Chapter 2

Wireless Data Transmission

At a Glance

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Lecture Notes

Overview

In this chapter, students are taught the basic properties of radio frequency based wireless transmission. They will learn about the different properties of a radio wave, as well as how wireless communications are made possible by a radio wave. The last section of the chapter discusses different modulation techniques for encoding information.

Chapter Objectives

After reading this chapter and completing the exercises, the student will be able to:

- Discuss the two types of a wireless transmission
- Explain the properties of a wave, such as amplitude, wavelength, frequency, and phase
- Describe the basic concepts and techniques related to the transmission of data by radio waves

Teaching Tips

Wireless Signals

1. Describe how the American Standard Code for Information Interchange (ASCII) code uses eight bits to represent all alphabet characters, numeral characters, and several symbol characters.
2. Provide students with a basic understanding of how signals are transmitted, both physically within a wired medium, and wirelessly using electromagnetic radiation.

Infrared Light

1. Explain what infrared light is, and show students how infrared light fits into the light spectrum. Students should understand that infrared light is not susceptible to RF interference.
2. Describe how an emitter transmits infrared signals to a detector, which receives the signal. Note that either a laser diode or light emitting diode (LED) can be used by the emitter.
3. Introduce the two different types of infrared transmission: directed transmission and diffused transmission. Explain that directed transmission requires line-of-sight, whereas a diffused transmission can be reflected off walls or ceilings.
4. List some of the advantages of infrared transmission, such as invulnerability to RF interference, and ability to contain a signal to a single room.
5. Emphasize the disadvantages of RF, such as the limitations on mobility overall, and the requirement for line of sight with directed transmissions. Students should also be aware that diffused transmission is limited to 4 Mbps.

6. Discuss some of the limitations of infrared light in general. You should point out that infrared cannot penetrate through materials such as wood and concrete, and can be limited in range by dust and infrared waves.

Teaching Tip	Infrared has often been used in the past for communication between devices, such as cell phones and laptops. However, infrared networks are not widely deployed in enterprise environments due to limitations in propagation and transmission speeds.

Radio Waves

1. Explain the properties of a radio wave, and describe how radio waves are created by electrical current passing through a wire.
2. Discuss how radio waves can penetrate solid objects such as walls, and note how it compares to infrared technologies.

Teaching Tip	Students may benefit from studying documentation online on the construction of antennas. Many do-it-yourself antennas exist, such as the Can-tenna.

How Radio Data Is Transmitted

Analog and Digital

1. Describe an analog signal as a signal that relies on changes in voltage or amplitude, which affect wave intensity.
2. Compare a digital signal to an analog signal, and describe how a digital signal works as a series of pulses, instead of a continuous stream such as with analog.
3. Explain that a modem (MODulator/DEModulator) is used to transmit digital signals over analog mediums, using a process called modulation to transform digital bits into an analog wave.

Frequency and Wavelength

1. Define wavelength as the distance between a single point in one wave cycle and the corresponding point in the next wave cycle. Explain that wavelength can be measured in meters.
2. Explain radio wave frequency as the number of times a cycle occurs within a single second. Point out the relationship between frequency and wavelength.
3. Describe a carrier signal as a continuous wave (CW) of constant amplitude and frequency, and note how this appears as an oscillating signal, or sine wave.
4. Students should understand that a carrier wave is modulated to include information, but carries no information by itself.

5. Explain how wave cycles are measured in Hertz (Hz), and teach students the following metric prefixes:
   a. Kilohertz (KHz) = 1,000 Hz
   b. Megahertz (MHz) = 1,000,000 Hz
   c. Gigahertz (GHz) 1,000,000,000 Hz
6. Elaborate on how an antenna functions by use of a copper wire, or similar material, and electrical pressure (voltage). Students must know that the alternating current caused by the flow of electrons in the antenna creates an electromagnetic wave (EM wave).

Transmission Speed

1. Define bits per second (bps) as a measure of transmission speed, and then explain what a baud is. Expand on why baud rate is not synonymous with bits per second.
2. Describe how early modems utilized modulation to send information using bauds, and note that improvements in modulation techniques allowed more bits to be transmitted per baud.
3. The dibit, tribit, and quad-bit should be explained as the change to a signal that represents two, three, or four bits respectively.
4. Explain the correct usage of the bandwidth term, which is a range of frequencies that can be used to transmit.

Quick Quiz 1

1. A ____________________ is a device that encodes a digital signal onto an analog signal using modulation.
   Answer: modem

2. True or False: Infrared light does not pass through objects such as solid walls or concrete barriers.
   Answer: True

3. Select the term below that applies to the measurement of the distance between two similar points in an analog wave?
   A. Phase
   B. Amplitude
   C. Frequency
   D. Wavelength
   Answer: D

4. One Gigahertz (GHz) is equal to how many Hertz (Hz)?
   A. 1,000
   B. 1,000,000
   C. 1,000,000,000
   D. 1,000,000,000,000
   Answer: C

5. The alternating current within an antenna creates which of the following?
    A. An electromagnetic wave
    B. A modulated signal
    C. A digital signal
    D. An infrared signal

    Answer: A

Analog Modulation

1. Describe analog modulation as representation of analog information by an analog signal.
2. Explain how amplitude modulation (AM) utilizes the height of a wave in a cycle that is changed by the modulating signal. Note that the carrier wave remains constant.
3. Elaborate on how frequency modulation (FM) works by changing the frequency of waves that occur in one second based on the amplitude of the modulating signal.
4. Compare amplitude modulation and frequency modulation, and explain that Frequency Modulation is less susceptible to interference.
5. Explain phase modulation (PM) as modulation technique that shifts the starting point of a cycle. Students should understand that phase modulation is not often used for analog data transmission.

Teaching Tip	DSL modems and cable modems use techniques similar to dialup modems in order to transmit data across a network. DSL modems, for example, utilize data bins that contain a certain number of bits that are modulated onto a specific range of frequencies.

Digital Modulation

1. Define digital modulation as the process of encoding digital information onto an analog wave.
2. Compare a digital signal, which consists of a 1 or 0 that can be represented as constant positive or negative voltage, to analog signals. Note the advantages of digital modulation over analog modulation:
    a. Better use of bandwidth
    b. Less power utilized
    c. Better performance
    d. Error-correcting techniques
3. Explain how a binary signal can alternate between positive and zero voltage, or positive and negative voltage, in order to represent a 1 or a 0.
4. Describe the return-to-zero (RZ) technique for binary signaling, which utilizes a rise in voltage to represent a 1 bit, and the absence of voltage to indicate a 0 bit.
5. Non-return-to-zero (NRZ) can be explained as a signaling technique that uses consistent voltage when consecutive bits remain unchanged.
6. Describe polar non-return-to-zero (polar NRZ) as using an increase in voltage to signal a 1 bit, and negative voltage to indicate a 0 bit.

7. Explain how the non-return-to-zero, invert-on-ones (NRZ-I) signal works by using an increase in voltage to indicate a one bit, and no change in voltage if the next bit is a zero.
8. Teach students the two reasons why different binary signaling methods exist. You should explain that electronic circuits tend to average signals that experience transitions, causing the signal to be harder to receive. You should also note that signals with long consecutive 1s or 0s tend to lose sync without a transition.
9. Discuss how amplitude shift keying (ASK) utilizes the presence of a carrier wave to indicate a 1 bit, and the lack of a carrier wave to indicate a zero bit.
10. Show students how frequency shift keying (FSK) works by changing the frequency of a carrier signal to indicate a one or a zero bit.
11. Phase shift keying (PSK) can be described as a modulation technique that uses variations in the starting point of a wave to indicate a one or a zero bit.
12. Explain how phase modulation angles are used by PSK to create different signals, and detail how this can be combined with quadrature amplitude modulation (QAM).
13. Students should be introduced to a constellation diagram which can be used to represent the complex signals that result from complicated modulation techniques.
14. Describe how binary phase shift keying (BPSK) utilizes a combination of amplitude modulation with PSK.

Spread Spectrum

1. Define a narrow-band transmission as a transmission that takes place on a single radio frequency, or a narrow range of frequencies.
2. Spread spectrum transmission can be explained as a signal that is spread over a frequency range, making it more resistant to interference.

Frequency Hopping Spread Spectrum (FHSS)

1. Frequency Hopping Spread Spectrum (FHSS) should be described as a way to transmit bursts of data on different frequencies to ensure the effects of interference are lessened.
2. Describe a hopping code as the sequence of changing frequencies that will be used by a transmitting device, and note that the receiving device must also know this code.
3. Explain to students how FHSS can detect and handle errors at lower protocol layers, and describe how forward error correction (FEC) can be used to send redundant data to minimize lost data.
4. Elaborate on how FHSS signals reduce interference with other radio signals, and explain how unintended receivers of an FHSS transmission might see a very short burst of interference.

Direct Sequence Spread Spectrum (DSSS)

1. Direct sequence spread spectrum (DSSS) should be explained as a spread spectrum technology that uses redundant code and a modulation technique such as quadrature phase shift keying (QPSK), resulting in data being modulated twice.

2. Explain how a barker code (or chipping code) is used to modulate radio waves, and note that it is sometimes called a pseudo-random code.
3. Demonstrate how a chipping code functions to modulate data for use with an 802.11 network.
4. Describe how an unintended receiver of a DSSS signal will see low-powered noise interference.
5. List some of the other advantages of using DSSS with a chipping code, such as significantly reduced susceptibility to narrowband interference and the ability to recover data when interference is detected.
6. Point out that DSSS capable wireless equipment is typically more expensive than FHSS equipment.

Quick Quiz 2

1. A____________________transmission occurs on a single radio frequency, or small range of frequencies, and is susceptible to interference.
   Answer: narrow-band

2. True or False: Direct Sequence Spread Spectrum (DSSS) equipment is more expensive than Frequency Hopping Spread Spectrum (FHSS) equipment.
   Answer: True

3. The__________ is the sequence in which frequencies are changed when using FHSS.
   Answer: hopping code

4. Which of the following is not true of digital modulation in comparison with analog modulation?
   A. Better use of bandwidth
   B. Higher power usage
   C. Better performance when interference is present
   D. More compatible error correction with other digital systems
   Answer: B

5. Which of the following tools can best be used to represent a signal that results from complex modulation?
   A. Oscilloscope
   B. Wireless NIC
   C. Modulation diagram
   D. Constellation diagram
   Answer: D

Class Discussion Topics

1. Start a class discussion about why broadcast radio stations use narrow band transmissions. How would a radio work if broadcast stations used Frequency Hopping Spread Spectrum or Direct Sequence Spread Spectrum?

2. Have students research and discuss what types of information can be represented as an analog wave, such as music or sound in general, or alternating electrical current.

Additional Projects

1. Use visual examples of modulated signals, and have students attempt to identify the type of modulation being used, such as frequency modulation in comparison with amplitude modulation or phase modulation.

2. Create scenarios in which students must choose which technology would be better suited for a given set of requirements, either infrared wireless transmission or radio frequency transmission.

Additional Resources

1. Wikipedia article on electromagnetic radiation and its properties: http://en.wikipedia.org/wiki/Electromagnetic_radiation

2. Information on the history of modem usage: http://www.techradar.com/news/internet/getting-connected-a-history-of-modems-657479

Key Terms

- **American Standard Code for Information Interchange (ASCII)** An arbitrary coding scheme that uses the numbers from 0 to 127 to represent alphanumeric characters and symbols.
- **amplitude** The height of a carrier wave.
- **amplitude modulation (AM)** A technique that changes the height of a carrier wave in response to a change in the height of the input signal.
- **amplitude shift keying (ASK)** A digital modulation technique whereby a 1 bit isrepresented by the existence of a carrier signal, whereas a 0 bit is represented by the absenceof a carrier signal.
- **analog modulation** A method of encoding an analog signal onto a carrier wave.
- **analog signal** A signal in which the intensity (amplitude or voltage) varies continuouslyand smoothly over a period of time.
- **antenna** A copper wire, rod, or similar device that has one end up in the air and the otherend connected to the ground through a receiver.
- **bandwidth** The range of frequencies that can be transmitted.
- **Barker code (chipping code)** A bit pattern used in a DSSS transmission. The term chippingcode is used because a single radio bit is commonly referred to as a chip.

- **baud** A change in a carrier signal.
- **baud rate** The number of times that a carrier signal changes per second.
- **binary phase shift keying (BPSK)** A simple digital modulation technique that uses fourphase changes to represent 2 bits per signal change.
- **bits per second (bps)** The number of bits that can be transmitted per second.
- **carrier signal** A signal of a particular frequency that is modulated to contain either analogor digital data.
- **constellation diagram** A graphical representation that makes it easier to visualize signalsusing complex modulation techniques such as QAM. It is generally used in laboratory andfield diagnostic instruments and analyzers to aid in design and troubleshooting of wirelesscommunications devices.
- **continuous wave (CW)** An analog or sine wave that is modulated to eventually carryinformation, becoming a carrier wave.
- **cycle** An oscillating sine wave that completes one full series of movements.
- **detector** A diode that receives a light-based transmission signal.
- **dibit** A signal unit that represents 2 bits.
- **diffused transmission** A light-based transmission that relies on reflected light.
- **digital modulation** A method of encoding a digital signal onto an analog carrier wave fortransmission over media that does not support direct digital signal transmission.
- **digital signal** Data that is discrete or separate.
- **direct sequence spread spectrum (DSSS)** A spread spectrum technique that uses anexpanded, redundant code to transmit each data bit.
- **directed transmission** A light-based transmission that requires the emitter and detector tobe directly aimed at one another.
- **electromagnetic wave (EM wave)** A signal composed of electrical and magnetic forces thatin radio transmission usually propagates from an antenna and can be modulated to carryinformation.
- **emitter** A laser diode or a light-emitting diode that transmits a light-based signal.
- **frequency** A measurement of radio waves that is determined by how frequently a cycleoccurs.
- **frequency hopping spread spectrum (FHSS)** A spread spectrum technique that uses arange of frequencies and changes frequencies during the transmission.
- **frequency modulation (FM)** A technique that changes the number of wave cycles inresponse to a change in the amplitude of the input signal.
- **frequency shift keying (FSK)** A digital modulation technique that changes the frequency ofthe carrier signal in response to a change in the binary input signal.
- **Gigahertz (GHz)** 1,000,000,000 Hertz.
- **Hertz (Hz)** The number of cycles per second.
- **hopping code** The sequence of changing frequencies used in FHSS.
- **infrared light** Light that is next to visible light on the light spectrum and that has manyof the same characteristics as visible light.
- **Kilohertz (KHz)** 1,000 Hertz.
- **light spectrum** All the different types of light that travel from the Sun to the Earth.
- **line of sight** The direct alignment as required in a directed transmission.
- **Megahertz (MHz)** 1,000,000 Hertz.

- **modem (MOdulator/DEModulator)** A device used to convert digital signals into an analogformat, and vice versa.
- **modulation** The process of changing a carrier signal.
- **narrow-band transmissions** Transmissions that use one radio frequency or a very narrowportion of the frequency spectrum.
- **non-return-to-zero (NRZ)** A binary signaling technique that increases the voltage torepresent a 1 bit but provides no voltage for a 0 bit.
- **non-return-to-zero, invert-on-ones (NRZ-I)** A binary signaling technique that changes thevoltage level only when the bit to be represented is a 1.
- **non-return-to-zero level (NRZ-L)***See* polar non-return-to-zero.
- **oscillating signal** A wave that illustrates the change in a carrier signal.
- **phase** The relative starting point of a wave, in degrees, beginning at zero degrees.
- **phase modulation (PM)** A technique that changes the starting point of a wave cycle inresponse to a change in the amplitude of the input signal. This technique is not used inanalog modulation.
- **phase shift keying (PSK)** A digital modulation technique that changes the starting point ofa wave cycle in response to a change in the binary input signal.
- **polar non-return-to-zero (polar NRZ)** A binary signaling technique that increases thevoltage to represent a 1 bit but drops to negative voltage to represent a 0 bit.
- **pseudo-random code** A code that is usually derived through a number of mathematicalcalculations as well as practical experimentation.
- **quadbit** A signal unit that represents 4 bits.
- **quadrature amplitude modulation (QAM)** A combination of phase modulation withamplitude modulation to produce 16 different signals.
- **quadrature phase shift keying (QPSK)** A digital modulation technique that combinesquadrature amplitude modulation with phase shift keying.
- **radio wave (radiotelephony)** An electromagnetic wave created when an electric currentpasses through a wire and creates a magnetic field in the space around the wire.
- **return-to-zero (RZ)** A binary signaling technique that increases the voltage to represent a1 bit, but the voltage is reduced to 0 before the end of the period for transmitting the 1 bit,and there is no voltage for a 0 bit.
- **sine wave** A wave that illustrates the change in a carrier signal.
- **spread spectrum transmission** A technique that takes a narrow signal and spreads it overa broader portion of the radio frequency band.
- **tribit** A signal unit that represents 3 bits.
- **voltage** Electrical pressure.
- **wavelength** The length of a wave as measured between two positive or negative peaks orbetween the starting point of one wave and the starting point of the next wave.