ITNT323

5- Channel : Capacity & Performance.

CHANNEL CAPACITY: Data Rate Limits

A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Two theoretical formulas were developed to calculate the data rate: one by Nyquist for a noiseless channel, another by Shannon for a noisy channel.

- Its a function of
  - data rate - in bits per second
  - bandwidth - in cycles per second or Hertz
  - noise - on comms link
  - error rate - of corrupted bits

1- Noiseless Channel: Nyquist Rate/Bandwidth

- For noise free channels
- If rate of signal transmission is **2B** *(Bandwidth)* then can carry signal with frequencies no greater than **B**
  - ie. given bandwidth B, highest signal rate is 2B
- For binary signals, **2B** bps needs bandwidth **B** Hz.
- Can increase datarate *(C)* by using **L** signal levels
- So increase rate by increasing signals
  - at cost of receiver complexity
  - limited by noise & other impairments

$$\text{BitRate} = 2 \times \text{bandwidth} \times \log_2 L$$

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

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

Example

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

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

2 - Noisy Channel: Shannon Capacity

- It Consider relation of data rate, noise & error rate
  - faster data rate shortens each bit so bursts of noise affects more bits
  - given noise level, higher rates means higher errors
- Shannon developed formula relating these to signal-to-noise ratio (in decibels)
- $SNR_{db} = 10 \log_{10}$ (Signal/Noise)
- Capacity $\mathbf{C = B \log_2(1+SNR)}$
  - theoretical maximum capacity
  - get lower in practise

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

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 the capacity C is calculated as

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

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 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

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

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.

3- Using Both Limits

In practice, we need to use both methods to find the limits and signal levels. Let us show this with an example.

Example

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. Then we use the Nyquist formula to find the number of signal levels.

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

Channel Measurements: PERFORMANCE

Several channel measurements are examined including bandwidth, throughput, latency, and jitter.

Up to now, we have discussed the tools of transmitting data (signals) over a network and how the data behave. One important issue in networking is the performance of the network—how good is it?

1- Bandwidth

One characteristic that measures network performance is bandwidth. However, the term can be used in two different contexts with two different measuring values: bandwidth in hertz and bandwidth in bits per second..

Example

The bandwidth of a subscriber line is 4 kHz for voice or data. The bandwidth of this line for data transmission can be up to 56,000 bps using a sophisticated modem to change the digital signal to analog. If the telephone company improves the quality of the line and increases the bandwidth to 8 kHz, we can send 112,000 bps by using the same mentioned technology.

2 - Throughput

The throughput is a measure of how fast we can actually send data through a network. Although, at first glance, bandwidth in bits per second and throughput seem the same, they are different. 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**.

The latency or 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. We can say that latency is made of four components: propagation time, transmission time, queuing time and processing delay.

Latency = propagation time + transmission time + queuing time + processing delay

Performance

Propagation Time

Propagation time measures the time required for a bit to travel from the source to the destination. The propagation time is calculated by dividing the distance by the propagation speed.

Propagation time = Distance / (Propagation Speed)

Transmission Time

The transmission time of a message depends on the size of the message and the bandwidth of the channel.

Transmission time = (Message size) / Bandwidth

Queuing Time

The third component in latency is the **queuing time, the time needed for each intermediate** or end device to hold the message before it can be processed. The queuing time is not a fixed factor; it changes with the load imposed on the network.

Example

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

We can calculate the throughput as

$$\text{Throughput} = (12{,}000 \times 10{,}000) / 60 = 2 \text{ Mbps}$$

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

Example

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

$$\text{Propagation time} = (12{,}000 \times 1{,}000) / (2.4 \times 10^8) = 50 \text{ ms}$$

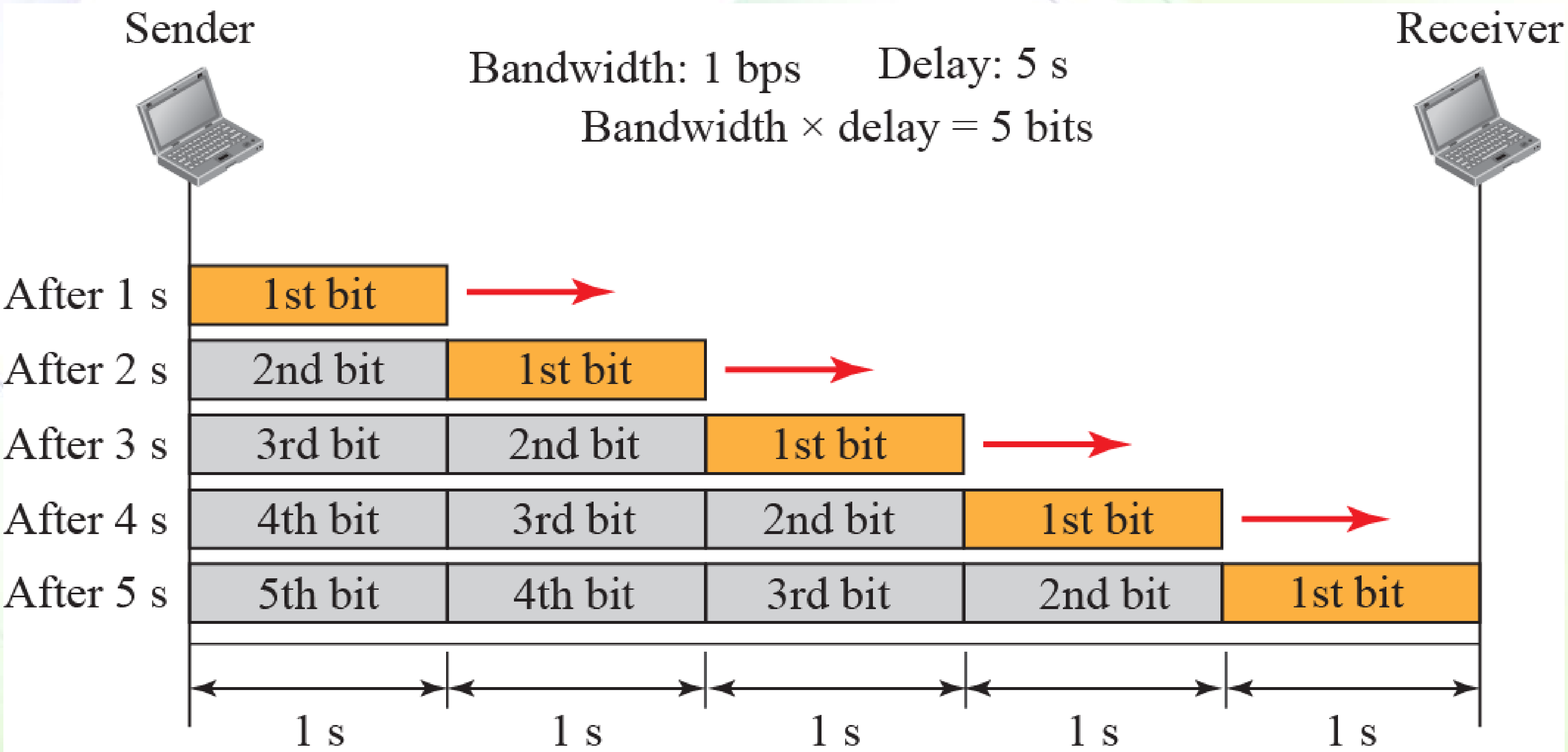
The example shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

3 - Bandwidth-Delay Product

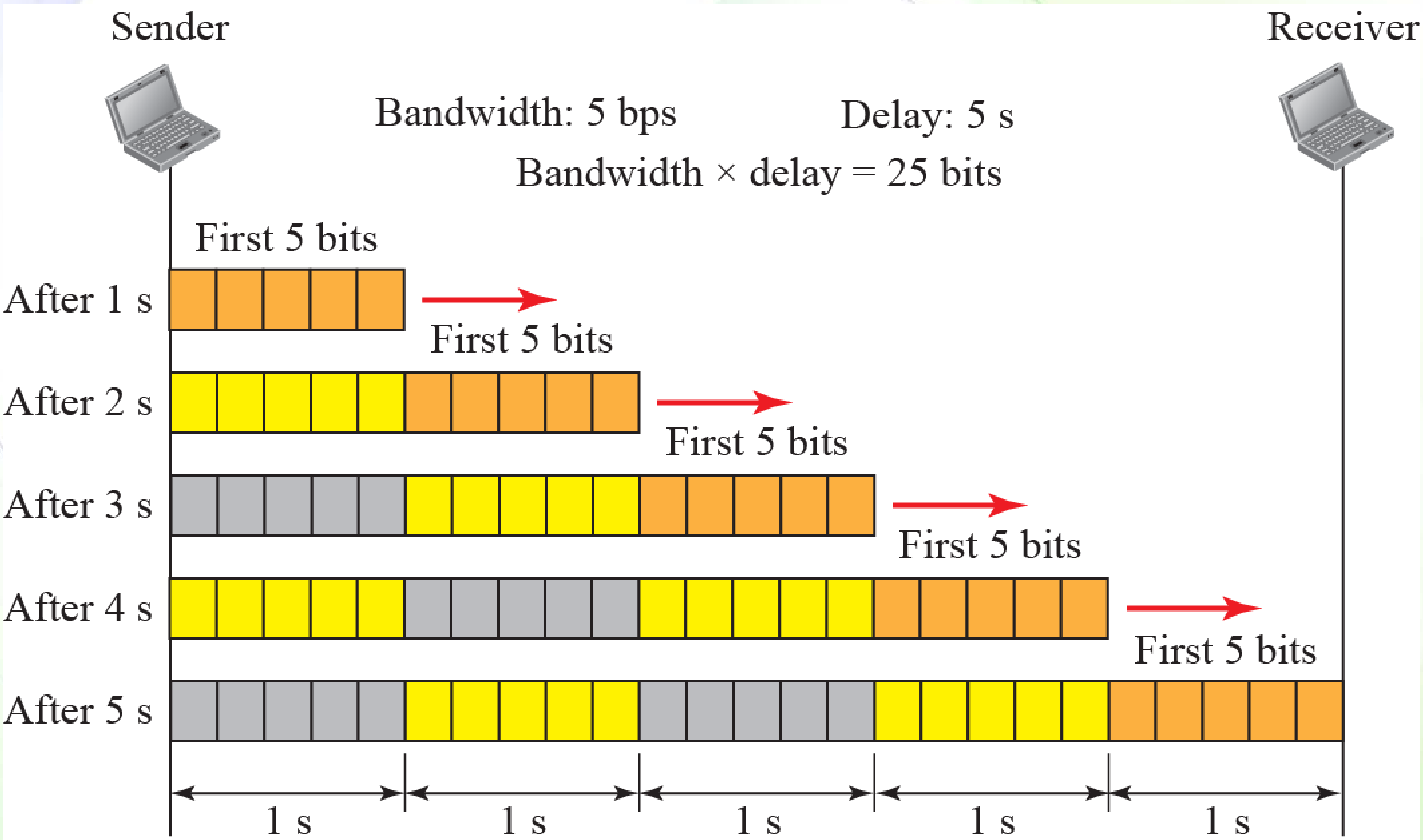
Bandwidth and delay are two performance metrics of a link. However, what is very important in data communications is the product of the two, the bandwidth-delay product. Let us elaborate on this issue, using two hypothetical cases as examples.

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

Filling the links with bits for Case 1



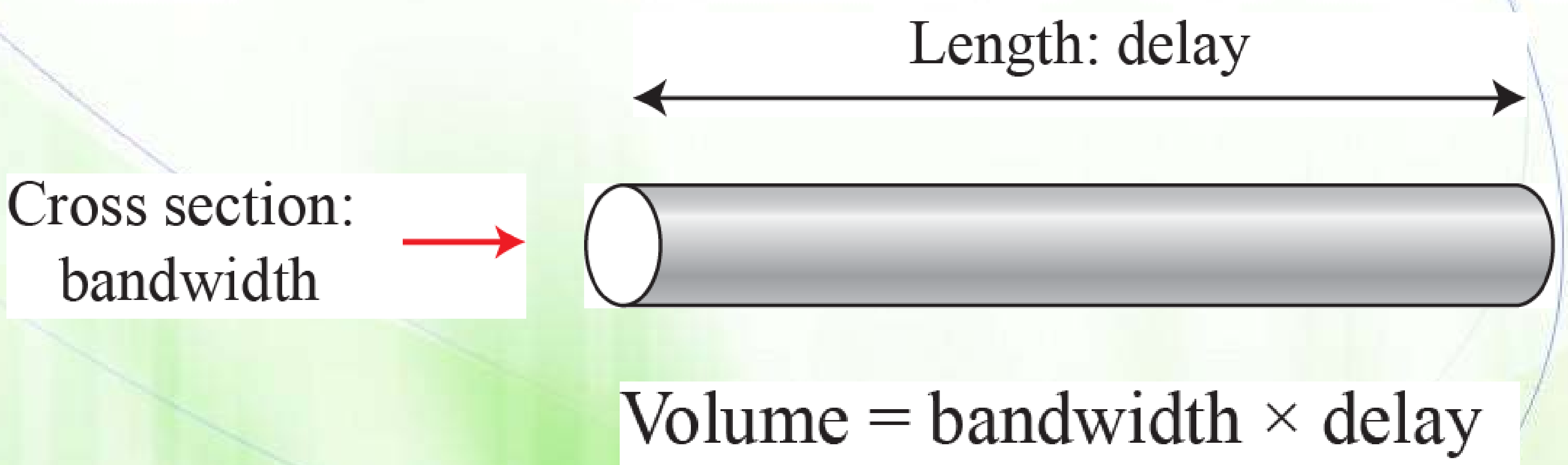
Filling the pipe with bits for Case 2



Example

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 next figure.

Concept of bandwidth-delay product



4- Jitter

Another performance issue that is related to delay is jitter. We can roughly say that jitter is a problem if different packets of data encounter different delays and the application using the data at the receiver site is time-sensitive (audio and video data, for example). If the delay for the first packet is 20 ms, for the second is 45 ms, and for the third is 40 ms, then the real-time application that uses the packets endures jitter.

Further Reading:-

- Data Communications and Networking , Forouzan, 5e , Chapter **- 3**, PP 80 .