IFC6501 - Wireless Data Communications

Session 1: Course Overview

Daniel Febrian Sengkey

Department of Electrical Engineering
Faculty of Engineering
Universitas Sam Ratulangi

Outline

Acknowledgement

When not specifically cited, the contents of this presentation are adapted from [1].

The Rules of the Game

1. You can attend the class anytime you want, but to sign the *List of Attendees* you should not come more than 15 minutes since the class started.
2. You should attend $>$ 80% of the meetings to get the final grade.
3. Contact me only by the means listed in this slide.
4. If you and your friend have something to be discussed please do it outside the class, except you are assigned to do so.
5. If you have a question, please raise your hand anytime during the class. No need to wait until the class finished.
6. Plagiarism in assignments will be rated as 0. If you cheating and/or plagiarizing in final test/assignment you will have '**E**' as your final grade.
7. You are college students, please behave with the appropriate attitude.

Topics

- Fundamental aspects in wireless communications.
- Wireless networks
- Simulation
- *See attachment for more details*

Scoring Components

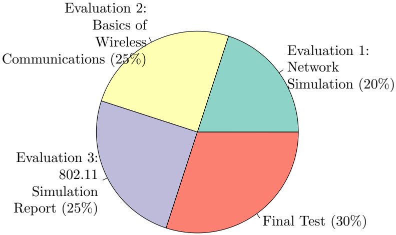

Figure 1 : Scoring components

- 3 Evaluations 70%
- A comprehensive Final Test 30%

- Grading system follows faculty regulation:
  - $n \geq 80$ Grade = A
  - $75 \leq n < 80$ Grade = B+
  - $70 \leq n < 75$ Grade = B+
  - $65 \leq n < 70$ Grade = B
  - $60 \leq n < 65$ Grade = C+
  - $55 \leq n < 60$ Grade = C
  - $35 \leq n < 55$ Grade = D
  - $n < 35$ Grade = E

Important Things to Consider

- We are going to use several applications and systems. Set your schedule for your self-study. It is for your own good.
- Simulation: OMNeT++
- Statistical processing: GNU R

Data Communication

Introduction

- The advancement in data communications and networking affects how we do business and the way we live.
- Business decisions have to be done quickly,and to achieve well qualified decision the decision maker require immediate access to accurate information.
- Data communications also introduces e-Learning and distance learning in the education field, that makes education contents available even for the people in the remote area.

Data Communications

Definitions

- **Telecommunication**: communication at a distance.[1]
- **Data**: information presented in whatever form is agreed upon by the parties creating and using the data.
- **Data communication**: exchange of data between two devices via some form of transmission medium.
- **Communication system**: combination of hardwares and softwares used in data communication.The communicating parties in data communication are parts of a communication system.

[1] *tele* means far in Greek.

Data Communications

Fundamental Characteristics

- Delivery
- Accuracy
- Timeliness
- Jitter

Networks

- Interconnection of a set of devices capable of communication.
- A device can be:
  - **Host** (an end system) such as workstation, server, and PC.
  - **Connecting device** such as router, switch, and bridge.

Networks

Criteria

- Performance
- Reliability
- Security

Networks

Criteria: Performance

- Can be measured in many ways, such as:
  - The *amount of time* required for a message to travel from one device to another,known as **Transit Time.**
  - The *elapsed time* between an inquiry and a response,known as **Response Time.**
- Depends on a number of factors, such as:
  - Number of users
  - Type of transmission medium
  - Capabilities of connected hardware
  - Software efficiency
- Oftenly evaluated in **throughput** and **delay**.

Networks

Criteria: Reliability

- Measured by:
  - Frequency of failure
  - Required time for recovery from a failure
  - Robustness during a catastrophe

Networks

Criteria: Security

- Protecting data from damage and development
- Protecting data from unauthorized access
- Implementing policies and procedures for recovery from breaches and data losses

Networks

Physical Structures

- Type of Connection
- Physical Topology

Networks

Physical Structures: Type of Connection - Point-to-Point

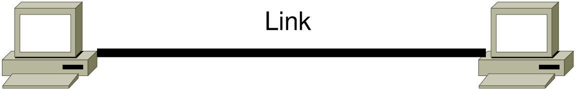

Figure 2 : Point-to-Point connection.

- Point-to-Point connection provides a dedicated link between two devices.
- Entire link capacity is reserved for transmission between those devices.

Networks

Physical Structures: Type of Connection - Multipoint

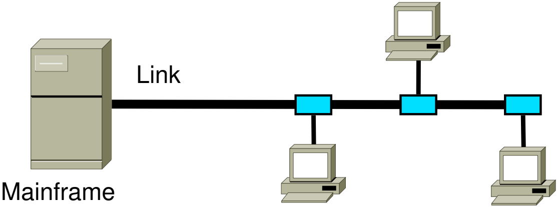

Figure 3 : Multipoint connection.

- Multipoint connection¡+-¿also known as multidrop connection. shares a single link to be used by multiple devices.
- The link capacity is shared, either spatially or temporally.

Networks

Physical Structures: Physical Topology

- Physical topology refers to the way in which a network is laid out *physically*.
- The topology of a network is the geometric representation of the relationship of all the links and linking devices[2] to one another.
- Basically there are four topologies:
  - Bus
  - Ring
  - Star
  - Mesh

[2]usually called nodes

Networks

Physical Structures: Physical Topology - Bus

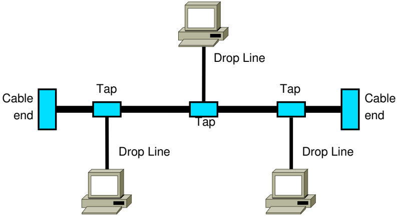

Figure 4 : Bus topology with three stations

- Used in the early local-area networks.
- In bus topology, a single cable act as a backbone to link all the devices.
- Nodes are connected to the bus cable by drop lines and taps.
- The number of supported taps, and distances between taps are limited.

Networks

Physical Structures: Physical Topology - Bus

- Advantages:
  - Requires less cabling than the other topologies.
  - Redundancy is eliminated.
- Disadvantages:
  - Difficult reconnection and fault isolation
  - Signal degradation due to reflection at the taps.
  - A single fault stops all transmission.

Networks

Physical Structures: Physical Topology - Ring

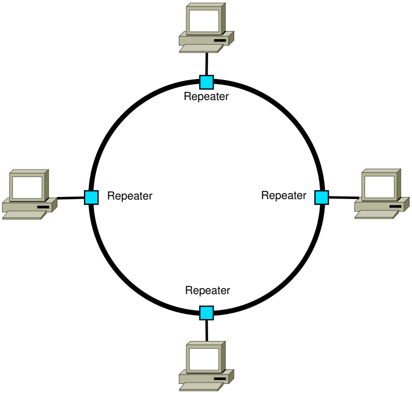

Figure 5 : Ring topology with four stations

Networks

Physical Structures: Physical Topology - Ring

- Each device has a dedicated point-to-point connection with only two devices on either side of it.
- Signal is passed along the ring in one direction, until the destination reached.
- Advantages:
  - Easy to install and reconfigure
  - Fault isolation is simplified.
- Disadvantage:
  - Unidirectional traffic can be a disadvantage.A break in can disable entire network.

Networks

Physical Structures: Physical Topology - Star

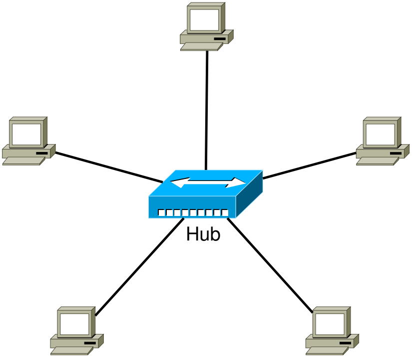

Figure 6 : Star topology with five stations

Networks

Physical Structures: Physical Topology - Star

- Each device has a dedicated point-to-point connection only to a central controller.
- Data are sent to the controller which then relays the data to the other connected devices.
- Advantages:
  - Easy to install and reconfigure
  - Fault isolation is simplified.
  - Robustness
- Disadvantage:
  - If the hub down, whole network is dead.

Networks

Physical Structures: Physical Topology - Mesh

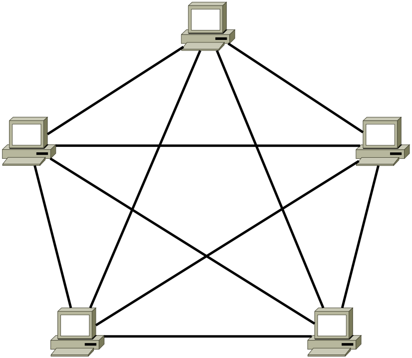

Figure 7 : Mesh topology with five stations

Networks

Physical Structures: Physical Topology - Mesh

- Each device has a dedicated point-to-point connection to every other device.
- Advantages:
  - Each dedicated links guarantees that each connection can carry its own data load.
  - Robustness
  - Privacy and security
  - Easy fault identification and isolation
- Disadvantage:
  - Requires $n(n-1)/2$ duplex mode links and in each device $n-1$ I/O ports. n represents the number of nodes.

Network Types

- Local Area Network (LAN)
- Wide Area Network
  - Point-to-point WAN
  - Switched WAN
- Internetwork (network of networks)

Network Types

Switching

- An internet is a switched network[3].
- The term comes from the data that being switched from node to node in the network.
- The most common types of switched networks are:
  - Circuit-switched network (e.g. POTS)
  - Packet-switched network
    - Datagram
    - Virtual Circuit switching

[3] Do not mix the term with the hardware switch.

Network Types

The Internet

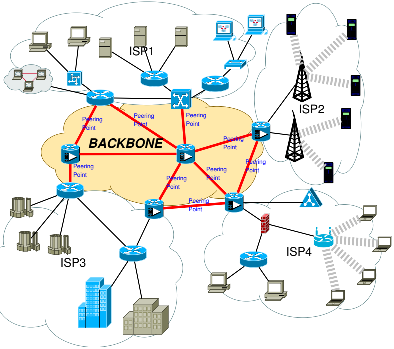

Figure 8 : A simplified model of the Internet.

Network Types

The Internet

- The **Internet** is the most notable internet.
- The interconnections between service providers, institutions (universities, corporation network) build the Internet.
- To gain access to the Internet, the LANs should have a connection to the service provider network.
- Later, the networks of the service providers are connected to the **Backbone Network**.

Network Types

Accessing The Internet

- Using telephone networks
  - Dial-up service
  - DSL Service
- Using cable networks
- Using wireless networks
- Direct connection to the Internet

TCP/IP Protocol Suite

- **Transmission Control Protocol/Internet Protocol (TCP/IP)** is the *de facto* protocol suite that runs in the Internet today.
- Protocol suite is a set of protocols organized in different layers.
- TCP/IP is a hierarchical protocol consists of interactive modules, where each module provides a specific functionality.
- Hierarchical means an *upper layer* protocol is supported by the services provided by one or more *lower level* protocols.
- Originally TCP/IP suite was defined as four software layers built upon the hardware, but in present condition it is considered as five-layer model.

TCP/IP Protocol Suite

Layers

- The layers[4] in the TCP/IP Protocol Suite are:
  1. Physical
  2. Data link
  3. Network
  4. Transport
  5. Application

[4] In the present consideration

TCP/IP Protocol Suite

Object in Each Layer

Table 1 : Objects in the TCP/IP Protocol Suite

Layer	Object
Physical	Bits
Data link	Frames
Networks	Datagrams
Transport	Segments or User Datagrams
Application	Messages

TCP/IP Protocol Suite

Physical Layer

- Responsible for carrying individual bits in a frame across the link.
- Although physical layer is the lowest layer in the suite, there is still another layer: the transmission medium.
- Devices are physically connected by the transmission medium, but it carries signals not bits.
- Physical layer handles the bits-to-signals and signals-to-bit transformation.

TCP/IP Protocol Suite

Data link Layer

- Data link handles data communication within the same link.
- Data link takes the datagram from network layer and moving it across the link.
- No specific protocol defined for this layer, so it supports all standard and proprietary protocols.
- Several protocols provide complete error detection and correction, some only provide error correction.

TCP/IP Protocol Suite

Network Layer

- Network layer is responsible for creating a host-to-host connection between source and destination.
- The source and destination may located in different networks.
- Routers work in this layer, and responsible to choose the best route for each packet.
- Network layer includes the main main protocol: Internet Protocol (IP).

TCP/IP Protocol Suite

Transport Layer

- Transport layer provides end-to-end connection.
- Transport layer at the source hosts:
  - Takes message from application layer,
  - *Encapsulates* it in a *segment* or *user datagram*,
  - and *sends* it through the logical connection to the transport layer at the destination host.
- In other words the transport layer is responsible for giving services to the application layer: to get a message from an application running at the source host and deliver it to the corresponding application program on the destination host.

- Two application layers exchange messages between each other as though there were a bridge between the two layers[5].
- The communication is between two *processes* (programs) running at this layer.
- To communicate , a process sends a request to the process at the other host and receives a response.

[5] Keep in mind that the communication goes through all layers.

Layered Architecture Operation

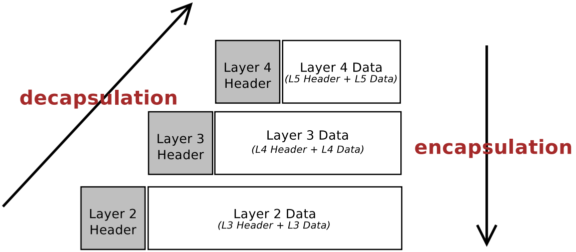

Figure 9 : Encapsulation and decapsulation concept

Layered Architecture Operation

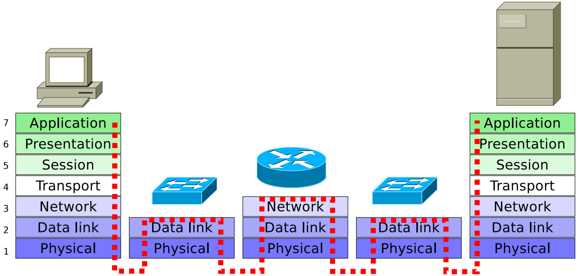

Figure 10 : Data communication in layered architecture.

Physical Layer

Introduction

- Physical layer is responsible to move data in form of electronic signals across transmission medium.
- Physical layer sits between the transmission medium and the rest of the communicating device.
- First, let us discuss the medium.

Transmission Medium [2]

- In data communication, nodes are always connected by physical path.
- This physical path is known as <u>transmission medium</u>.
- Transmission medium connects the receiver and the transmitter.
- Electromagnetic wave is the element that being transmitted between connected parties.

Transmission Medium [2]

Forms of Transmission Medium

- **Guided Media:** electromagnetic waves are guided along a solid medium, such as copper twisted pair, copper coaxial cable, or optical fiber.
- **Unguided Media:** the transmission occurs through the atmosphere, outer space, or water.

Data and Signals

- Data communications is referring to data exchange between a source and a destination.
- At the physical layer, data communications means exchanging *signals*.
- The data were converted into signals so they could be transmitted via the transmission medium.
- The form of the signals could be analog or digital.

Analog and Digital Data

- <u>Analog Data:</u> continuous information.
- Example: sounds made by human voice.
- <u>Digital Data:</u> discrete information.
- Example:the data stored in computer memory in binary form.

Analog and Digital Signals

- Signals also can be analog or digital, like the data they represent.
- An analog signal has infinitely many levels of intensity over a period of time.
- On the contrary, a digital signal can only has a limited number of defined values.
- Figure 11 shows an example of analog signal plotted on a pair of perpendicular axes. Figure 12 shows the plot of digital signal.

Analog and Digital Signals

Example of Analog Signal

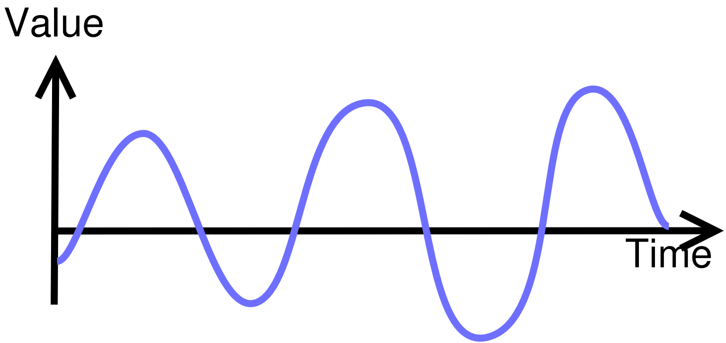

Figure 11 : Analog signal

Analog and Digital Signals

Example of Digital Signal

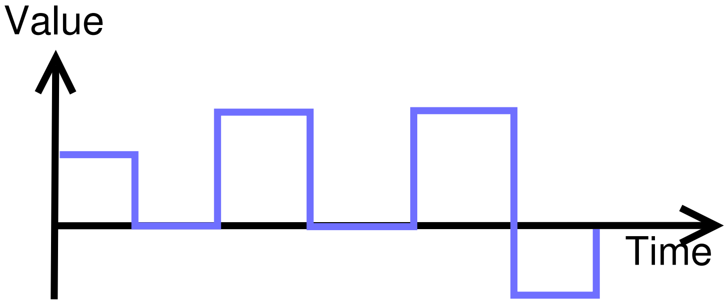

Figure 12 : Digital signal

Periodic and Nonperiodic Signals

- Both types of signals can take one of two forms: periodic or nonperiodic signal.
- A periodic signal completes a patter within a measurable time frame, called a period.
- The pattern repeated over subsequent identical periods.
- A full pattern is known as a cycle.
- On the other hand, a nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time.
- In data communication we commonly use **periodic analog signals** and **nonperiodic digital signals**.

Periodic Analog Signals

- Periodic signals can be classified as simple or composite.
- A composite signal is composed of multiple simple signals.

Sine Wave

- A sine wave has three parameters:
  - Peak amplitude (A)
  - Frequency (f)
  - Phase (ϕ)
- Figure 13 shows two signals with the same phase and frequency, but different amplitudes.

Sine Wave

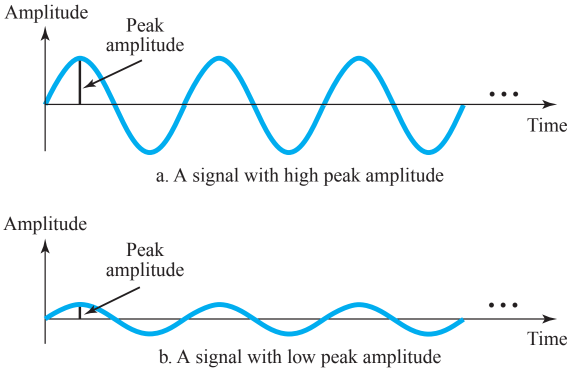

Figure 13 : Two sine waves, with different amplitude.

Sine Wave

Parameters [2]

- Frequency (f) is the rate at which the signal repeats. It is measured as cycle(s) per second, or Hertz (Hz).
- Period (T) is the amount of time needed for one repetition.
- The relation between frequency and period can be mathematically expressed as:

$$T = \frac{1}{f} \Leftrightarrow f = \frac{1}{T} \tag{1}$$

- Phase (ϕ) is a measure of relative position in time within a single period of signal.
- Peak amplitude (A) is the maximum value or strength of the signal over time. Typically measured in volts.

Sine Wave

Parameters [2]

- Sine wave is mathematically expressed as

$$s(t) = A \cdot sin(2\pi ft + \phi) \quad (2)$$

- with t as time, measured in seconds.

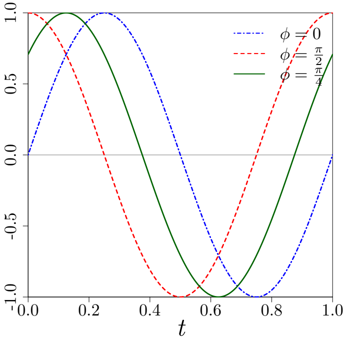

Figure 14 : Plot of sine waves with $f = 1$, $A = 1$, and various values of ϕ.

Sine Wave

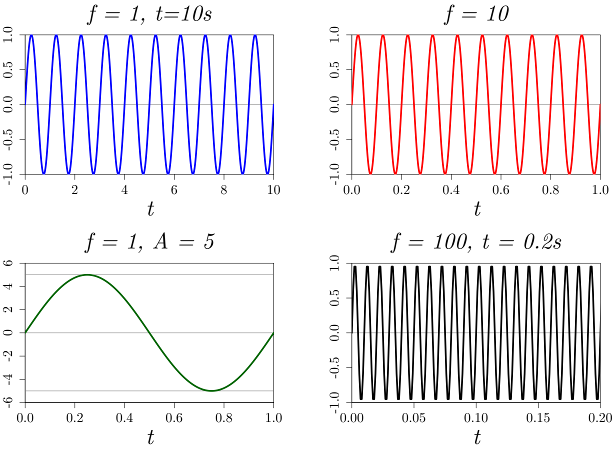

Figure 15 : Sine waves of various frequencies and amplitudes.

Sine Wave

Wavelength

- Wavelength (λ) binds the period (T) or the frequency (f) of a sine wave to the propagation speed of the medium.
- Wavelength is the distance a simple signal can travel in one period.
- Wavelength calculated as propagation speed in the medium (v) multiplied with period (T).

$$\lambda = v \times T \tag{3}$$

Sine Wave

Wavelength

- Since $T = \frac{1}{f}$ then

$$\lambda = \frac{v}{f}$$

- Therefore for electromagnetic signal in vacuum it becomes:

$$\lambda = \frac{c}{f} \tag{4}$$

- with $c \approx 3 \times 10^8\ m/s$, which is known as <u>the speed of light in vacuum</u>.

Composite Signals

- Simple sine waves have many applications in daily life (e.g. in electricity).
- However, in data communications, a single sine wave carries no information.
- To communicate data, we need a composite signals.
- According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

Composite Signals

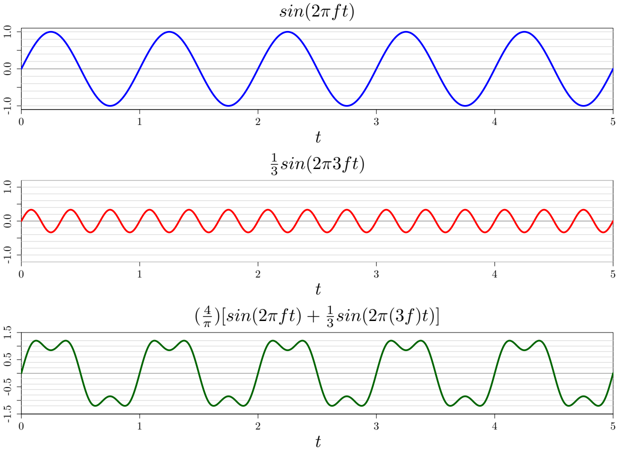

Figure 16 : Simple sine waves and a composite signal.

Bandwidth

- Bandwith (B) is the range of frequencies in a composite signals.
- Commonly, it is a difference between two numbers, the highest and the lowest frequencies.
- It is mathematically expressed as[6]

$$B = f_{max} - f_{min} \tag{5}$$

[6] Forouzan uses f_h and f_l for the highest and the lowest frequencies, respectively.

Digital Signal

- Digital signal consists of 0 and 1.
- The binary digits can be encoded by using different voltages.
- A digital signal can have more than two levels, which in each level we can send more than a single bit.
- Figure 17 shows two digital signals with different levels.
  - The first signal (a) has two levels, 1 bit per level.
  - The second signal (b) has four levels, 2 bits per level.

Digital Signal

Levels

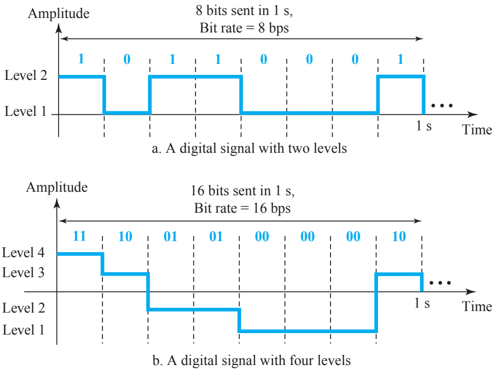

Figure 17 : Two digital signals with different levels.

Digital Signal

- The relationship between levels and bits is mathematically expressed as

$$\text{Number of bits per level} = \log_2 L \tag{6}$$

where L is the number of levels of a signal.

Bit Rate

- Period and frequency are not the appropriate characteristics for digital signals since most of them are nonperiodic.
- Therefore bit rate is used to describe digital signals instead of period or frequency.
- Bit rate is the number of bits sent in a second, hence the unit is bits per second (bps).
- In Figure 17, the bit rate of the first signal is 8 bps while the second signal has 16 bps.

Bit Length

- **Bit length** is in place of wavelength for the digital signal.
- Bit length is the distance one bits occupies on the transmission medium.
- Bit length is mathematically expressed as

$$\text{Bit length} = \text{propagation speed} \times \text{bit duration} \tag{7}$$

Transmission of Digital Signals

- There are two approaches to transmit a digital signal:
  - **Baseband transmission**: sending digital signal without changing it to an analog signal.
  - **Broadband transmission**: sending digital signal by changing it to an analog signal[7].
- Baseband transmission needs a **low-pass channel**, which has a bandwidth that starts from zero.
- On the other hand broadband transmission, by utilizing modulation, uses a bandpass channel, which the bandwidth does not start from zero.
- Due to the requirements, bandpass channel is more available than the low-pass channel.

---

[7] The signal is *modulated*.

Transmission Impairment

- Received signal may be different from transmitted signal.
- The cause is the signal suffers transmission impairments.
- In analog signal, the quality may be deteriorated.
- In digital signal, there can be bit transformation: 1 received as 0 or vice versa.
- The causes of impairment are attenuation, distortion, and noise.

Attenuation

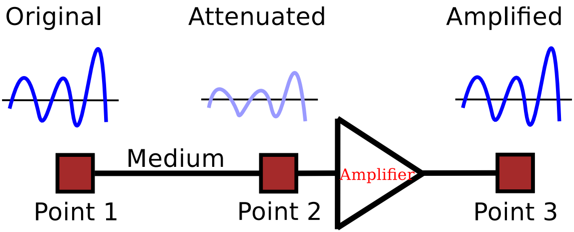

Figure 18 : Illustration of attenuation.

- Attenuation means a loss of energy.
- To show whether the signal has gain or loss strength, engineers use the unit of **decibel**.

Attenuation

- Decibel (dB) measures relative strength between two signals, or one signal at two different locations. Note that:
  - $dB < 0$ means attenuation.
  - $dB > 0$ means amplification.
- Attenuation in decibel is mathematically expressed as

$$dB = 10 \log_{10} \frac{P_2}{P_1} \tag{8}$$

- P_1 and P_2 are the **powers** of a signal at locations 1 and 2, respectively.

Distortion

- Distortion means the signal changes in for or shape.
- Distortion can occur in a composite signal that consists of several frequencies.
- Each signal component has its own propagation speed through a medium.
- Different propagation speeds cause variance of delay. It means each component arrived at different time.
- In other words, the received signal has different phases from the transmitted signal.

Distortion

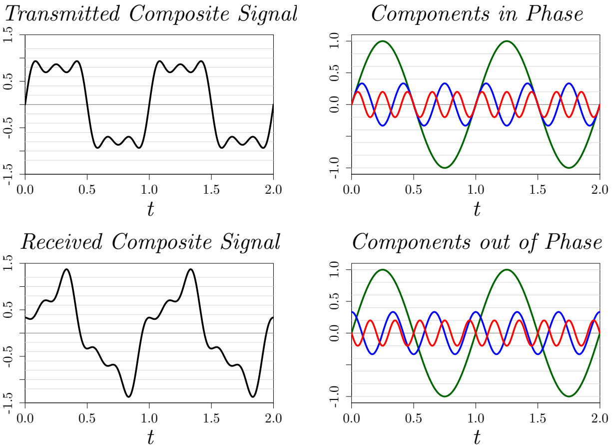

Figure 19 : Distortion affecting the received signals.

Noise

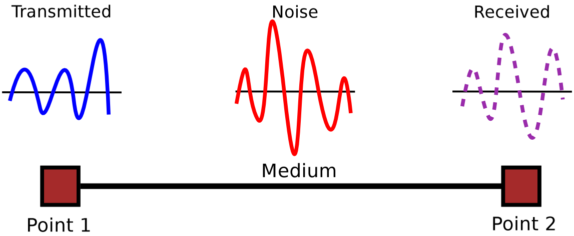

Figure 20 : Noise effect.

- Thermal noise
- Induced noise
- Crosstalk
- Impulse noise

Noise

- Signal-to-noise-ratio (SNR) is the ratio between signal power to the noise power. SNR is mathematically expressed as

$$\mathrm{SNR} = \frac{\text{signal power}}{\text{noise power}} \tag{9}$$

- Since SNR is the ratio between two powers, then it is often described in decibel units $\mathrm{SNR}_{\mathrm{dB}}$, defined as

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

Data Rate Limits

- Data rate is a very important factor in data communications.
- Data rate is depend on:
  - Available bandwidth
  - Level of signals
  - Channel quality (level of noise)
- There are two theoretical formulas to calculate the data rate: Nyquist formula and Shannon formula.

Nyquist Bit Rate

- Nyquist bit rate formula is used to define the maximum bit rate in a noiseless channel[8].
- The formula is

$$\text{BitRate} = 2 \times \text{bandwidth} \times \log_2 L \tag{11}$$

where

BitRate	= bit rate (bps)
bandwidth	= bandwidth of the channel (Hz)
L	= number of signal levels

- Although more signal levels means higher data rate, unfortunately it also means more burden to the system.

[8]Noise = 0; Therefore $\text{SNR}_{dB} = \infty$

Shannon Capacity

- Noiseless channel does not exist in reality.
- The Shannon capacity includes noise to determine the highest data rate:

$$\text{Capacity} = \text{bandwidth} \times \log_2(1 + \text{SNR}) \tag{12}$$

where

Capacity	= capacity of the channel (bps)
bandwidth	= bandwidth of the channel (Hz)
SNR	= signal-to-noise ration

Using Both Limits

- We can use both methods to find the limits and signal levels.
- Suppose we have a channel with 1 MHz bandwidth, SNR = 63.
- By using the Shannon Capacity in Equation (12) we got

$$
\begin{aligned}
C &= B \log_2(1 + \mathrm{SNR}) \\
&= 10^6 \cdot \log_2(1 + 63) \\
&= 10^6 \cdot \log_2(64) \\
&= 10^6 \cdot 6 \\
&= 6 \times 10^6 \text{ bps}
\end{aligned}
$$

- The capacity of the channel according to Shannon formula is 6 Mbps.

Using Both Limits

- We use lower limit for better performance, say 4 Mbps.
- By using the Nyquist Bitrate in Equation (11) we got

$$
\begin{aligned}
\text{BitRate} &= 2 \times B \times \log_2 L \\
4 \times 10^6 &= 2 \times 10^6 \times \log_2 L \\
4 \times \cancel{10^6} &= 2 \times \cancel{10^6} \times \log_2 L \\
4 &= 2 \times \log_2 L \\
\cancel{4} &= \cancel{2} \times \log_2 L \\
2 &= \log_2 L \\
\sqrt{L} &= 2 \\
L &= 4
\end{aligned}
$$

- The number of signal levels is 4.

Bandwidth

- Bandwidth is a characteristic that measures network performance.
- There are two context of bandwidth:
  - Range of frequencies in a composite signal, or the range of frequencies a channel can pass. This type of bandwidth is measured in Hertz (Hz).
  - Number of bits per second that a channel, link, or network can transmit.
- Although they have different context, both types of bandwidth are related.

Throughput

- 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 ($T < B$).
- If bandwidth is the potential measurement, then throughput is the <u>actual</u> measurement.
- Throughput is affected by network congestion, bottleneck, etc.

Latency

- Latency (delay) defines how long it takes for an entire message to completely arrive at the destination.
- The measurement starts when the first bit is sent out from the source.
- Latency is the sum of four components and can be mathematically expressed as:

$$\begin{aligned} \text{Latency} &= \text{propagation time} + \text{transmission time} \\ &+ \text{queuing time} + \text{processing delay} \end{aligned} \tag{13}$$

Latency

Propagation Time

- Propagation time measures the time required for a bit to travel from source to the destination.
- Propagation time can be mathematically expressed as:

$$\text{Propagation Time} = \frac{\text{distance}}{\text{propagation speed}} \tag{14}$$

Latency

Transmission Time

- Transmission time is the duration, started from when the first bit left the sender until the last bit arrived at the receiver.
- Transmission time depends on message size and bandwidth of the channel.
- Transmission time can be mathematically expressed as:

$$\text{Transmission time} = \frac{\text{(Message Size)}}{\text{bandwidth}} \tag{15}$$

Latency

Queuing Time and Processing Delay

- Queuing is the amount of time needed by an intermediate device to hold the message before it can be processed.
- The queuing time is fluctuating according to the present condition of the network.
- Processing delay is the amount of time needed by an device to process a message.
- For example, a router – when it receives a packet – should determine whether to self-process the packet or forward it, then if the packet should be forwarded, the packet should determine where to forward it.

Bandwidth-Delay Product

- Bandwidth-delay product is the number of bits that can fill a link.
- The measurement is important if we need to send data in burst and wait for the acknowledgement of each burst before sending the next one.
- To use the maximum capability of the link, we need to make the size of our burst 2 times the bandwidth-delay product and fill up; fill up the full-duplex channel.
- Consider these following cases:

  Case 1: A link with 1 bps bandwidth and 1 s delay, see Figure 21.

  Case 2: A link with 5 bps bandwidth and 5 s delay, see Figure 22.

Bandwidth-Delay Product

Case 1

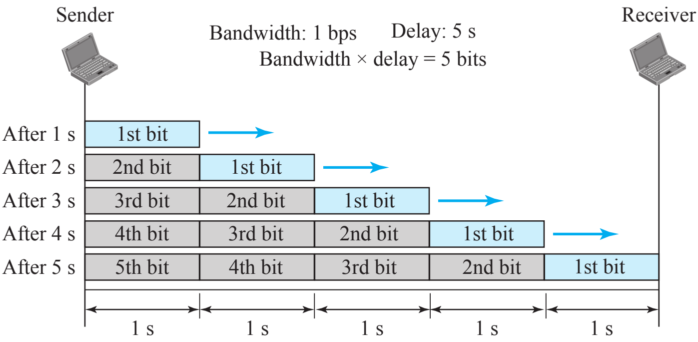

Figure 21 : Bandwidth-link product, case 1.

Bandwidth-Delay Product

Case 2

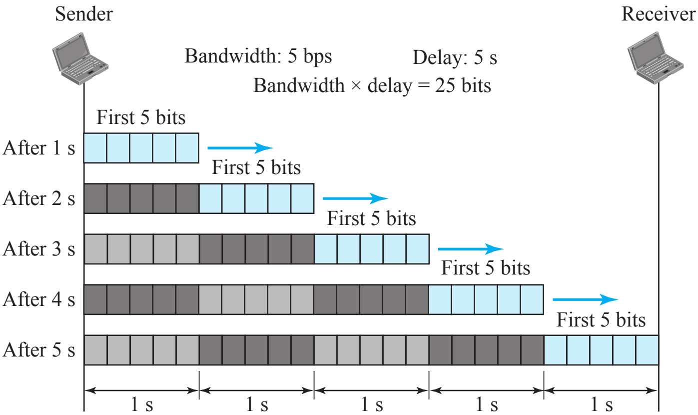

Figure 22 : Bandwidth-link product, case 2.

Jitter

- Jitter is the variance of delays encountered by the transmission.
- Jitter becomes a problem when the application is time-sensitive, (e.g. audio and video data).

Exercise

1. A signal has 300 cycles per second. What is its frequency in Hertz?
2. What is the period of a signal that has 200 cycles per second?
3. A signal is propagating in a medium with propagation speed = $2 \times 10^8\ m/s$. The period of the signal is 0.00005 s. Calculate its wavelength!
4. The wavelength of a signal is 0.125 m. Suppose it is propagating in vacuum, then what is its frequency?
5. The frequency of a signal is 900 MHz and the wavelength is 0.25 m. What is the propagation speed of the medium?

Exercise

6. Suppose a signal travels through a transmission medium and its power is reduced to one-half. Calculate the attenuation of the signal (in dB)[1]!
7. A signal propagates from A to B. The power at A is 100 W, while the power at B is 50 W. Determine the state of the signal, whether it is amplified or attenuated!
8. A signal propagates through a noiseless channel. What is the $\mathrm{SNR}_{\mathrm{dB}}$ of such channel for signal power S?

Exercise

9. Attenuation due to path loss in wireless is mathematically expressed as

$$\mathrm{PL} = 20\log(f) + 20\log(d) - 147.56\mathrm{dB} \tag{16}$$

    - Equation (8) shows the attenuation/amplification by comparing signal powers at site 2 and site 1. If the received signal power always decreased due to path loss as shown by Equation 16, modify the Equation 8 to calculate the attenuation if transmitted and received signal powers are known!
    - Both Equations (8) and (16) are used to calculate attenuation. If we ignore other wireless link budget parameters, give the mathematical correlation between both equations!

Exercise

10. A Wireless Service provider is going to cover the customers at a new area. You are acting as the consultant for this WISP and the managers are requesting your consideration about their going-to-be-deployed wireless backbone.
    <u>If the sensitivity threshold is -67 dBm, calculate the minimum transmit power by using the mathematical correlation between Equations (8) and (16) you found in the previous question!</u>
    The following information are available to you:
    - The sites are located at the coordinates shown in Figure 23.
    - These sites will form a ring topology, so a site is connected to the other two.
    - This WISP uses 802.11n technology, and the frequency in-use follows the regulation issued by the Indonesian government.

Exercise

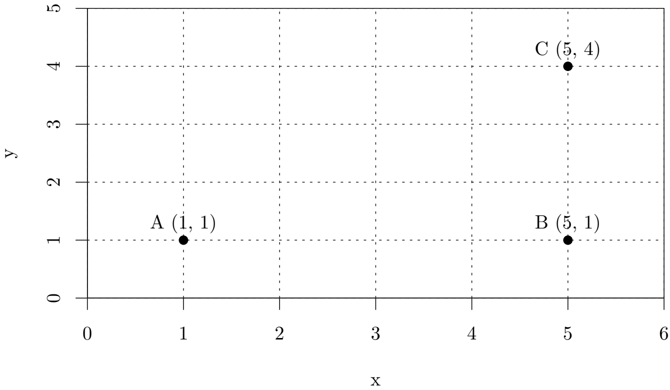

Figure 23 : Locations of the backbone sites.

Exercise

11. If the bandwidth of the channel is 5 Kbps, how long does it take to send a frame of 100,000 bits out of this device?
12. What is the length of a bit in a channel with a propagation speed of $2 \times 10^8 \mathrm{m/s}$ if the channel bandwidth is 100 Mbps?
13. How many bits can fit on a link with a 2 ms delay if the bandwidth of the link is 1 Mbps?
14. What is the total delay for a frame of size 5 million bits that is being sent on a link with 10 routers, each having a queuing time of $2\mu\mathrm{s}$ and processing time of $1\mu\mathrm{s}$ the length of the link is 2000 Km. The propagation speed is $2 \times 10^8 \mathrm{m/s}$ The link has a bandwidth of 5 Mbps. Which component of the total delay is dominant? Which one is negligible?

Next session..

- OMNeT++
- Finish TicToc Tutorial before class!
- Have OMNeT++, R (and optionally RStudio) installed in your notebooks. Each student who has notebook is highly advised to bring his/her own notebook.

References I

[1] B. Forouzan, Data Communications and Networking, 5th ed. New York: McGraw-Hill Education, 2013.

[2] W. Stallings, Data and Computer Communications, 8th ed. NJ: Pearson/Prentice Hall, 2007.