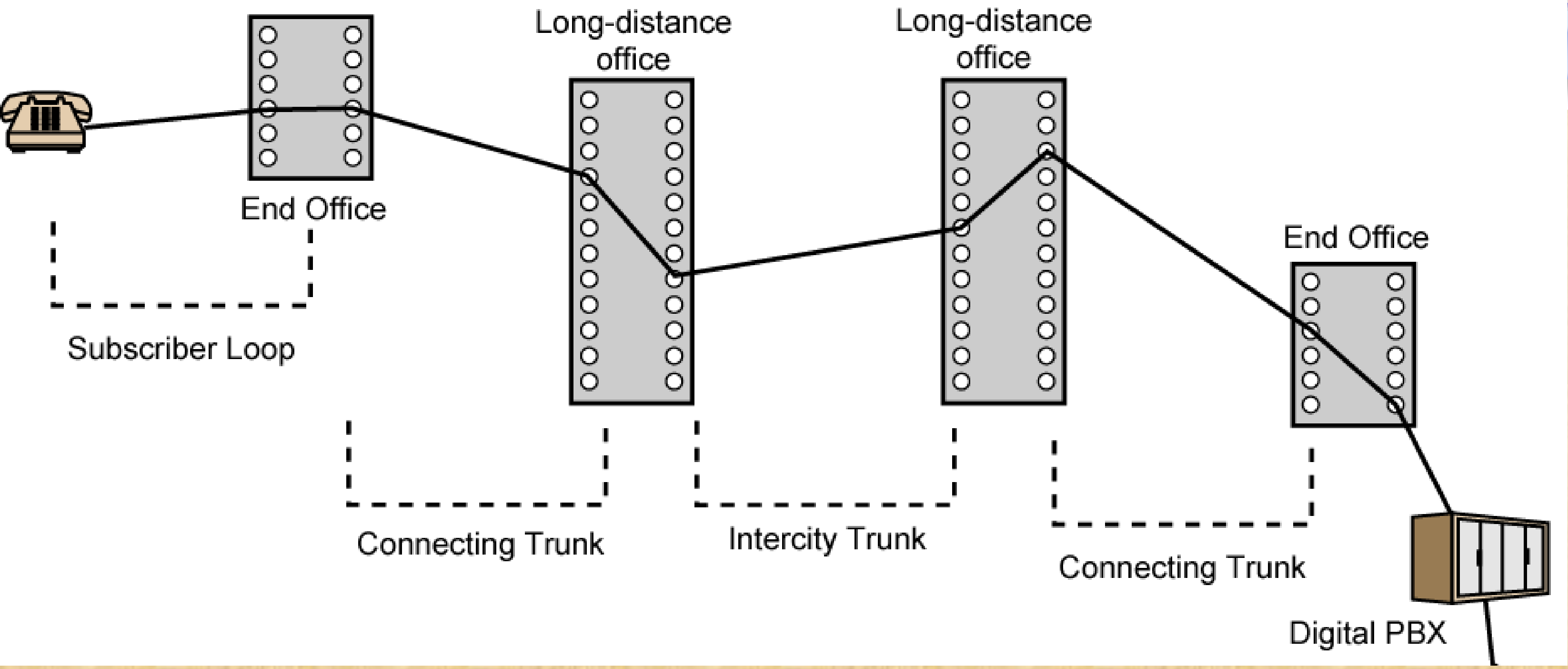
Circuit Switching

- Circuit switching:
  - There is a dedicated communication path between two stations (end-to-end)
  - The path is a connected sequence of links between network nodes. On each physical link, a logical channel is dedicated to the connection.
- Communication via circuit switching has three phases:
  - Circuit establishment (link by link)
    - Routing & resource allocation (FDM or TDM)
  - Data transfer
  - Circuit disconnect
    - Deallocate the dedicated resources
- The switches must know how to find the route to the destination and how to allocate bandwidth (channel) to establish a connection.

Circuit Switching Properties

- Inefficiency
  - Channel capacity is dedicated for the whole duration of a connection
  - If no data, capacity is wasted
- Delay
  - Long initial delay: circuit establishment takes time
  - Low data delay: after the circuit establishment, information is transmitted at a fixed data rate with no delay other than the propagation delay. The delay at each node is negligible.
- Developed for voice traffic (public telephone network) but can also applied to data traffic.
  - For voice connections, the resulting circuit will enjoy a high percentage of utilization because most of the time one party or the other is talking.
  - But how about data connections?

Public Circuit Switched Network



Subscribers: the devices that attach to the network.

Subscriber loop: the link between the subscriber and the network.

Exchanges: the switching centers in the network.

End office: the switching center that directly supports subscribers.

Trunks: the branches between exchanges. They carry multiple voice-frequency circuits using either FDM or synchronous TDM.

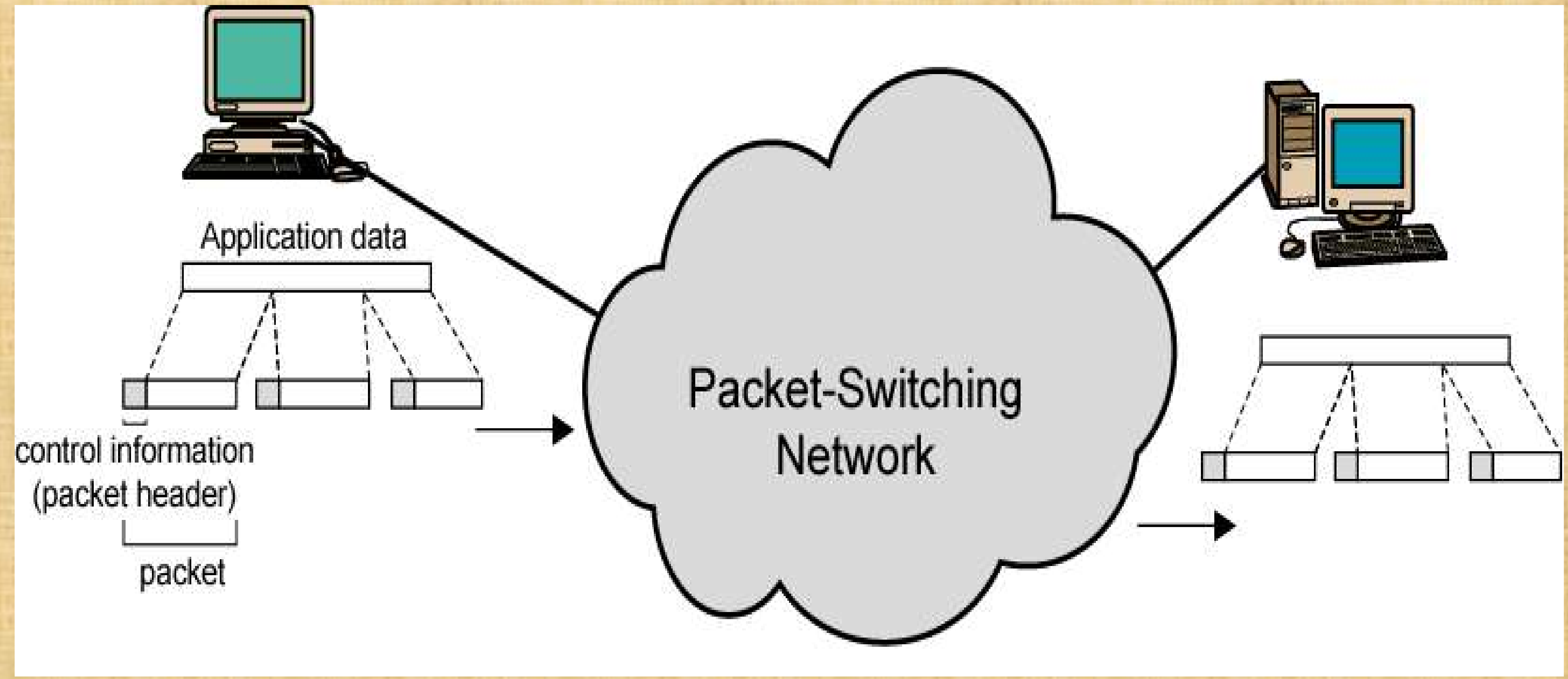
Packet Switching Principles

- Problem of circuit switching
  - designed for voice service
  - Resources dedicated to a particular call
  - For data transmission, much of the time the connection is idle (say, web browsing)
  - Data rate is fixed
    - Both ends must operate at the same rate during the entire period of connection
- Packet switching is designed to address these problems.

Basic Operation

- Data are transmitted in short packets
  - Typically at the order of 1000 bytes
  - Longer messages are split into series of packets
  - Each packet contains a portion of user data plus some control info
- Control info contains at least
  - Routing (addressing) info, so as to be routed to the intended destination
  - Recall the content of an IP header!
- **store and forward**
  - On each switching node, packets are received, stored briefly (buffered) and passed on to the next node.

Use of Packets



Advantages of Packet Switching

- Line efficiency
  - Single node-to-node link can be dynamically shared by many packets over time
  - Packets are queued up and transmitted as fast as possible
- Data rate conversion
  - Each station connects to the local node at its own speed
- In circuit-switching, a connection could be blocked if there lacks free resources. On a packet-switching network, even with heavy traffic, packets are still accepted, by delivery delay increases.
- Priorities can be used
  - On each node, packets with higher priority can be forwarded first. They will experience less delay than lower-priority packets.

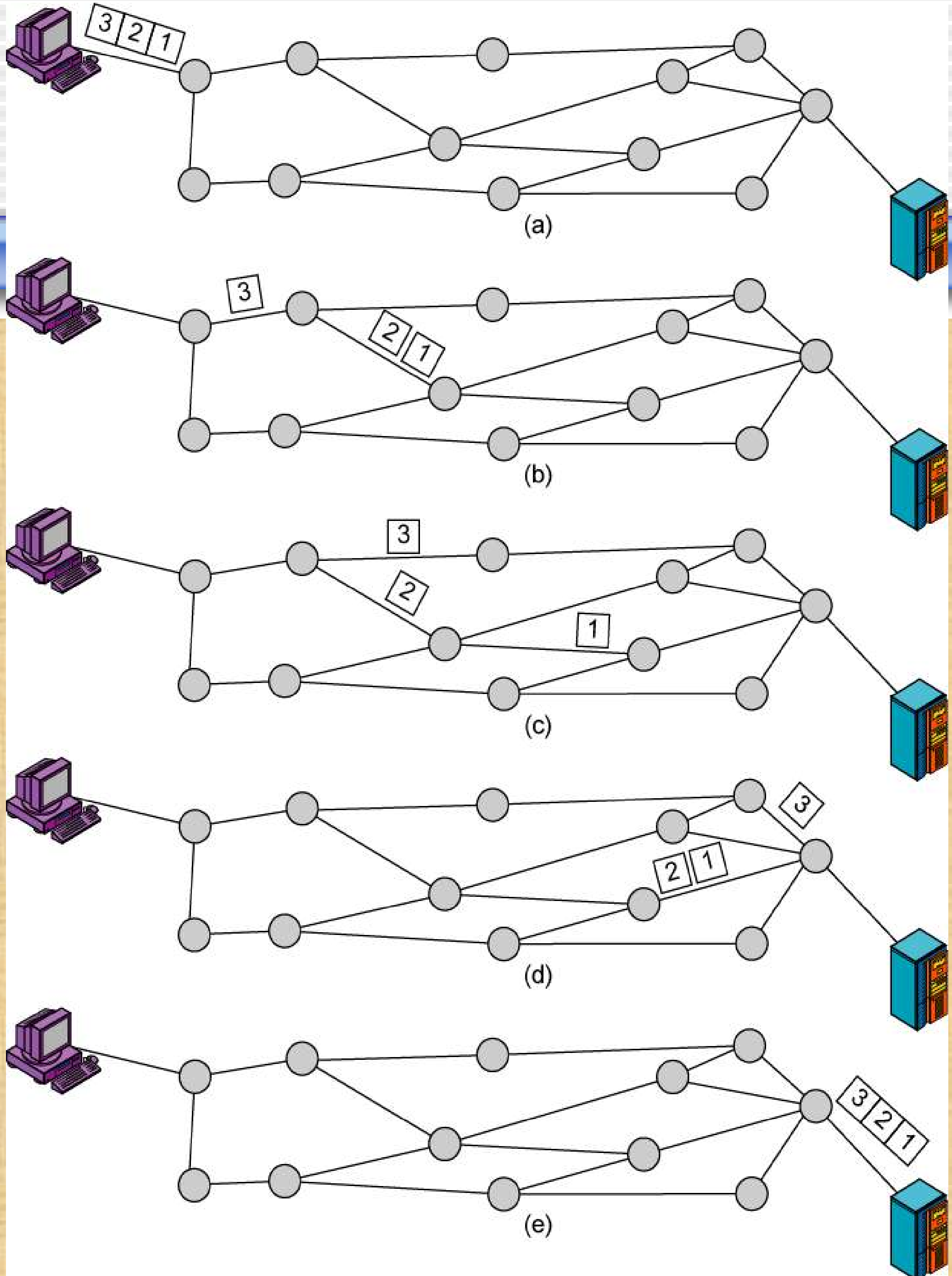
Packet Switching Technique

- A station breaks long message into packets
- Packets are sent out to the network sequentially, one at a time
- How will the network handle this stream of packets as it attempts to route them through the network and deliver them to the intended destination?
  - Two approaches
    - **Datagram** approach
    - **Virtual circuit** approach

Datagram

- Each packet is treated independently, with no reference to packets that have gone before.
  - Each node chooses the next node on a packet's path.
- Packets can take any possible route.
- Packets may arrive at the receiver out of order.
- Packets may go missing.
- It is up to the receiver to re-order packets and recover from missing packets.
- Example: Internet

Datagram

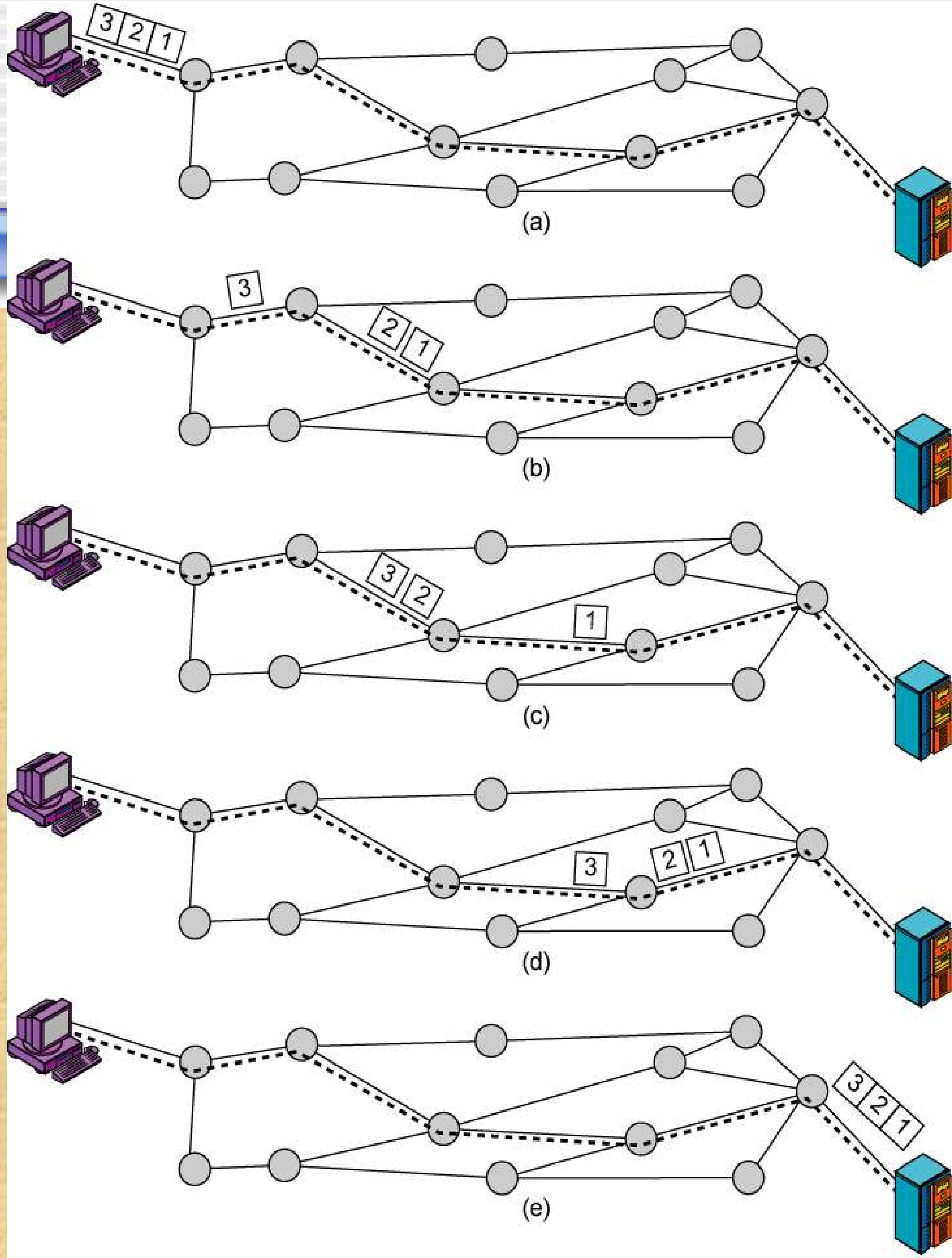


Virtual Circuit

- In virtual circuit, a preplanned route is established before any packets are sent, then all packets follow the same route.
- Each packet contains a **virtual circuit identifier** instead of destination address, and each node on the preestablished route knows where to forward such packets.
  - The node need not make a routing decision for each packet.
- Example: X.25, Frame Relay, ATM

Virtual Circuit

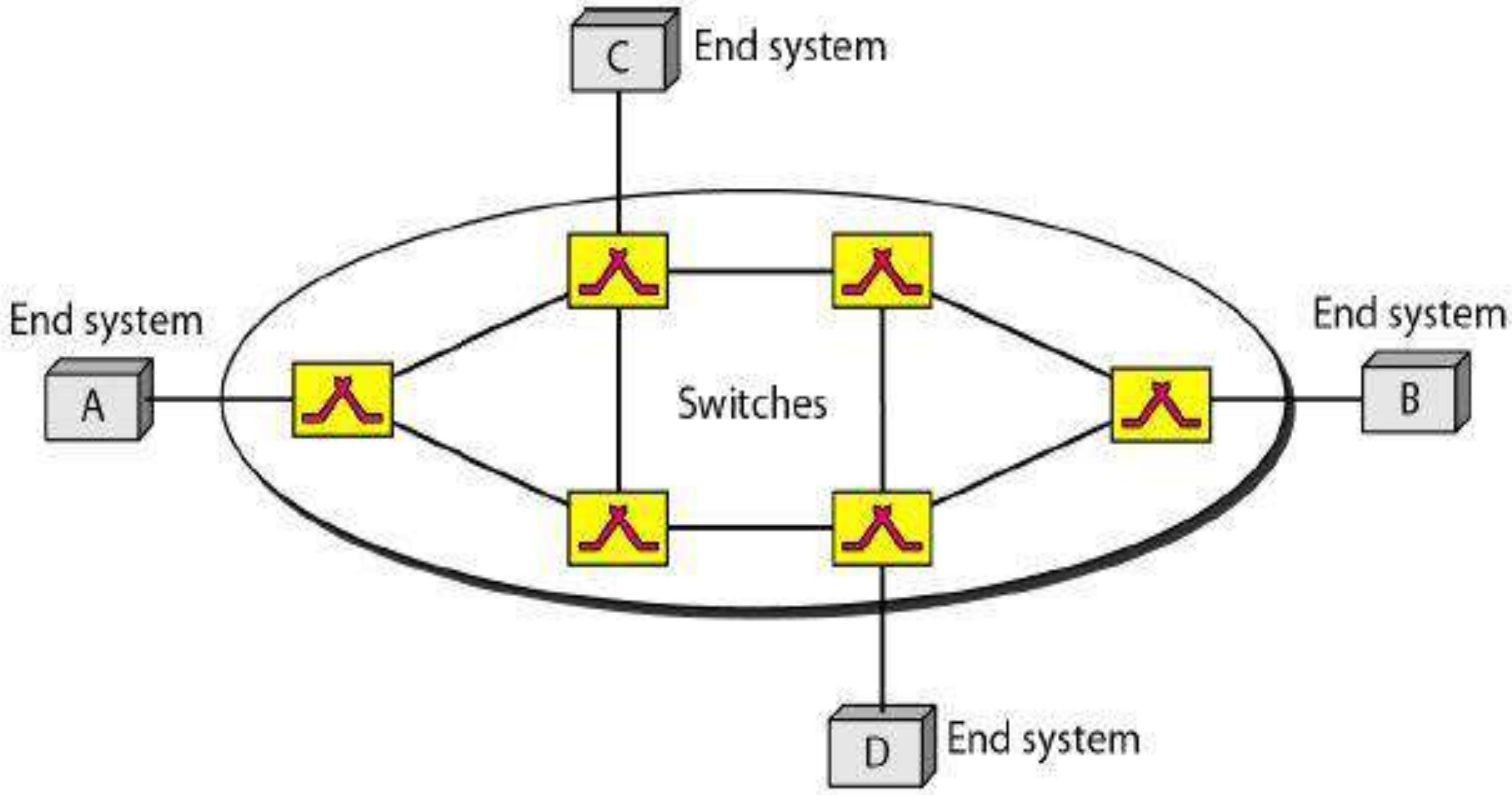
- A route between stations is set up prior to data transfer.
- All the data packets then follow the same route.
- But there is no dedicated resources reserved for the virtual circuit! Packets need to be stored-and-forwarded.



Virtual Circuits v Datagram

- Virtual circuits
  - Network can provide sequencing (packets arrive at the same order) and error control (retransmission between two nodes).
  - Packets are forwarded more quickly
    - Based on the virtual circuit identifier
    - No routing decisions to make
  - Less reliable
    - If a node fails, all virtual circuits that pass through that node fail.
- Datagram
  - No call setup phase
    - Good for bursty data, such as Web applications
  - More flexible
    - If a node fails, packets may find an alternate route
    - Routing can be used to avoid congested parts of the network

Establishment of Virtual Circuits



Virtual-circuit network Addressing

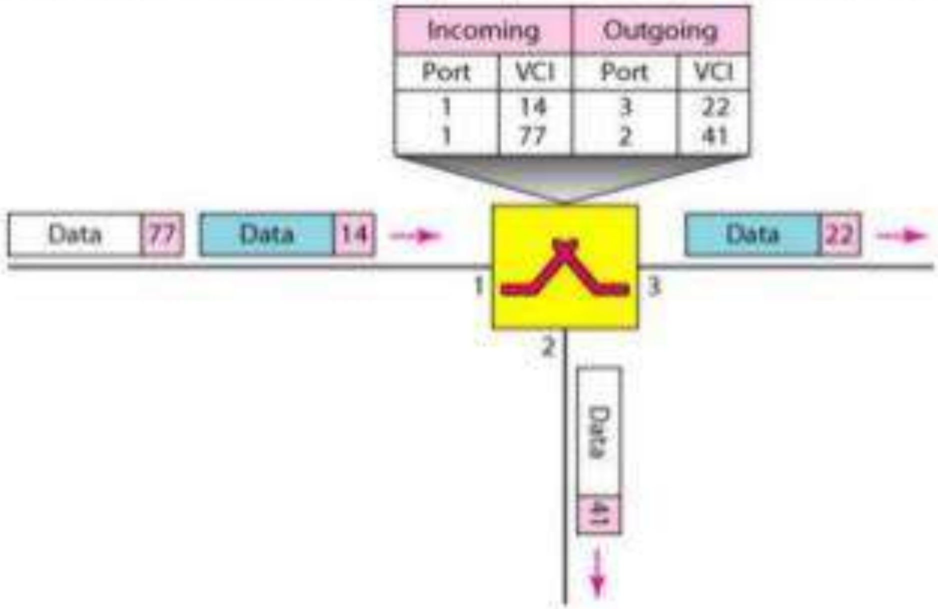
- Global addressing:

- Source and destination needs unique addresses (used by the switches **only to create a virtual-circuit identifier)** during the set up phase

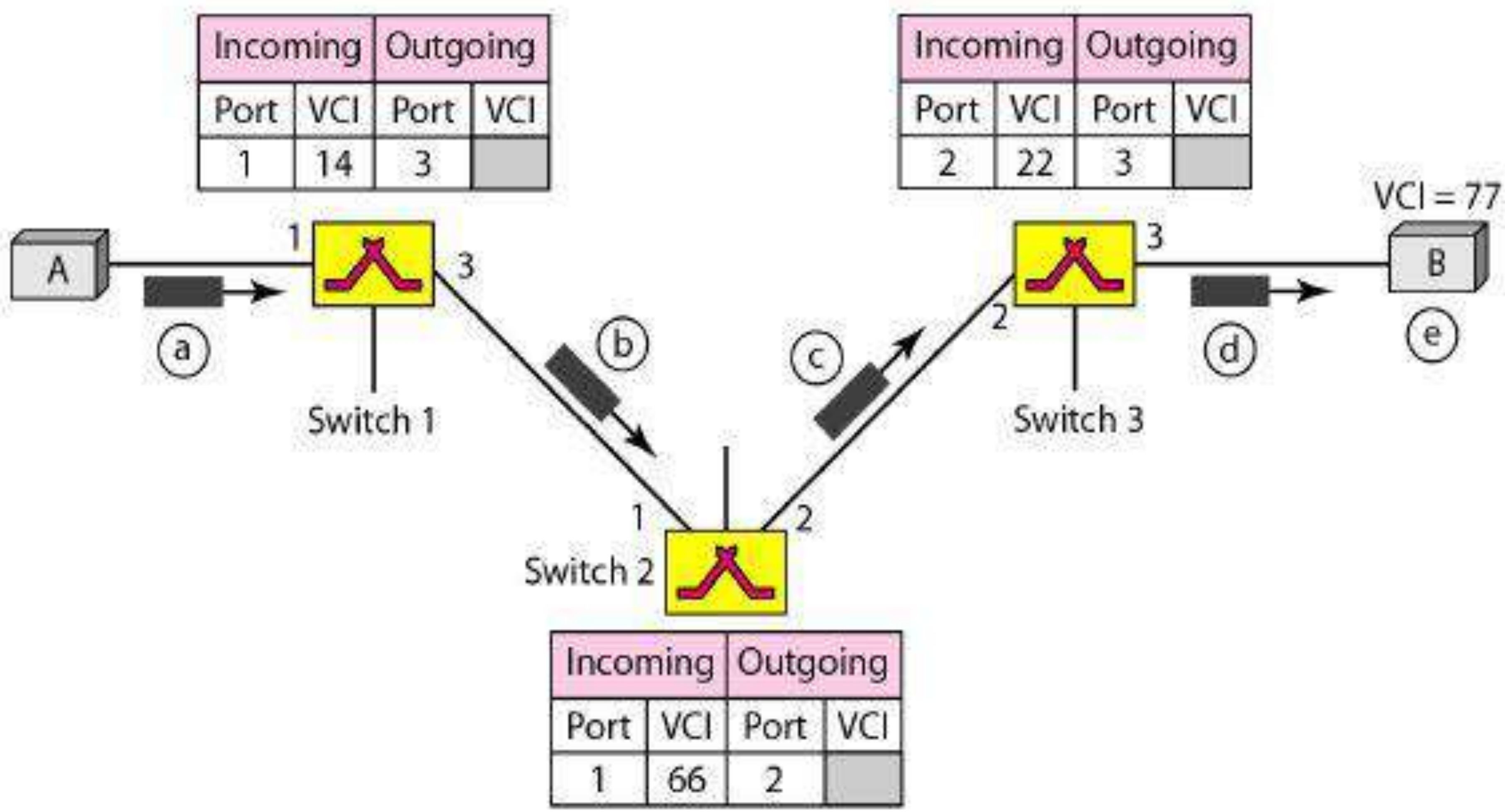
- Local addressing (**virtual-circuit identifier –VCI)**:

- Actually used for data transfer

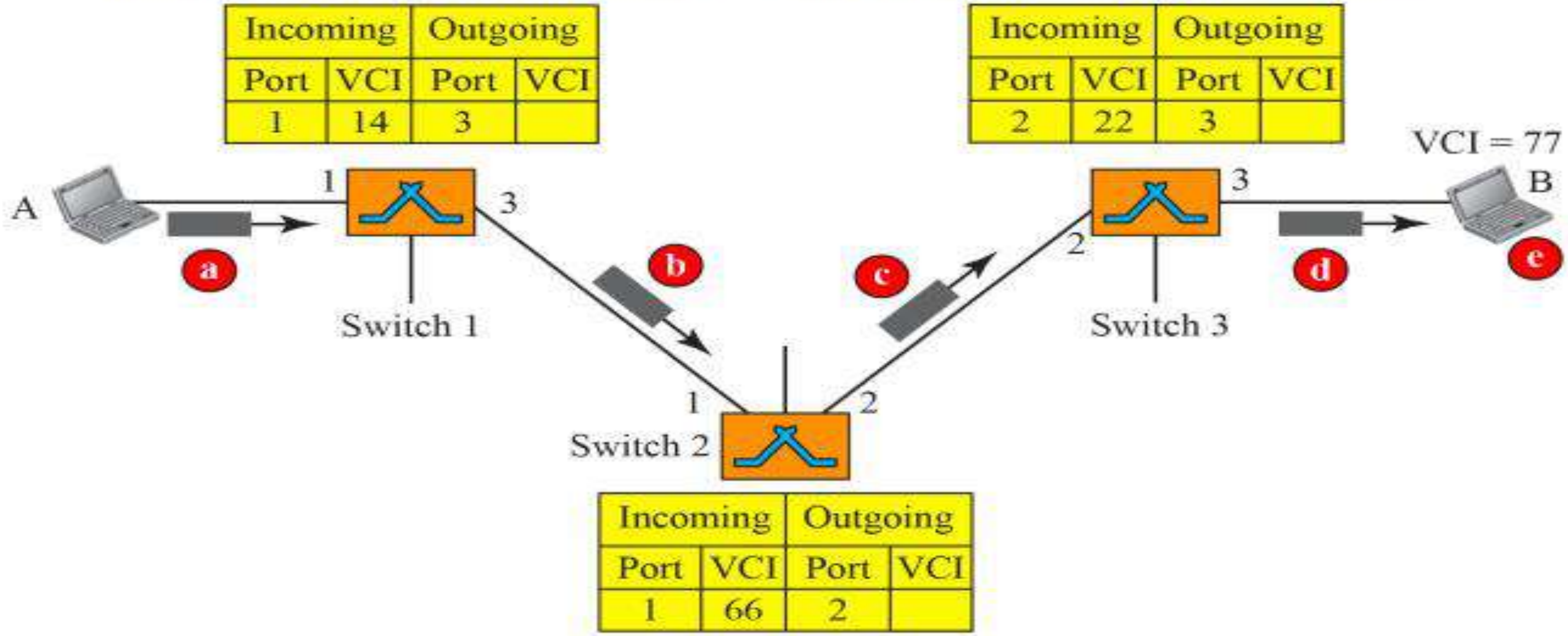
- A small address used by a frame between two switches.



Virtual circuit setup



1. The figure shown below is about "Setup Request" in a virtual circuit network. In this figure, the source A sends a setup frame to switch 1. Then, the 1st switch acts as a packet switch which only knows the incoming virtual circuit identifier (VCI) but does not know the outgoing VCI yet. The 2nd and the 3rd switches do the same as the 1st switch.



The next figure is about "Setup Acknowledgement." Here, the destination B sends an acknowledgment to the 3rd switch and the empty spot of the forwarding table is filled. Then, the 2nd and the 1st switches do the same as the 3rd switch.

Your task is to simulate "Setup Request" and "Setup Acknowledgment" using a set of programing codes.

If you are not able to write a set of programming codes, you may write a pseudocode (50 points).

Figure 8.15 *Setup acknowledgment in a virtual-circuit network*

The Ack frame completes the entries in the switching tables
The Ack carries the global addresses (S&D) so the switch know which entry in the table is to be completed

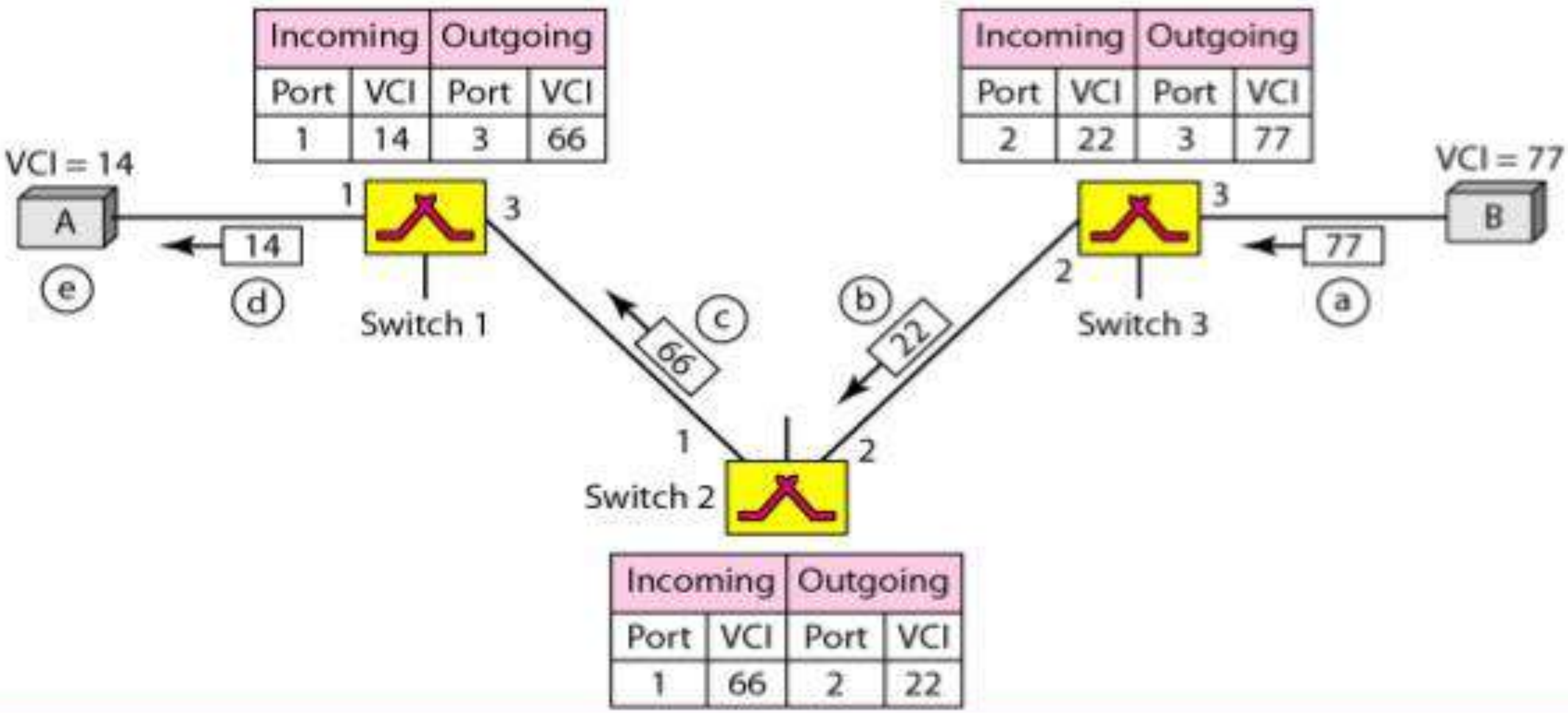
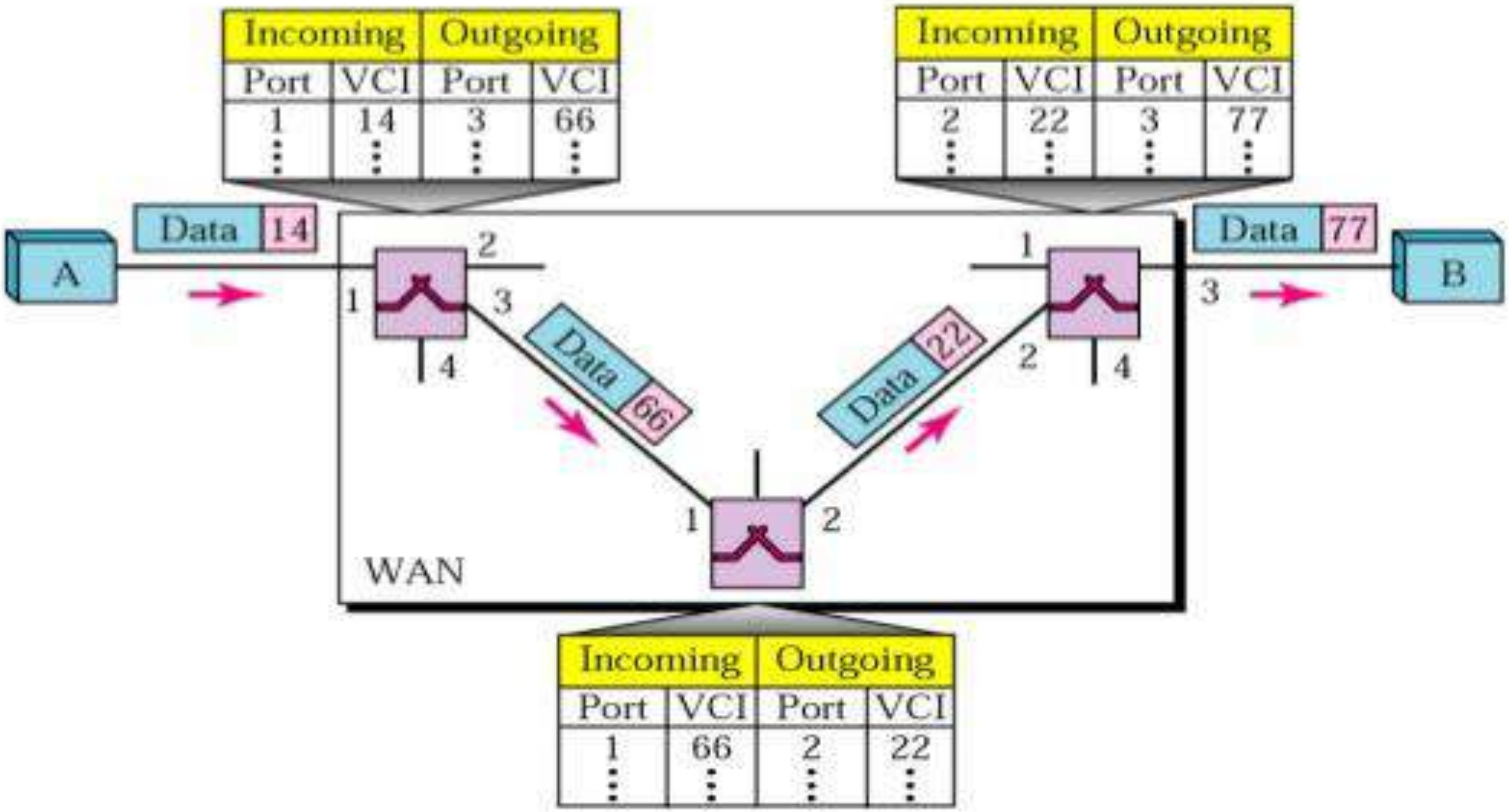


Figure 18.5 Source-to-destination data transfer



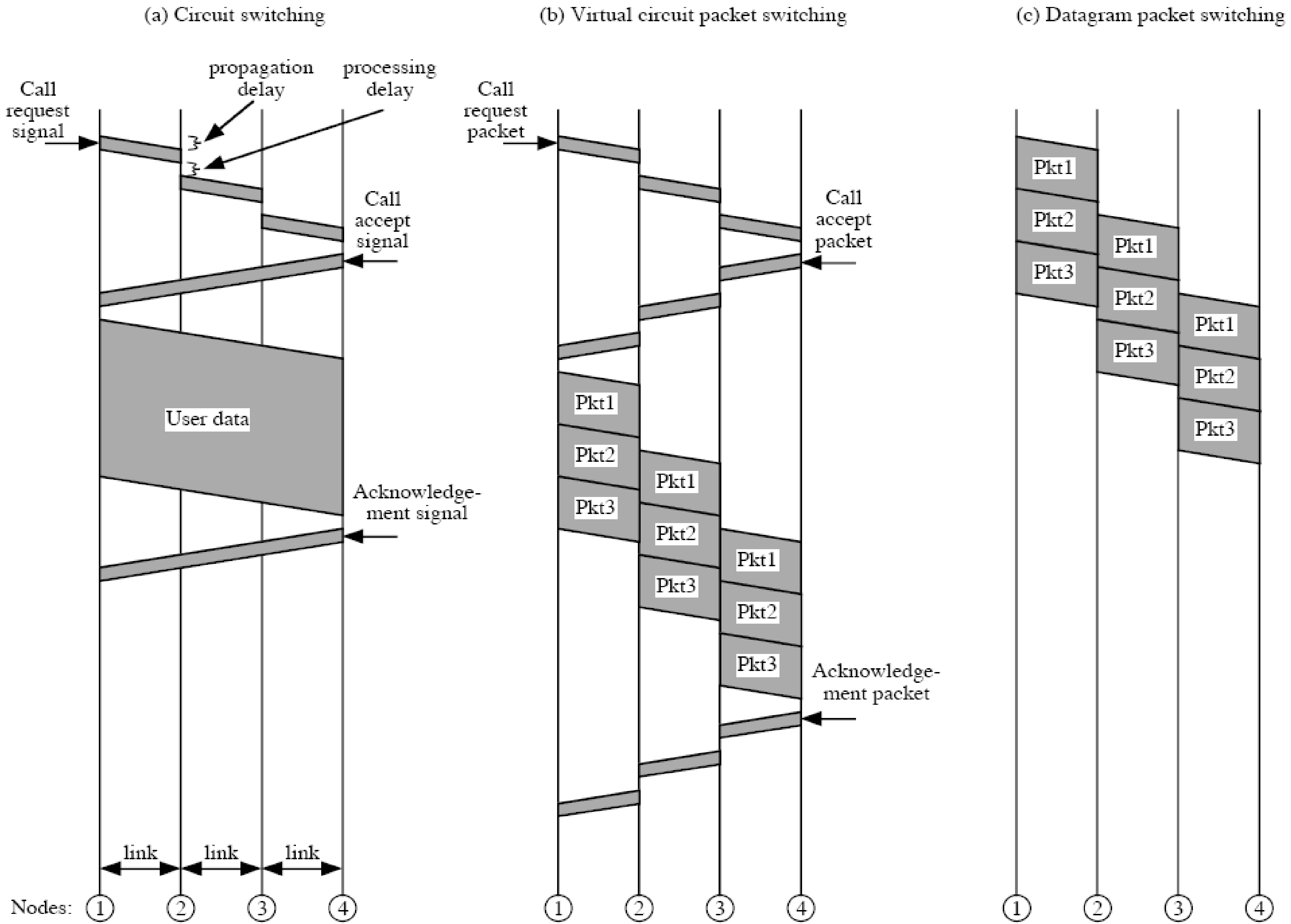


Figure 10.15 Event Timing for Circuit Switching and Packet Switching

Comparison of communication switching techniques

Circuit Switching	Datagram Packet Switching	Virtual Circuit Packet Switching
Dedicated transmission path	No dedicated path	No dedicated path
Continuous transmission of data	Transmission of packets	Transmission of packets
Fast enough for interactive	Fast enough for interactive	Fast enough for interactive
Messages are not stored	Packets may be stored until delivered	Packets stored until delivered
The path is established for entire conversation	Route established for each packet	Route established for entire conversation
Call setup delay; negligible transmission delay	Packet transmission delay	Call setup delay; packet transmission delay
Busy signal if called party busy	Sender may be notified if packet not delivered	Sender notified of connection denial
Overload may block call setup; no delay for established calls	Overload increases packet delay	Overload may block call setup; increases packet delay
Electromechanical or computerized switching nodes	Small switching nodes	Small switching nodes
User responsible for message loss protection	Network may be responsible for individual packets	Network may be responsible for packet sequences
Usually no speed or code conversion	Speed and code conversion	Speed and code conversion
Fixed bandwidth	Dynamic use of bandwidth	Dynamic use of bandwidth
No overhead bits after call setup	Overhead bits in each packet	Overhead bits in each packet