Network Performance Metrics

Network Performance Metrics

- Throughput,
- Packet delivery ratio,
- End-to-end delay,
- Propagation delay,
- Queuing delay,
- Computational delay,
- Transmission delay,
- RTT

Physical Layer

Main Function:

- To move data in the **form of electromagnetic signals** across a transmission medium.

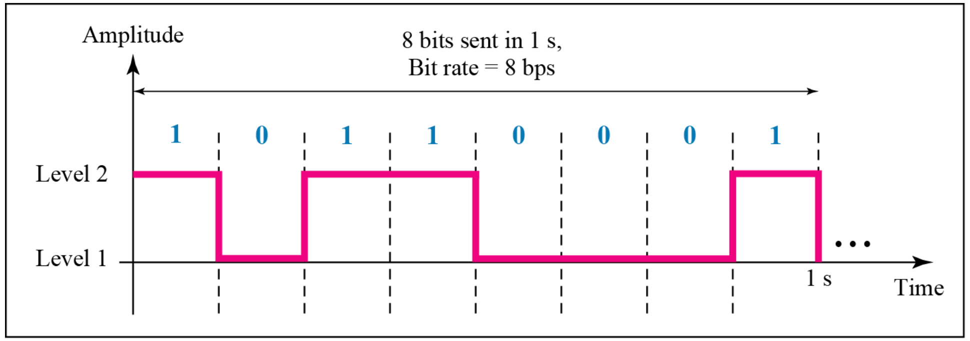
Data to be transmitted are not in a form that can be transmitted over a network.

For example:

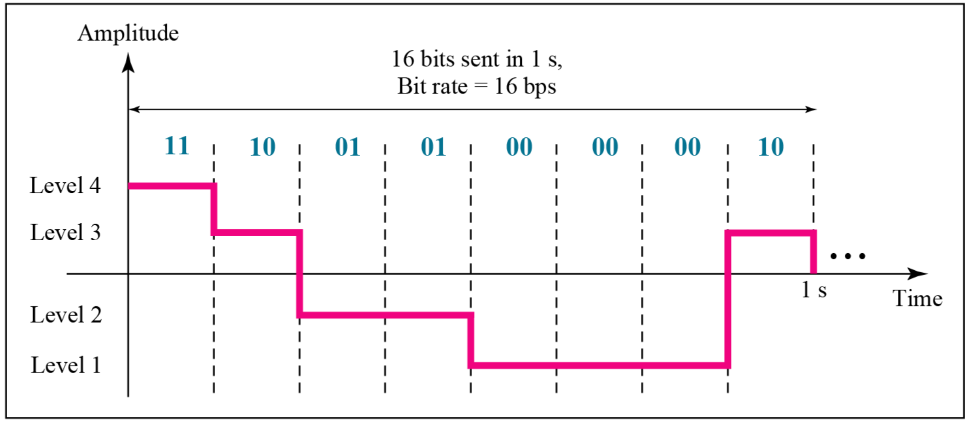
- A photograph must first be changed to a form that transmission media can accept.
- Transmission media work by conducting energy along a physical path.
- For transmission, data needs to be changed to **signals.**

Digital Signal

- Two digital signals:
  - One with **two** signal levels and
  - The other with **four** signal levels



a. A digital signal with two levels



b. A digital signal with four levels

Example A:

A digital signal has eight levels. How many bits are needed per level?

$$\boxed{\text{Number of bits per level} = \log_2 8 = 3}$$

Example B:

A digital signal has nine levels. How many bits are needed per level?

Digital Signal

- **Bit Rate:**
  - The number of bits sent in 1s, expressed in **bits per second (bps)**

Example A:

Assume we need to download text documents at the rate of 100 pages per sec. What is the required bit rate of the channel?

Solution

Lets assume:

- A page is an average of 24 lines with 80 characters in each line.
- If we assume that one character requires 8 bits (ascii),
- The bit rate is:

$$100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}$$

Example B:

A digitized voice channel is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

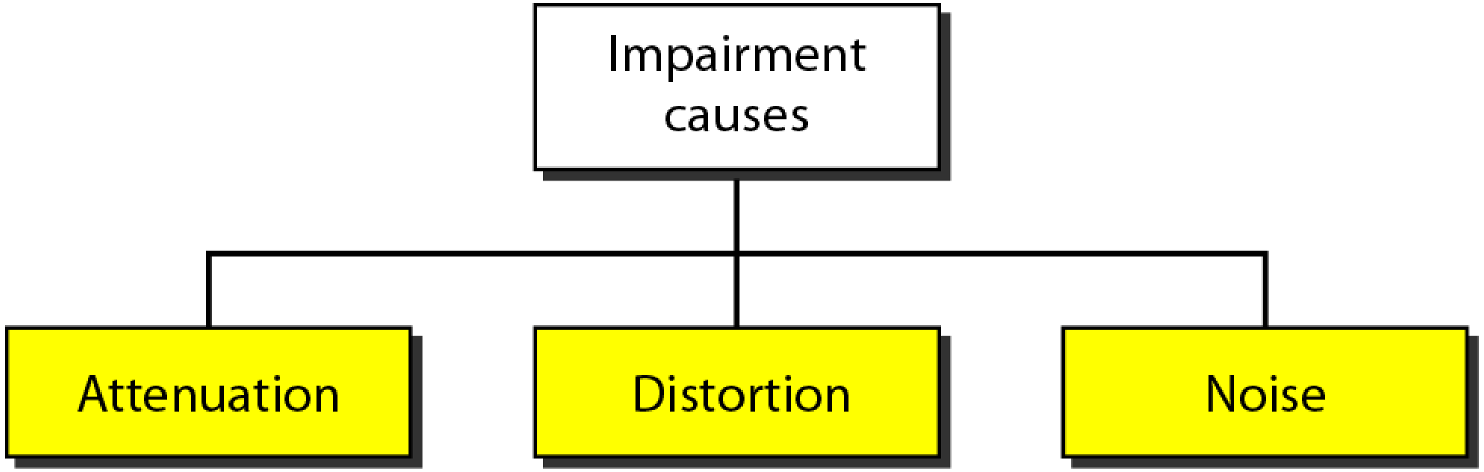
Solution

The bit rate can be calculated as

$$2 \times 4000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}$$

Transmission Impairment

If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel;
we need to convert the digital signal to an analog signal before transmission.



Transmission Impairment

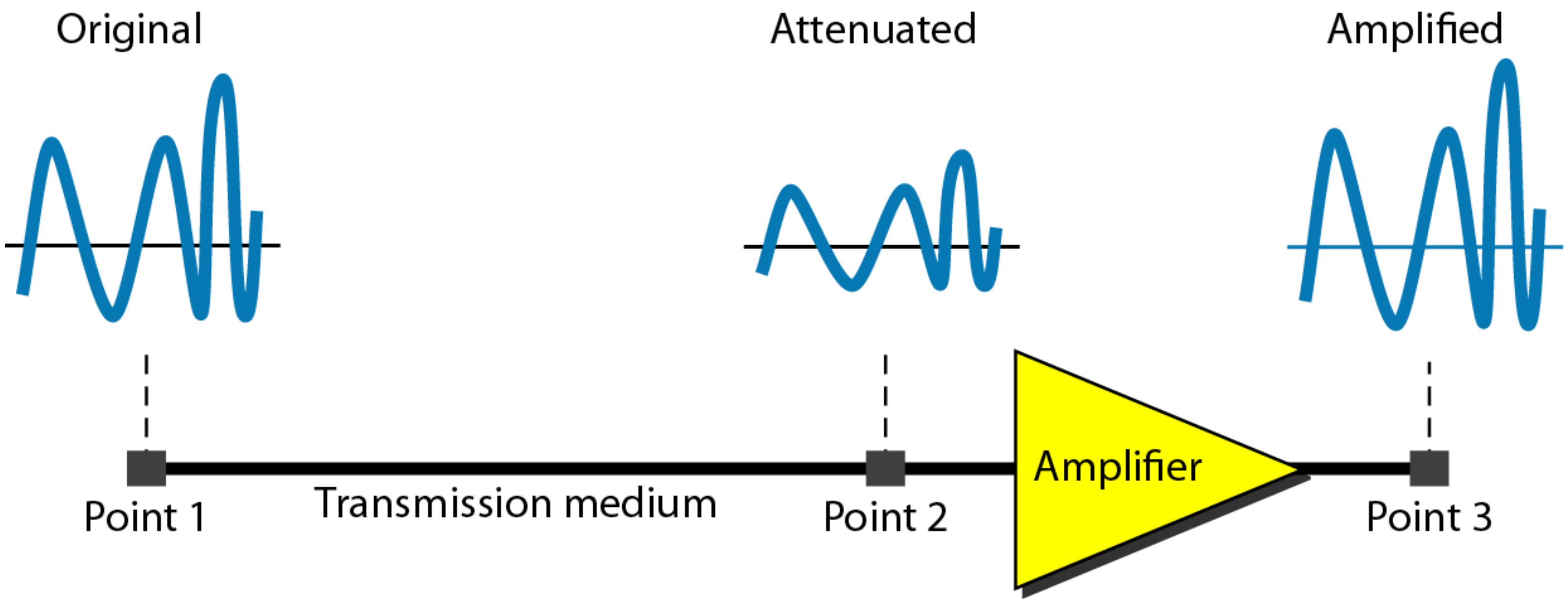
Attenuation

Means loss of energy -> Weaker signal

- When a signal travels through a medium it loses energy overcoming the resistance of the medium
- Amplifiers are used to compensate for this loss of energy by amplifying the signal.

Decibel (dB)

- Measures the relative strengths of two signals or one signal at two different points



$$dB = 10 \log_{10} \frac{P_2}{P_1}$$

Attenuation

Example:

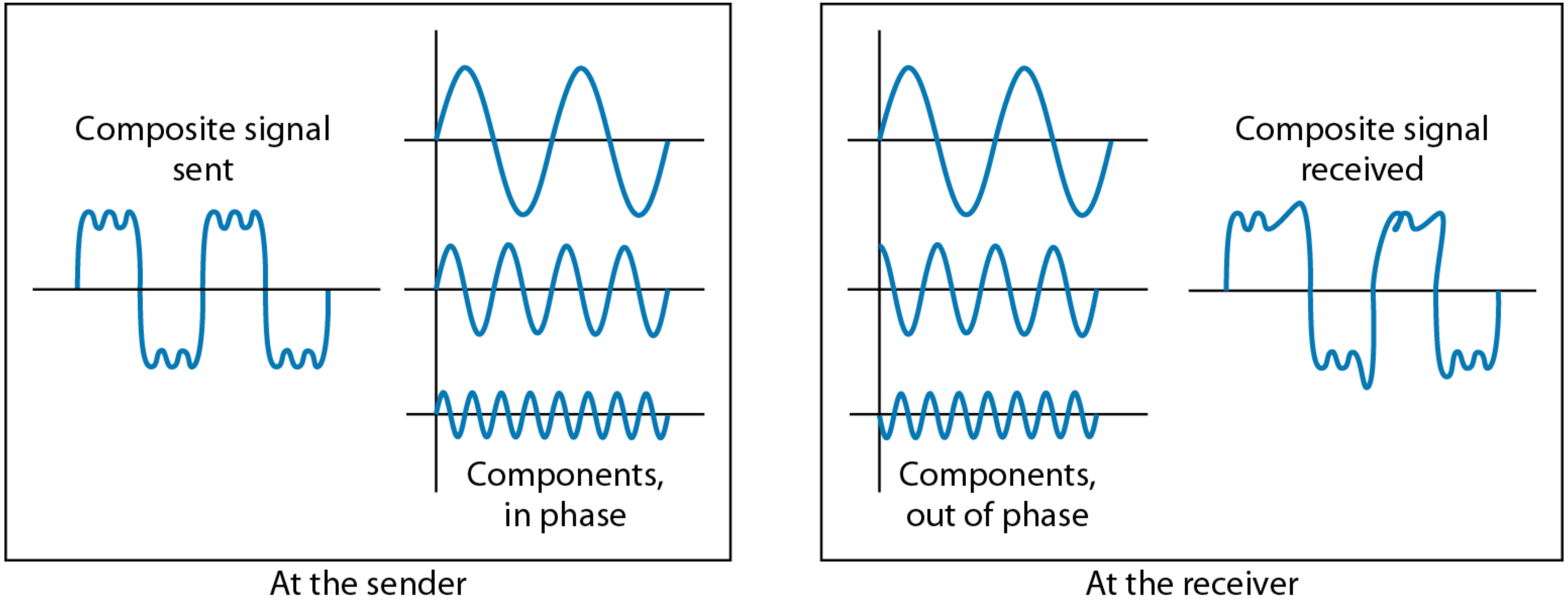
Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 is (1/2)P1. In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

Distortion

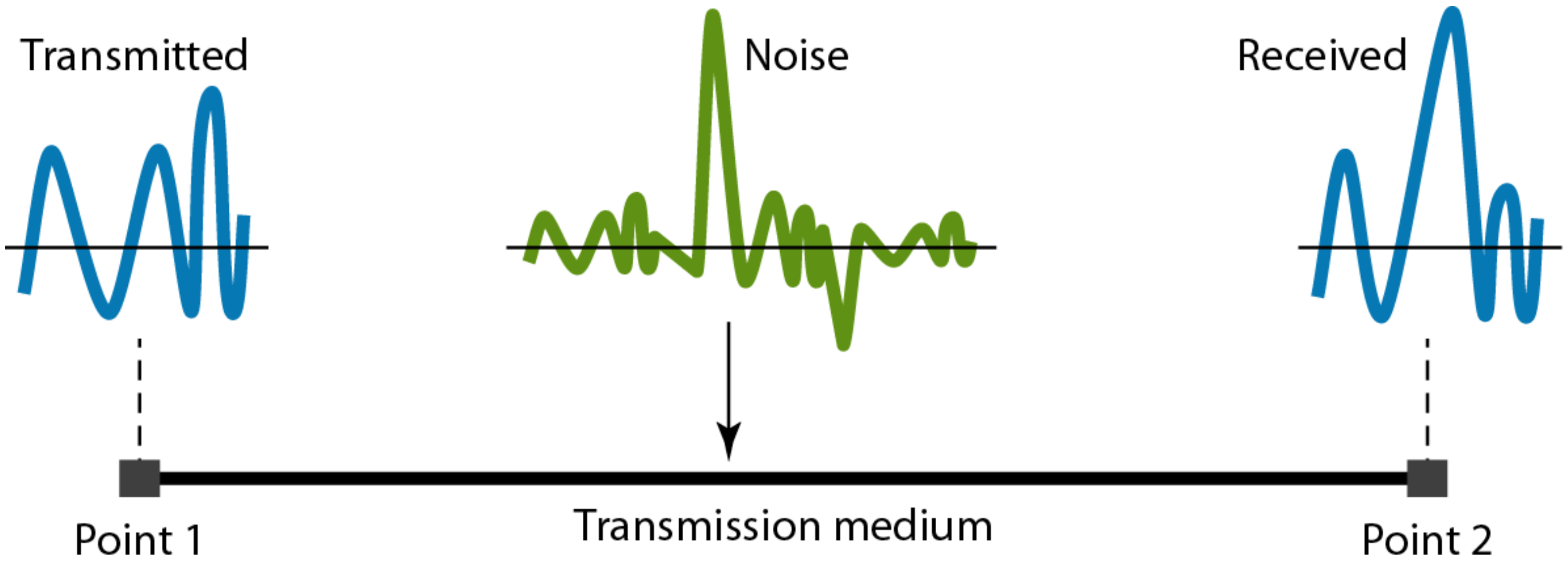
- Signal changes its **form** or **shape**
- Distortion occurs in composite signals



Noise

Different types of Noise:

- **Thermal** - Random noise of electrons in the wire creates an extra signal
- **Induced** - Devices act are transmitter antenna and medium as receiving antenna.
- **Crosstalk** - Between two wires.
- **Impulse** - Spikes that result from power lines, lightning, etc.



Signal to Noise Ratio

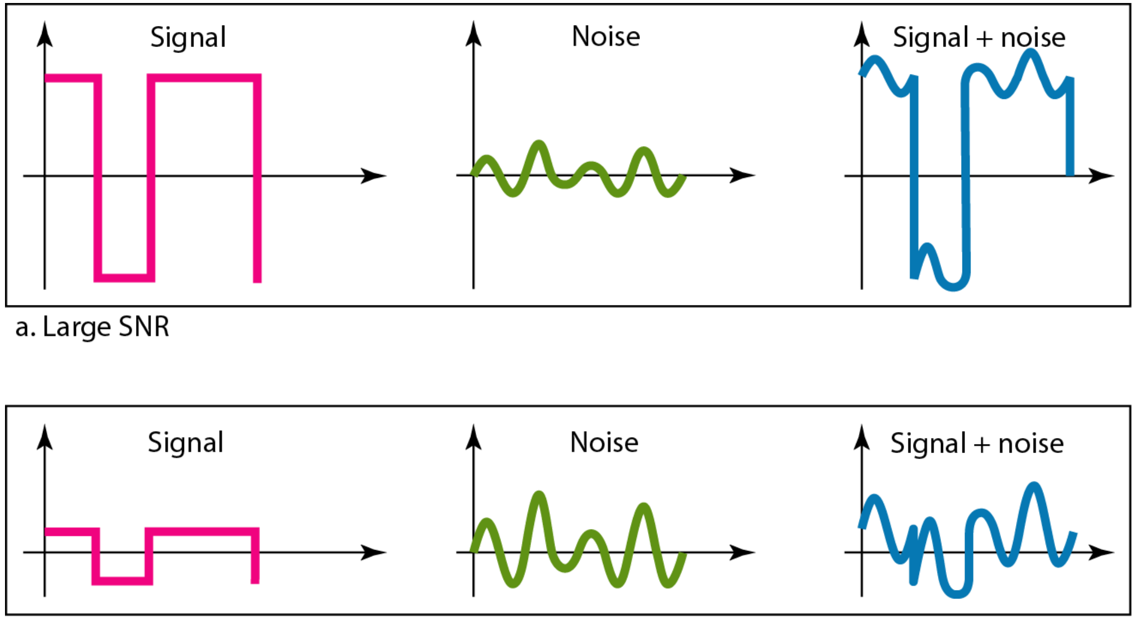
Indicates the strength of the signal wrt the noise power in the system.

Example A: The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB} ?

Solution

$$SNR = \frac{10{,}000\ \mu W}{1\ mW} = 10{,}000$$

$$SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$



a. Large SNR

b. Small SNR

Example B: The values of SNR and SNR_{dB} for a noiseless channel are:

$$SNR = \frac{\text{signal power}}{0} = \infty$$

$$SNR_{dB} = 10 \log_{10} \infty = \infty$$

We can never achieve this ratio in real life; it is an ideal.

Data Rate Limits

Very important consideration:

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 the signals we use
3. The **quality** of the channel (the level of noise)

Two theoretical formulas were developed to calculate the data rate:

1. Nyquist for a noiseless channel
2. Shannon for a noisy channel.

Noiseless Channel: Nyquist Bit Rate

Nyquist bit rate formula defines the **theoretical maximum bit rate.**

$$\text{Bit Rate} = 2 \times BW \times \log_2 L$$

Where:

BW is bandwidth of the channel,
L is the number of signal levels used to represent data, and
Bit Rate is the bit rate in bits per second.

Increasing the levels of a signal may reduce the reliability of the system

Example A: 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?
Solution

$$\text{Bit Rate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Noisy Channel: Shannon Capacity

Shannon Capacity defines the **theoretical highest data rate for a noisy channel.**

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

Example A: We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000 Hz (300 to 3300 Hz) assigned for data communications. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

Solution

$$\text{Bit Rate} = 3000 \log_2(1+3162) = 3000 \times 11.62 = 34860 \text{ bps}$$

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

Performance Metrices

BANDWIDTH

Bandwidth in hertz,

*R*efers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.

Bandwidth in bits per second,

*R*efers to the speed of bit transmission in a channel or link.

RELATIONSHIP

- An clear relationship between the bandwidth in hertz and bandwidth in bits per second.
- An increase in bandwidth in hertz means an increase in bandwidth in bits per second.
- The relationship depends on whether we have baseband transmission or transmission with modulation.

Performance Metrices

THROUGHPUT

- Measure of how fast we can actually send data through a network
  - Bandwidth in bits per second and throughput are different from each other.
- A *link* may have ***a bandwidth of B bps***, but we ***can only send T bps*** through this *link* with ***T always less than B.***

- Bandwidth is a potential measurement of a link;
- Throughput is an actual measurement of how fast we can send data.

- ***Example***, *we may have a link with a bandwidth of 1 Mbps, but the devices connected to the end of the link may handle only 200 kbps. This means that we cannot send more than 200 kbps through this link.*

- **Example:** Imagine a highway designed to transmit 1000 cars per minute from one point to another.
  - If there is congestion on the road, this figure may be reduced to 100 cars per minute.
  - The bandwidth is 1000 cars per minute; the throughput is 100 cars per minute.

Example A: A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution

Throughput = (12000 × 10000) / 60 = 2 Mbps

Performance Metrices (…contd)

LATENCY / DELAY

Defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.

Latency = Propagation Time + Transmission Time + Queuing Time + Processing Delay

a) Propagation Time:

Measures the time required for a bit to travel from the source to the destination.

Propagation time = Distance / Propagation Speed

Example A: What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4×10^8 m/s in cable.

Solution

$$(12000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

Performance Metrices (…contd)

LATENCY / DELAY

- **Transmission Time**
  Depends on the size of the message and the bandwidth of the channel

Transmission time = (Message size) / Bandwidth

Example: What are the propagation time and the transmission time for a 2.5-KB (kilobyte) message (an email) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s m/s. Assume the propagation speed to be in cable.

Solution

$$\text{Propagation time} = (12{,}000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

$$\text{Transmission time} = (2500 \times 8) / 10^9 = 0.020 \text{ ms}$$

Performance Metrices (…contd)

LATENCY / DELAY

- Queueing Time
  Time needed for each intermediate or end device to hold the message before it can be processed.

  - **An intermediate device,**
    - Queues the arrived messages and
    - Processes them one by one

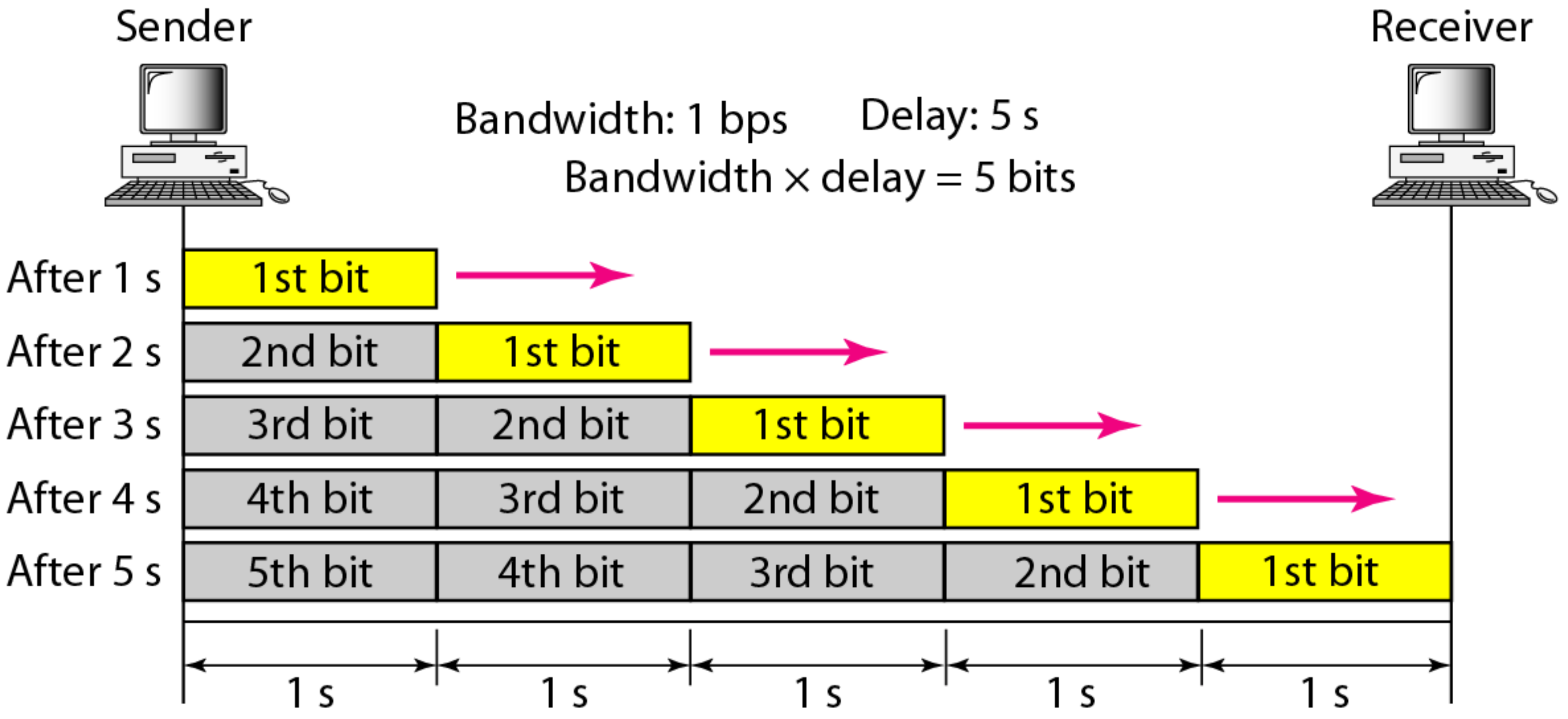
  - **Queuing time** is **Not a Fixed Factor**; depends upon:
    - **Load imposed on the network**.
      - When there is **heavy traffic** on the network, the **queuing time increases**.
      - If there are many messages, each message will have to wait

Performance Metrices:

Bandwidth Delay Product

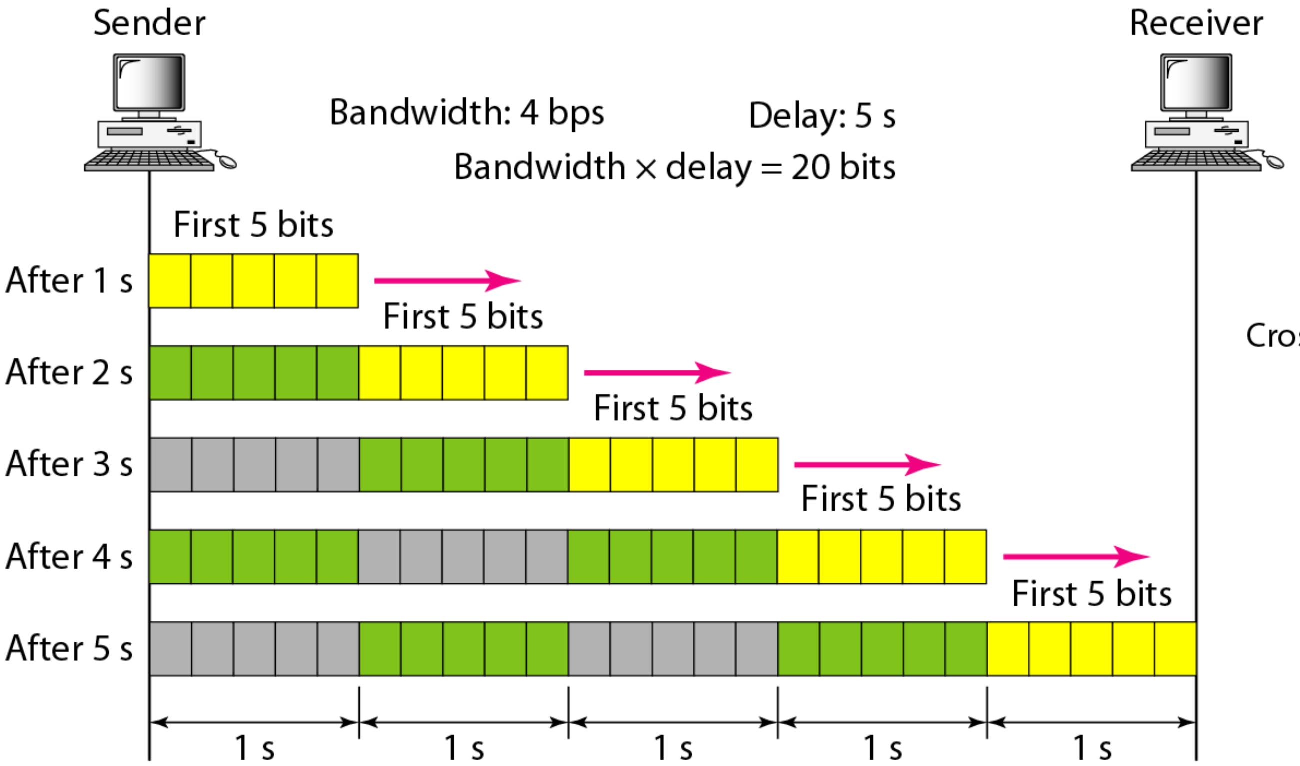
- Bandwidth and delay are two performance metrics of a link.
- **Bandwidth-delay product:** *Very important in data communications*.

- ***CASE 1 :*** *Filling the link with bits (a link with a bandwidth of 1 bps).*

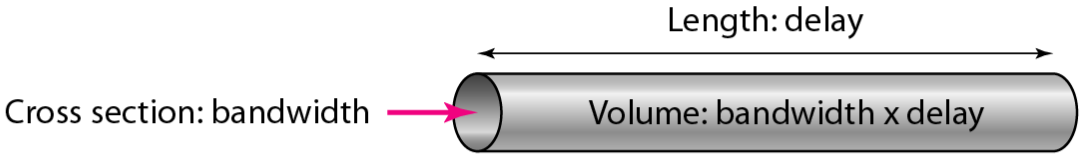


Bandwidth Delay Product

- ***CASE 2 :*** *Filling the link with bits (a bandwidth of 5 bps).*



The bandwidth-delay product defines the number of bits that can fill the link.



Performance Metrices:
Bandwidth Delay Product

- BDP is the product of bandwidth and delay is the number of bits that can **fill the link**.
- Important if we need to send data in bursts and wait for the acknowledgment of each burst before sending the next one.

- *For maximum capability of the link*,
  - Size of burst 2 times the product of bandwidth and delay;
  - We need to fill up the **full-duplex channel** (two directions).

  - The sender should send a burst of data of (2 × bandwidth × delay) bits.
  - The sender then waits for receiver acknowledgment for part of the burst before sending another burst.

- The amount *2 × bandwidth × delay* is the *number of bits* that *can be in transition at any time*.

Packet Delivery Ratio

Refers to the no. of packets received by the destination node to the no. of packets sent by the source.

$$PDR = \frac{\sum No.of\ packets\ recived\ by\ receiver}{\sum No.of\ packets\ sent\ by\ the\ transmitter}$$

Relation wrt Throughput

- **PDR** focus on packet transmission reliability by measuring the successful delivery of individual packets.
- **Throughput** considers overall efficiency of the network; by determining the overall total data transmitted over a certain period.

- ***PDR :*** Implies **reliability** of the network.
  - High PDR – implies – Low packet losses > Ensuing Efficient Data Transfer
- ***Throughput :*** Implies **capacity of network** to handle volumes of data
  - Considers, packet size and network bandwidth and congestion.

Round Trip Time (RTT)

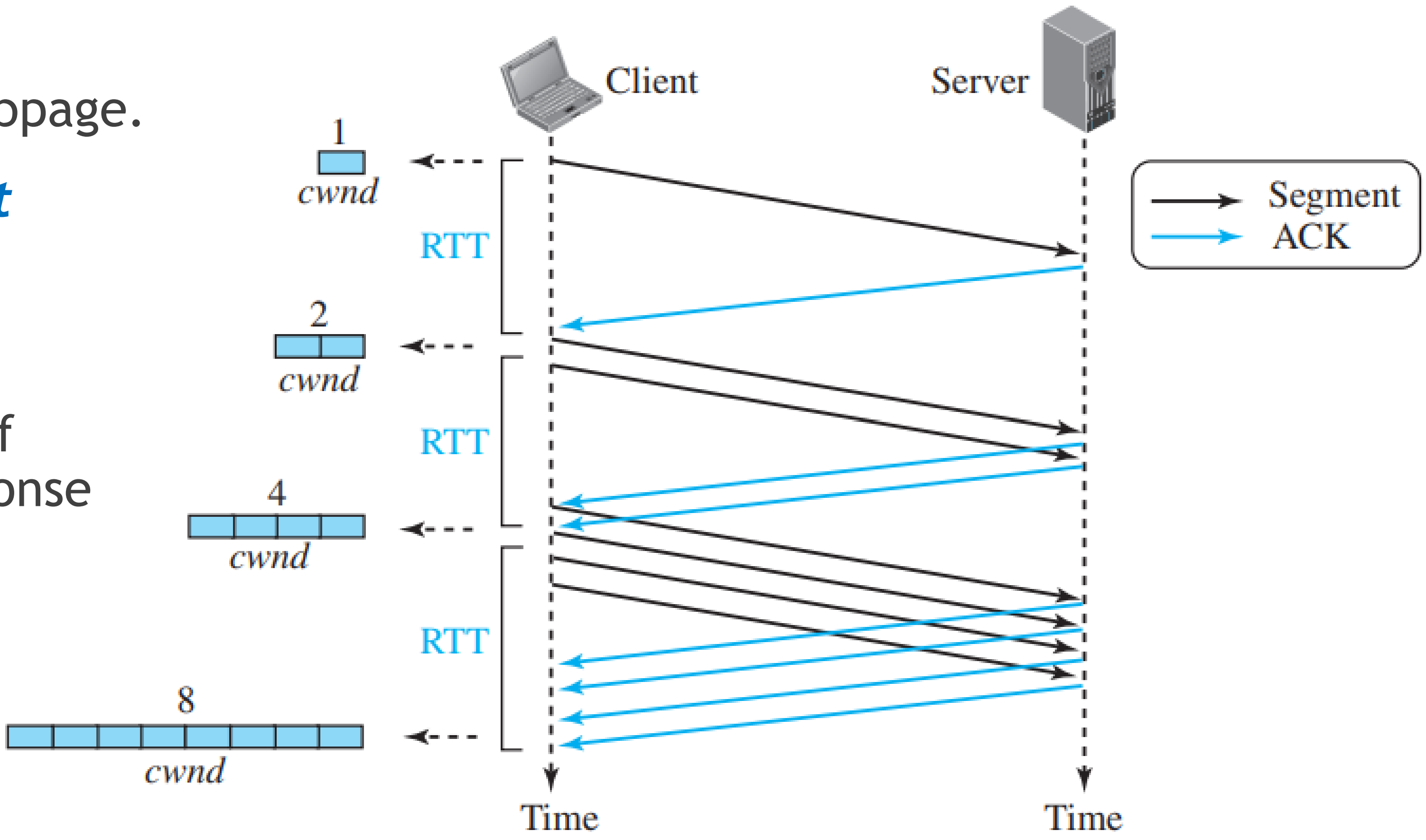
RTT is the **time** it takes to **get a response after a network request is initiated**,

Example: Click on any button on a webpage.

Can be measured using ***ping*** or ***tracert*** command.

Measured in milli-seconds.

Depends on: Distance, medium, No. of network hops, congestion, server response time, LAN traffic,



Reference

Forouzan, A. Behrouz. *Data Communications & Networking*. 5th Edition. Tata McGraw-Hill Education.

Chapter 3 *Physical Layer*

Topics: 3.3, 3.4, 3.5, 3.6

Switching

Switching Networks

Long distance transmission is typically done over a network of switched nodes

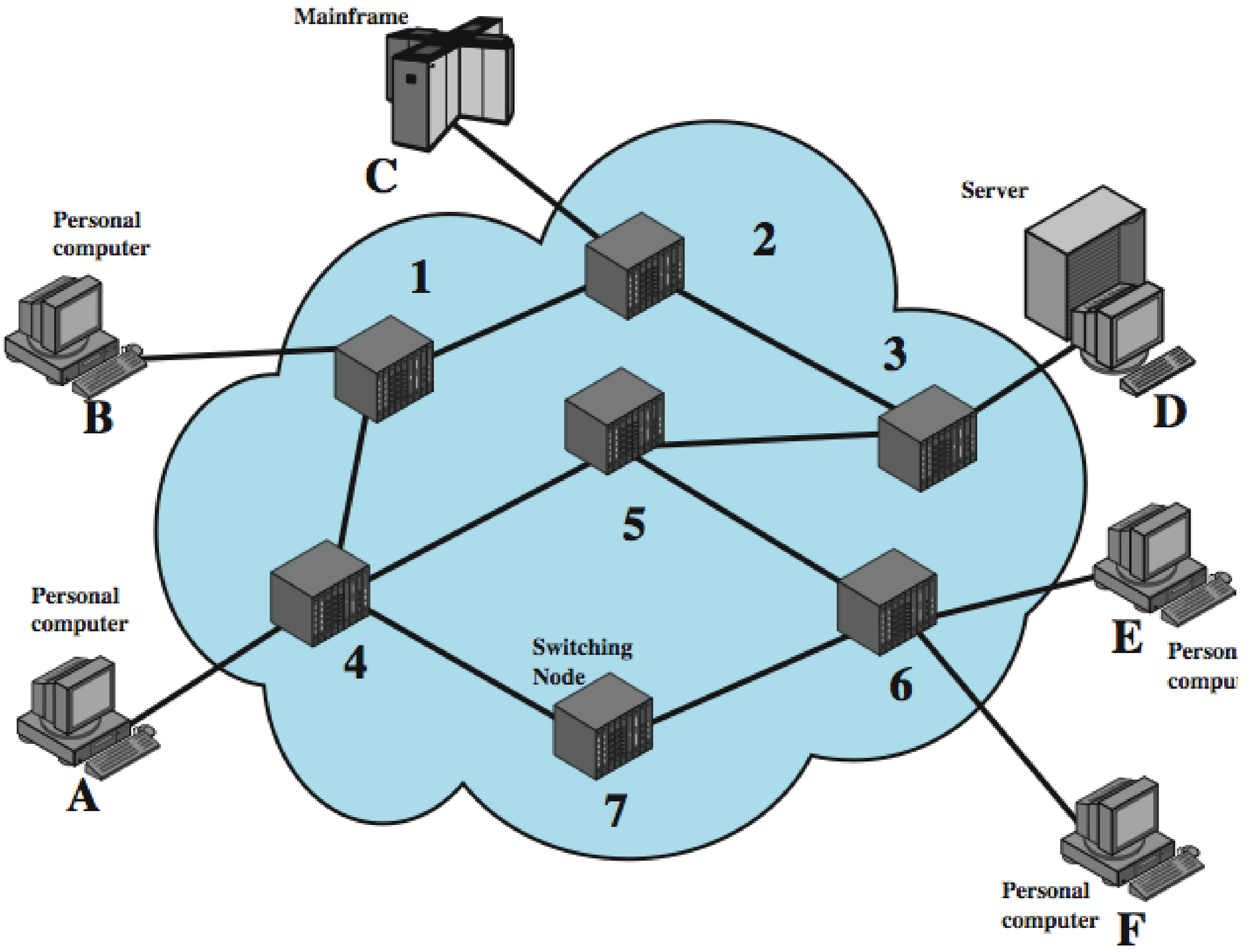
Nodes not concerned with content of data

End devices are stations

- Computer, terminal, phone, etc.

Switching Network is a collection of nodes and connections is a communications network

Data routed by being switched from node to node



Nodes

Nodes may connect to other nodes only, or to stations and other nodes

Node to node links usually multiplexed

Network is usually partially connected

- Some redundant connections are desirable for reliability

Two different switching technologies

- **Circuit switching**
- **Packet switching**

Circuit Switching

Uses a dedicated path between two stations

Has three phases

- establish
- transfer
- Disconnect

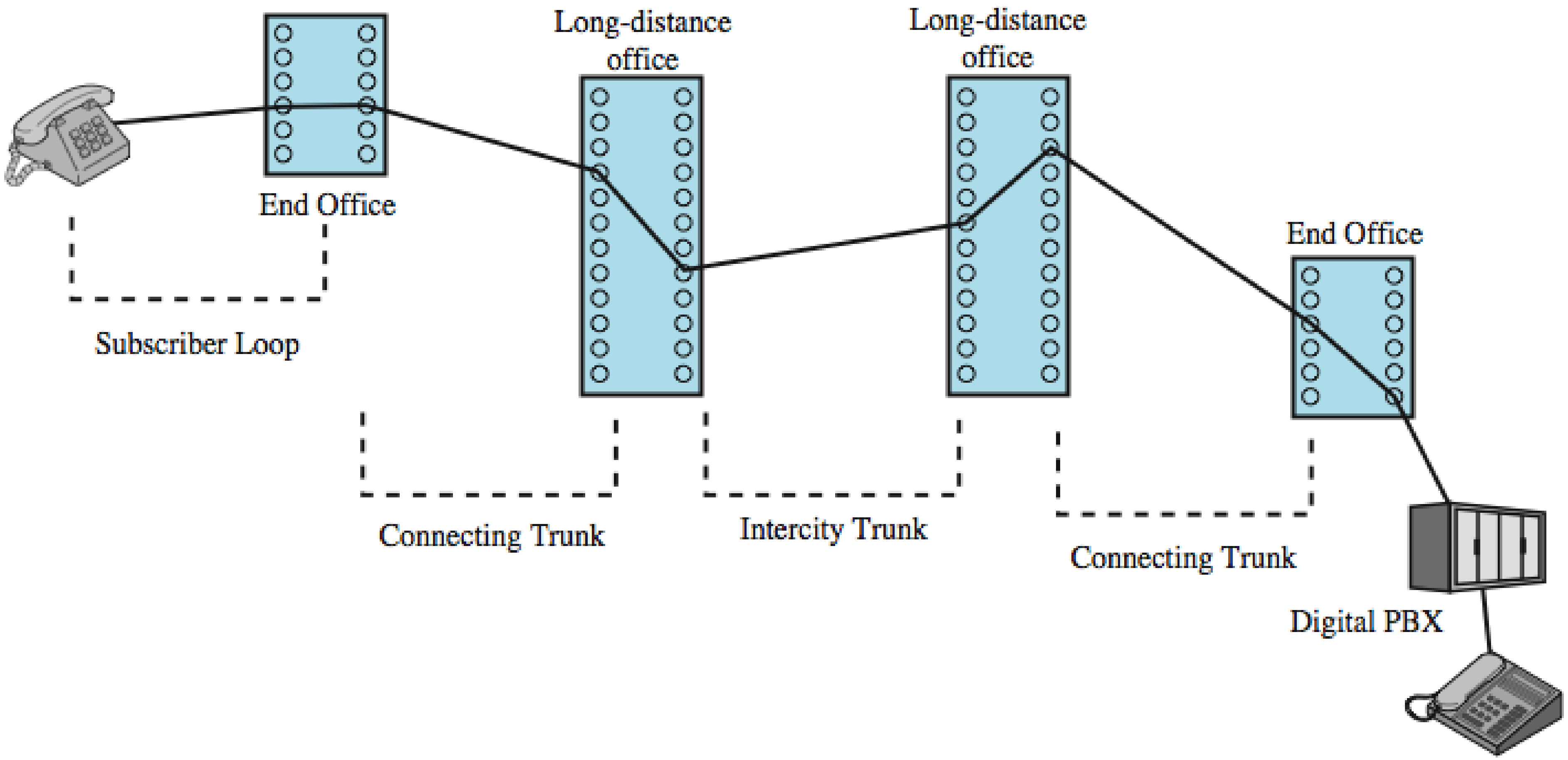
Disadvantages

- inefficient
- channel capacity dedicated for duration of connection
- if no data, capacity wasted

Set up (connection) takes time

Once connected, transfer is transparent

Example: Public Circuit Switched Network



Telecomms Components

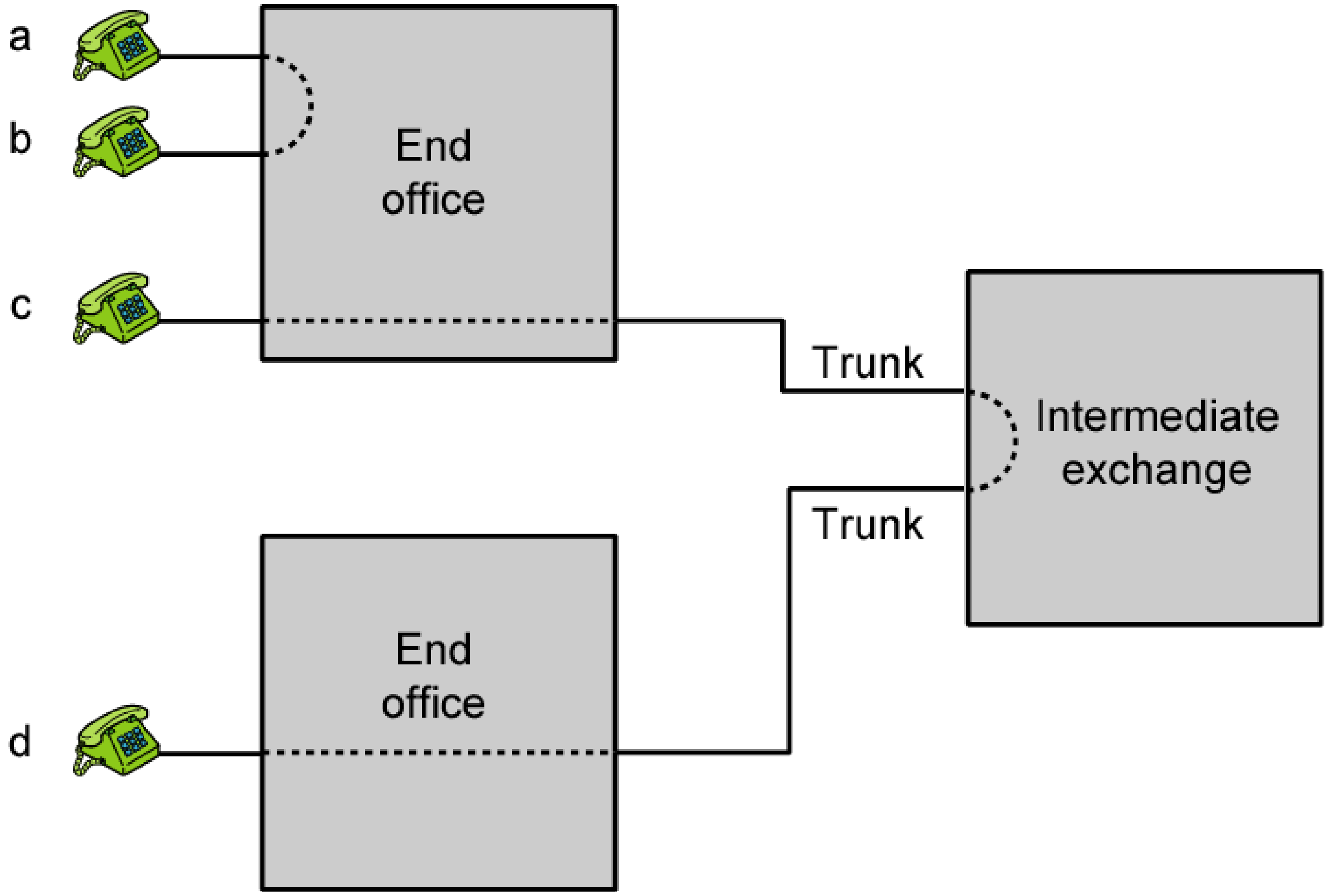
Subscriber
- Devices attached to network

Subscriber line
- Local Loop
- Subscriber loop
- Connection to network
- Few km up to few tens of km

Exchange
- Switching centers
- End office - supports subscribers

Trunks
- Branches between exchanges
- Multiplexed

Circuit Establishment



Circuit Switching Concepts

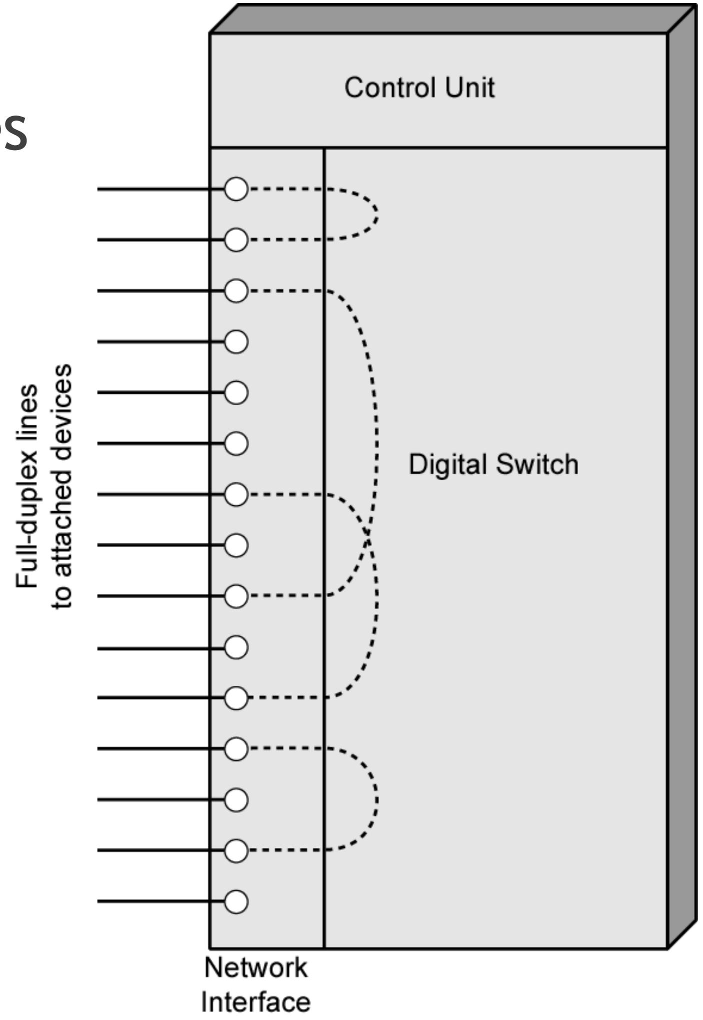
Digital Switch

- Provide transparent signal path between devices

Network Interface

Control Unit

- ***Establish connections***
  - Generally on demand
  - Handle and acknowledge requests
  - Determine if destination is free
  - construct path
- ***Maintain connection***
- ***Disconnect***



Blocking or Non-blocking

Blocking

- A network is unable to connect stations because all paths are in use
- Used on voice systems
  - Short duration calls

Non-blocking

- Permits all stations to connect (in pairs) at once
- Used for some data connections

Packet Switching Principles

Packet Switching: Data transmitted in small packets

- Typically 1000 octets
- Longer messages split into series of packets
- Each packet contains a portion of user data plus some control info

Store and forward approach

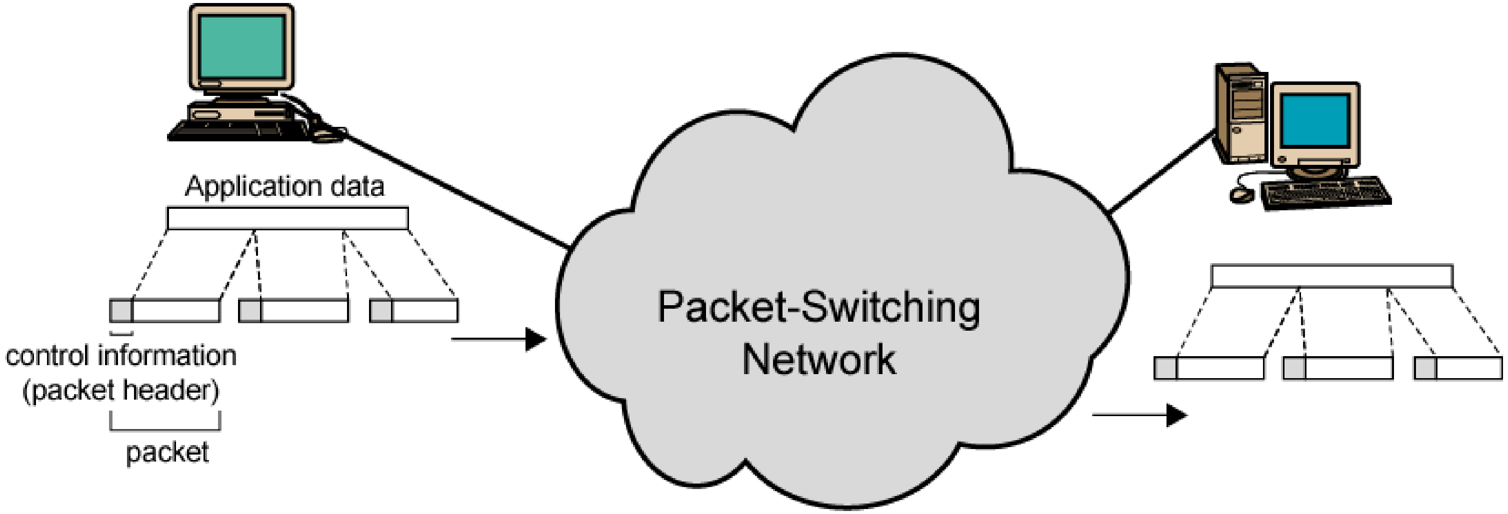
- Packets are received, stored briefly (buffered) and past on to the next node
- Station breaks long message into packets & sent one at a time to the network

Control info

- Routing (addressing) info

Packets handled in two ways

- Datagram
- Virtual circuit



Advantages

Line efficiency

- Single node to node link can be shared by many packets over time
- Packets queued and transmitted as fast as possible

Data rate conversion

- Each station connects to the local node at its own speed
- Nodes buffer data if required to equalize rates

Packets are accepted even when network is busy

- Delivery may slow down

Priorities can be used

Datagram

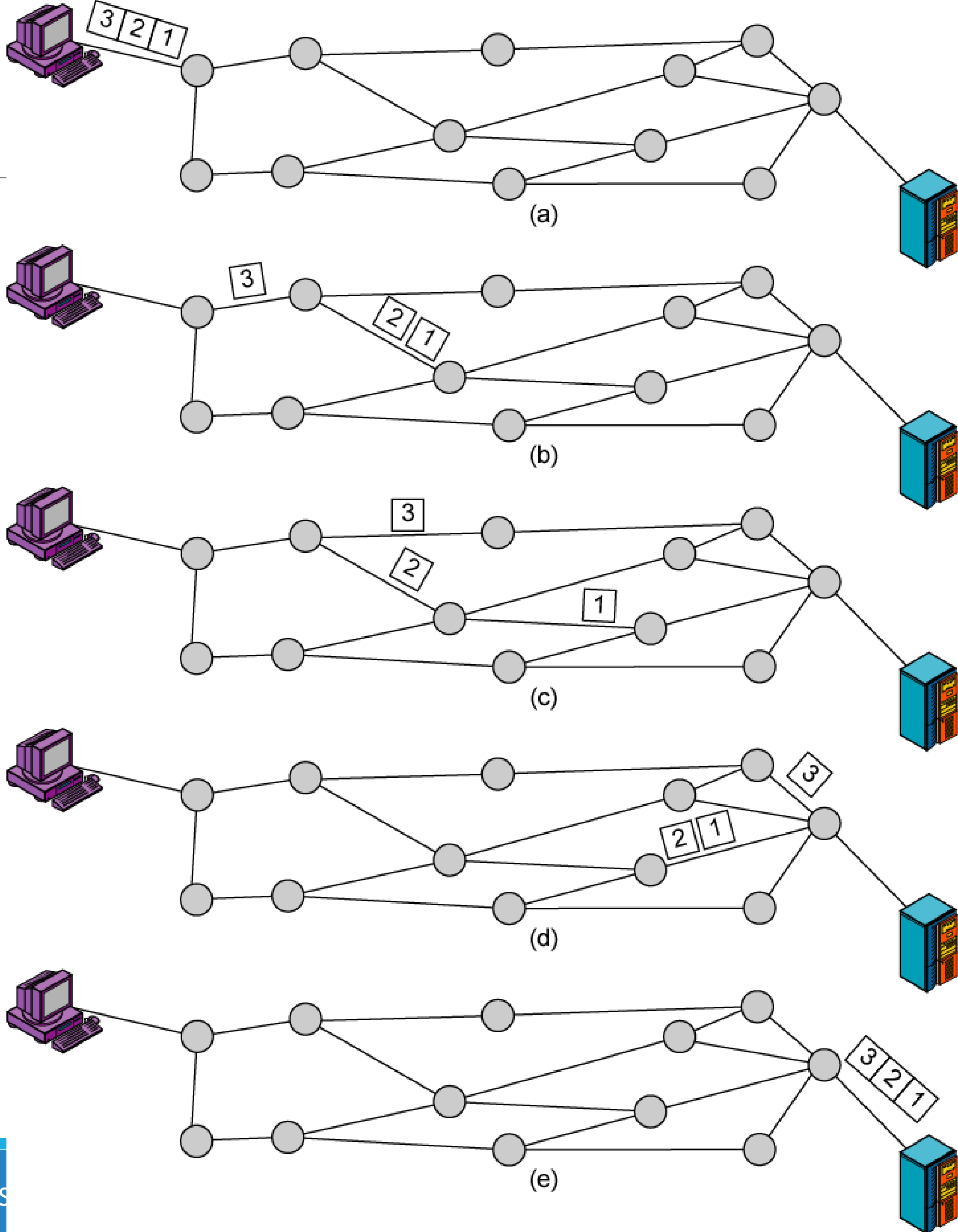
Each packet treated independently

Packets can take any practical route

Packets may arrive out of order

Packets may go missing

Up to <u>receiver to re-order packets and recover from missing packets</u>



Virtual Circuit

Preplanned route established before any packets sent

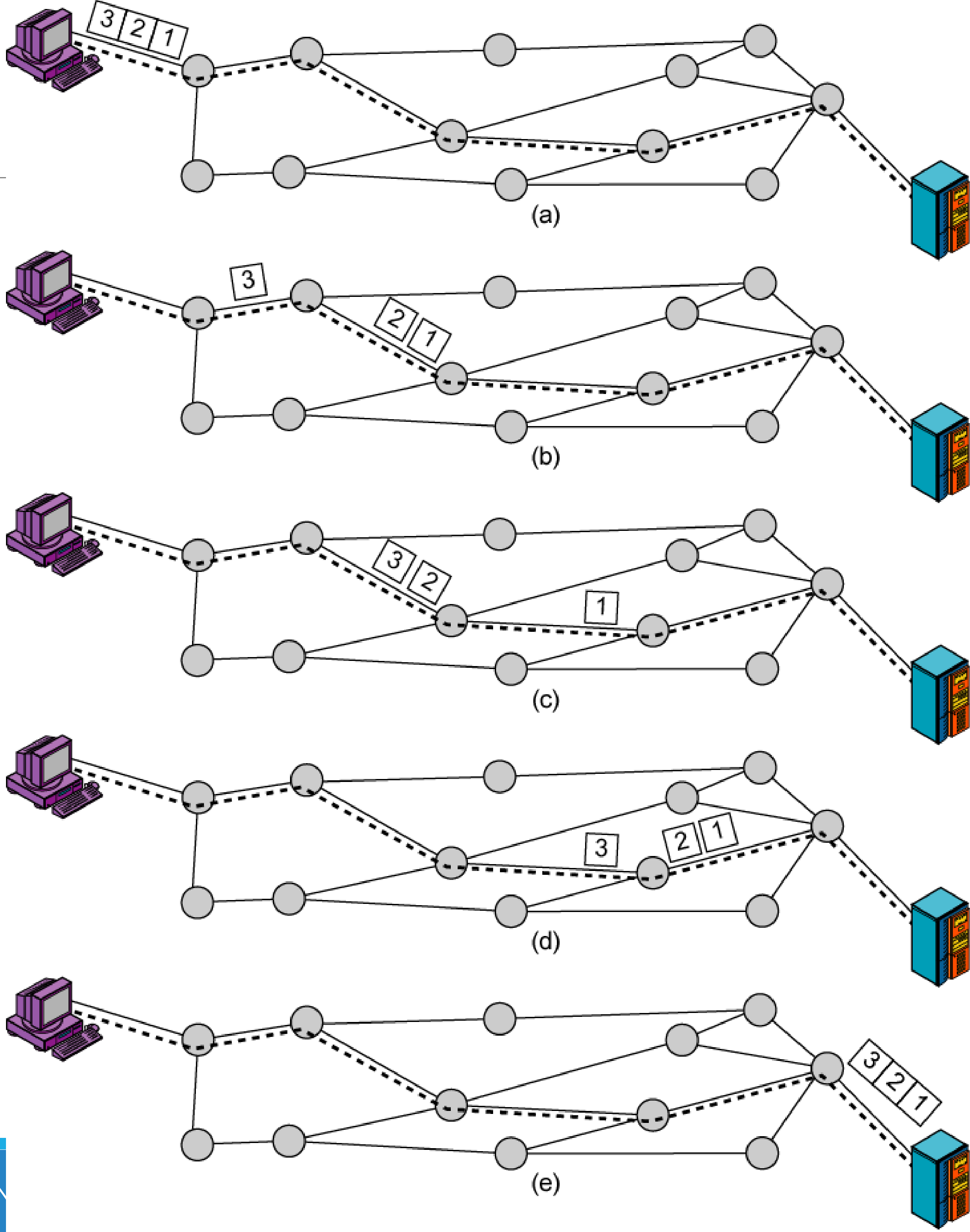
Call request and call accept packets establish connection (handshake)

Each packet contains a virtual circuit identifier instead of destination address

No routing decisions required for each packet

Clear request to drop circuit

Not a dedicated path



Virtual Circuits vs. Datagram

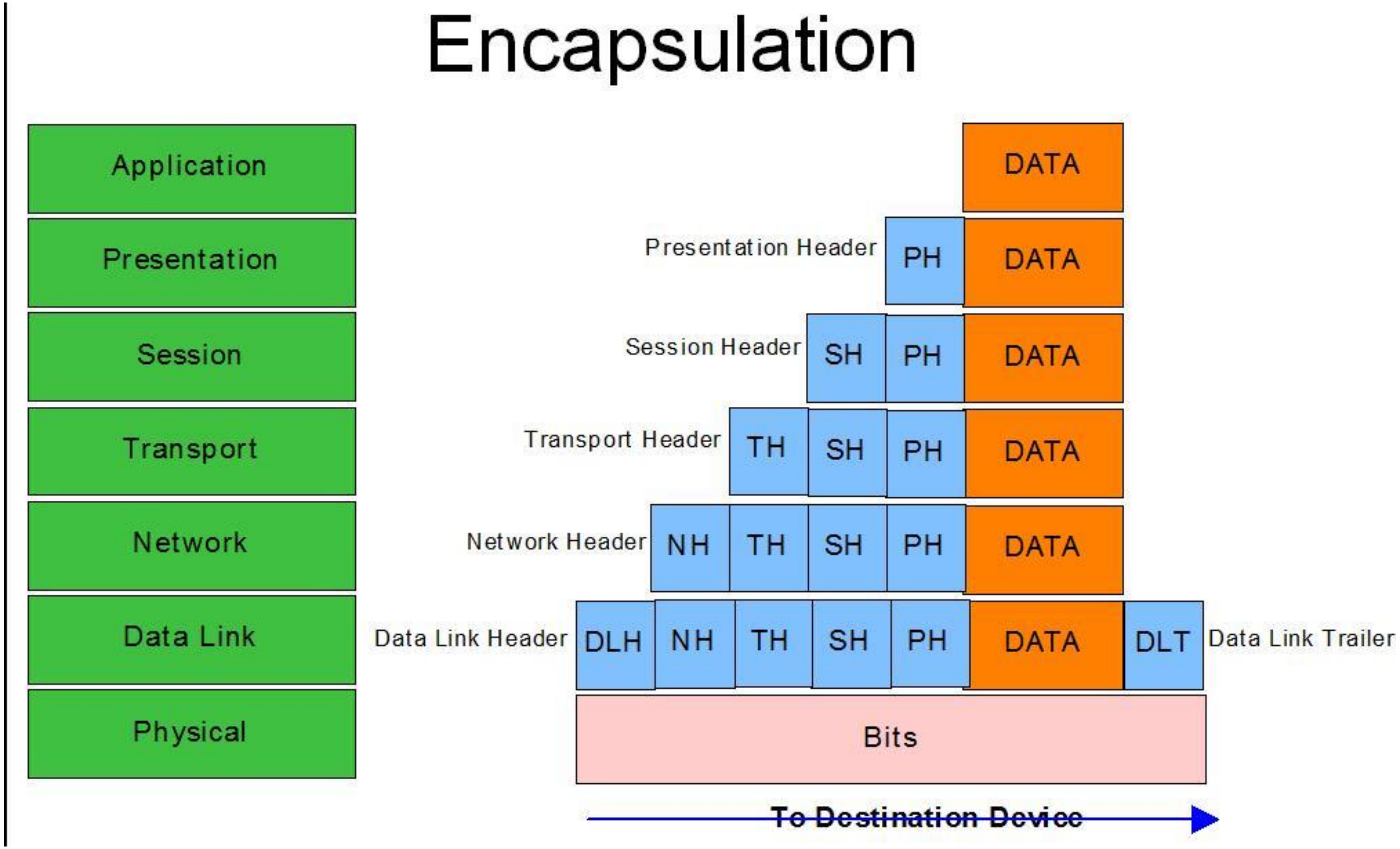
Virtual circuits

- Network can provide sequencing and error control
- Packets are forwarded more quickly
  - No routing decisions to make
- Less reliable
  - Loss of a node loses all circuits through that node

Datagram

- No call setup phase
  - Better if few packets
- More flexible
  - Routing can be used to avoid congested parts of the network

Data Encapsulation in OSI Model



Data Encapsulation

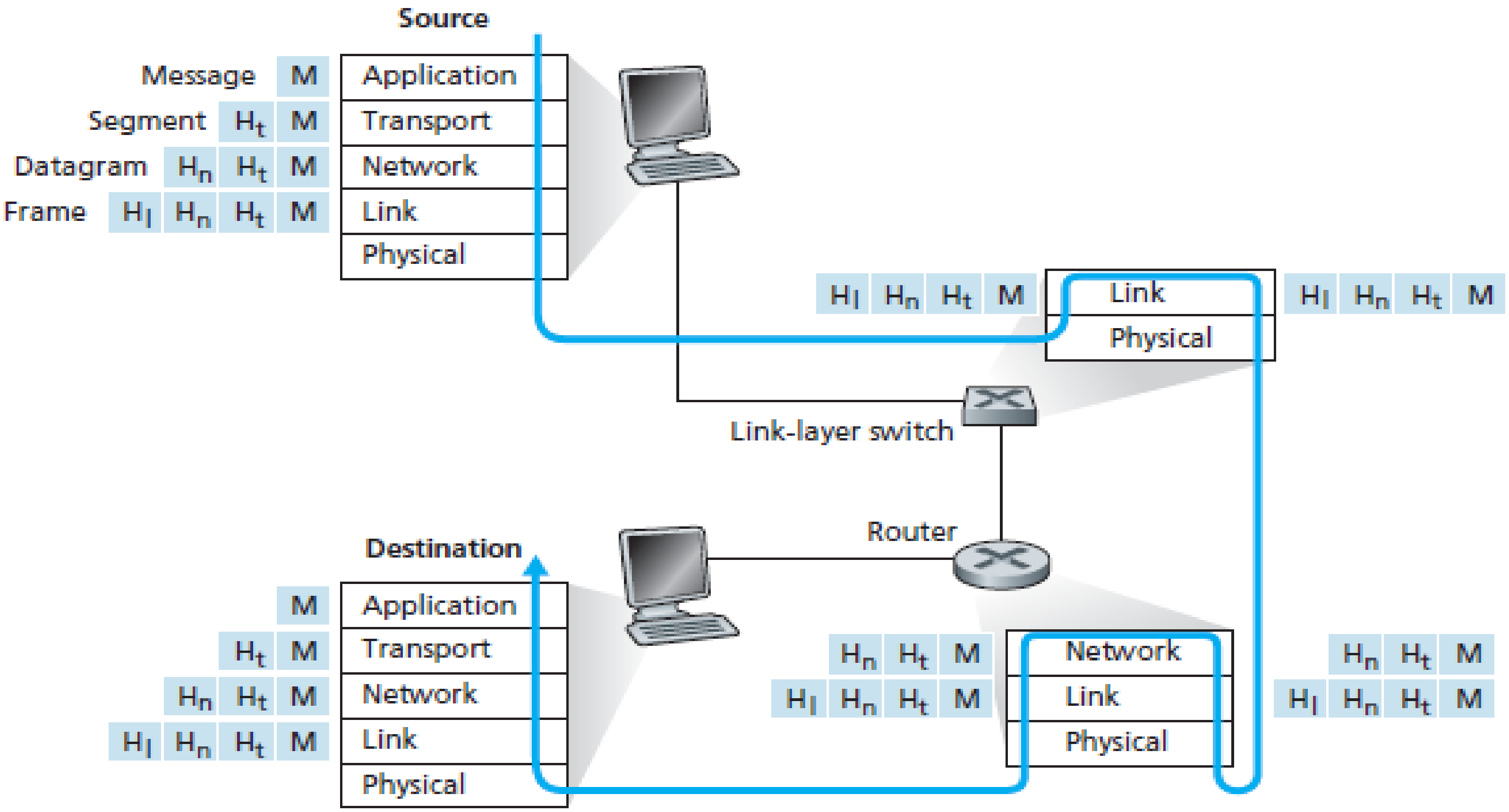


Figure 1.24 ♦ Hosts, routers, and link-layer switches; each contains a different set of layers, reflecting their differences in functionality

Problem

Consider two hosts, A and B, connected by a single link of rate *R* bps. Suppose that the two hosts are separated by *m* meters, and suppose the propagation speed along the link is *s* meters/sec. Host A is to send a packet of size *L* bits to Host B.

a. Ignoring processing and queuing delay, obtain an expression for the end-to-end delay.

b. Suppose *s*=2.5*10^8 meters/sec, *L*=120 bits, and *R*=56kbps. Find the distance *m* so that the propagation delay equals transmission delay.

Solution:

a) $d_{end-to-end} = (m/s + L/R)$ seconds.

d) Want

$$m = \frac{L}{R}s = \frac{120}{56\times 10^3}\left(2.5\times 10^8\right) = 536\,\text{km}.$$

Reference

Forouzan, A. Behrouz. *Data Communications & Networking*. 5th Edition. Tata McGraw-Hill Education.

Chapter 7 Transmission Media

Chapter 8 Switching