Chapter

1

Overview of Wireless Standards, Organizations, and Fundamentals

IN THIS CHAPTER, YOU WILL LEARN ABOUT THE FOLLOWING:

- ✓ **History of WLAN**
- ✓ **Standards organizations**
  - Federal Communications Commission
  - International Telecommunication Union Radiocommunication Sector
  - Institute of Electrical and Electronics Engineers
  - Internet Engineering Task Force
  - Wi-Fi Alliance
  - International Organization for Standardization
- ✓ **Core, distribution, and access**
- ✓ **Communications fundamentals**

Wireless local area network (WLAN) technology has a long history that dates back to the 1970s with roots as far back as the 19th century. This chapter will start with a brief history of WLAN technology. Learning a new technology can seem like a daunting task. There are so many new acronyms, abbreviations, terms, and ideas to become familiar with. One of the keys to learning any subject is to learn the basics. Whether you are learning to drive a car, fly an airplane, or install a wireless computer network, there are basic rules, principles, and concepts that, once learned, provide the building blocks for the rest of your education.

The Institute of Electrical and Electronics Engineers (IEEE) 802.11 technology, more commonly referred to as Wi-Fi, is a standard technology for providing local area network (LAN) communications using radio frequencies (RFs). The IEEE designated the 802.11-2012 standard as a guideline to provide operational parameters for WLANs. There are numerous standards organizations and regulatory bodies that help govern and direct wireless technologies and the related industry. Having some knowledge of these various organizations can provide you with insight as to how IEEE 802.11 functions, and sometimes even how and why the standards have evolved the way they have.

As you become more knowledgeable about wireless networking, you may want or need to read some of the standards documents that are created by the different organizations. Along with the information about the standards bodies, this chapter includes a brief overview of their documents.

In addition to reviewing the various standards organizations that guide and regulate Wi-Fi, this chapter discusses where WLAN technology fits in with basic networking design fundamentals. Finally, this chapter reviews some fundamentals of communications and data keying that are not part of the CWNA exam but that may help you better understand wireless communications.

History of WLAN

In the 19th century, numerous inventors and scientists, including Michael Faraday, James Clerk Maxwell, Heinrich Rudolf Hertz, Nikola Tesla, David Edward Hughes, Thomas Edison, and Guglielmo Marconi, began to experiment with wireless communications. These innovators discovered and created many theories about the concepts of electrical magnetic *radio frequency (RF)*.

Wireless networking technology was first used by the US military during World War II to transmit data over an RF medium using classified encryption technology to send battle plans across enemy lines. The *spread spectrum* radio technologies often used in today's

WLANs were also originally patented during the era of World War II, although they were not implemented until almost two decades later.

In 1970, the University of Hawaii developed the first wireless network, called ALOHAnet, to wirelessly communicate data between the Hawaiian Islands. The network used a LAN communication Open Systems Interconnection (OSI) layer 2 protocol called ALOHA on a wireless shared medium in the 400 MHz frequency range. The technology used in ALOHAnet is often credited as a building block for the Medium Access Control (MAC) technologies of Carrier Sense Multiple Access with Collision Detection (CSMA/CD) used in Ethernet and Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) used in 802.11 radios. You will learn more about CSMA/CA in Chapter 8, "802.11 Medium Access."

In the 1990s, commercial networking vendors began to produce low-speed wireless data networking products, most of which operated in the 900 MHz frequency band. The Institute of Electrical and Electronics Engineers (IEEE) began to discuss standardizing WLAN technologies in 1991. In 1997, the IEEE ratified the original 802.11 standard that is the foundation of the WLAN technologies that you will be learning about in this book.

This legacy 802.11 technology was deployed between 1997 and 1999 mostly in warehousing and manufacturing environments for the use of low-speed data collection with wireless barcode scanners. In 1999, the IEEE defined higher data speeds with the 802.11b amendment. The introduction of data rates as high as 11 Mbps, along with price decreases, ignited the sales of wireless home networking routers in the small office, home office (SOHO) marketplace. Home users soon became accustomed to wireless networking in their homes and began to demand that their employers also provide wireless networking capabilities in the workplace. After initial resistance to 802.11 technology, small companies, medium-sized businesses, and corporations began to realize the value of deploying 802.11 wireless networking in their enterprises.

If you ask the average user about their 802.11 wireless network, they may give you a strange look. The name that people often recognize for the technology is *Wi-Fi*. Wi-Fi is a marketing term, recognized worldwide by millions of people as referring to 802.11 wireless networking.

What Does the Term *Wi-Fi* Mean?

Many people mistakenly assume that *Wi-Fi* is an acronym for the phrase *wireless fidelity* (much like *hi-fi* is short for *high fidelity*), but Wi-Fi is simply a brand name used to market 802.11 WLAN technology. Ambiguity in IEEE framework standards for wireless communications allowed manufacturers to interpret the 802.11 standard in different ways. As a result, multiple vendors could have IEEE 802.11–compliant devices that did not interoperate with each other. The organization Wireless Ethernet Compatibility Alliance (WECA) was created to further define the IEEE standard in such a way as to force interoperability between vendors. WECA, now known as the Wi-Fi Alliance, chose the term *Wi-Fi* as a marketing brand. The Wi-Fi Alliance champions enforcing interoperability among wireless devices. To be Wi-Fi compliant, vendors must send their products to a Wi-Fi Alliance test lab that thoroughly tests compliance to the Wi-Fi certification. More information about the origins of the term Wi-Fi can be found online at Wi-Fi Net News:

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http://wifinetnews.com/archives/2005/11/wi-fi_stands_fornothing_and_
everything.html
```

Wi-Fi radios are used for numerous enterprise applications and can also be found in laptops, smartphones, cameras, televisions, printers, and many other consumer devices. According to the Wi-Fi Alliance, the billionth Wi-Fi chipset was sold in 2009. Less than 4 years later in 2012, annual shipments of Wi-Fi devices are more than 1.75 billion and continuing to grow, with estimates of annual shipments doubling to over 3.5 billion Wi-Fi chipsets by 2017. In a survey that the Wi-Fi Alliance conducted, 68 percent of Wi-Fi users would rather give up chocolate than do without Wi-Fi. Since the original standard was created in 1997, 802.11 technology has grown to enormous proportions; Wi-Fi has become part of our worldwide communications culture. A recent report from Telecom Advisory Services estimates that technologies that rely on unlicensed spectrum adds $222 billion dollars per year to the U.S. economy. Over $91 billion dollars can be attributed to Wi-Fi.

Standards Organizations

Each of the standards organizations discussed in this chapter help to guide a different aspect of the wireless networking industry.

The International Telecommunication Union Radiocommunication Sector (ITU-R) and local entities such as the Federal Communications Commission (FCC) set the rules for what the user can do with a radio transmitter. These organizations manage and regulate frequencies, power levels, and transmission methods. They also work together to help guide the growth and expansion that is being demanded by wireless users.

The Institute of Electrical and Electronics Engineers (IEEE) creates standards for compatibility and coexistence between networking equipment. The IEEE standards must adhere to the rules of the communications organizations, such as the FCC.

The Internet Engineering Task Force (IETF) is responsible for creating Internet standards. Many of these standards are integrated into the wireless networking and security protocols and standards.

The Wi-Fi Alliance performs certification testing to make sure wireless networking equipment conforms to the 802.11 WLAN communication guidelines, which are similar to the IEEE 802.11-2012 standard.

The International Organization for Standardization (ISO) created the Open Systems Interconnection (OSI) model, which is an architectural model for data communications.

You will look at each of these organizations in the following sections.

Federal Communications Commission

To put it simply, the *Federal Communications Commission (FCC)* regulates communications within the United States as well as communications to and from the United States. Established by the Communications Act of 1934, the FCC is responsible for regulating interstate and international communications by radio, television, wire, satellite, and cable. The task of the FCC in wireless networking is to regulate the radio signals that are used for wireless networking. The FCC has jurisdiction over the 50 states, the District of Columbia, and US possessions. Most countries have governing bodies that function similarly to the FCC.

The FCC and the respective controlling agencies in other countries typically regulate two categories of wireless communications: licensed spectrum and unlicensed spectrum. The difference is that unlicensed users do not have to go through the license application procedures before they can install a wireless system. Both licensed and unlicensed communications are typically regulated in the following five areas:

- Frequency
- Bandwidth
- Maximum power of the intentional radiator (IR)
- Maximum equivalent isotropically radiated power (EIRP)
- Use (indoor and/or outdoor)
- Spectrum sharing rules

Real World Scenario

What Are the Advantages and Disadvantages of Using an Unlicensed Frequency?

As stated earlier, licensed frequencies require an approved license application, and the financial costs are typically very high. One main advantage of an unlicensed frequency is that permission to transmit on the frequency is free. Although there are no financial costs, you still must abide by transmission regulations and other restrictions. In other words, transmitting in an unlicensed frequency may be free, but there still are rules.

The main disadvantage to transmitting in an unlicensed frequency band is that anyone else can also transmit in that same frequency space. Unlicensed frequency bands are often very crowded; therefore, transmissions from other individuals can cause interference with your transmissions. If someone else is interfering with your transmissions, you have no legal recourse as long as the other individual is abiding by the rules and regulations of the unlicensed frequency.

Essentially, the FCC and other regulatory bodies set the rules for what the user can do regarding RF transmissions. From there, the standards organizations create the standards to work within these guidelines. These organizations work together to help meet the demands of the fast-growing wireless industry.

The FCC rules are published in the Code of Federal Regulations (CFR). The CFR is divided into 50 titles that are updated yearly. The title that is relevant to wireless networking is Title 47, *Telecommunications*. Title 47 is divided into many parts; Part 15, “Radio Frequency Devices,” is where you will find the rules and regulations regarding wireless networking related to 802.11. Part 15 is further broken down into subparts and sections. A complete reference will look like this example: 47CFR15.3.

International Telecommunication Union Radiocommunication Sector

A global hierarchy exists for management of the RF spectrum worldwide. The United Nations has tasked the *International Telecommunication Union Radiocommunication Sector (ITU-R)* with global spectrum management. The ITU-R strives to ensure interference-free communications on land, sea, and in the skies. The ITU-R maintains a database of worldwide frequency assignments through five administrative regions.

The five administrative regions are broken down as follows:

Region A: The Americas Inter-American Telecommunication Commission (CITEL)

`www.citel.oas.org`

Region B: Western Europe European Conference of Postal and Telecommunications Administrations (CEPT)

`www.cept.org`

Region C: Eastern Europe and Northern Asia Regional Commonwealth in the field of Communications (RCC)

`www.en.rcc.org.ru`

Region D: Africa African Telecommunications Union (ATU)

`www.atu-uat.org`

Region E: Asia and Australasia Asia-Pacific Telecommunity (APT)

`www.aptsec.org`

In addition to the five administrative regions, the ITU-R defines three radio regulatory regions. These three regions are defined geographically, as shown in the following list. You should check an official ITU-R map to identify the exact boundaries of each region.

- Region 1: Europe, Middle East, and Africa
- Region 2: Americas
- Region 3: Asia and Oceania

The ITU-R radio regulation documents are part of an international treaty governing the use of spectrum. Within each of these regions, the ITU-R allocates and allots frequency bands and radio channels that are allowed to be used, along with the conditions regarding their use. Within each region, local government RF regulatory bodies, such as the following, manage the RF spectrum for their respective countries:

Australia Australian Communications and Media Authority (ACMA)

Japan Association of Radio Industries and Businesses (ARIB)

New Zealand Ministry of Economic Development

United States Federal Communications Commission (FCC)

It is important to understand that communications are regulated differently in many regions and countries. For example, European RF regulations are very different from the regulations used in North America. When deploying a WLAN, please take the time to learn about rules and policies of the local *regulatory domain authority*. However, since the rules vary around the globe, it is beyond the capabilities of this book to reference the different regulations. Additionally, the CWNA exam will not reference the RF regulations of the FCC or those specific to any other country.

NOTE More information about the ITU-R can be found at `www.itu.int/ITU-R`.

Institute of Electrical and Electronics Engineers

The *Institute of Electrical and Electronics Engineers*, commonly known as the *IEEE*, is a global professional society with about 400,000 members in 160 countries. The IEEE's mission is to "foster technological innovation and excellence for the benefit of humanity." To networking professionals, that means creating the standards that we use to communicate.

The IEEE is probably best known for its LAN standards, the IEEE 802 project.

NOTE The 802 project is one of many IEEE projects; however, it is the only IEEE project addressed in this book.

IEEE projects are subdivided into working groups to develop standards that address specific problems or needs. For instance, the IEEE 802.3 working group was responsible for the creation of a standard for Ethernet, and the IEEE 802.11 working group was responsible for creating the WLAN standard. The numbers are assigned as the groups are formed, so the 11 assigned to the wireless group indicates that it was the 11th working group formed under the IEEE 802 project.

As the need arises to revise existing standards created by the working groups, task groups are formed. These task groups are assigned a sequential single letter (multiple letters are assigned if all single letters have been used) that is added to the end of the standard number (for example, 802.11a, 802.11g, and 802.3at). Some letters are not assigned. For example *o* and *l* are not assigned to prevent confusion with the numbers 0 and 1. Other letters may not be assigned to task groups to prevent confusion with other standards. For example, 802.11x has not been assigned because it can be easily confused with the 802.1X standard and because 802.11*x* has become a common casual reference to the 802.11 family of standards.

You can find more information about the IEEE at `www.ieee.org`.

It is important to remember that the IEEE standards, like many other standards, are written documents describing how technical processes and equipment should function. Unfortunately, this often allows for different interpretations when the standard is being implemented, so it is common for early products to be incompatible between vendors, as was the case with some of the early 802.11 products.

The history of the 802.11 standard and amendments is covered extensively in Chapter 5, "IEEE 802.11 Standards." The CWNA exam (CWNA-106) is based on the most recently published version of the standard, 802.11-2012. The 802.11-2012 standard can be downloaded from `http://standards.ieee.org/about/get/802/802.11.html`

Internet Engineering Task Force

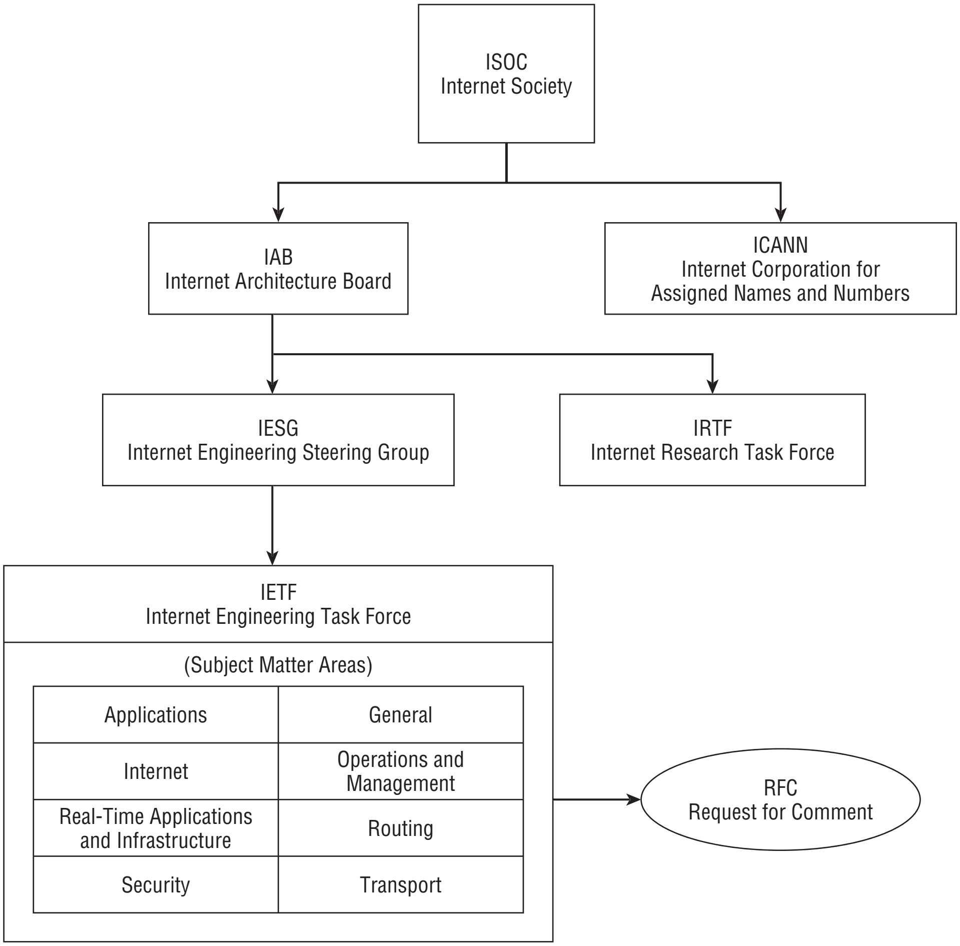
The *Internet Engineering Task Force*, commonly known as the *IETF*, is an international community of people in the networking industry whose goal is to make the Internet work better. The mission of the IETF, as defined by the organization in a document known as RFC 3935, is "to produce high quality, relevant technical and engineering documents that influence the way people design, use, and manage the Internet in such a way as to make the Internet work better. These documents include protocol standards, best current practices, and informational documents of various kinds." The IETF has no membership fees, and anyone may register for and attend an IETF meeting.

The IETF is one of five main groups that are part of the Internet Society (ISOC). The ISOC groups include the following:

- Internet Engineering Task Force (IETF)
- Internet Architecture Board (IAB)
- Internet Corporation for Assigned Names and Numbers (ICANN)
- Internet Engineering Steering Group (IESG)
- Internet Research Task Force (IRTF)

The IETF is broken into eight subject matter areas: Applications, General, Internet, Operations and Management, Real-Time Applications and Infrastructure, Routing, Security, and Transport. Figure 1.1 shows the hierarchy of the ISOC and a breakdown of the IETF subject matter areas.

FIGURE 1.1 ISOC hierarchy


ISOC
Internet Society
IAB
Internet Architecture Board
ICANN
Internet Corporation for Assigned Names and Numbers
IESG
Internet Engineering Steering Group
IRTF
Internet Research Task Force
IETF
Internet Engineering Task Force
(Subject Matter Areas)
Applications
General
Internet
Operations and Management
Real-Time Applications and Infrastructure
Routing
Security
Transport
RFC
Request for Comment

The IESG provides technical management of the activities of the IETF and the Internet standards process. The IETF is made up of a large number of groups, each addressing specific topics. An IETF working group is created by the IESG and is given a specific charter or specific topic to address. There is no formal voting process for the working groups. Decisions in working groups are made by rough consensus, or basically a general sense of agreement among the working group.

The results of a working group are usually the creation of a document known as a *Request for Comments (RFC)*. Contrary to its name, an RFC is not actually a request for comments, but a statement or definition. Most RFCs describe network protocols, services, or policies and may evolve into an Internet standard. RFCs are numbered sequentially, and once a number is assigned, it is never reused. RFCs may be updated or supplemented by higher-numbered RFCs. As an example, Mobile IPv4 was described in RFC 3344 in 2002. This document was updated in RFC 4721. In 2012, RFC 5944 made RFC 3344 obsolete. At the top of the RFC document, it states whether the RFC is updated by another RFC and also if it makes any other RFCs obsolete.

Not all RFCs are standards. Each RFC is given a status, relative to its relationship with the Internet standardization process: Informational, Experimental, Standards Track, or Historic. If it is a Standards Track RFC, it could be a Proposed Standard, Draft Standard, or Internet Standard. When an RFC becomes a standard, it still keeps its RFC number, but it is also given an "STD *xxxx*" label. The relationship between the STD numbers and the RFC numbers is not one-to-one. STD numbers identify protocols, whereas RFC numbers identify documents.

Many of the protocol standards, best current practices, and informational documents produced by the IETF affect WLAN security. In Chapter 13, "802.11 Network Security Architecture," you will learn about some of the varieties of the Extensible Authentication Protocol (EAP) that is defined by the IETF RFC 3748.

Wi-Fi Alliance

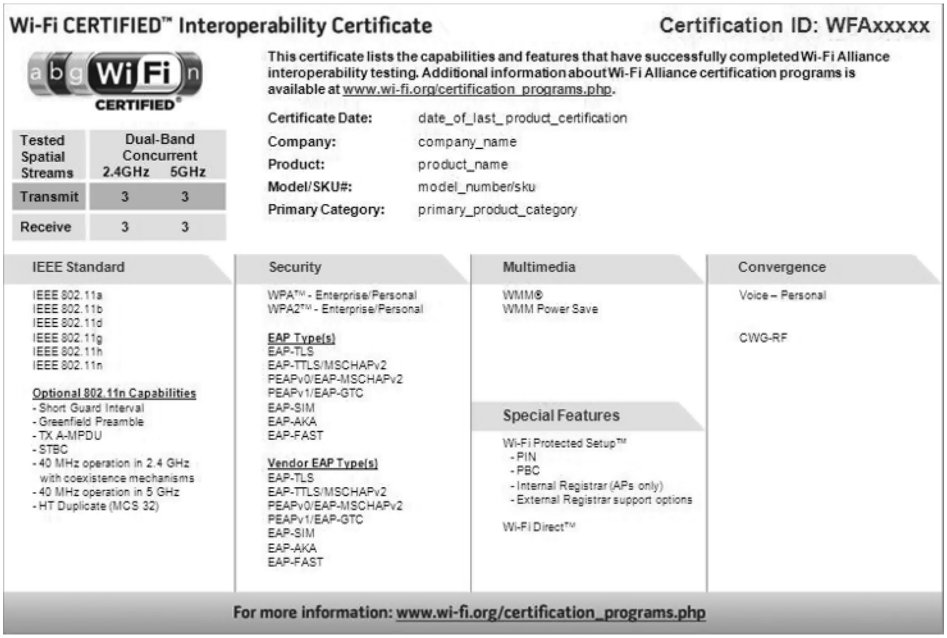
The *Wi-Fi Alliance* is a global, nonprofit industry association of more than 550 member companies devoted to promoting the growth of WLANs. One of the primary tasks of the Wi-Fi Alliance is to market the Wi-Fi brand and raise consumer awareness of new 802.11 technologies as they become available. Because of the Wi-Fi Alliance's overwhelming marketing success, the majority of the worldwide Wi-Fi users are likely to recognize the Wi-Fi logo seen in Figure 1.2.

FIGURE 1.2 Wi-Fi logo

The Wi-Fi Alliance's main task is to ensure the interoperability of WLAN products by providing certification testing. During the early days of the 802.11 standard, the Wi-Fi

Alliance further defined some of the ambiguous standards requirements and provided a set of guidelines to ensure compatibility between different vendors. This is still done to help simplify the complexity of the standards and to ensure compatibility. As seen in Figure 1.3, products that pass the Wi-Fi certification process receive a Wi-Fi Interoperability Certificate that provides detailed information about the individual product's Wi-Fi certifications.

FIGURE 1.3 Wi-Fi Interoperability Certificate



Wi-Fi CERTIFIED™ Interoperability Certificate **Certification ID: WFAxxxxx**

a b g Wi Fi n
CERTIFIED®

This certificate lists the capabilities and features that have successfully completed Wi-Fi Alliance interoperability testing. Additional information about Wi-Fi Alliance certification programs is available at www.wi-fi.org/certification_programs.php.

Tested Spatial Streams	Dual-Band Concurrent 2.4GHz	5GHz
Transmit	3	3
Receive	3	3

Certificate Date:	date_of_last_product_certification
Company:	company_name
Product:	product_name
Model/SKU#:	model_number/sku
Primary Category:	primary_product_category

IEEE Standard

IEEE 802.11a
IEEE 802.11b
IEEE 802.11d
IEEE 802.11g
IEEE 802.11h
IEEE 802.11n

Optional 802.11n Capabilities
- Short Guard Interval
- Greenfield Preamble
- TX A-MPDU
- STBC
- 40 MHz operation in 2.4 GHz with coexistence mechanisms
- 40 MHz operation in 5 GHz
- HT Duplicate (MCS 32)

Security

WPA™ - Enterprise/Personal
WPA2™ - Enterprise/Personal

EAP Type(s)
EAP-TLS
EAP-TTLS/MSCHAPv2
PEAPv0/EAP-MSCHAPv2
PEAPv1/EAP-GTC
EAP-SIM
EAP-AKA
EAP-FAST

Vendor EAP Type(s)
EAP-TLS
EAP-TTLS/MSCHAPv2
PEAPv0/EAP-MSCHAPv2
PEAPv1/EAP-GTC
EAP-SIM
EAP-AKA
EAP-FAST

Multimedia

WMM®
WMM Power Save

Special Features

Wi-Fi Protected Setup™
- PIN
- PBC
- Internal Registrar (APs only)
- External Registrar support options

Wi-Fi Direct™

Convergence

Voice – Personal

CWG-RF

For more information: www.wi-fi.org/certification_programs.php

The Wi-Fi Alliance, originally named the Wireless Ethernet Compatibility Alliance (WECA), was founded in August 1999. The name was changed to the Wi-Fi Alliance in October 2002.

The Wi-Fi Alliance has certified more than 15,000 Wi-Fi products for interoperability since testing began in April 2000. Multiple Wi-Fi CERTIFIED programs exist that cover basic connectivity, security, quality of service (QoS), and more. Testing of vendor Wi-Fi products is performed in independent authorized test laboratories in eight countries. A listing of these testing laboratories can be found on the Wi-Fi Alliance's website. The guidelines for interoperability for each Wi-Fi CERTIFIED program are usually based on key components and functions that are defined in the IEEE 802.11-2012 standard and various 802.11 amendments. In fact, many of the same engineers who belong to 802.11 task groups are also contributing members of the Wi-Fi Alliance. However, it is important to understand that the IEEE and the Wi-Fi Alliance are two separate organizations. The IEEE 802.11 task group defines the WLAN standards, and the Wi-Fi Alliance defines interoperability certification programs. The Wi-Fi CERTIFIED programs include the following:

Core Technology and Security The core technology and security program certifies 802.11a, b, g, n, and/or ac interoperability to ensure that the essential wireless data transmission works as expected. Each device is tested according to its capabilities. Table 1.1 lists the five different core Wi-Fi transmission technologies along with the frequencies and maximum data rate that each is capable of.

TABLE 1.1 Five generations of Wi-Fi

Wi-Fi technology	Frequency band	Maximum data rate
802.11a	5 GHz	54 Mbps
802.11b	2.4 GHz	11 Mbps
802.11g	2.4 GHz	54 Mbps
802.11n	2.4 GHz, 5 GHz, 2.4 or 5 GHz (selectable), or 2.4 and 5 GHz (concurrent)	450 Mbps
802.11ac	5 GHz	1.3 Gbps

Each certified product is required to support one frequency band as a minimum, but it can support both.

NOTE

Although 802.11n specifies data rates of up to 600 Mbps, and 802.11ac specifies data rates of up to 6.93 Gbps, as of this writing, equipment to support these maximum data rates had not been developed yet. Therefore, the Wi-Fi certification tests do not test up to the maximum 802.11n or 802.11ac specified data rates.

In addition to having the required transmission capabilities, each device must support *robust security network (RSN)* capabilities, security mechanisms that were originally defined in the IEEE 802.11i amendment. Devices must support Wi-Fi Protected Access (WPA) and Wi-Fi Protected Access 2 (WPA2) security mechanisms for personal (WPA2-Personal) or enterprise (WPA2-Enterprise) environments. Additionally, enterprise devices must support *Extensible Authentication Protocol (EAP)*, which is used to validate the identity of the wireless device or user. In 2012, support for Protected Management Frames extended WPA2 protection to unicast and multicast management action frames. You will find a more detailed discussion of WPA and WPA2 security in Chapter 13, “802.11 Network Security Architecture.”

Wi-Fi Multimedia Wi-Fi Multimedia (WMM) is based on the QoS mechanisms that were originally defined in the IEEE 802.11e amendment. WMM enables Wi-Fi networks to prioritize traffic generated by different applications. In a network where WMM is supported by both the access point and the client device, traffic generated by time-sensitive applications such as voice or video can be prioritized for transmission on the half-duplex RF medium. WMM certification is mandatory for all core certified devices that support 802.11n. WMM certification is optional for core certified devices that support 802.11 a, b, or g. WMM mechanisms are discussed in greater detail in Chapter 9, “MAC Architecture.”

WMM Power Save WMM Power Save (WMM-PS) helps conserve battery power for devices using Wi-Fi radios by managing the time the client device spends in sleep mode. Conserving battery life is critical for handheld devices such as barcode scanners and voice over Wi-Fi (VoWiFi) phones. To take advantage of power-saving capabilities, both the device and the access point must support WMM Power Save. WMM-PS and legacy power-saving mechanisms are discussed in greater detail in Chapter 9.

Wi-Fi Protected Setup Wi-Fi Protected Setup defines simplified and automatic WPA and WPA2 security configurations for home and small-business users. Users can easily configure a network with security protection by using either near field communication (NFC), a personal identification number (PIN) or a button located on the access point and the client device.

Wi-Fi Direct Wi-Fi Direct enables Wi-Fi devices to connect directly without the use of an access point, making it easier to print, share, synch, and display. Wi-Fi Direct is ideal for mobile phones, cameras, printers, PCs, and gaming devices needing to establish a one-to-one connection, or even connecting a small group of devices. Wi-Fi Direct is simple to configure (in some cases as easy as pressing a button), provides the same performance and range as other Wi-Fi certified devices, and is secured using WPA2 security.

Converged Wireless Group-RF Profile Converged Wireless Group-RF Profile (CWG-RF) was developed jointly by the Wi-Fi Alliance and the Cellular Telecommunications and Internet Association (CTIA), now known as The Wireless Association. CWG-RF defines performance metrics for Wi-Fi and cellular radios in a converged handset to help ensure that both technologies perform well in the presence of the other. All CTIA-certified handsets now include this certification.

Voice Personal Voice Personal offers enhanced support for voice applications in residential and small-business Wi-Fi networks. These networks include one access point, mixed voice and data traffic from multiple devices (such as phones, PCs, printers, and other consumer electronic devices), and support for up to four concurrent phone calls. Both the access point and the client device must be certified to achieve performance matching the certification metrics.

Voice Enterprise Voice Enterprise offers enhanced support for voice applications in enterprise Wi-Fi networks. Enterprise-grade voice equipment must provide consistently good voice quality under all network load conditions and coexist with data traffic. Both access point and client devices must support prioritization using WMM, with voice traffic being placed in the highest-priority queue (Access Category Voice, AC_VO). Voice Enterprise equipment must also support seamless roaming between APs, WPA2-Enterprise security, optimization of power through the WMM-Power Save mechanism, and traffic management through WMM-Admission Control.

Tunneled Direct Link Setup Tunneled Direct Link Setup (TDLS) enables devices to establish secure links directly with other devices after they have joined a traditional Wi-Fi network. This will allow consumer devices such as TVs, gaming devices, smartphones, cameras, and printers to communicate quickly, easily, and securely between each other.

Passpoint Passpoint is designed to revolutionize the end user experience when connecting to Wi-Fi hotspots. This will be done by automatically identifying the hotspot and connecting to it, automatically authenticating the user to the network using Extensible Authentication Protocol (EAP), and providing secure transmission using WPA2-Enterprise encryption. Passpoint is also known as Hotspot 2.0.

WMM-Admission Control WMM-Admission Control allows Wi-Fi networks to manage network traffic based upon channel conditions, network traffic load, and type of traffic (voice, video, best effort data, or background data). The access point allows only the traffic that it can support to connect to the network, based upon the available network resources. This allows users to confidently know that, when the connection is established, the resources will be there to maintain it.

IBSS with Wi-Fi Protected Setup IBSS with Wi-Fi Protected Setup provides easy configuration and strong security for ad hoc (peer-to-peer) Wi-Fi networks. This is designed for mobile products and devices that have a limited user interface, such as smartphones, cameras, and media players. Features include easy push button or PIN setup, task-oriented short-term connections, and dynamic networks that can be established anywhere.

Miracast Miracast seamlessly integrates the display of streaming video content between devices. Wireless links are used to replace wired connections. Devices are designed to identify and connect with each other, manage their connections, and optimize the transmission of video content. It provides wired levels of capabilities but the portability of Wi-Fi. Miracast provides 802.11n performance, ad hoc connections via Wi-Fi Direct, and WPA2 security.

As 802.11 technologies evolve, new Wi-Fi CERTIFIED programs will be defined by the Wi-Fi Alliance.

Wi-Fi Alliance and Wi-Fi CERTIFIED

Learn more about the Wi-Fi Alliance at `www.wi-fi.org`. The Wi-Fi Alliance website contains many articles, FAQs, and white papers describing the organization along with additional information about the certification programs. The Wi-Fi Alliance technical white papers are recommended extra reading when preparing for the CWNA exam. The Wi-Fi Alliance white papers can be accessed at `www.wi-fi.org/knowledge-center/white-papers`.

International Organization for Standardization

The *International Organization for Standardization*, commonly known as the *ISO*, is a global, nongovernmental organization that identifies business, government, and society needs and develops standards in partnership with the sectors that will put them to use. The ISO is responsible for the creation of the Open Systems Interconnection (OSI) model, which has been a standard reference for data communications between computers since the late 1970s.

Why Is It ISO and Not IOS?

ISO is not a mistyped acronym. It is a word derived from the Greek word *isos*, meaning *equal*. Because acronyms can be different from country to country, based on varying translations, the ISO decided to use a word instead of an acronym for its name. With this in mind, it is easy to see why a standards organization would give itself a name that means *equal*.

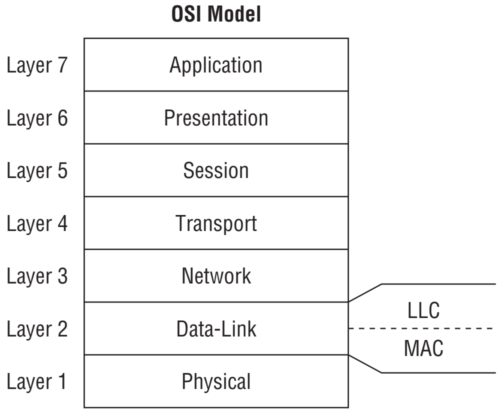
The OSI model is the cornerstone of data communications, and learning to understand it is one of the most important and fundamental tasks a person in the networking industry can undertake. Figure 1.4 shows the seven layers of the OSI.

The IEEE 802.11-2012 standard defines communication mechanisms only at the Physical layer and MAC sublayer of the Data-Link layer of the OSI model. How 802.11 technology is used at these two OSI layers is discussed in detail throughout this book.

NOTE

You should have a working knowledge of the OSI model for both this book and the CWNA exam. Make sure you understand the seven layers of the OSI model and how communications take place at the different layers. If you are not comfortable with the concepts of the OSI model, spend some time reviewing it on the Internet or from a good networking fundamentals book prior to taking the CWNA test. More information about the ISO can be found at `www.iso.org`.

FIGURE 1.4 The seven layers of the OSI model



Core, Distribution, and Access

If you have ever taken a networking class or read a book about network design, you have probably heard the terms *core*, *distribution*, and *access* when referring to networking architecture. Proper network design is imperative no matter what type of network topology is used. The core of the network is the high-speed backbone or the superhighway of the network. The goal of the core is to carry large amounts of information between key data centers or distribution areas, just as superhighways connect cities and metropolitan areas.

The core layer does not route traffic or manipulate packets but rather performs high-speed switching. Redundant solutions are usually designed at the core layer to ensure the fast and reliable delivery of packets. The distribution layer of the network routes or directs traffic toward the smaller clusters of nodes or neighborhoods of the network.

The distribution layer routes traffic between virtual LANs (VLANs) and subnets. The distribution layer is akin to the state and county roads that provide medium travel speeds and distribute the traffic within the city or metropolitan area.

The access layer of the network is responsible for slower delivery of the traffic directly to the end user or end node. The access layer mimics the local roads and neighborhood streets that are used to reach your final address. The access layer ensures the final delivery of packets to the end user. Remember that speed is a relative concept.

Because of traffic load and throughput demands, speed and throughput capabilities increase as data moves from the access layer to the core layer. The additional speed and throughput tends to also mean higher cost.

Just as it would not be practical to build a superhighway so that traffic could travel between your neighborhood and the local school, it would not be practical or efficient to build a two-lane road as the main thoroughfare to connect two large cities such as

New York and Boston. These same principles apply to network design. Each of the network layers—core, distribution, and access—is designed to provide a specific function and capability to the network. It is important to understand how wireless networking fits into this network design model.

Wireless networking can be implemented as either point-to-point or point-to-multipoint solutions. Most wireless networks are used to provide network access to the individual client stations and are designed as point-to-multipoint networks. This type of implementation is designed and installed on the access layer, providing connectivity to the end user. 802.11 wireless networking is most often implemented at the access layer. In Chapter 10, "WLAN Architecture," you will learn about the difference between autonomous access points, cooperative access points, and controller-based access points. All access points are deployed at the access layer; however, controller-based access points commonly tunnel 802.11 wireless traffic to WLAN controllers, which are normally deployed at the distribution or core layer.

Wireless bridge links are typically used to provide connectivity between buildings in the same way that county or state roads provide distribution of traffic between neighborhoods. The purpose of wireless bridging is to connect two separate, wired networks wirelessly. Routing data traffic between networks is usually associated with the distribution layer. Wireless bridge links cannot usually meet the speed or distance requirements of the core layer, but they can be very effective at the distribution layer. An 802.11 bridge link is an example of wireless technology being implemented at the distribution layer.

Although wireless is not typically associated with the core layer, you must remember that speed and distance requirements vary greatly between large and small companies and that one person's distribution layer could be another person's core layer. Very small companies may even implement wireless for all end-user networking devices, forgoing any wired devices except for the connection to the Internet. Higher-bandwidth proprietary wireless bridges and some 802.11 mesh network deployments could be considered an implementation of wireless at the core layer.

Communications Fundamentals

Although the CWNA certification is considered one of the entry-level certifications in the Certified Wireless Network Professional (CWNP) wireless certification program, it is by no means an entry-level certification in the computing industry. Most of the candidates for the CWNA certificate have experience in other areas of information technology. However, the background and experience of these candidates varies greatly.

Unlike professions for which knowledge and expertise is learned through years of structured training, most computer professionals have followed their own path of education and training.

When people are responsible for their own education, they typically will gain the skills and knowledge that are directly related to their interests or their job. The more fundamental knowledge is often ignored because it is not directly relevant to the tasks at hand. Later, as their knowledge increases and they become more technically proficient, people realize that they need to learn about some of the fundamentals.

Many people in the computer industry understand that, in data communications, bits are transmitted across wires or waves. They even understand that some type of voltage change or wave fluctuation is used to distinguish the bits. When pressed, however, many of these same people have no idea what is actually happening with the electrical signals or the waves.

In the following sections, you will review some fundamental communications principles that directly and indirectly relate to wireless communications. Understanding these concepts will help you to better understand what is happening with wireless communications and to more easily recognize and identify the terms used in this profession.

Understanding Carrier Signals

Because data ultimately consists of bits, the transmitter needs a way of sending both 0s and 1s to transmit data from one location to another. An AC or DC signal by itself does not perform this task. However, if a signal fluctuates or is altered, even slightly, the signal can be interpreted so that data can be properly sent and received. This modified signal is now capable of distinguishing between 0s and 1s and is referred to as a *carrier signal*. The method of adjusting the signal to create the carrier signal is called *modulation*.

Three components of a wave that can fluctuate or be modified to create a carrier signal are amplitude, frequency, and phase.

NOTE

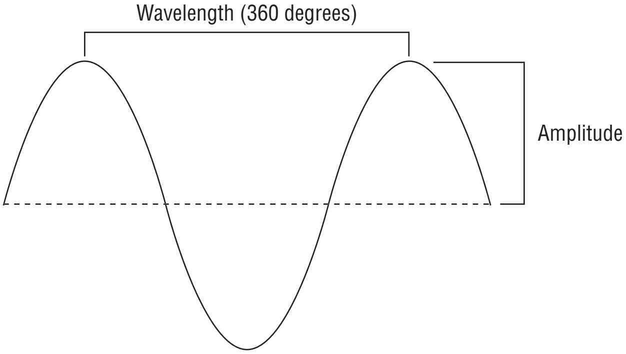
This chapter reviews the basics of waves as they relate to the principles of data transmission. Chapter 2, “Radio Frequency Fundamentals,” covers radio waves in much greater detail.

All radio-based communications use some form of modulation to transmit data. To encode the data in a signal sent by AM/FM radios, mobile telephones, and satellite television, some type of modulation is performed on the radio signal that is being transmitted. The average person typically is not concerned with how the signal is modulated, only that the device functions as expected. However, to become a better wireless network administrator, it is useful to have a better understanding of what is actually happening when two stations communicate. The rest of this chapter provides an introduction to waves as a basis for understanding carrier signals and data encoding and introduces you to the fundamentals of encoding data.

Amplitude and Wavelength

RF communication starts when radio waves are generated from an RF transmitter and picked up, or “heard,” by a receiver at another location. RF waves are similar to the waves that you see in an ocean or lake. Waves are made up of two main components: wavelength and amplitude (see Figure 1.5).

FIGURE 1.5 This drawing shows the wavelength and amplitude of a wave



Amplitude *Amplitude* is the height, force, or power of the wave. If you were standing in the ocean as the waves came to shore, you would feel the force of a larger wave much more than you would a smaller wave. Transmitters do the same thing, but with radio waves. Smaller waves are not as noticeable as bigger waves. A bigger wave generates a much larger electrical signal picked up by the receiving antenna. The receiver can then distinguish between highs and lows.

Wavelength *Wavelength* is the distance between similar points on two back-to-back waves. When measuring a wave, the wavelength is typically measured from the peak of a wave to the peak of the next wave. Amplitude and wavelength are both properties of waves.

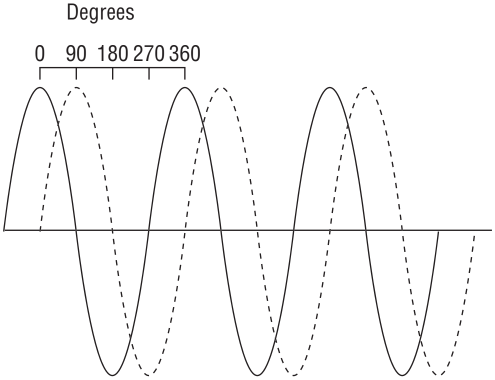
Frequency

Frequency describes a behavior of waves. Waves travel away from the source that generates them. How fast the waves travel, or more specifically, how many waves are generated over a 1-second period of time, is known as frequency. If you were to sit on a pier and count how often a wave hits it, you could tell someone how frequently the waves were coming to shore. Think of radio waves in the same way; however, radio waves travel much faster than the waves in the ocean. If you were to try to count the radio waves that are used in wireless networking, in the time it would take for one wave of water to hit the pier, several billion radio waves would have also hit the pier.

Phase

Phase is a relative term. It is the relationship between two waves with the same frequency. To determine phase, a wavelength is divided into 360 pieces referred to as *degrees* (see Figure 1.6). If you think of these degrees as starting times, then if one wave begins at the 0 degree point and another wave begins at the 90 degree point, these waves are considered to be 90 degrees out of phase.

FIGURE 1.6 This drawing shows two waves that are identical; however, they are 90 degrees out of phase with each other.



In an ideal world, waves are created and transmitted from one station and received perfectly intact at another station. Unfortunately, RF communications do not occur in an ideal world. There are many sources of interference and many obstacles that will affect the wave in its travels to the receiving station. In Chapter 2, we will introduce you to some of the outside influences that can affect the integrity of a wave and your ability to communicate between two stations.

Time and Phase

Suppose you have two stopped watches and both are set to noon. At noon you start your first watch, and then you start your second watch 1 hour later. The second watch is 1 hour behind the first watch. As time goes by, your second watch will continue to be 1 hour behind. Both watches will maintain a 24-hour day, but they are out of sync with each other. Waves that are out of phase behave similarly. Two waves that are out of phase are essentially two waves that have been started at two different times. Both waves will complete full 360-degree cycles, but they will do it out of phase, or out of sync with each other.

Understanding Keying Methods

When data is sent, a signal is transmitted from the transceiver. In order for the data to be transmitted, the signal must be manipulated so that the receiving station has a way of distinguishing 0s and 1s. This method of manipulating a signal so that it can represent multiple pieces of data is known as a *keying method*. A keying method is what changes a signal into a carrier signal. It provides the signal with the ability to encode data so that it can be communicated or transported.

There are three types of keying methods that are reviewed in the following sections: amplitude-shift keying (ASK), frequency-shift keying (FSK), and phase-shift keying (PSK). These keying methods are also referred to as *modulation techniques*. Keying methods use two different techniques to represent data:

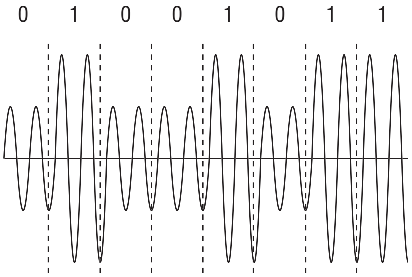
Current State With current state techniques, the current value (the current state) of the signal is used to distinguish between 0s and 1s. The use of the word *current* in this context does not refer to current as in voltage but rather to current as in the present time. Current state techniques will designate a specific or current value to indicate a binary 0 and another value to indicate a binary 1. At a specific point in time, it is the value of the signal that determines the binary value. For example, you can represent 0s and 1s by using an ordinary door. Once a minute you can check to see whether the door is open or closed. If the door is open, it represents a 0, and if the door is closed, it represents a 1. The current state of the door, open or closed, is what determines 0s or 1s.

State Transition With state transition techniques, the change (or transition) of the signal is used to distinguish between 0s and 1s. State transition techniques may represent a 0 by a change in a wave's phase at a specific time, whereas a 1 would be represented by no change in a wave's phase at a specific time. At a specific point in time, it is the presence of a change or the lack of presence of a change that determines the binary value. The upcoming section "Phase-Shift Keying" provides examples of this in detail, but a door can be used again to provide a simple example. Once a minute you check the door. In this case, if the door is moving (opening or closing), it represents a 0, and if the door is still (either open or closed), it represents a 1. In this example, the state of transition (moving or not moving) is what determines 0s or 1s.

Amplitude-Shift Keying

Amplitude-shift keying (ASK) varies the amplitude, or height, of a signal to represent the binary data. ASK is a current state technique, where one level of amplitude can represent a 0 bit and another level of amplitude can represent a 1 bit. Figure 1.7 shows how a wave can modulate an ASCII letter *K* by using amplitude-shift keying. The larger amplitude wave is interpreted as a binary 1, and the smaller amplitude wave is interpreted as a binary 0.

FIGURE 1.7 An example of amplitude-shift keying (ASCII code of an uppercase *K*)



This shifting of amplitude determines the data that is being transmitted. The way the receiving station performs this task is to first divide the signal being received into periods of time known as *symbol periods*. The receiving station then samples or examines the wave during this symbol period to determine the amplitude of the wave. Depending on the value of the wave's amplitude, the receiving station can determine the binary value.

As you will learn later in this book, wireless signals can be unpredictable and also subjected to interference from many sources. When noise or interference occurs, it usually affects the amplitude of a signal. Because a change in amplitude due to noise could cause the receiving station to misinterpret the value of the data, ASK has to be used cautiously.

Frequency-Shift Keying

Frequency-shift keying (FSK) varies the frequency of the signal to represent the binary data. FSK is a current state technique, where one frequency can represent a 0 bit and another frequency can represent a 1 bit (Figure 1.8). This shifting of frequency determines the data that is being transmitted. When the receiving station samples the signal during the symbol period, it determines the frequency of the wave, and depending on the value of the frequency, the station can determine the binary value.

FIGURE 1.8 An example of frequency-shift keying (ASCII code of an uppercase *K*)

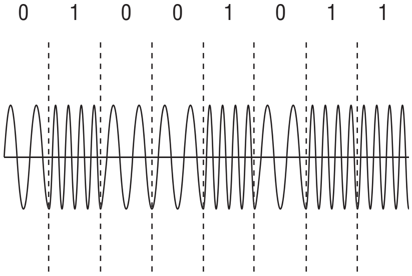


Figure 1.8 shows how a wave can modulate an ASCII letter *K* by using frequency-shift keying. The faster frequency wave is interpreted as a binary 1, and the slower frequency wave is interpreted as a binary 0.

FSK is used in some of the legacy deployments of 802.11 wireless networks. With the demand for faster communications, FSK techniques would require more expensive technology to support faster speeds, making it less practical.

Why Have I Not Heard about Keying Methods Before?

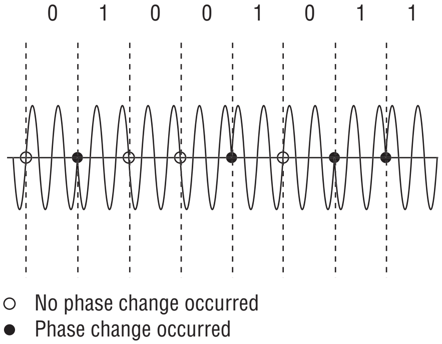
You might not realize it, but you *have* heard about keying methods before. AM/FM radio uses amplitude modulation (AM) and frequency modulation (FM) to transmit the radio stations that you listen to at home or in your automobile. The radio station modulates the voice and music into its transmission signal, and your home or car radio demodulates it.

Phase-Shift Keying

Phase-shift keying (PSK) varies the phase of the signal to represent the binary data. PSK is can be a state transition technique, where the change of phase can represent a 0 bit and the lack of a phase change can represent a 1 bit, or vice versa. This shifting of phase determines the data that is being transmitted. PSK can also be a current state technique, where the value of the phase can represent a 0 bit or a 1 bit. When the receiving station samples the signal during the symbol period, it determines the phase of the wave and the status of the bit.

Figure 1.9 shows how a wave can modulate an ASCII letter *K* by using phase-shift keying. A phase change at the beginning of the symbol period is interpreted as a binary 1, and the lack of a phase change at the beginning of the symbol period is interpreted as a binary 0.

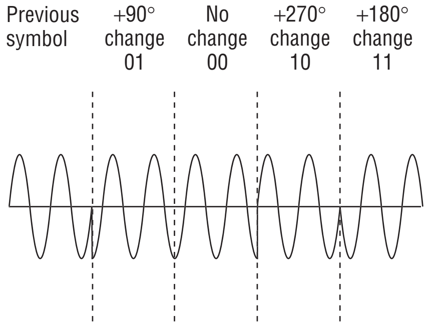
FIGURE 1.9 An example of phase-shift keying (ASCII code of an uppercase *K*)



PSK technology is used extensively for radio transmissions as defined by the 802.11-2012 standard. Typically, the receiving station samples the signal during the symbol period, compares the phase of the current sample with the previous sample, and determines the difference. This degree of difference, or *differential*, is used to determine the bit value.

More advanced versions of PSK can encode multiple bits per symbol. Instead of using two phases to represent the binary values, you can use four phases. Each of the four phases is capable of representing two binary values (00, 01, 10, or 11) instead of one (0 or 1), thus shortening the transmission time. When more than two phases are used, this is referred to as *multiple phase-shift keying (MPSK)*. Figure 1.10 shows how a wave can modulate an ASCII letter *K* by using a multiple phase-shift keying method. Four possible phase changes can be monitored, with each phase change now able to be interpreted as 2 bits of data instead of just 1. Notice that there are fewer symbol times in this figure than there are in Figure 1.9.

FIGURE 1.10 An example of multiple phase-shift keying (ASCII code of an uppercase *K*)



Where Else Can I Learn More about 802.11 Technology and the Wi-Fi Industry?

Reading this book from cover to cover is a great way to start understanding Wi-Fi technology. In addition, because of the rapidly changing nature of 802.11 WLAN technologies, the authors of this book recommend these additional resources:

Wi-Fi Alliance As mentioned earlier in this chapter, the Wi-Fi Alliance is the marketing voice of the Wi-Fi industry and maintains all the industry's certifications. The knowledge center section of the Wi-Fi Alliance website, `www.wi-fi.org`, is an excellent resource.

CWNP The Certified Wireless Networking Professional program maintains learning resources such as user forums and a WLAN white paper database. The website `www.cwnp.com` is also the best source of information about all the vendor-neutral CWNP wireless networking certifications.

WLAN Vendor Websites Although the CWNA exam and this book take a vendor-neutral approach about 802.11 education, the various WLAN vendor websites are often excellent resources for information about specific Wi-Fi networking solutions. Many of the major WLAN vendors are mentioned throughout this book, and a listing of most of the major WLAN vendor websites can be found in Chapter 11, "WLAN Deployment and Vertical Markets."

Wi-Fi Blogs In recent years, numerous personal blogs about the subject of Wi-Fi have sprung up all over the Internet. One great example is the Revolution Wi-Fi blog written by CWNE #84, Andrew vonNagy, at

`http://revolutionwifi.blogspot.com`

Summary

This chapter explained the history of wireless networking and the roles and responsibilities of key organizations involved with the wireless networking industry:

- FCC and other regulatory domain authorities
- IEEE
- IETF
- Wi-Fi Alliance

To provide a basic understanding of the relationship between networking fundamentals and 802.11 technologies, we discussed these concepts:

- OSI model
- Core, distribution, and access

To provide a basic knowledge of how wireless stations transmit and receive data, we introduced some of the components of waves and modulation:

- Carrier signals
- Amplitude
- Wavelength
- Frequency
- Phase
- Keying methods, including ASK, FSK, and PSK

When you are troubleshooting RF communications, having a solid knowledge of waves and modulation techniques can help you understand the fundamental issues behind communications problems and help lead you to a solution.

Exam Essentials

Know the four industry organizations. Understand the roles and responsibilities of the regulatory domain authorities, the IEEE, the IETF, and the Wi-Fi Alliance.

Understand core, distribution, and access. Know where 802.11 technology is deployed in fundamental network design.

Understand wavelength, frequency, amplitude, and phase. Know the definitions of each RF characteristic.

Understand the concepts of modulation. ASK, FSK, and PSK are three carrier signal modulation techniques.

Review Questions

1. 802.11 technology is typically deployed at which fundamental layer of network architecture?

   A. Core

   B. Distribution

   C. Access

   D. Network

2. Which organization is responsible for enforcing maximum transmit power rules in an unlicensed frequency band?

   A. IEEE

   B. Wi-Fi Alliance

   C. ISO

   D. IETF

   E. None of the above

3. 802.11 wireless bridge links are typically associated with which network architecture layer?

   A. Core

   B. Distribution

   C. Access

   D. Network

4. The 802.11-2012 standard was created by which organization?

   A. IEEE

   B. OSI

   C. ISO

   D. Wi-Fi Alliance

   E. FCC

5. What organization ensures interoperability of WLAN products?

   A. IEEE

   B. ITU-R

   C. ISO

   D. Wi-Fi Alliance

   E. FCC

6. What type of signal is required to carry data?
   - **A.** Communications signal
   - **B.** Data signal
   - **C.** Carrier signal
   - **D.** Binary signal
   - **E.** Digital signal

7. Which keying method is most susceptible to interference from noise?
   - **A.** FSK
   - **B.** ASK
   - **C.** PSK
   - **D.** DSK

8. Which sublayer of the OSI model's Data-Link layer is used for communication between 802.11 radios?
   - **A.** LLC
   - **B.** WPA
   - **C.** MAC
   - **D.** FSK

9. While performing some research, Janie comes across a reference to a document titled RFC 3935. Which of the following organization's website would be best to further research this document?
   - **A.** IEEE
   - **B.** Wi-Fi Alliance
   - **C.** WECA
   - **D.** FCC
   - **E.** IETF

10. The Wi-Fi Alliance is responsible for which of the following certification programs?
    - **A.** 802.11i
    - **B.** WEP
    - **C.** 802.11-2012
    - **D.** WMM
    - **E.** PSK

11. Which wave properties can be modulated to encode data? (Choose all that apply.)
    - **A.** Amplitude
    - **B.** Frequency

C. Phase

D. Wavelength

12. The IEEE 802.11-2012 standard defines communication mechanisms at which layers of the OSI model? (Choose all that apply.)

A. Network

B. Physical

C. Transport

D. Application

E. Data-Link

F. Session

13. The height or power of a wave is known as what?

A. Phase

B. Frequency

C. Amplitude

D. Wavelength

14. Samantha received a gaming system as a gift. She would like to have it communicate with her sister Jennifer's gaming system so that they can play against each other. Which of the following technologies, if deployed in the two gaming systems, should provide for the easiest configuration of the two systems to communicate with each other?

A. Wi-Fi Personal

B. Wi-Fi Direct

C. 802.11n

D. CWG-RF

E. Wi-Fi Protected Setup

15. What other Wi-Fi Alliance certifications are required before a Wi-Fi radio can also be certified as Voice Enterprise compliant? (Choose all that apply.)

A. WMM-Power Save

B. Wi-Fi Direct

C. WPA2-Enterprise

D. Voice Personal

E. WMM-Admission Control

16. Which of the following wireless communications parameters and usage are typically governed by a local regulatory authority? (Choose all that apply.)

A. Frequency

B. Bandwidth

- **C.** Maximum transmit power
- **D.** Maximum EIRP
- **E.** Indoor/outdoor usage

17. The Wi-Fi Alliance is responsible for which of the following certification programs? (Choose all that apply.)

- **A.** WECA
- **B.** Voice Personal
- **C.** 802.11v
- **D.** WAVE
- **E.** WMM-PS

18. A wave is divided into degrees. How many degrees make up a complete wave?

- **A.** 100
- **B.** 180
- **C.** 212
- **D.** 360

19. What are the advantages of using unlicensed frequency bands for RF transmissions? (Choose all that apply.)

- **A.** There are no government regulations.
- **B.** There is no additional financial cost.
- **C.** Anyone can use the frequency band.
- **D.** There are no rules.

20. The OSI model consists of how many layers?

- **A.** Four
- **B.** Six
- **C.** Seven
- **D.** Nine