IT - 305 Data Communication **Lecture #8**
September 04, 2019

Outline *Overview of Data Communications: Introduction to Communications Network, Types of Networks- Point-to-point Circuits, Circuit-switched Networks, Message-switched Networks, Packet-switched Networks, Types of Packet Switched Networks- Wide Area Networks (WAN), Internet Service Providers (ISPs), Local Area Networks (LANs).*

Contents

1 Time Domain Concepts

Viewed as a function of time, an electromagnetic signal can be either **analog** or **digital**.

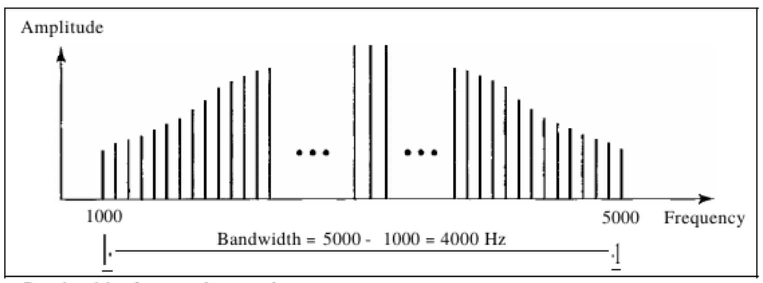
2 Data and Signals

2.1 Bandwidth

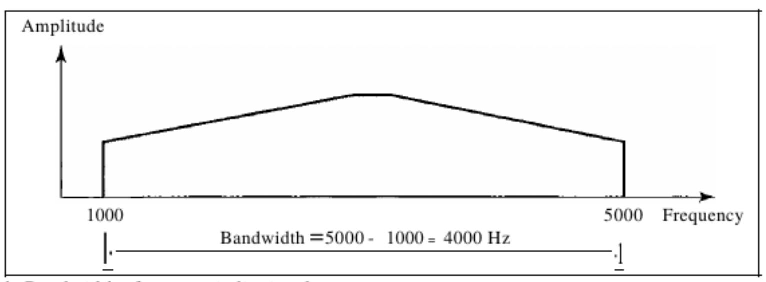
The range of frequencies contained in a composite signal is its **bandwidth**.

Example 2.1. If a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000-1000, or 4000.

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

Figure 1: The bandwidth of periodic and non-periodic composite signals

Figure 1 shows the concept of bandwidth. Figure 1-a shows a periodic composite signal with bandwidth contains all integer frequencies between 1000 and 5000 (1000,1001,1002,...). The bandwidth of the non-periodic signals has the same range, but frequencies are continuous.

Example 2.2. If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700,and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V .
Solution
Let f_h be the highest frequency, f_l the lowest frequency, and $\boldsymbol{B}$ the bandwidth. Then $\boldsymbol{B} = f_h - f_i = 900 - 100 = 800$ Hz.
Figure 2 shows the bandwidth of the signal.

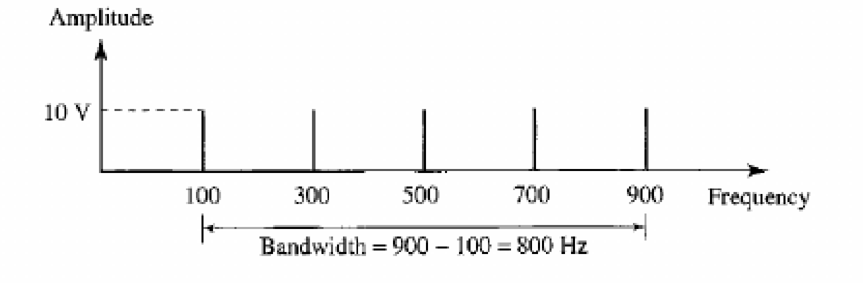


Figure 2: Bandwidth

2.2 Digital Signals

Information can be represented by a digital signal. For example, 1 can be encoded as positive voltage and a 0 as zero voltage.

2.2.1 Level

A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

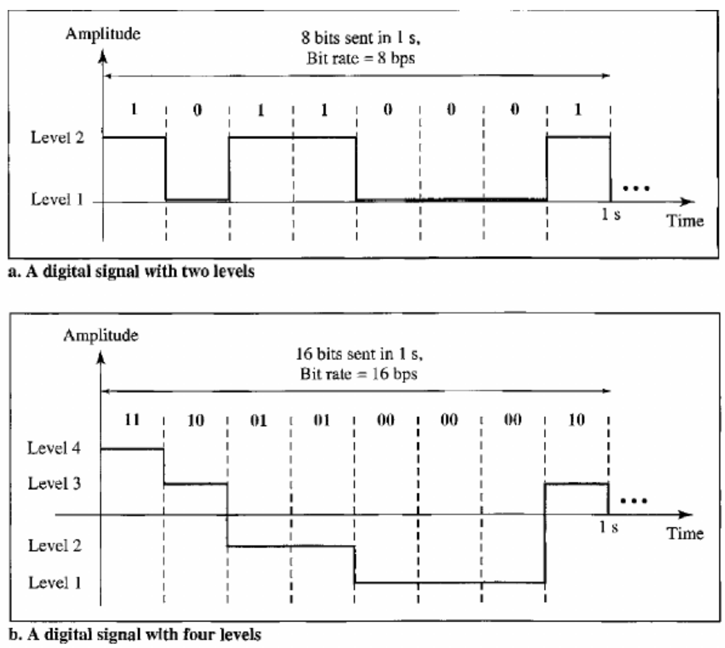


Figure 3: Two digital signals: (a) two signal levels (b) Four signal levels

We send 1 bit per level in Figure 3(a) and 2 bits per level in 3(b). In general, if a signal has L levels, each level need $log_2 L$ bits

Example 2.3. A digital signal has eight levels. How many bits are needed per level?
Solution: Number of bits per level = $log_2 8 = 3$. Each signal level is represented by 3 bits.

3 Transmission of Digital Signals

How can we send a digital signal from point A to point B? We can transmit a digital signal by using one of two different approaches: baseband or broadband transmission.

3.1 Baseband transmission

Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal.

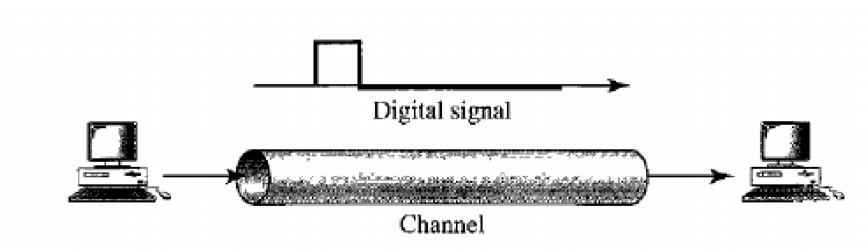


Figure 4: Baseband transmission

Baseband transmission requires that we have a **low-pass channel**, a channel with a bandwidth that starts from zero.

Example 3.1. The entire bandwidth of a cable connecting two computers is one single channel. As another example, we may connect several computers to a bus, but not allow more than two stations to communicate at a time.

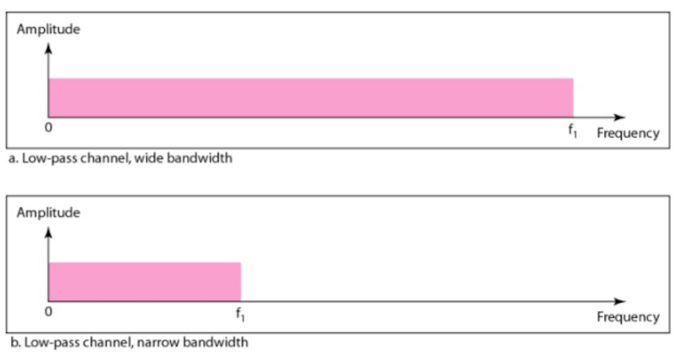


Figure 5: Bandwidth of two low pass channels

3.2 Broadband Transmission (Using Modulation)

Broadband transmission or modulation means changing the digital signal to an analog signal for transmission. Modulation allows us to use a bandpass channel-a channel with a bandwidth that does not start from zero. This type of channel is more available than a low-pass channel.
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.

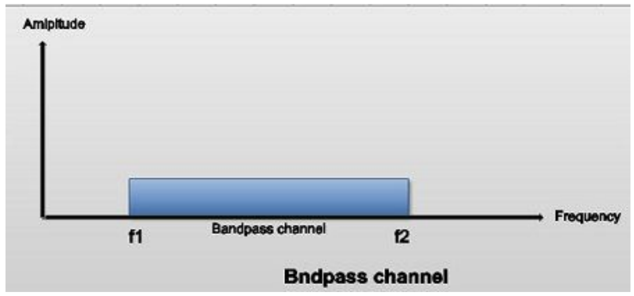


Figure 6: Baseband transmission using a dedicated medium. Note that f_1 is close to zero, and f_2 is very high

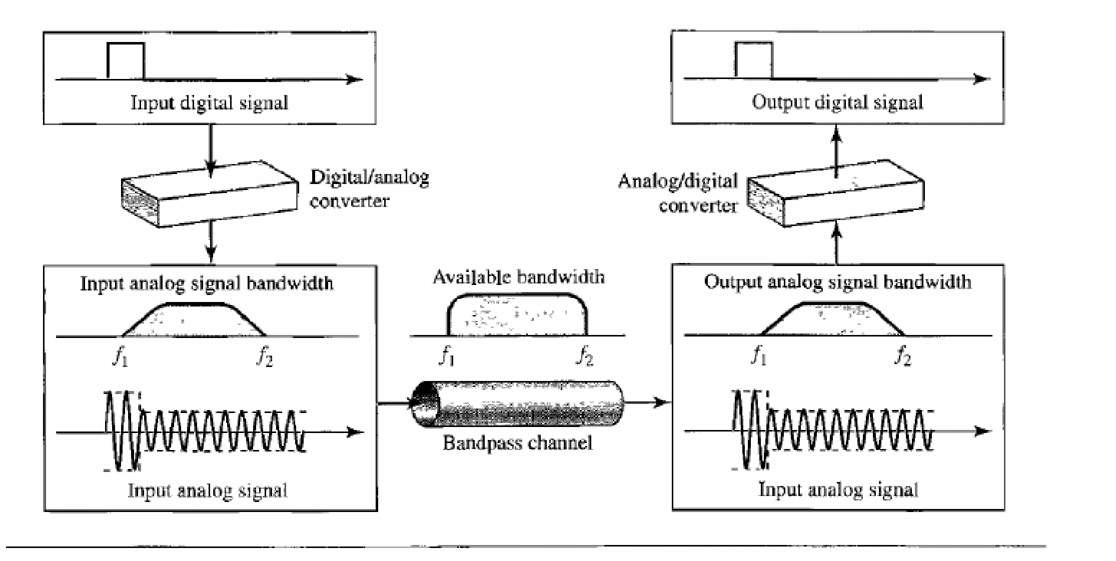


Figure 7: Modulation of digital signal for transmission on a bandpass channel

4 Data Rate Limits

Data rate depends on three factors:

- The bandwidth available
- The level of the signals we use
- The quality of the channel (the level of noise)

Two theoretical formulas were developed to calculate the data rate:

- Nyquist for noiseless channel
- Another by Shannon for a noisy channel.

4.1 Noiseless Channel : Nyquist Bit Rate

The Nyquist Bit rate formula defines the theoretical maximum bit rate.

$$BitRate = 2 \times bandwidth \times log_2 L \tag{1}$$

Here, bandwidth is the bandwidth of the channel, L is the number of signal levels used to represent data, and BitRate is the bit rate in bits per second.
Increasing the levels of a signal may reduce the reliability of the system.

Example 4.1. 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
$BitRate = 2 \times 3000 \times log_2 2 = 6000bps$

Example 4.2. Example 3.35 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 $BitRate = 2 \times 3000 \times log_2 4 = 12,000bps$

4.2 Noisy Channel: Shannon Capacity

In reality, we cannot have a noiseless channel; the channel is always noisy. In 1944, Claude Shannon introduced a formula, called the Shannon capacity, to determine the theoretical highest data rate for a noisy channel.

$$Capacity = bandwidth \times log_2(1 + SNR) \tag{2}$$

Here, bandwidth is the bandwidth of the channel, SNR is the signal-to-noise ratio, and capacity is the capacity of the channel in bits per second.
Note that in the Shannon formula there is no indication of the signal level, which means that no matter how many levels we have, we cannot achieve a data rate higher than the capacity of the channel. In other words, the formula defines a characteristic of the channel, not the method of transmission.

Example 4.3. 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

$$C = Blog_2(1 + SNR) = Blog_2(1 + 0) = Blog_2 1 = B \times 0 = 0 \tag{3}$$

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 4.4. 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

$$C = Blog2(1 + SNR) = 3000log2(l + 3162) = 3000log23163 = 3000x11.62 = 34,860bps \tag{4}$$

Example 4.5. The signal-to-noise ratio is often given in decibels. Assume that $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

$$SNR_{dB} = 10log_{10}SNR$$
$$SNR = 10^{SNR_{dB}/10}$$
$$SNR = 10^{3.6} = 3981$$
$$C = Blog_2(1 + SNR) = 2 \times 10^6 \times log_2 3982 = 24Mbps$$

4.3 Using Both Limits

In practice, we need to use both methods to find the limits and signal levels.

Example 4.6. 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.
$C = Blog_2(1 + SNR) = 10^6 log_2(1 + 63) = 10^6 log_2 64 = 6Mbps$

To find the number of signal levels
$4Mbps = 2 \times 1MHz \times log_2 L$
$L = 4$

`The Shannon capacity gives us the upper limit;`

`The Nyquist formula tells us how many signal lvels we need.`

5 Performance

5.1 Bandwidth

One characteristic that measures network performance is bandwidth. The term can be used in two different contexts with two different measuring values;

- **Bandwidth in hertz:** Is the range of frequencies contained in a composite signal or the range of frequencies a channel can pass. For example, we can say the bandwidth of a subscriber telephone line is 4 kHz.

- **Bandwidth in bits per second:** The term bandwidth can also refer to the number of bits per second that a channel, a link, or even a network can transmit. For example, one can say the bandwidth of a Fast Ethernet network (or the links in this network) is a maximum of 100 Mbps. This means that this network can send 100 Mbps.

5.2 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. 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. Imagine a highway designed to transmit 1000 cars per minute from one point to another. However, 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 5.1. 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?

$$Throughput = \frac{12,000 \times 10,000}{60} = 2Mbps \tag{5}$$