DRONACHARYA
College of Engineering

Computer Science & Engineering

Data Communication and Computer Networks

(MTCSE-101-A)

ANALOG AND DIGITAL

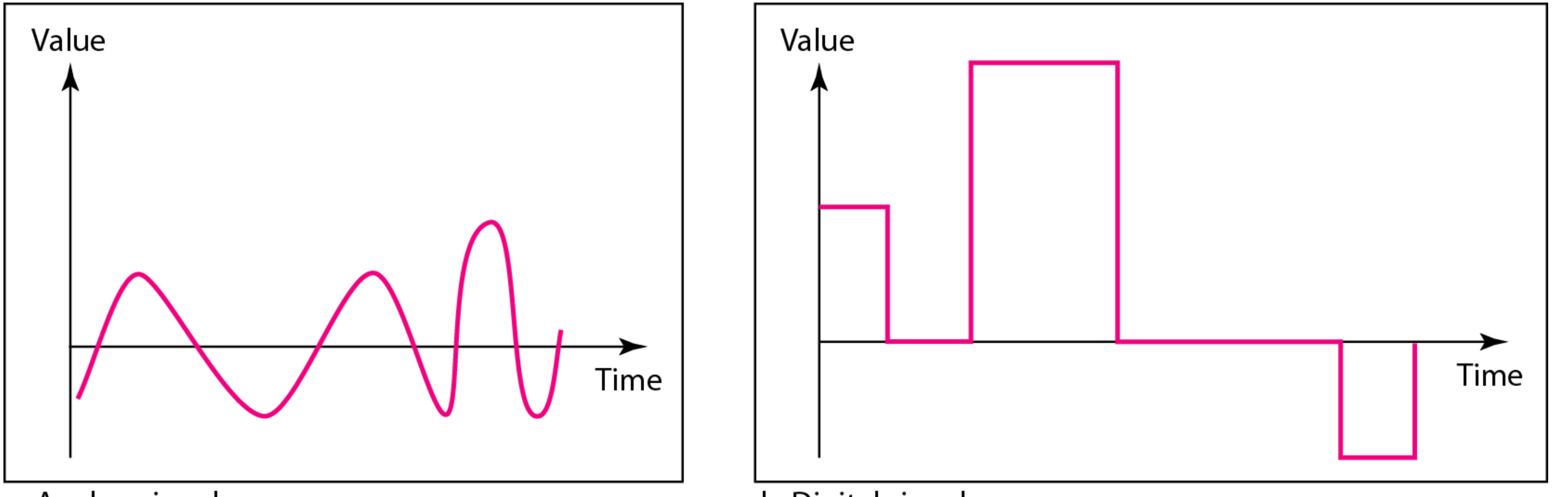
Data can be analog or digital

- Analog data refers to information that is continuous
- Analog data take on continuous values
- Analog signals can have an infinite number of values in a range

- Digital data refers to information that has discrete states
- Digital data take on discrete values
- Digital signals can have only a limited number of values

In data communications, we commonly use
periodic analog signals and nonperiodic digital signals.

Comparison of analog and digital signals

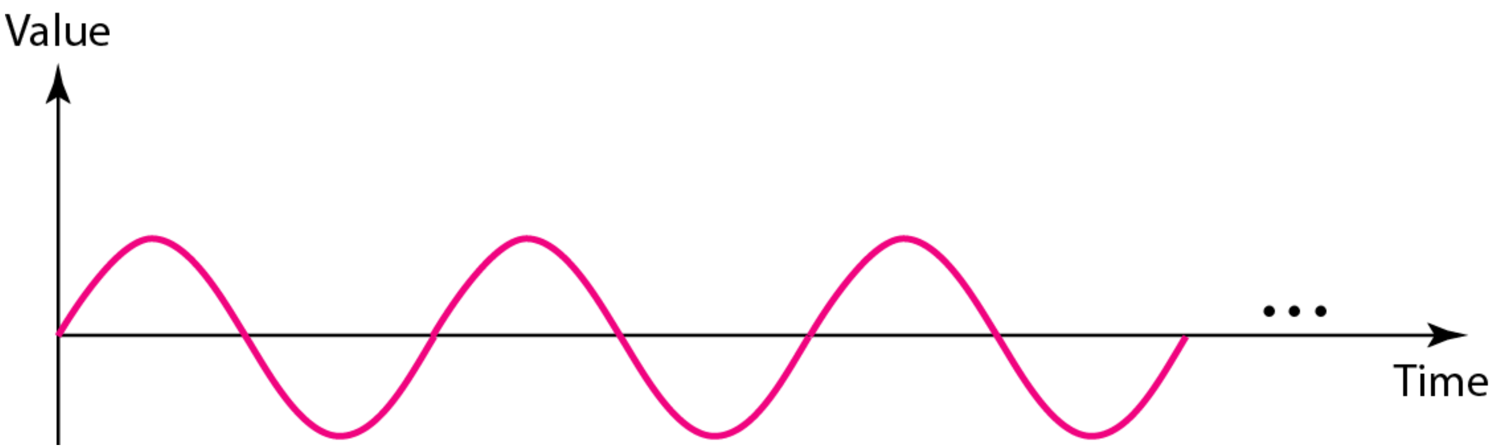


a. Analog signal b. Digital signal

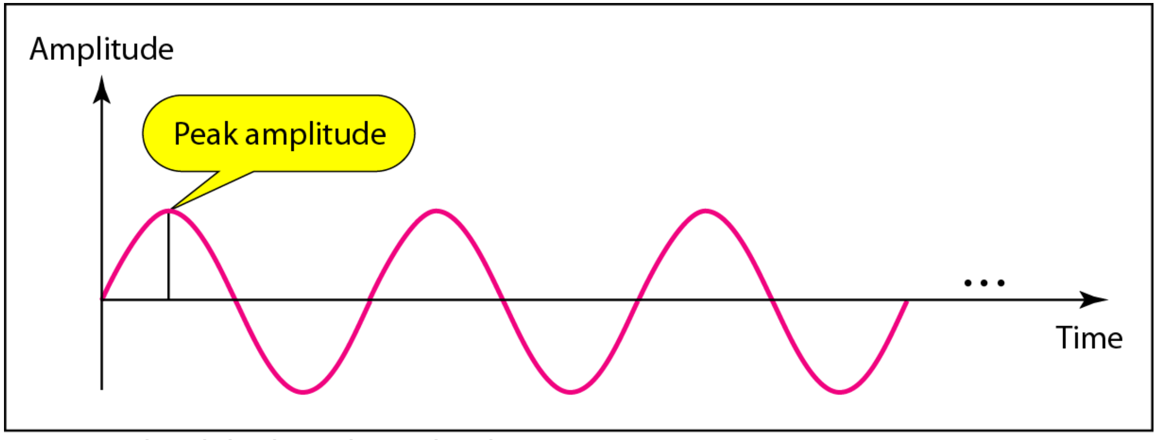
PERIODIC ANALOG SIGNALS

Periodic analog signals can be classified as simple or composite.

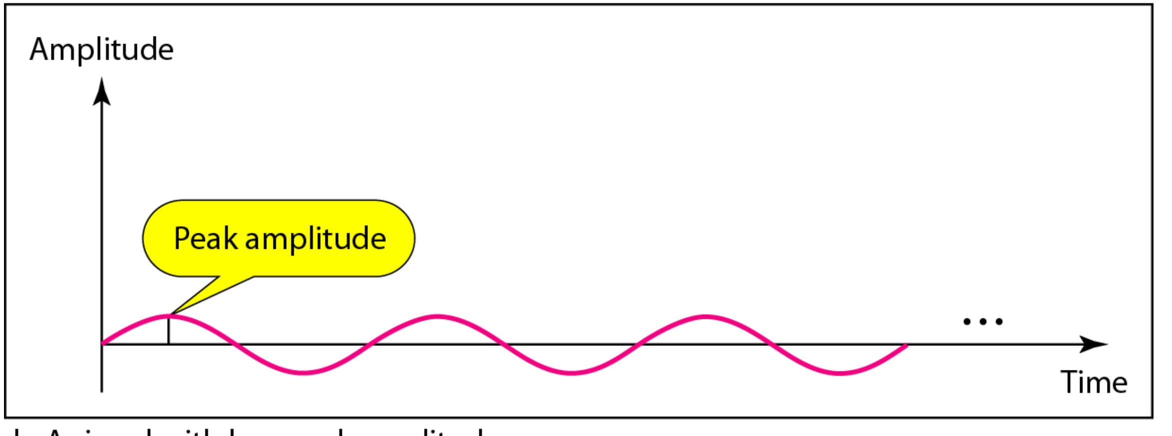
- A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals.
- A composite periodic analog signal is composed of multiple sine waves.



Signal amplitude



a. A signal with high peak amplitude



b. A signal with low peak amplitude

Frequency

Frequency is the rate of change with respect to time.

- ❑ Change in a short span of time means high frequency.
- ❑ Change over a long span of time means low frequency.

- ❑ If a signal does not change at all, its frequency is zero
- ❑ If a signal changes instantly, its frequency is infinite.

Frequency and Period

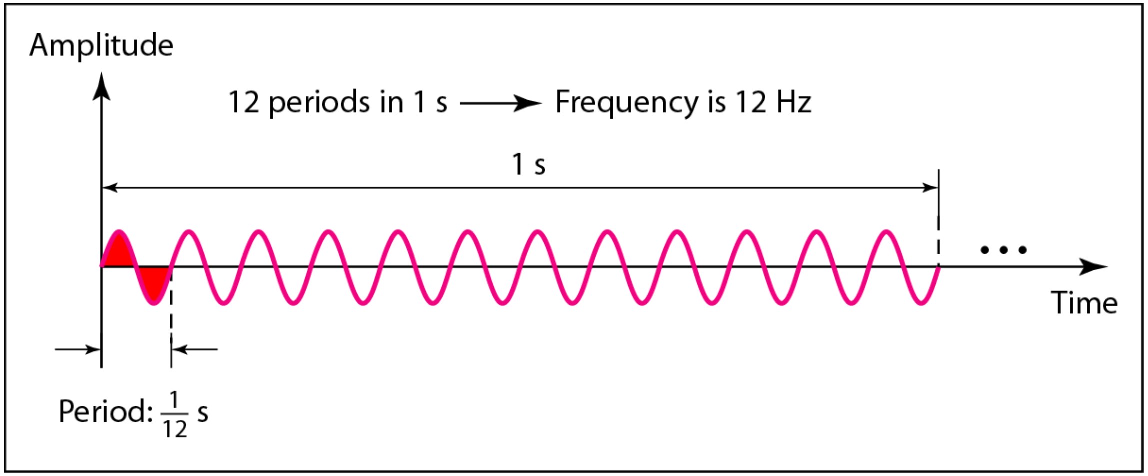
Frequency and period are the inverse of each other.

$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

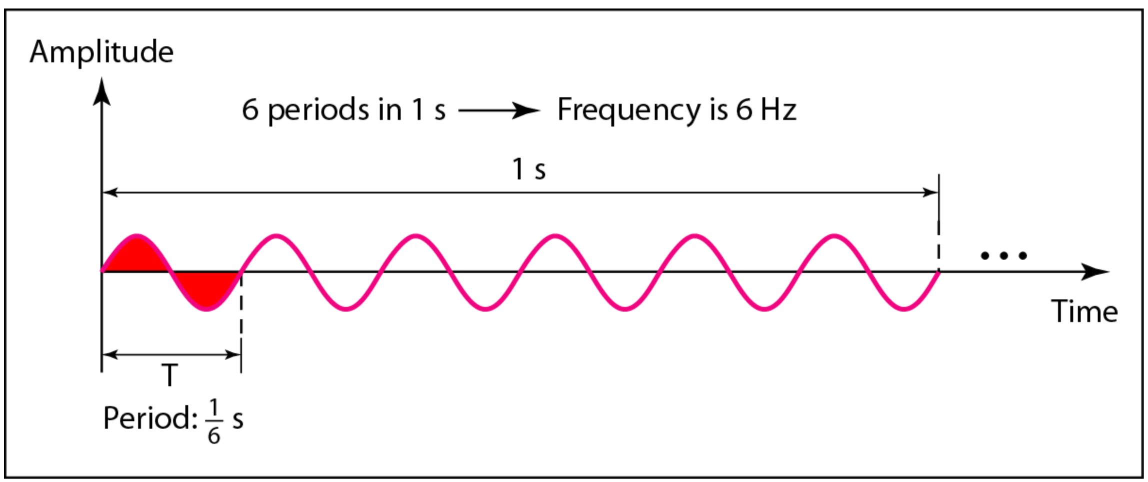
Units of period and frequency

Unit	*Equivalent*	*Unit*	*Equivalent*
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^{3} Hz
Microseconds (μs)	10^{-6} s	Megahertz (MHz)	10^{6} Hz
Nanoseconds (ns)	10^{-9} s	Gigahertz (GHz)	10^{9} Hz
Picoseconds (ps)	10^{-12} s	Terahertz (THz)	10^{12} Hz

Two signals with the same amplitude, but different frequencies



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Examples

The power we use at home has a frequency of 60 Hz. What is the period of this sine wave ?

$$\boxed{T = \frac{1}{f} = \frac{1}{60} = 0.0166 \text{ s} = 0.0166 \times 10^{3} \text{ ms} = 16.6 \text{ ms}}$$

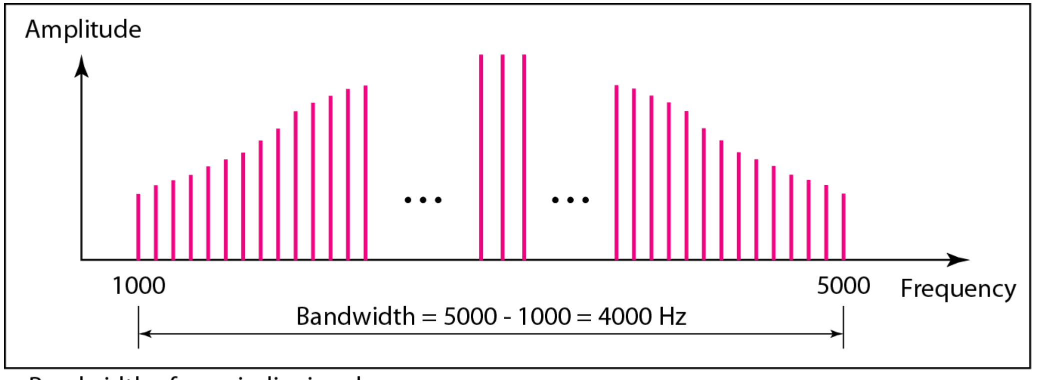
The period of a signal is 100 ms. What is its frequency in kilohertz?

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

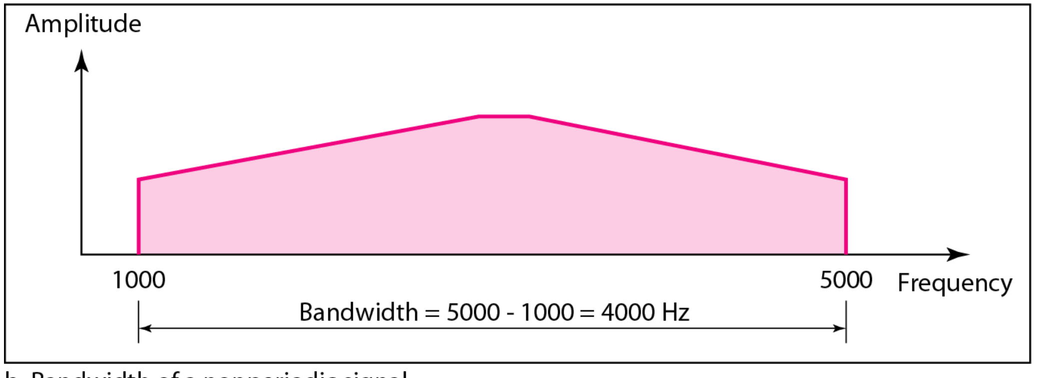
$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

Bandwidth

The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.



a. Bandwidth of a periodic signal



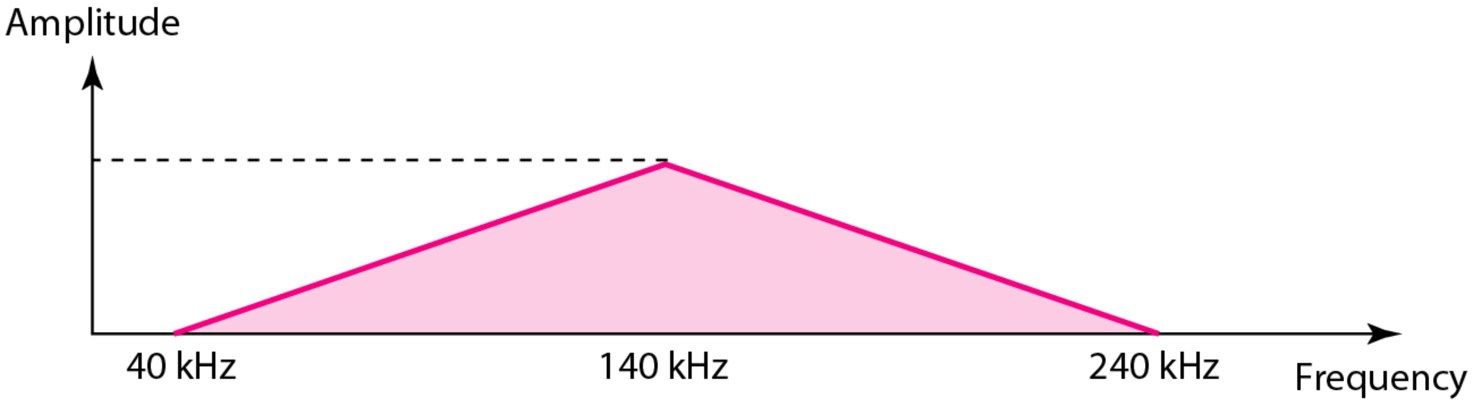
b. Bandwidth of a nonperiodic signal

Example

A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Solution

The lowest frequency must be at 40 kHz and the highest at 240 kHz.



PERFORMANCE

One important issue in networking is the performance of the network—how good is it?

In networking, we use the term bandwidth in two contexts

The first, bandwidth in hertz,
refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.

The second, bandwidth in bits per second,
refers to the speed of bit transmission in a channel or link.

Examples

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.

Throughput

The throughput is a measure of how fast we can actually send data through a network.

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. In other words, the bandwidth is a potential measurement of a link; the throughput is an actual measurement of how fast we can send data.

For 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

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

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

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

Latency (Delay)

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.

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

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

Propagation time = Distance/Propagation speed

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 × 108 m/s in cable.

Solution

We can calculate the propagation time as

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

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.

Transmission time

In data communications we don't send just 1 bit, we send a message. The first bit may take a time equal to the propagation time to reach its destination; the last bit also may take the same amount of time. However, there is a time between the first bit leaving the sender and the last bit arriving at the receiver. The first bit leaves earlier and arrives earlier;
the last bit leaves later and arrives later.

- The time required for transmission of a message 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-kbyte message if the bandwidth of the network is 1 Gbps? Assume that the distance is 12,000 km and that light travels at 2.4 × 108 m/s.

Solution

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

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

Note that in this case, because the message is short and the bandwidth is high, the dominant factor is the propagation time, not the transmission time.

The transmission time can be ignored.

Example

What are the propagation time and the transmission time for a 5-Mbyte message if the bandwidth of the network is 1 Mbps? Assume that the distance is 12,000 km and that light travels at 2.4×10^8 m/s.

Solution

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

$$\text{Transmission time} = \frac{5{,}000{,}000 \times 8}{10^6} = 40 \text{ s}$$

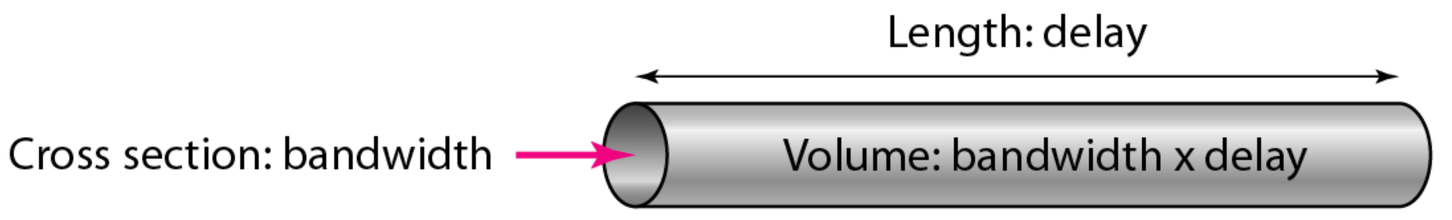
Note that in this case, because the message is very long and the bandwidth is not very high, the dominant factor is the transmission time, not the propagation time.
The propagation time can be ignored.

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. When there is heavy traffic on the network, the queuing time increases. An intermediate device, such as a router, queues the arrived messages and processes them one by one. If there are many messages, each message will have to wait.

Concept of bandwidth-delay product

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

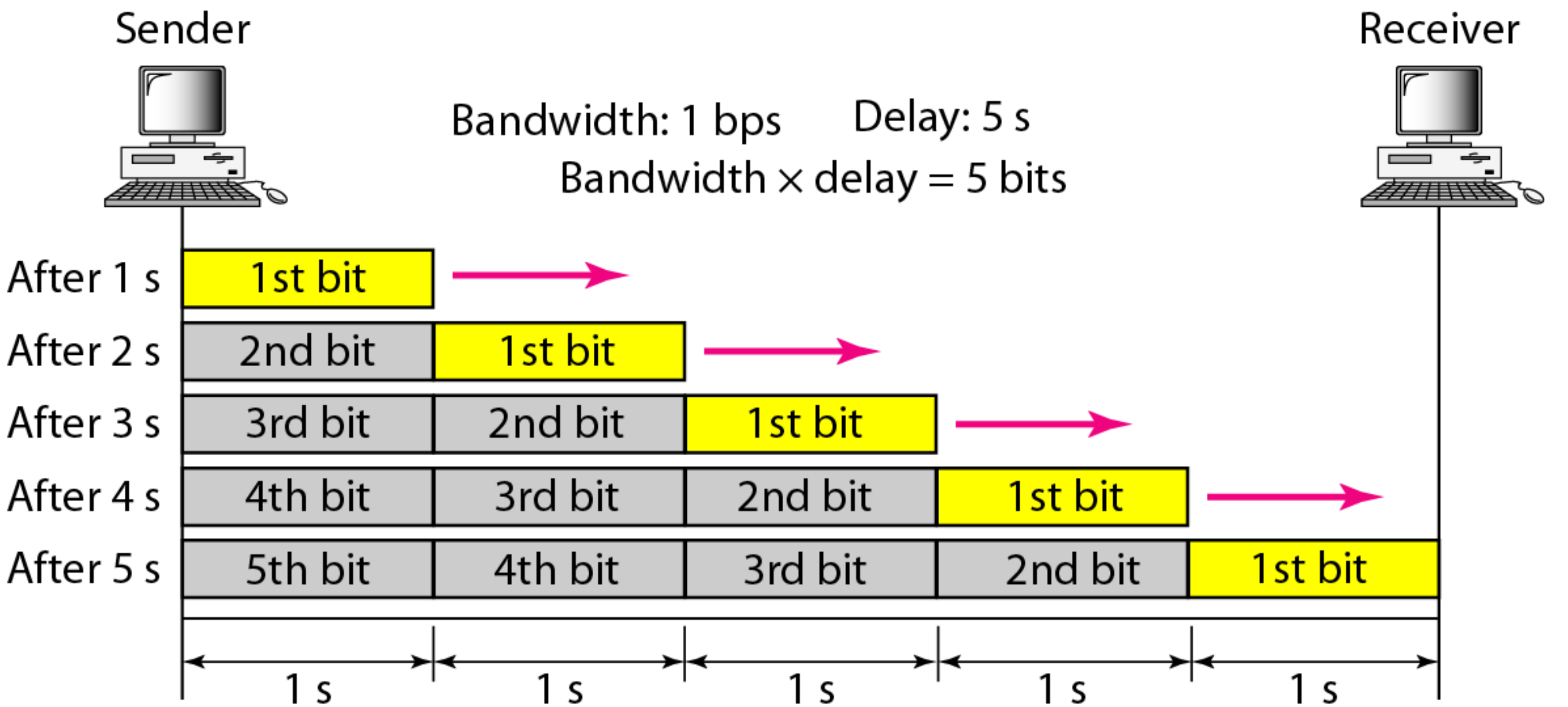


We can think about the link between two points as a pipe.

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.

Filling the link with bits in case 1



Filling the link with bits in case 2