Week # 4 – Lecture # 7 – Physical / Data link layer

Lecture outline

- Signal (Analog, Digital)
- Multiplexing/Demultiplexing Techniques
- Modulation / Demodulation
- Data Link Layer
- Media Access Control (MAC) Layer
- Data Link Layer Services

ANALOG AND DIGITAL

Data can be analog or digital. The term **analog data** refers to information that is continuous; **digital data** refers to information that has discrete states. Analog data take on continuous values. Digital data take on discrete values.

- Data can be analog or digital.
- Analog data are continuous and take continuous values.
- Digital data have discrete states and take discrete values.

Signals can be analog or digital. Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values.

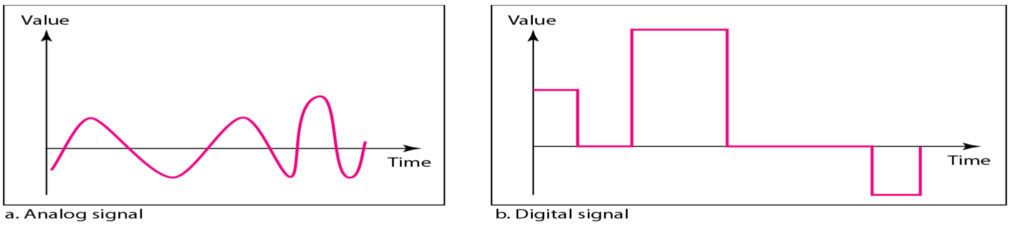


Figure: Comparison of analog and digital signals

In data communications, we commonly use periodic analog signals and no periodic digital signals.

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.

Topics discussed in this section:

- Sine Wave
- Wave length
- Time and Frequency Domain
- Composite Signals
- Bandwidth

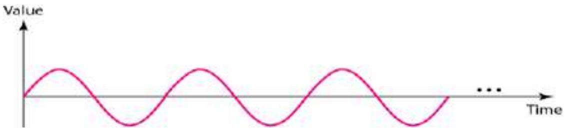


Figure: A sine wave

Example

The power in your house can be represented by a sine wave with a peak amplitude of 150 to 220 V. However, it is common knowledge that the voltage of the power in U.S. homes is 110 to 120 V. This discrepancy is due to the fact that these are root mean square (rms) values. The signal is squared and then the average amplitude is calculated.

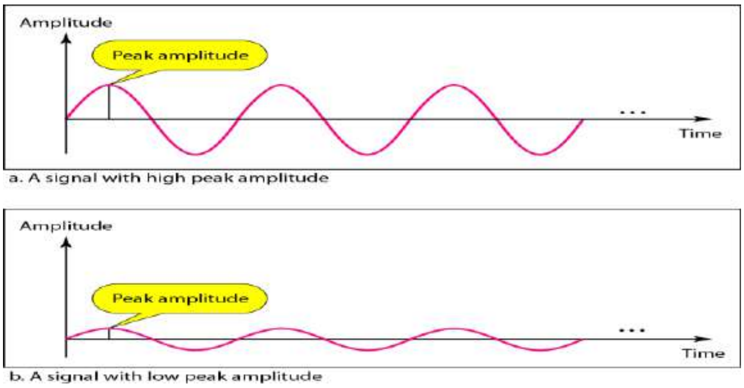


Figure: Two signals with the same phase and frequency, but different amplitudes

Example

The voltage of a battery is a constant; this constant value can be considered a sine wave, as we will see later. For example, the peak value of an AA battery is normally 1.5 V.

Frequency and period are the inverse of each other.

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

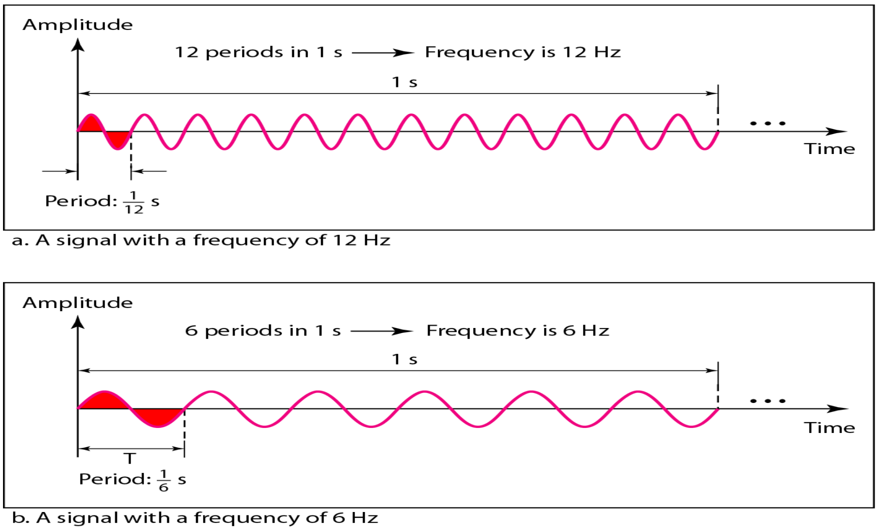


Figure: Two signals with the same amplitude and phase, but different frequencies

Example

The power we use at home has a frequency of 60 Hz. The period of this sine wave can be determined as follows:

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

Example

Express a period of 100 ms in microseconds.

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 100 \times 10^{-3} \times 10^{6} \text{ µs} = 10^{2} \times 10^{-3} \times 10^{6} \text{ µs} = 10^{5} \text{ µs}$$

Example

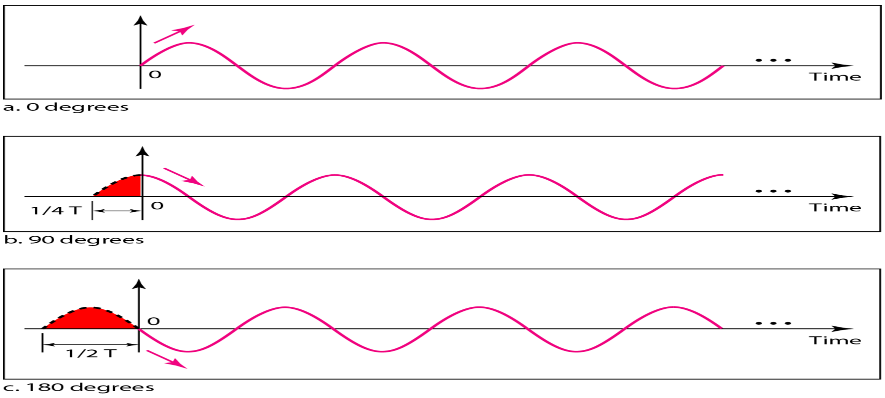
The period of a signal is 100 ms. What is its frequency in kilohertz?

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$
$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

- 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 instantaneously, its frequency is infinite.

Phase describes the position of the waveform relative to time 0.

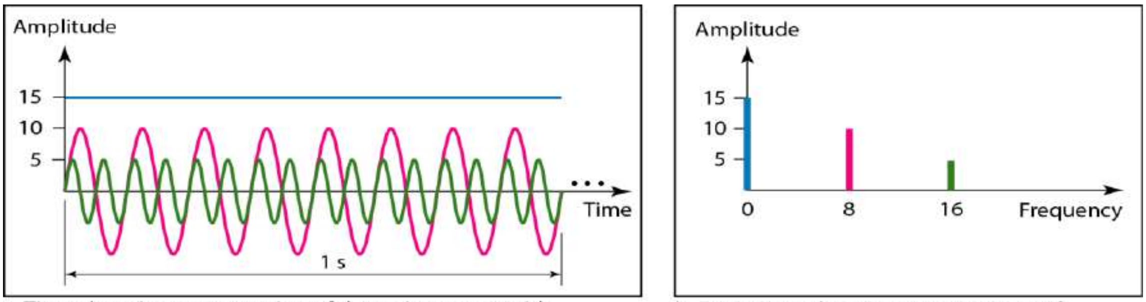
Three sine waves with the same amplitude and frequency, but different phases



Example

The frequency domain is more compact and useful when we are dealing with more than one sine wave. For example, Figure shows three sine waves, each with different amplitude and frequency. All can be represented by three spikes in the frequency domain.

- A single-frequency sine wave is not useful in data communications; we need to send a composite signal, a signal made of many simple sine waves.



a. Time-domain representation of three sine waves with frequencies 0, 8, and 16

b. Frequency-domain representation of the same three signals

Figure: The time domain and frequency domain of three sine waves

- If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies; if the composite signal is non-periodic, the decomposition gives a combination of sine waves with continuous frequencies.

Example

A periodic composite signal with frequency f. This type of signal is not typical of those found in data communications. We can consider it to be three alarm systems, each with a different frequency. The analysis of this signal can give us a good understanding of how to decompose signals.

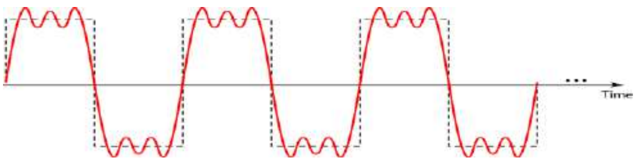
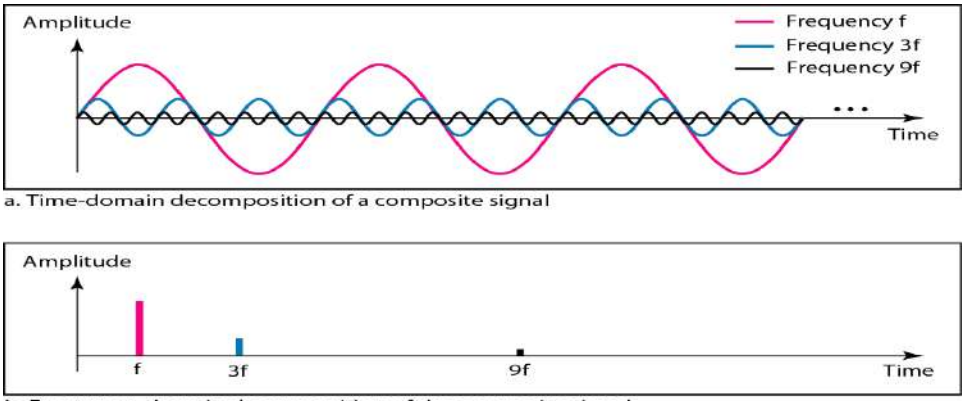


Figure: A composite periodic signal



b. Frequency-domain decomposition of the composite signal

Figure: Decomposition of a composite periodic signal in the time and frequency domains

Example

A non-periodic composite signal. It can be the signal created by a microphone or a telephone set when a word or two is pronounced. In this case, the composite signal cannot be periodic, because that implies that we are repeating the same word or words with exactly the same tone.

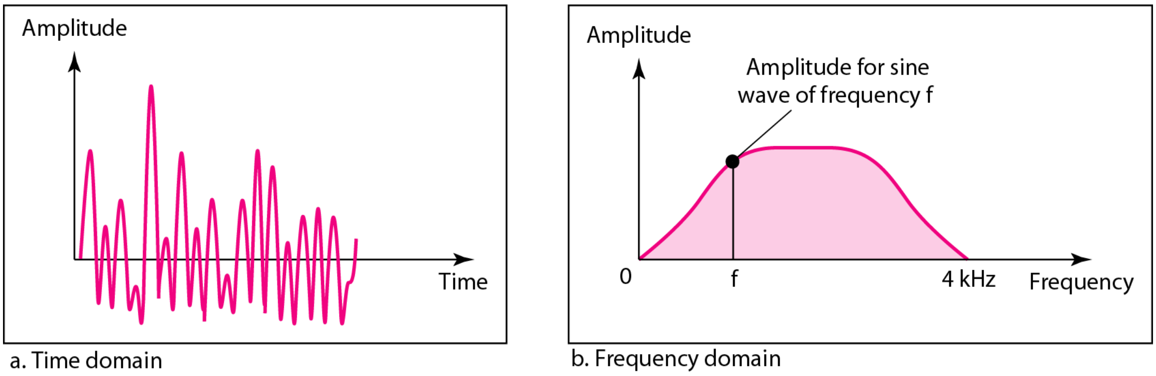


Figure: The time and frequency domains of a non-periodic signal

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

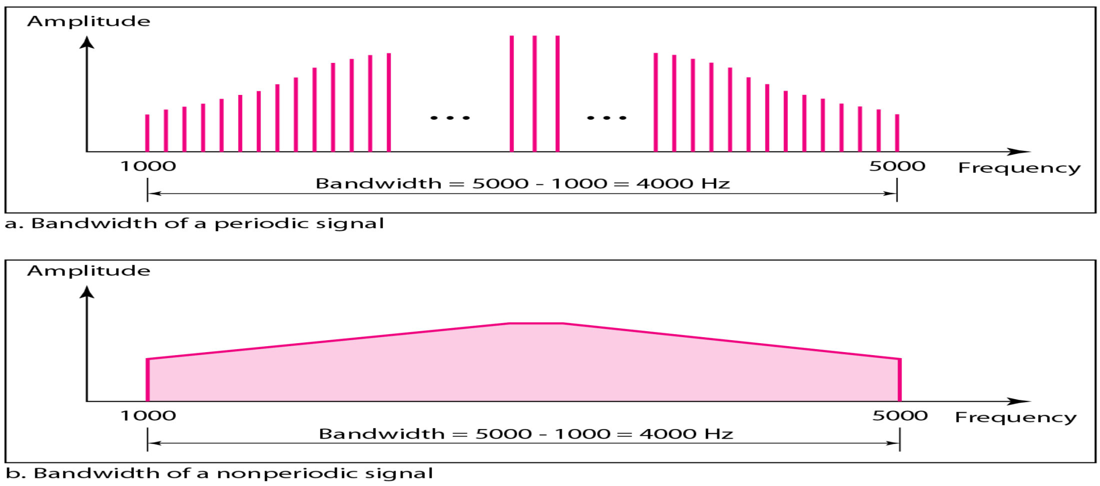
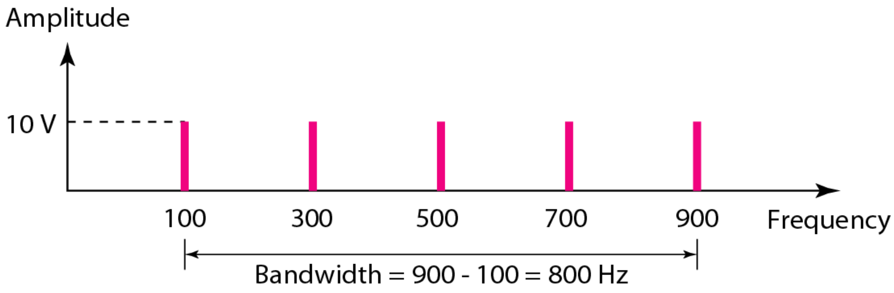


Figure: The bandwidth of periodic and non-periodic composite signals

Example Start from here

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.

$$\boxed{B = f_h - f_l = 900 - 100 = 800 \text{ Hz}}$$



Example

A non-periodic 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.

DIGITAL SIGNALS

In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

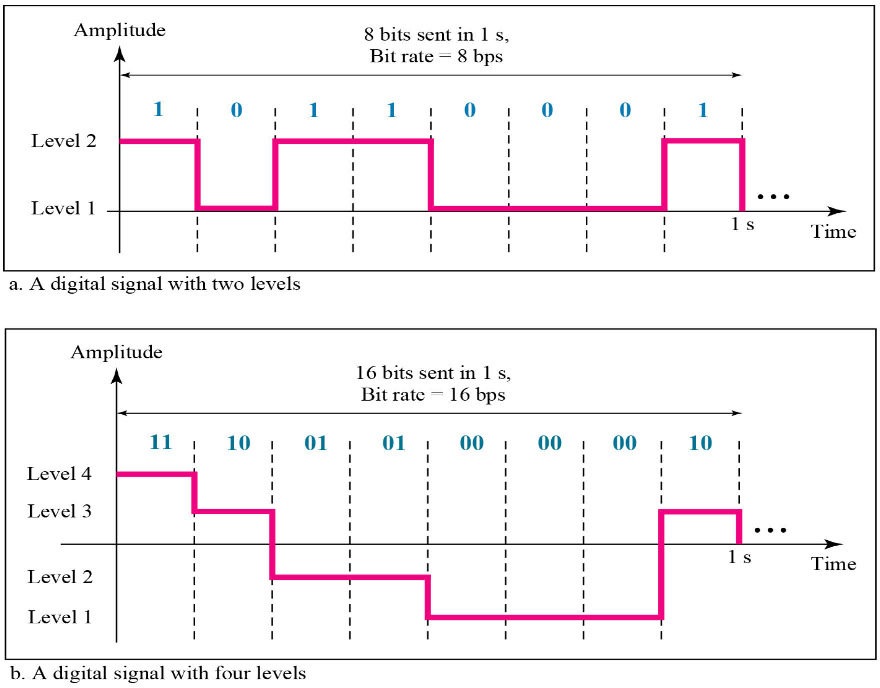


Figure: Two digital signals: one with two signal levels and the other with four signal levels

Week # 4 – Lecture # 8 – Data link layer (Layer 2)

Multiplexing and Demultiplexing

Multiplexing is a technique used to combine and send the multiple data streams over a single medium. The process of combining the data streams is known as multiplexing and hardware used for multiplexing is known as a multiplexer. Multiplexing is achieved by using a device called Multiplexer (MUX) that combines n input lines to generate a single output line. Multiplexing follows many-to-one, i.e., n input lines and one output line.

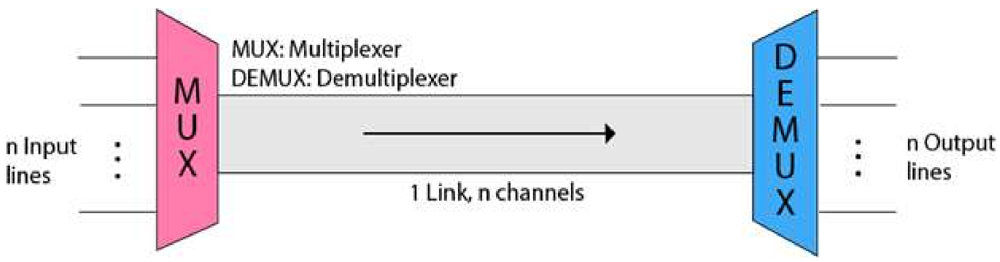
Demultiplexing is achieved by using a device called Demultiplexer (DEMUX) available at the receiving end. DEMUX separates a signal into its component signals (one input and n outputs). Therefore, we can say that demultiplexing follows the one-to-many approach.

Multiplexing

Multiplexing (Muxing) is a term used in the field of communications and computer networking. It generally refers to the process and technique of transmitting multiple analog or digital input signals or data streams over a single channel. Since multiplexing can integrate multiple low-speed channels into one high-speed channel for transmission, the high-speed channel is effectively utilized. By using multiplexing, communication carriers can avoid maintaining multiple lines, therefore, operating costs are effectively saved.

Demultiplexing

Demultiplexing (Demuxing) is a term relative to multiplexing. It is the reverse of the multiplexing process. Demultiplex is a process reconverting a signal containing multiple analog or digital signal streams back into the original separate and unrelated signals.



Modulation / Demodulation

There are two important processes used in data communication namely, modulation and demodulation. Both these processes make a communication successful by the transfer of data and information with the minimum distortion, minimum losses and efficient use of spectrum. The electronic device that is employed to perform modulation and demodulation is called modem. It performs modulation and demodulation of information during its transmission.

What is Modulation?

The process of superimposing a message signal on a carrier signal so that the message can be transmitted over long distances is called modulation. Here, the carrier signal is the signal of high frequency which is used to carry the message signal. The following figure shows the block diagram of modulation.

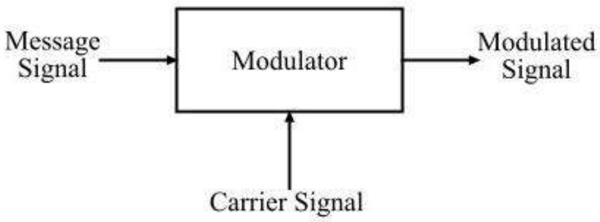


Figure - Modulation

The modulation of a signal is performed at the transmitting end in the communication system with the help of a modulator circuit (a part of modem). In the modulation, a specific parameter, i.e., amplitude, frequency or phase, of the carrier signal is altered in accordance with the modulating signal or message signal. After modulation, the modulated signal is transmitted over the communication channel by a transmitter.

Spatial parameters: polarization & direction of propagation

The common types of modulation that are being extensively used in data communication are − amplitude modulation, frequency modulation, phase modulation, polarization modulation, pulse code modulation, quadrature amplitude modulation, etc. The modulation process is widely used in transmission of signals using electromagnetic waves, radio waves, optics (in fiber optics), etc.

PCM: sampling, quantization & encoding
Sampling: Measuring the amp. of con. sig. at discrete instants
Quantization: Converting analog samples into binary no. that are 0 and 1.
Encoding: Each quantized sample is converted into an 8-bit codeword. QAM: QAM is a modulation format that combines two carriers whose amplitudes are modulated independently with the same optical frequency and whose phases are 90 degree apart. both amplitude and phase change within a QAM signal. to generate two signals that are 90° out of phase with each other and then sum them

What is Demodulation?

The process of obtaining the original message from the modulated signal is called **demodulation**. In simple words, demodulation is the process of separating a message signal from a carrier signal. The process of demodulation is shown in the following block diagram.

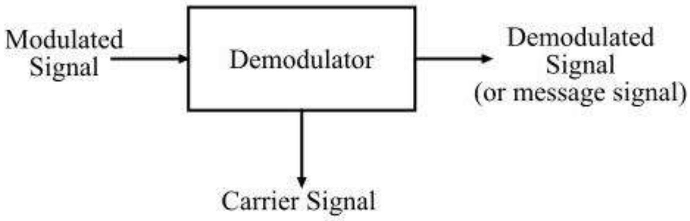


Figure - Demodulation

The electronic circuit that is used to perform the demodulation process is called demodulator; it is the part of the modem. The process of demodulation is performed at the receiver end of a communication system.

Question 1: What is modulation in a computer network?

Answer 1: Modulation helps in adding information into a carrier. This information transmits in periodic waveforms that decodes into a readable format using a computer network.

Question 2: Which is the best modulation technique?

Answer 2: Amplitude modulations are more prone to noise distortion; however, Phase and Frequency Modulation works much better at a constant noise level and requires lesser power for clearer transmissions.

Introduction to data link layer (link level communication)

Our Goals in this chapter are as follows:

Understand the basic principles behind the link layer services. There are many different services which are offered at data link layer. These services are listed below:

- error detection, correction
- sharing a broadcast channel: multiple access
- link layer addressing
- local area networks: Ethernet, VLANs

Here are some important terminologies which should be clear before looking into details of this chapter:

Node:

Hosts and **routers** are generally named as network nodes.

Link:

Communication channels that connect adjacent nodes along communication path are called links.

- wired links
- wireless links
- LANs

Frame:

Layer-2 packet is called frame. Encapsulation of datagram into a frame, adding data link layer header.

The responsibility of data-link layer:

The data link layer has responsibility of transferring frames from one node to physically adjacent node over a link. In this regard different data link layer protocols/technologies can be used over different links. For instance, Ethernet on first link, frame relay on intermediate links, Wi-Fi on last link. Each link protocol provides different set of services, e.g., a protocol may or may not provide reliable data transfer over a link.

Details of link layer services

Although the basic service of link layer is to move a frame from one node to an adjacent node over a single communication link, the details of the provided service can vary from one link-layer protocol to the next. Possible services that can be offered by a link-layer protocol include:

Framing: Almost all link-layer protocols encapsulate each network-layer datagram within a link-layer frame before transmission over the link. A frame consists of a data field (payload), in which the network-layer datagram is inserted, and a number of header fields. The structure of the frame is specified by the link-layer protocol. We'll see several different frame formats when we examine specific link-layer protocols later on.

Link access:

A medium access control (**MAC**) protocol specifies the rules by which a frame is transmitted onto the link. For point-to-point links that have a single sender at one end of the link and a single receiver at the other end of the link, the MAC protocol is simple (or non-existent) - the sender can send a frame whenever the link is idle. The more interesting case is when multiple nodes share a single broadcast link—the so-called multiple access problem. Here, the MAC protocol serves to coordinate the frame transmissions of the many nodes.

Reliable delivery:

When a link-layer protocol provides reliable delivery service, it guarantees to move each network-layer datagram across the link without error. Recall that certain transport-layer protocols (such as TCP) also provide a reliable delivery service. Similar to a transport-layer reliable delivery service, a link-layer reliable delivery service can be achieved with acknowledgments and re-transmissions. A link-layer reliable delivery service is often used for links that are prone to high error rates, such as a wireless link, with the goal of correcting an error locally—on the link where the error occurs—rather than forcing an end-to-end re-transmission of the data by a transport or application layer protocol. However, link-layer reliable delivery can be considered an unnecessary overhead for low bit-error links, including fiber, coax, and many twisted-pair copper links. For this reason, many wired link-layer protocols do not provide a reliable delivery service.

Error detection and correction:

The link-layer hardware in a receiving node can incorrectly decide that a bit in a frame is zero when it was transmitted as a one, and vice versa. Such bit errors are introduced by signal attenuation and electromagnetic noise. Because there is no need to forward a datagram that has an error, many link-layer protocols provide a mechanism to detect such bit errors. This is done by having the transmitting node include error-detection bits in the frame, and having the receiving node perform an error check. Error detection in the link layer is usually more sophisticated and is implemented in hardware. Error correction is similar to error detection, except that a receiver not only detects when bit errors have occurred in the frame but also determines exactly where in the frame the errors have occurred (and then corrects these errors).

Error Detection Techniques

There are three main techniques for detecting errors in frames: Parity Check, Checksum, and Cyclic Redundancy Check (CRC).

Parity Check

The parity check is done by adding an extra bit, called parity bit to the data to make a number of 1s either even in case of even parity or odd in case of odd parity. While creating a frame, the sender counts the number of 1s in it and adds the parity bit in the following way

In case of even parity: If a number of 1s is even then parity bit value is 0. If the number of 1s is odd then parity bit value is 1.

In case of odd parity: If a number of 1s is odd then parity bit value is 0. If a number of 1s is even then parity bit value is 1.

On receiving a frame, the receiver counts the number of 1s in it. In case of even parity check, if the count of 1s is even, the frame is accepted, otherwise, it is rejected. A similar rule is adopted for odd parity check. The parity check is suitable for single bit error detection only.

Checksum

In this error detection scheme, the following procedure is applied:

Data is divided into fixed sized frames or segments. The sender adds the segments using 1's complement arithmetic to get the sum. It then complements the sum to get the checksum and sends it along with the data frames. The receiver adds the incoming segments along with the checksum using 1's complement arithmetic to get the sum and then complements it. If the result is zero, the received frames are accepted; otherwise, they are discarded.

Cyclic Redundancy Check (CRC)

Cyclic Redundancy Check (CRC) involves binary division of the data bits being sent by a predetermined divisor agreed upon by the communicating system. The divisor is generated using polynomials.

Here, the sender performs binary division of the data segment by the divisor. It then appends the remainder called CRC bits to the end of the data segment. This makes the resulting data unit exactly divisible by the divisor. The receiver divides the incoming data unit by the divisor. If there is no remainder, the data unit is assumed to be correct and is accepted. Otherwise, it is understood that the data is corrupted and is therefore rejected.

Error Correction Techniques

Error correction techniques find out the exact number of bits that have been corrupted and as well as their locations. There are two ways:

Backward Error Correction (Retransmission): If the receiver detects an error in the incoming frame, it requests the sender to retransmit the frame. It is a relatively simple technique. But it can be efficiently used only where retransmitting is not expensive as in fiber optics and the time for retransmission is low relative to the requirements of the application.

Forward Error Correction: If the receiver detects some error in the incoming frame, it executes error-correcting code that generates the actual frame. This saves bandwidth required for retransmission. It is inevitable in real-time systems. However, if there are too many errors, the frames need to be retransmitted.

Implementation of data link layer

Before diving into our detailed study of the link layer, let's conclude this introduction by considering the question of where the link layer is implemented in a host. For the most part, **the link layer is implemented in a network adapter**, also sometimes known as a network interface card (NIC). At the heart of the network adapter is the link-layer controller, usually a single, special-purpose chip that implements many of the link-layer services (framing, link access, error detection, and so on). Thus, much of a link-layer controller's functionality is implemented in hardware. For example, Intel's 8254x controller implements the Ethernet protocols we'll study later on.

On the sending side, the controller takes a datagram that has been created and stored in host memory by the higher layers of the protocol stack, encapsulates the datagram in a link-layer frame (filling in the frame's various fields), and then transmits the frame into the communication link, following the link-access protocol. On the receiving side, a controller receives the entire frame, and extracts the network-layer datagram. If the link layer performs error detection, then it is the sending controller that sets the error-detection bits in the frame header and it is the receiving controller that performs error detection.

It is recommended to see figure 5.2 in the book. It shows a network adapter attaching to a host's bus (e.g., a PCI or PCI-X bus), where it looks much like any other I/O device to the other host components. It also shows that while most of the link layer is implemented in hardware, part of the link layer is implemented in software that runs on the host's CPU. The software components of the link layer implement higher-level link layer functionality such as assembling link-layer addressing information and activating the controller hardware. On the receiving side, link-layer software responds to controller interrupts (e.g., due to the receipt of one or more frames), handling error conditions and passing a datagram up to the network layer. Thus, the link layer is a combination of hardware and software—the place in the protocol stack where software meets hardware.

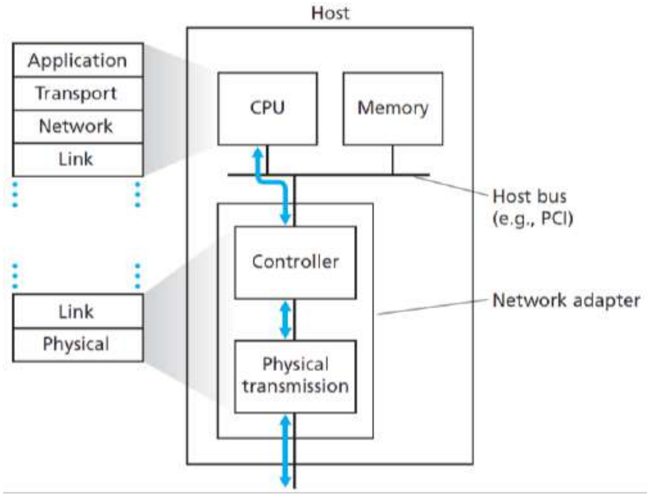


Figure 5.2: Network adapter: its relationship to other host components and to protocol stack functionality