Physical Layer: Data and Signals

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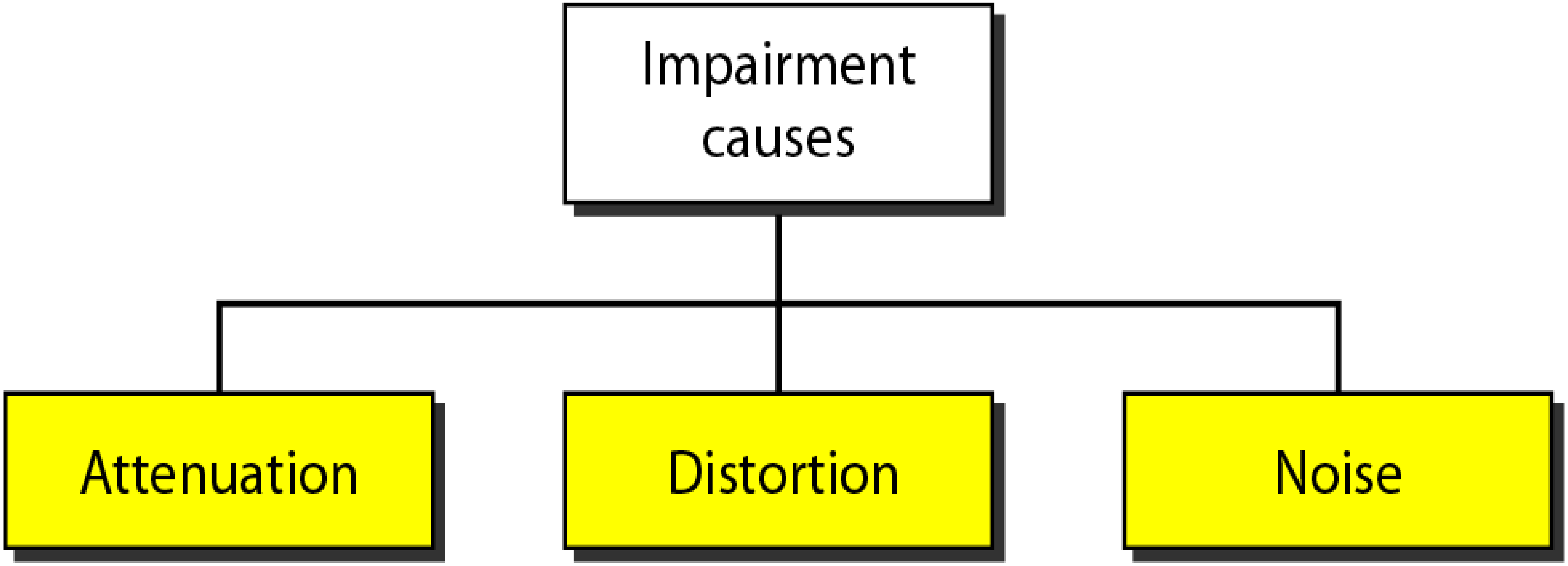
Reading Material for this discussion

- DATA COMMUNICATIONS AND NETWORKING, Fourth Edition by Behrouz A. Forouzan, Tata McGraw-Hill
  – Chapter 3, Topics 3.4, 3.5, 3.6

3-4 TRANSMISSION IMPAIRMENT

- Signals travel through transmission media, which are not perfect.
- The imperfection causes signal impairment.
  - Signal at the beginning of the medium is not the same as the signal at the end of the medium.

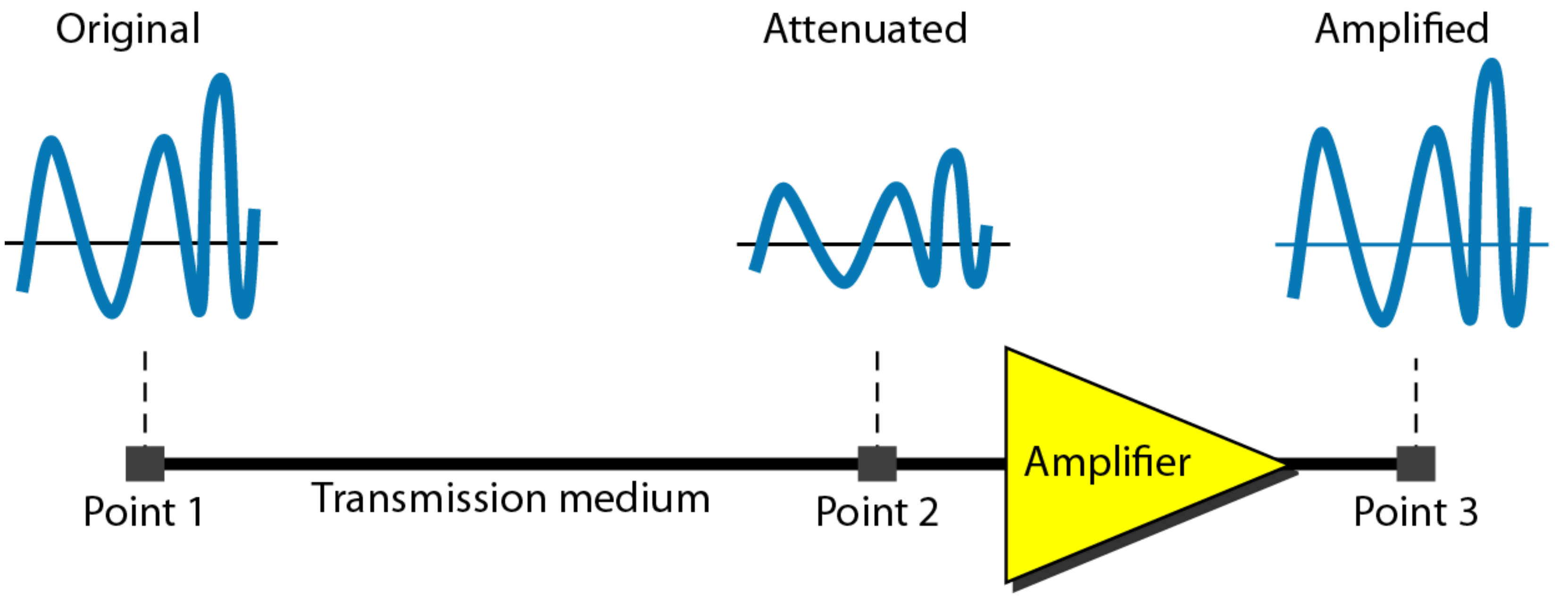
Figure 3.25 *Causes of impairment*



Attenuation

- When signal travels through a medium, it loses some of its energy in overcoming the resistance of the medium.
  - a wire carrying electric signals gets warm, after a while.
  - Some of the electrical energy in the signal is converted to heat.
- Amplifiers are used to amplify the signal.

Figure 3.26 *Attenuation*



Decibel (dB)

- Measures
  - Relative strengths of two signals
    - OR
  - Relative strengths of one signal at two different points
- Decibel is negative if a signal is attenuated and positive if a signal is amplified

Decibel (dB)

If variables PI and P2 are the powers of a signal at points 1 and 2, respectively

$$N_{dB} = 10log_{10}(\frac{P_2}{P_1})$$

- **When the voltage and current are given:**

$N_{dB} = 20log_{10}(\frac{V_2}{V_1})$	i.e. P α V^2
$N_{dB} = 20log_{10}(\frac{I_2}{I_1})$	i.e. P α I^2

Example 3.26

Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P_2 is (1/2)P_1. In this case, the attenuation (loss of power) can be calculated as

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

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

Example 3.27

A signal travels through an amplifier, and its power is increased 10 times. This means that $P_2 = 10P_1$. In this case, the amplification (gain of power) can be calculated as

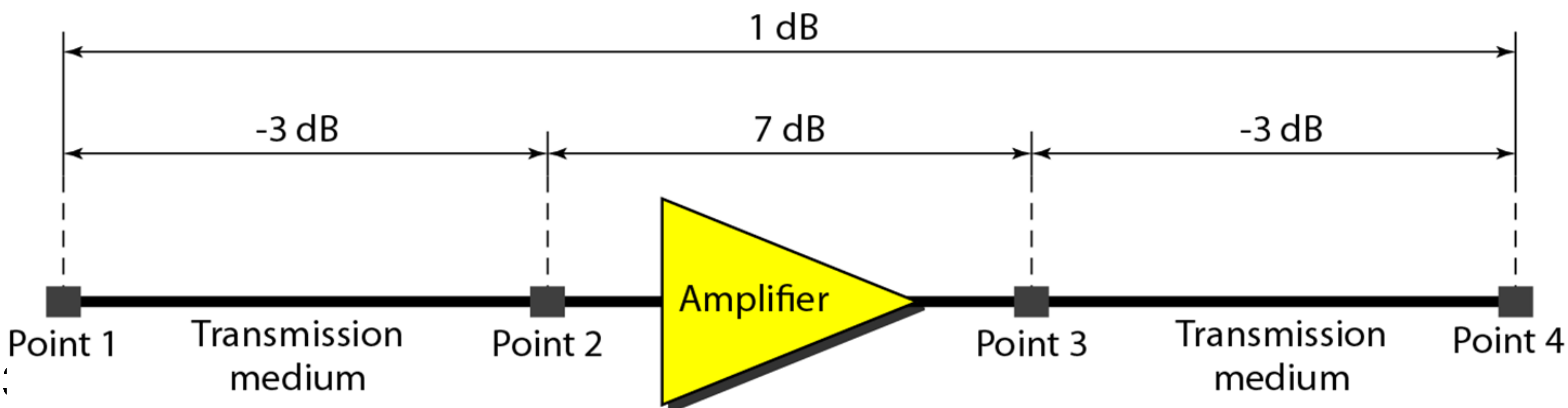
$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10P_1}{P_1}$$

$$= 10 \log_{10} 10 = 10(1) = 10 \text{ dB}$$

Example 3.28

Reason to use decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two. In Figure below a signal travels from point 1 to point 4. In this case, the decibel value can be calculated as

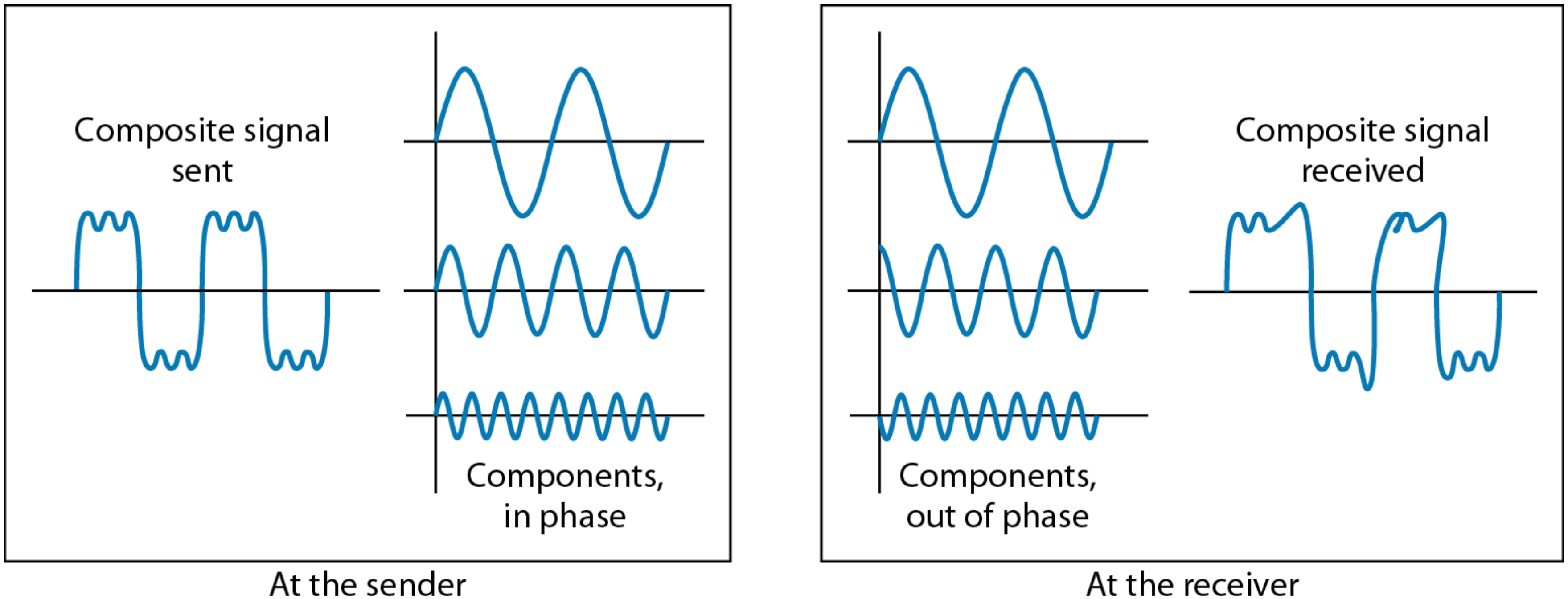
$$\text{dB} = -3 + 7 - 3 = +1$$



Distortion

- Signal changes its form or shape. Occurs in a composite signal made of different frequencies.
- We send a composite signal to communicate data.
- A composite signal is made of many simple sine waves.
- Each signal component has its own propagation speed through a medium and, hence its own delay in arriving at the final destination.
- Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration.
- Thus, signal components at the receiver have phases different from what they had at the sender.
- Shape of the composite signal is therefore not the same

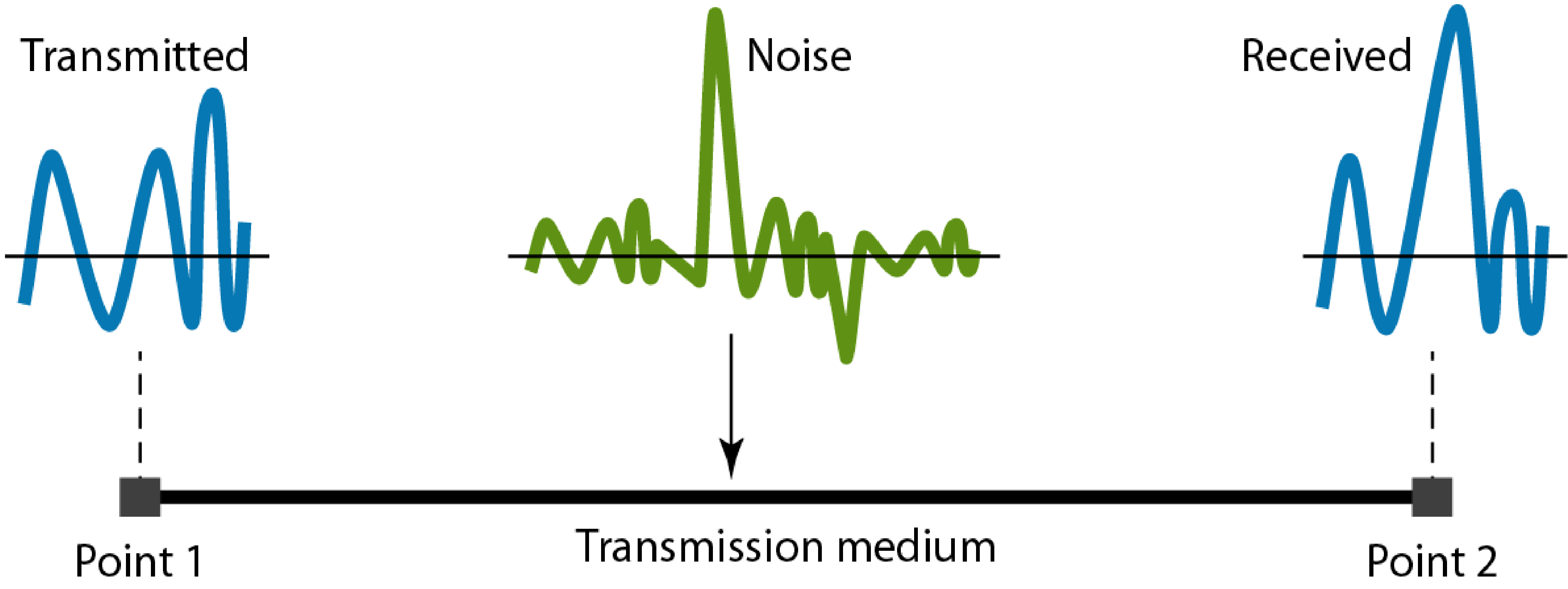
Figure 3.28 *Distortion*



Noise

- Noise corrupts the signal
- Thermal noise
  - random motion of electrons in a wire which creates an extra signal not originally sent by the transmitter.
- Induced noise
  - Motors and similar appliances act as a sending antenna, and the transmission medium acts as the receiving antenna.
- Crosstalk
  - One wire acts as a sending antenna and the other as the receiving antenna.
- Impulse noise
  - A signal with high energy in a very short time that comes from power lines, lightning, and so on.

Figure 3.29 *Noise*



Signal to Noise Ratio

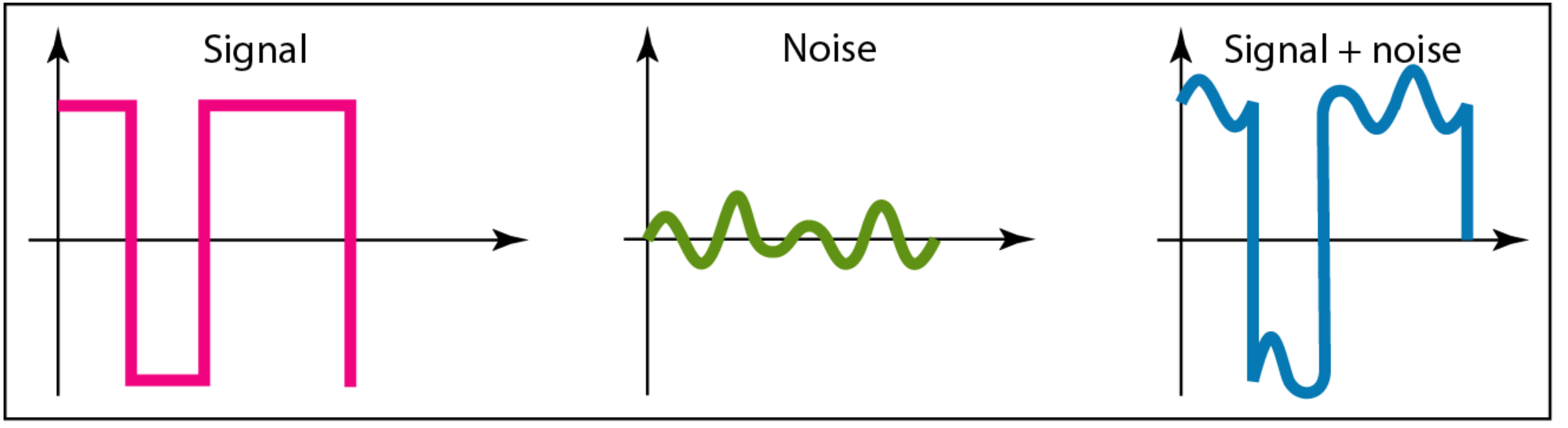
- ratio of the signal power to the noise power

$$\mathrm{SNR} = \frac{\text{average signal power}}{\text{average noise power}}$$

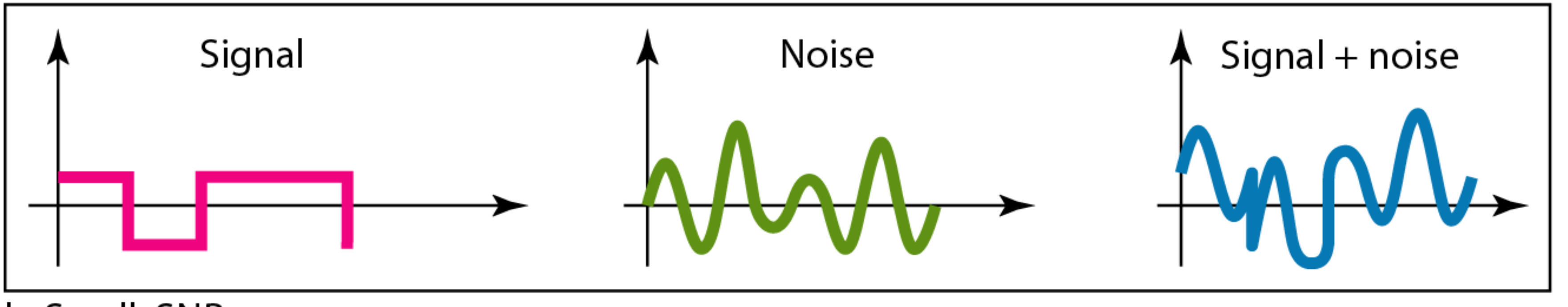
- High SNR means signal is less corrupted by noise; a low SNR means signal is more corrupted by noise.
- As SNR is ratio of two powers, it can be described in decibel units

$$\mathrm{SNR}_{\mathrm{dB}} = 10\log_{10}\mathrm{SNR}$$

Figure 3.30 *Two cases of SNR: a high SNR and a low SNR*



a. Large SNR



b. Small SNR

Example 3.31

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

The values of SNR and SNR_{dB} can be calculated as follows:

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

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

3-5 DATA RATE LIMITS

- *how fast we can send data, in bits per second, over a channel.*

- *Two theoretical formulas:*
  - *Nyquist for a noiseless channel.*
  - *Shannon for a noisy channel*

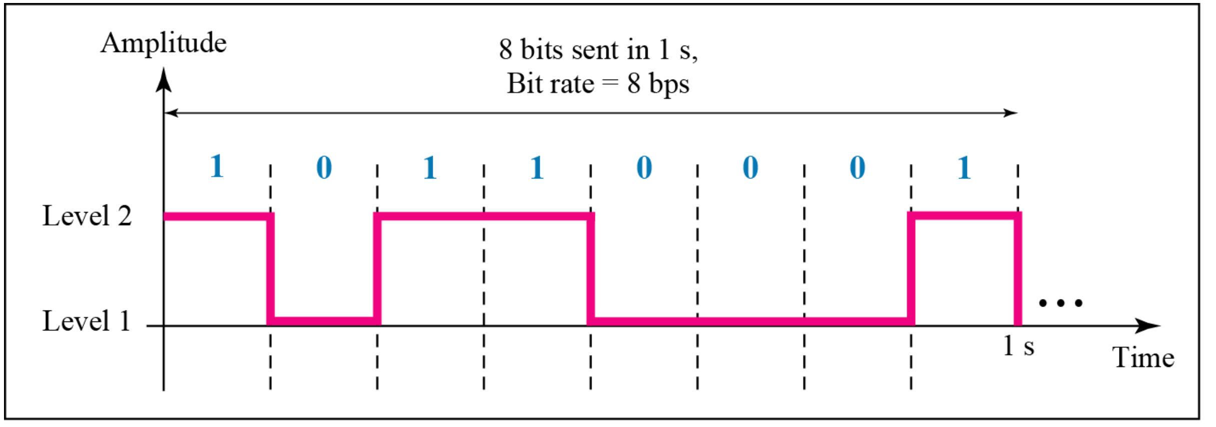
Nyquist bit rate formula for a noiseless channel

- For a noiseless channel, Nyquist bit rate formula defines theoretical maximum bit rate.

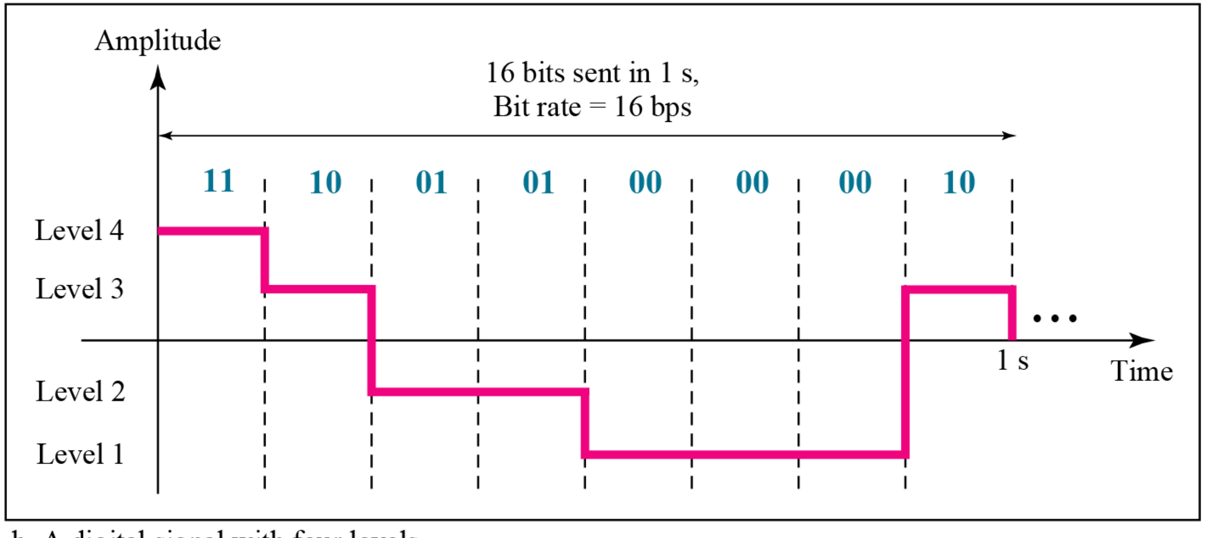
$$\text{Bit Rate} = 2 \,.\, B \,.\, \log_2 L$$

- B= bandwidth of the channel
- L = number of signal levels used to represent data
- BitRate = bit rate in bits per second

Figure 3.16 *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 3.34

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

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

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

Nyquist bit rate formula

- When we increase L number of signal levels, we impose a burden on the receiver.
- If the number of levels in a signal is 2, receiver can easily distinguish between a 0 and a 1.
- If level of a signal is 64, receiver must distinguish between 64 different levels
- Thus increasing the levels of a signal reduces the reliability of the system

Noisy Channel: Shannon Capacity

- to determine theoretical highest data rate for a noisy channel:

$$C = B \,.\, \log_2(1 + SNR)$$

- B= bandwidth of the channel, SNR = signal-to noise ratio, Capacity = capacity of the channel in bits per second.

Example 3.37

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. For this channel the capacity C is calculated as

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

- ***capacity of this channel is zero regardless of bandwidth. i.e., we cannot receive any data through this channel.***
- ***there is no indication of signal level, formula defines a characteristic of channel, not method of transmission.***

Example

A telephone line normally has a bandwidth of 3000 Hz (300 Hz to 3300 Hz). The signal-to-noise ratio is usually 3162. Calculate the theoretical highest bit rate of the telephone line.

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

Note

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

Network Criteria

- Performance
- Reliability
- Security

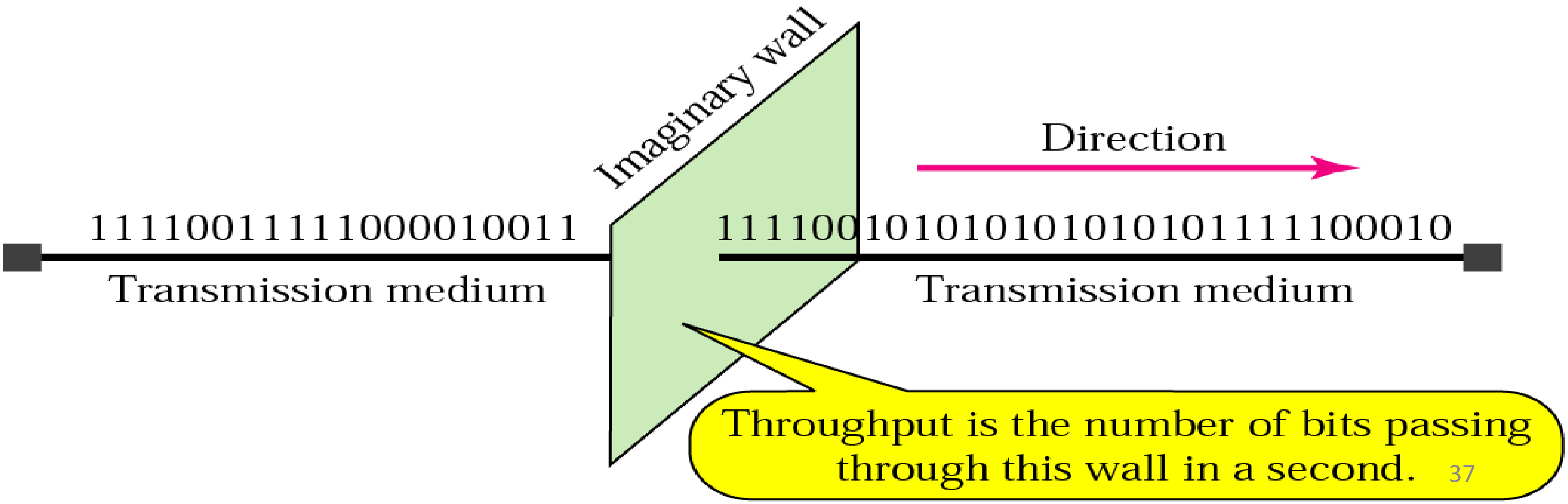
Performance

- Bandwidth
- Throughput
- Latency
- Bandwidth Delay Product
- Jitter
- Goodput

Bandwidth

- In networking, bandwidth has two contexts.
- Bandwidth in Hertz,
  - range of frequencies in a composite signal or range of frequencies that a channel can pass.
- Bandwidth in bps
  - speed of bit transmission in a channel or link.
  - For example, bandwidth of a Fast Ethernet network is a maximum of 100 Mbps.
  - This means Ethernet network can send 10^8 bits per sec

- Throughput
  - how fast we can actually send data through a network
  - Bandwidth in bps and throughput are same?
  - Bandwidth bps > Throughput bps
  - Bandwidth = potential measurement/capacity of a link
  - Throughput = actual measurement of how fast we can send data
  - Eg. Highway, Ethernet (100Mbps, 1 Gbps)
  - Link bandwidth = 1 Mbps, devices connected at end of link can handle 200Kbps



Example 3.44

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

$$\boxed{\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}}$$

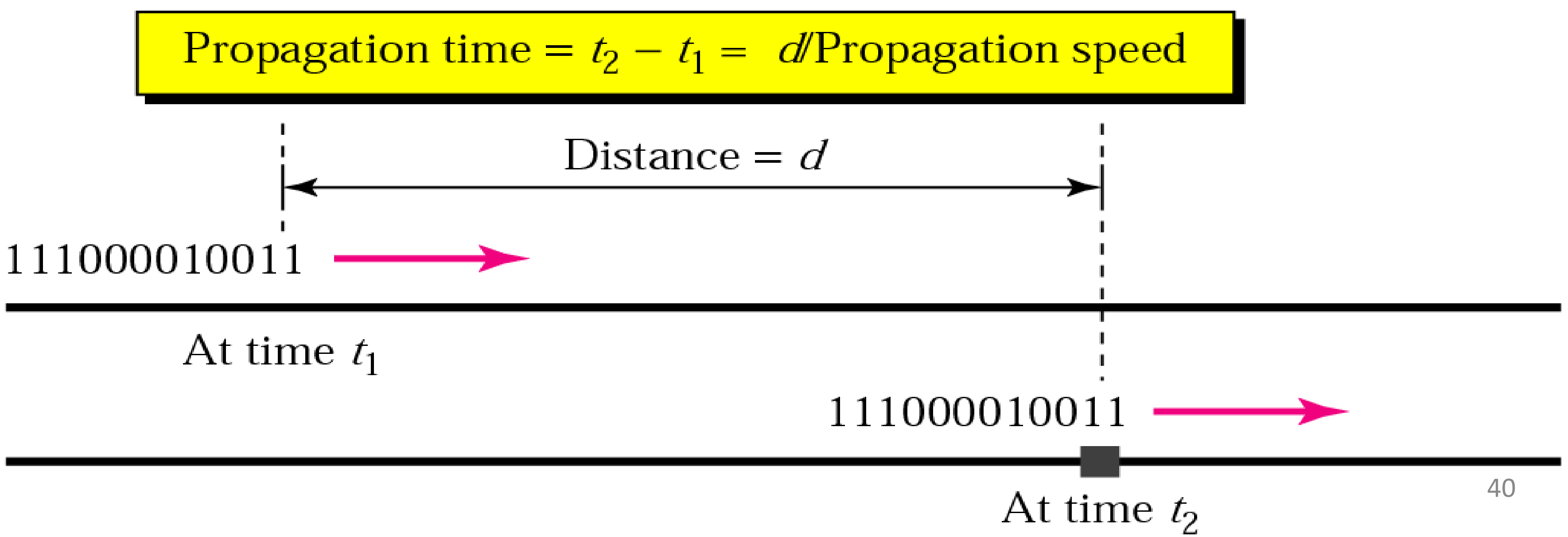
The throughput is almost one-fifth of the bandwidth in this case.

Latency (Delay)

- 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

Propagation Time

- Time required for a bit to travel from source to destination
- Propagation time = Distance/Propagation Speed
- The propagation speed of electromagnetic signals depends on the medium and on the frequency of the signal.
- In a vacuum, light is propagated with a speed of 3 x 10^8 m/s.
- It is lower in air and much lower in cable



Example 3.45

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

We can calculate the propagation time as

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

Trasmission time

- We transmit message – a number of bits
- Time required for transmission of a message depends on size of message and bandwidth of channel
  - Message size = number of bits
  - Transmission time = Message size/Bandwidth

Transmission Time and Propagation Time

- What are the propagation time and the transmission time

1. for a 2.5-kbyte data if the bandwidth of network is 1 Gbps?
2. for a 5-Mbyte data if the bandwidth of the network is 1 Mbps?

- Assume that distance between transmitter and receiver is 12,000 km and signal travels at 2.4×10^8 m/s

Case 1

- Propagation time = distance/speed=12,000 x 1000/2.4 x 10^8 = 50 ms
- Transmission time = message size/bandwidth = 2500 x 8/ 10^9 = 0.020 ms
- Message is short and bandwidth is high, dominant factor is propagation time, not transmission time.
- The transmission time can be ignored.
- Common for IOT devices

Case 2

- Propagation time = 12,000 x 1000/2.4 x 10^8 = 50 ms
- Transmission time = 5,000,000 x 8/10^6 = 40 s
- Message is very long and bandwidth is not very high, dominant factor is transmission time, not propagation time
- The propagation time can be ignored.

- Queuing Time
  - Time needed for each intermediate or end device to hold message before it can be processed
  - Changes with the load in network
  - With heavy traffic queuing time increases
- Processing Time
  - Time required at intermediate nodes and receiver to process the data before it is available to the end user

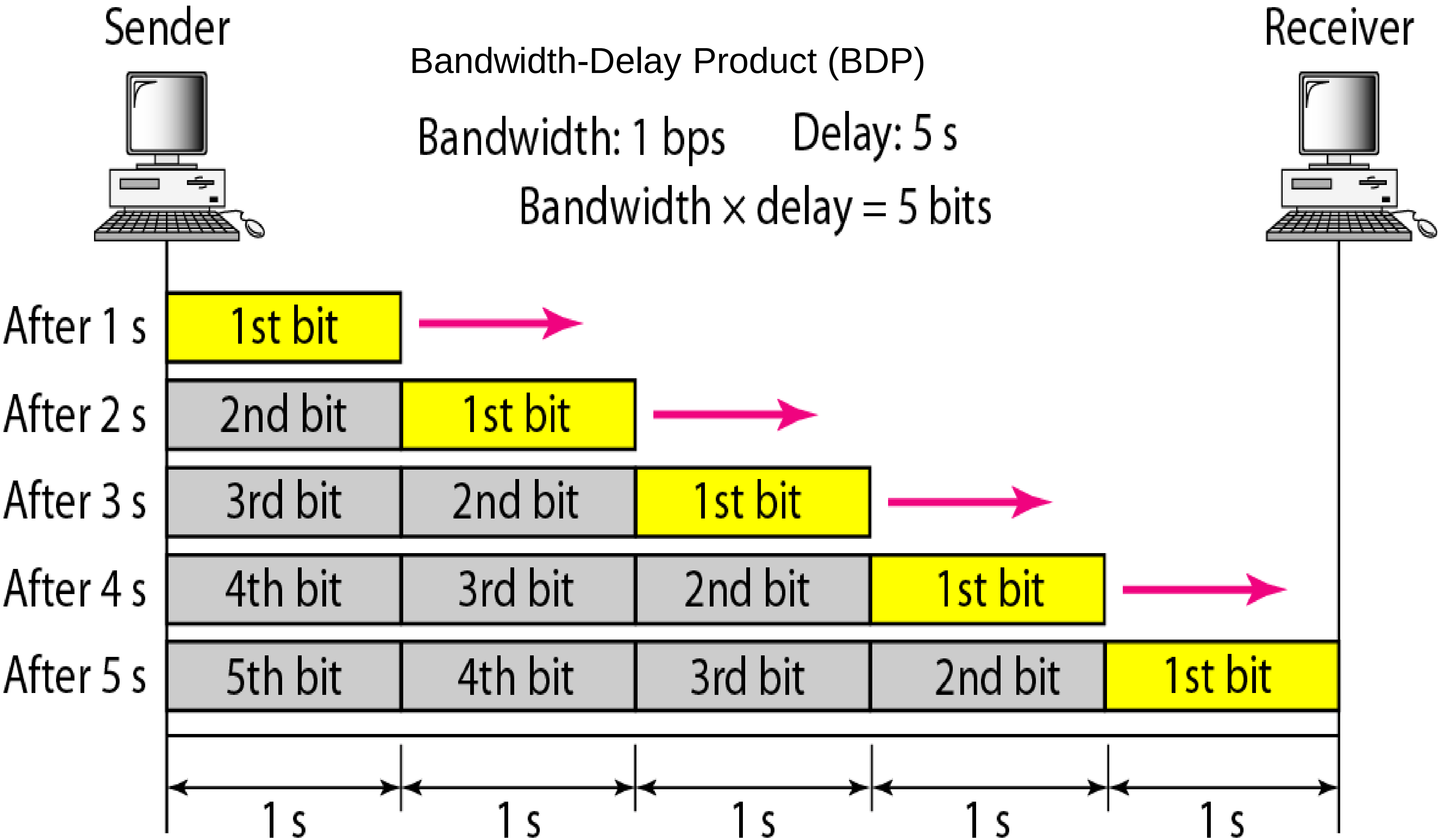
Goodput

- The application-level throughput of a communication
- Amount of useful information bits that is delivered per second to the receiver node
- Handshaking packets, Dropped packets or packet retransmissions as well as protocol overhead are excluded.
- Goodput < Throughput
- A file is transferred over network connection in 1 sec.
- File is broken into packets of 1500 bytes with
  - Header = 20 bytes (source, destination address)
  - Trailer = 20 bytes (checksum)
  - Data = 1460 bytes
  - Throughput = 1500x8/1 = 12000 bps = 12 kbps
  - Maximum goodput = 1460x8/1 = 11680 bps = 11.68 kbps

Bandwidth-Delay Product (BDP)

- Bandwidth and delay are two performance metrics of a link
- In data communication the bandwidth-delay product is important

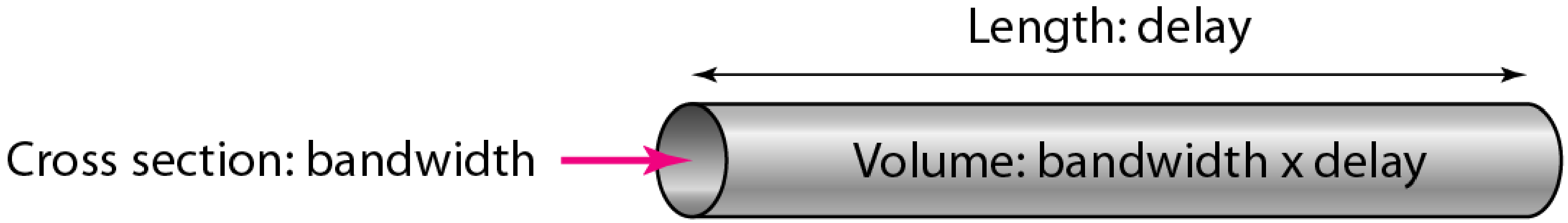
Bandwidth-Delay Product (BDP)



1 x 5 is the maximum number of bits that can fill the link
There can be no more than 5 bits at any time on the link
The bandwidth delay product defines the number of bits that can fill the link

Example 3.48

We can think about the link between two points as a pipe. The cross section of the pipe represents the bandwidth, and the length of the pipe represents the delay. We can say the volume of the pipe defines the bandwidth-delay product, as shown in Figure 3.33.



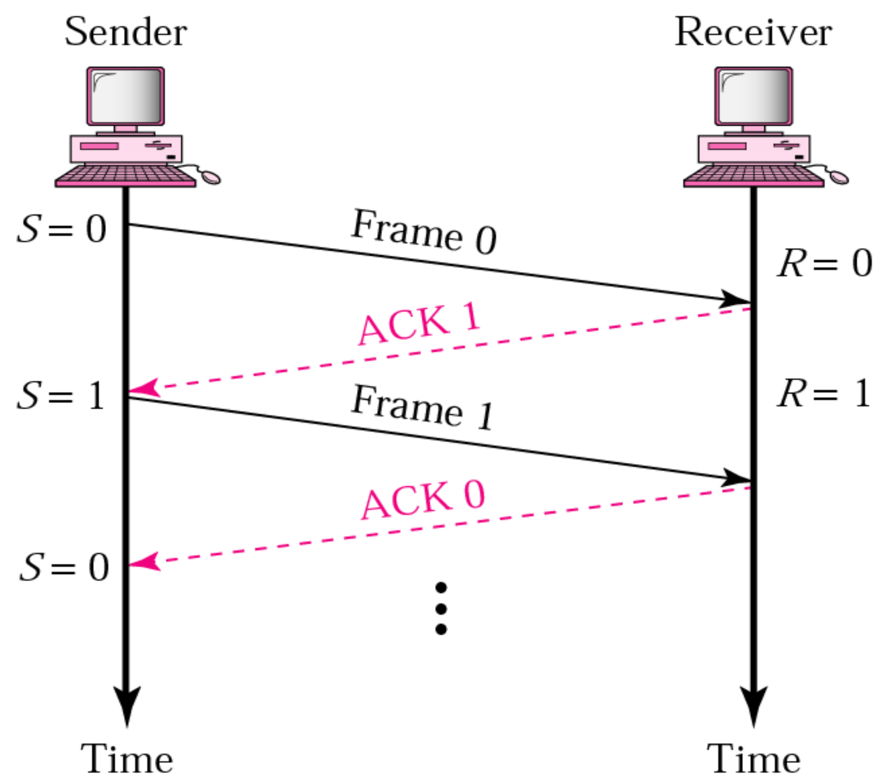
Bandwidth-Delay Product (BDP)

- BDP measurement is important if we need to send data in bursts and wait for the acknowledgment of each burst before sending the next one.
- Remember Pipelining in Computer Architecture?

Link Utilization in Stop and Wait Protocol

- Assume that, in a Stop-and-Wait Protocol, the bandwidth of the line is 1 Mbps, and 1 bit takes 20 ms to make a round trip. What is the bandwidth-delay product? If the system data frames are 1000 bits in length, what is the utilization percentage of the link?

Link Utilization = Actual data sent/How much can be sent



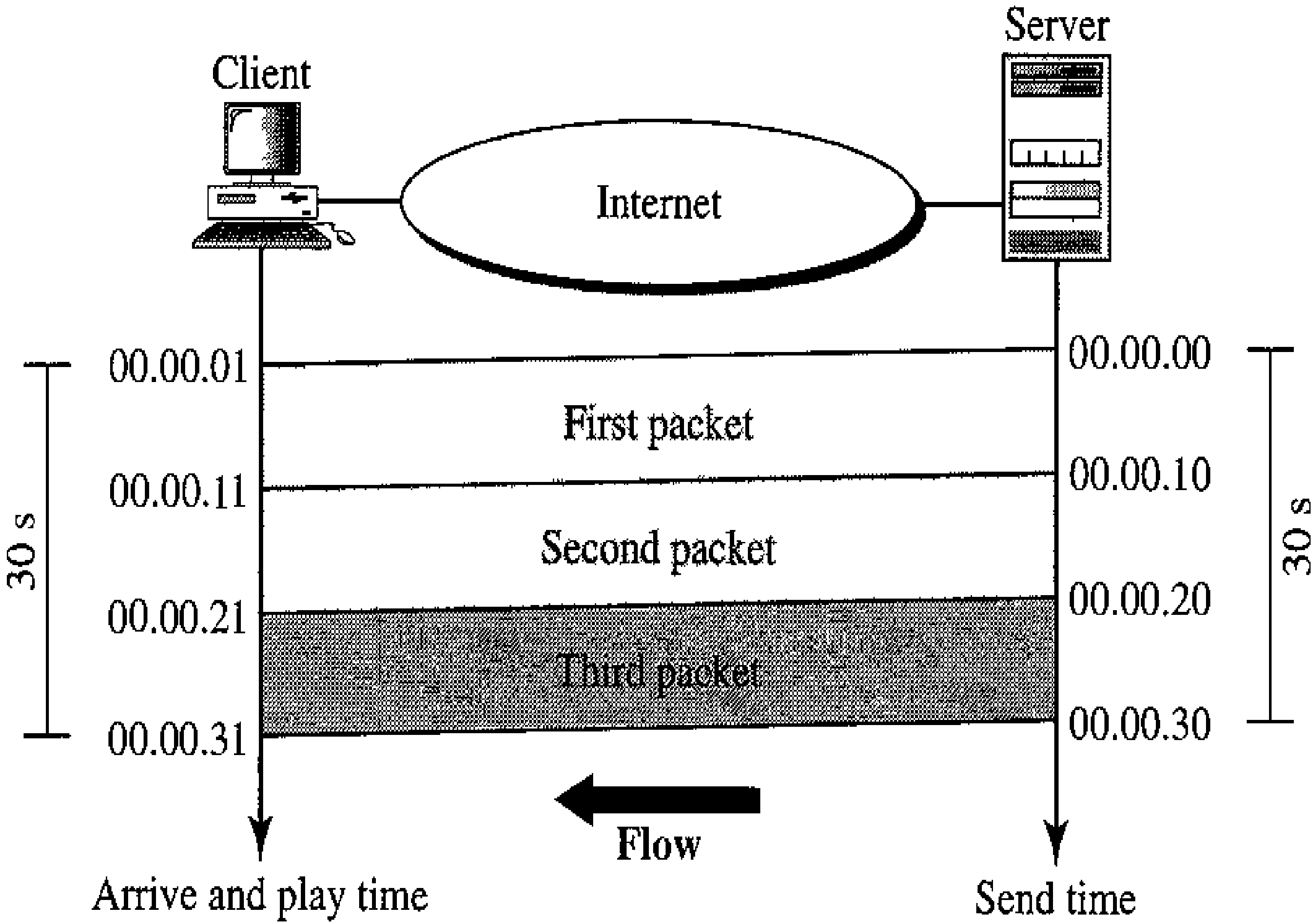
The bandwidth-delay product is

$$(1 \times 10^6) \times (20 \times 10^{-3}) = 20{,}000 \text{ bits}$$

The system can send 20,000 bits during the time it takes for the data to go from the sender to the receiver and then back again. However, the system sends only 1000 bits. We can say that the link utilization is only 1000/20,000, or 5 percent. For this reason, for a link with a high bandwidth or long delay, the use of Stop-and-Wait ARQ wastes the capacity of the link.

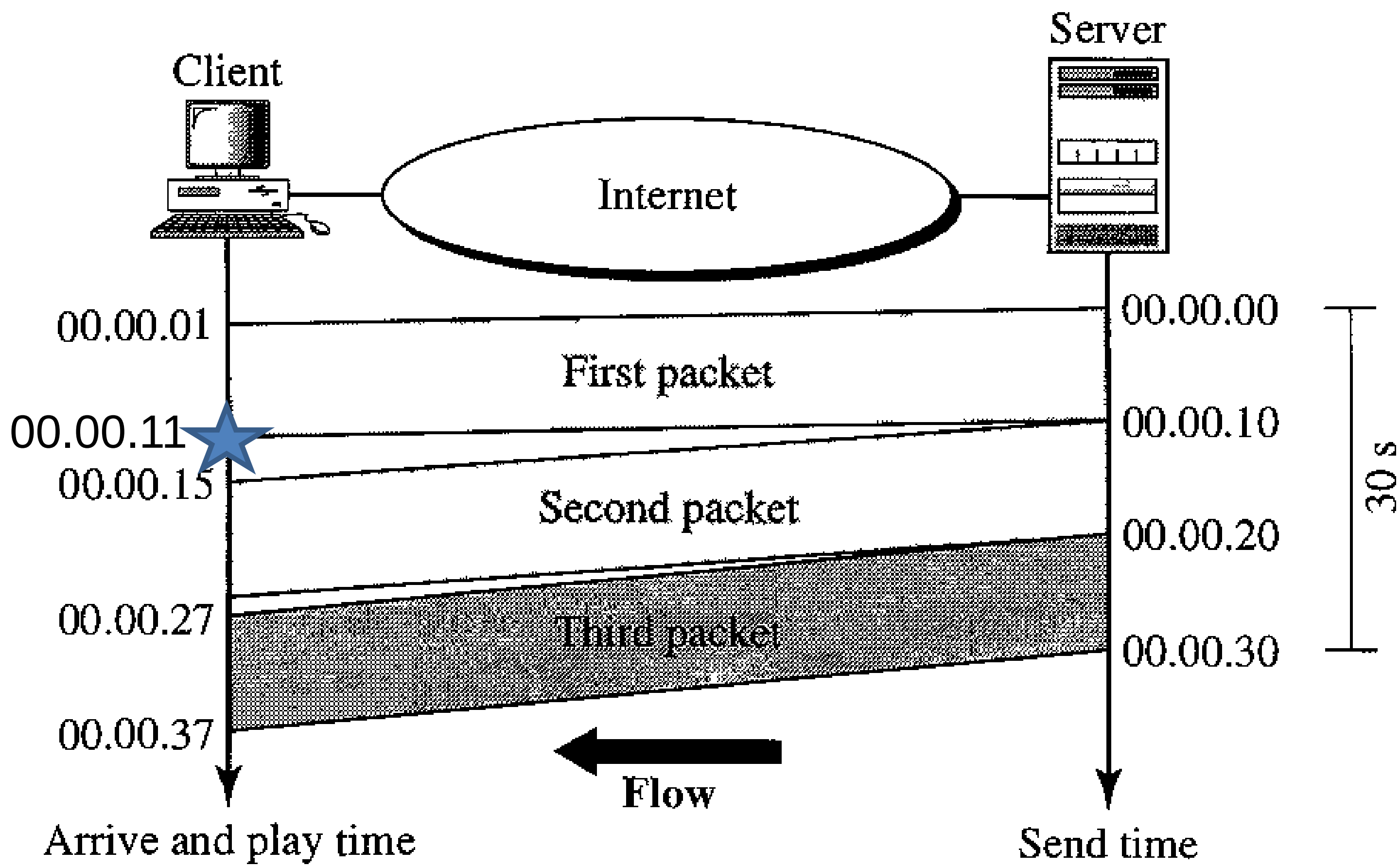
- Jitter
- Different packets of data encounter different delays and application using the data at the receiver site is time-sensitive (audio and video data, for example).

No Jitter



3 packets with 10s video information; Transmission Delay is 1 s for all; thus it is uniform for all 3 packets

Jitter in transmission
3 packets with 10s video information
Delay is 1 sec for 1st packet, 7 sec for 2nd and 3rd ; thus is non-uniform



Finished playing 1st pkt.

Network Criteria

- *Reliability*
  - measured by
    - the frequency of failure of link/network,
    - the time it takes a link to recover from a failure,
    - the network's robustness in a catastrophe

Network Criteria

- *Security*
  - includes
    - Confidentiality - protecting data from unauthorized access,
    - Integrity - protecting data from manipulation
    - Avability - access data from network whenever required

Example 3.41

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.

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

Example 3.41 (continued)

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.

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

- In network of 100 computers 2 farthest computers are 1 km apart. The signal propagation speed in cable is 1 x 10^6 m/s, data to be send is 10 Kbytes. Network supports Bandwidth of 10 Mbps and processing time of frame is 2 ms at receiver. The transmitter (Tx) requires 1 ms to generate new frame. Assume acknowledgement and data require same time for transmission. Then
  - How many frames can be transmitted by transmitter without waiting for the acknowledgement from receiver (Rx) using pipelining
  - What should be time out period at transmitter to retransmit the corrupted or unreceived frame

- Propagation Time = 1000 m/ 1 x 10^6 m/s=1 ms
- Transmission Time = 10 x 10^3 x 8 bits/ 1 x 10^6 bps = 8 ms
- Processing Time= 1 ms (at Tx) and 2 ms (at Rx)
- Latency (Tx→Rx) = Prop. T. +Proc. T.+ Tran. T. = 1+1+8= 10 ms
- Latency (Rx→Tx) = 1 + 2 + 8 = 11 ms
- RTT=10+11=21 ms or greater (Tx will not get ACK of its transmitted frames before this = Timeout period of transmitter)
- Tx can send 21 frames

Two parties A and B are located 10 KM apart of each other. Both parties want to transfer the data of 10GB/Day between each other as and when needed. The parties have following available options.

1.A pair of Coaxial Cable with bandwidth of 200Mbps in both direction with attenuation of 1.5 dB per 500 meters and overall one-time cost of ₹ 50/10 meters.
2.A single fiber cable with end points data rate support of 750 Mbps with attenuation of 0.01 dB per 1 KM and overall one-time cost of ₹500/1 meter.
3.A box of DVD, which carries, 10 DVDs of 1 GB capacity each, in it. It has one time cost of ₹15/DVD and also has 45 minutes of average time to travel between two parties.

Evaluate these possibilities of communication on the criteria of Cost/Bit, Throughput, Latency and amplifier requirements.
Also suggest your choice of medium from the given possibilities and support it with proper arguments.

Throughput:
As per the information provided the channel capacity is the throughput in case 1 and 2 that is 200 Mbps and 750 Mbps respectively,

For storage media the throughput is : 10×10^9 / 45 X 60 = 3.7 Mbps

Amplifier requirement : an amplifier is required at every 3 dB attenuation
Case 1: 9 Amplifiers required before reaching the receiver
Case 2: No amplifier required
Case 3: No amplifier required

Cost per bit: We will consider per day data only, so Cost for Coaxial is 50000 for 10 KM, 500000 for Fibre for 10 KM, 150 Rs. Of DVD so cost per bit is 10 GB/ 50000 = 5e-6 rs per bit, for fibre 5e-5 rs per bit, for DVD 1.5e-8 rs per bit

Latency: 45 Minutes for DVD, Coaxial Cable Transmission time(10 GB/ 200 Mbps) + propagation time(10 KM/2 X 10^8 m/s) = 50.000005 S
For fibre Transmission time(10 GB/ 750 Mbps) + propagation time(10 KM/3 X 10^8 m/s) = 10.330003 S

A file of 12 Mbytes is to be transmitted. A network with bandwidth of 10Mbps
can pass only an average of 12000 frames of 1000 bytes per minute.

1. What is the throughput of the network?
2. What will be the propagation delay if the distance between the Tx and Rx is 1000 km and propagation speed is 10×10^7m/s in the cable?
3. If queuing time is 2 ms then assuming the processing time as zero, what will be the latency?

Thank You!