Chapter 3: Spread Spectrum Technologies

Overview

Comprehend the differences between, and explain the different types of spread spectrum technologies and how they relate to the IEEE 802.11 standard's PHY clauses:

FHSS, DSSS, HR/DSSS, ERP, and OFDM

Identify the underlying concepts of how spread spectrum technology works:

Modulation and Coding

Identify and apply the concepts which make up the functionality of spread spectrum Technology:

Colocation
Channel Centers and Widths
Carrier Frequencies
Dwell Time and Hop Time
Throughput Versus Data Rate
Bandwidth
Communication Resilience

This chapter introduces the concepts of spread spectrum radio communication and the way it is implemented in the IEEE 802.11 standards. A comparison is made to narrowband communications for contrasting purposes.

From here the chapter moves on to the specific ways spread spectrum technology is used in IEEE 802.11, including frequency hopping spread spectrum, direct sequence spread spectrum, and orthogonal frequency division multiplexing, though the latter is not technically a spread spectrum technology.

Next, spread spectrum concepts such as modulation and coding are covered. Finally, the various spread spectrum factors you need to understand so that you can implement and administer a WLAN are addressed, including colocation, channels, throughput, and data rates.

Spread Spectrum Technologies and IEEE 802.11 Standards

The original IEEE 802.11−1997 standard specified three Physical layer technologies to be used for WLANs.

These three technologies are the Clause 14 frequency hopping spread spectrum (FHSS) PHY, the Clause 15 direct sequence spread spectrum (DSSS) PHY, and the Clause 16 infrared PHY (IR).

The FHSS and DSSS PHYs use the 2.4 GHz Industrial, Scientific, and Medical (ISM) band for communications. The IR PHY never came to market and will not be covered further here.

The following sections introduce you to the FHSS and DSSS PHYs. This introduction will afford a high level understanding of how these two spread spectrum technologies work and what capabilities they provide.

Additionally, you will learn about the orthogonal frequency division PHY (OFDM) that was originally released as the IEEE 802.11a amendment, the high rate DSSS (HR/DSSS) PHY that was originally released as the IEEE 802.11b amendment, and the enhanced rate PHY (ERP) that was originally released as the IEEE 802.11g amendment.

These latter three PHYs have been added to the standard since 1997.You will also learn about the much anticipated high throughput (HT) PHY to be released as the IEEE 802.11n amendment.

Near the end of the chapter, provides a single point of reference to the different features and capabilities of the IEEE 802.11 PHYs.

Spread Spectrum Versus Narrowband Technology

To understand the benefits of spread spectrum technology, you must first understand the differences between narrowband and spread spectrum RF solutions.

Narrowband wireless communications can be defined as wireless communications using a single frequency center with no redundancy to communicate information at high power levels chosen to overpower interference in that frequency band.

Spread spectrum wireless communications can be defined as wireless communications using a range of frequencies to communicate information at low power levels. More specifically, spread spectrum and OFDM use multiple frequency centers over a relatively large frequency band to send multiple copies of information (as in DSSS) or error correcting codes (as in OFDM) so that the information makes it through despite some RF symbols being unrecoverable.

Spread spectrum has also been defined as a wireless communications technology that uses more bandwidth than is required to deliver information. Spread spectrum also uses low power and can do so because all interference does not need to be overcome, due to the redundancy and/or error correction.

The differences between these two technologies are important, and these differences have been the driving force behind the varied usages of both technologies. Narrowband wireless communications, for example, are used by the radio stations you listen to in your car or on your home radio. You have learned, through experience, that these stations use a specific frequency for broadcasting.

For example, you may tune your radio to 103.9 on the FM band . You do not tune the radio to between 103.1 and 103.7 or some other range of frequencies.

You may have also heard things like "50,000 watts of broadcasting power." This is certainly more output power than you would find in even an enterprise class WLAN device at 100 mW or even 4 W at the antenna.

The high output power is both a factor of narrowband transmission and, possibly more important, the need for the signal to travel far.

One of the most important problems that has been reduced, though not eliminated, by using spread spectrum technology is the issue of interference.

For example, radio stations using the same narrowband frequency must be many miles apart; however, WLANs using the same spread spectrum channel (range of frequencies) can easily exist on the same block and, with the right antennas and output power settings, even in the same building with very little problem from interference.

This is a factor more of the low power characteristic of spread spectrum technologies and OFDM in the IEEE standards than it is of spread spectrum technology itself. If we implemented an illegal access point (AP) connected to an antenna with a total output power of 50,000 watts, it would drown out my neighbor's WLANs for many kilometres. It would also get me into very big trouble with the EMEA.

If the WLAN equipment we are implementing today were based on narrowband technology, we would be in continual disputes over the frequency space. One single device communicating on the same frequency a kilometres away would cause enough interference to bring our WLAN nearly to a halt.

As long as power regulations are followed, this will not be a problem with spread spectrum technology at any point in the future. Currently, spread spectrum and spread spectrum like technologies are being improved to offer more data throughput, but these improvements are being made with a focus on maintaining the ability to implement the wireless devices in a license free manner with as little unintentional interference as possible.

An additional wireless communications problem, multipath, is also partly overcome by the use of spread spectrum technology. Spread spectrum systems spread the communications across multiple frequencies. Each frequency has a different RF wavelength, and these varying wavelengths will react differently to the environment through which they propagate, due to the size differences between the various wavelengths compared to the objects they encounter in the environment.

This phenomenon results in a lesser multipath impact on some wavelengths and a greater multipath impact on other wavelengths. The end result is that enough of the frequencies will often "get through" to the receiving antenna without being substantially impacted by multipath. This, in conjunction with the redundant data used in DSSS systems, allows for greater resilience in spread spectrum networks.

The multipath problem that is reduced by the utilization of spread spectrum technology is known as *intersymbol interference (ISI).* ISI occurs when the main signal and the reflected signal paths arrive at the receiving antenna with a time variation between them *(delay spread)* great enough to cause bits to overlap. Wireless technologies have varying delay spread tolerance, and this tolerance can be summarized by the following guideline:

Higher data rates have lower delay spread tolerance, and lower data rates havehigher delay spread tolerance.

This guideline is one of the reasons for reducing the data rate; the other major reason is a simple factor of signal strength. Balancing data rate with ISI and other signal quality factors is an important element in achieving stable communications on WLANs.

Due to the benefits of spread spectrum technologies, they have dominated the WLAN market. Spread spectrum is used in wireless personal area networks (WPANs), wireless metropolitan area networks (WMANs), and other proprietary technologies.

The ability to have multiple networks or devices communicating on different channels or frequencies in the same unlicensed RF space has been a big part of this growth. Due to the low output power constraints imposed by the FCC/EMEA and other regulatory agencies on spread spectrum technologies implemented in the IEEE 802.11 standard (as amended), you can implement multiple WLANs in a single building on the same channels assuming there is enough distance between them.

You wouldn't want to try implementing a WLAN using a single access point with very high output power, because all the clients would have to share the same access point, and this would greatly reduce overall throughput.

FHSS

FHSS is the first IEEE 802.11 PHY that I will cover. FHSS, as implemented in the IEEE standards, provides a 1 or 2 Mbps data rate using the 2.4 GHz ISM band. Within North America, FHSS uses seventy nine 1 MHz channels centered on every 1 MHz from 2.400 GHz to 2.4835 GHz. The IEEE 802.11 standards specify channel centers and the distance between them that fit within this range.

The *frequency−hopping* portion of this spread spectrum technology is revealing as to its functionality. FHSS systems use a small frequency bandwidth, which I will simply call a frequency, within the 79 MHz allocated, to communicate and then hop to another frequency and then another until a hopping pattern known as a *hopping sequence* has been completed.

When the hopping sequence is completed, it is then repeated, and this process continues until the information being communicated has been transferred. Additionally, a *dwell time* is specified, which determines how long each frequency will be utilized before hopping to the next position in the hopping sequence.

FHSS provides for resistance to interference through the use of small frequency bandwidths and transfer algorithms that accommodate for errors in transmissions. For example, if data is communicated on a particular frequency and interference is encountered, that data will simply be retransmitted once the radios move on to the next frequency in the hopping sequence. Of course, this will reduce the actual data throughput of the system, but this resilience provides for reasonably stable communications.

In modern networks, the reality is that speed is very important. This is where FHSS falls short. While it may provide for resilience in the face of interference, it does not provide for speeds greater than 2 Mbps and, therefore, is not widely implemented today. The exception to this is the Bluetooth devices that are very popular. Bluetooth does use FHSS. Since Bluetooth devices do not usually need high data rates for typical uses (wireless headsets, wireless mice, wireless keyboards, etc.) in one to one link scenarios, the limited speeds of FHSS are not as problematic.

DSSS

DSSS, the second IEEE 802.11 PHY covered here, supports speeds of 1 or 2 Mbps just like FHSS systems. Later amendments to the IEEE 802.11 standard provided for higher data rates and accomplished this through a different implementation of DSSS, which you will read about shortly.

The IEEE specifies that DSSS should operate in the 2.4 GHz ISM band and that it should use frequencies ranging from 2.401 to 2.473 GHz in North America. The IEEE further specifies that the DSSS supported by IEEE 802.11 devices should implement differential binary phase shift keying (DBPSK) at 1 Mbps and differential quadrature phase shift keying (DQPSK) at 2 Mbps. DBPSK and DQPSK are modulation techniques that use phase based modulation.

The IEEE standards divide the DSSS Physical layer into two components: the Physical layer convergence procedure (PLCP) and the physical medium dependent (PMD). The PMD defines that actual method used to transmit data between two wireless devices, and the PLCP acts as an abstraction layer between the PMD and the Medium Access Control (MAC) services.

DSSS systems are also resistant to narrowband interference like FHSS systems. This is because of the use of spread spectrum technologies; however, because DSSS systems use narrow bandwidths and do not hop from one frequency to another, they may be more susceptible to interference than FHSS systems.

If a narrowband signal is broadcast on the same frequency as the center channel frequency you've chosen for your DSSS WLAN, it will cause continual interference.

If a similar situation should occur with a FHSS system, it would only cause interference when the system hopped to that frequency. In most cases, however, the narrowband interference will be benign, since it only takes out a few copies of the bits (DSSS transmits redundant copies of the data). As long as one copy gets through, it is as though the interference does not exist because there is no loss of information.

HR/DSSS

High rate DSSS (HR/DSSS) is the PHY defined in the IEEE 802.11b−1999 amendment. Due to the fact that this amendment document specifies the details of HR/DSSS functionality, many refer to HR/DSSS devices as 802.11b devices.

HR/DSSS PHY is backward compatible with IEEE 802.11 DSSS equipment, but it is not compatible with IEEE 802.11 FHSS equipment. This is because of the use of different modulation schemes (frequency hopping versus direct sequence).

The primary objective of TGb (task group b) was to provide higher data rates within the 2.4 GHZ ISM band and compatibility with modulations used by DSSS PHY. This was accomplished using the same frequency range as used by DSSS, specifically, from 2.4000 to 2.4835 GHz. Using *complementary code keying (CCK),* TGb was able to achieve data rates of 5.5 and 11 Mpbs. This resulted in a collection of data rates, 1, 2, 5.5, and 11 Mbps.

OFDM and ERP−OFDM

Orthogonal frequency division multiplexing, or *OFDM*, is not a spread spectrum technology, though it is often called such, but is sometimes said to be spread spectrum ike because of its similar resilience against interference.

A special implementation of OFDM is used in IEEE 802.11g, and it has been widely implemented in IEEE 802.11a technology as well. OFDM offers high data rates and exceptional resistance to interference and corruption. OFDM is actually a digital modulation method that splits the signal into multiple narrowband subcarriers at different frequencies.

Another way of saying this is to say that OFDM splits a high speed information signal into multiple lower speed information signals and then transmits these lower speed signals in parallel.

Due to the interference problems you would encounter if the single high speed or high bandwidth signal were transmitted, the use of multiple lower speed or lower bandwidth subcarriers actually results in higher data rates.

Whether OFDM is a spread spectrum technology or not has been debated among WLAN engineers, but the FCC has specified that, though OFDM may not be spread spectrum, it is similar enough in features to be used in the unlicensed bands.

OFDM is now used in both the 5 GHz U−NII bands (IEEE 802.11a) and the 2.4 GHz ISM band (IEEE 802.11g), though it was first introduced to WLANs through the IEEE 802.11a standard.

The benefits of OFDM include spectral efficiency (meaning that the use of the electromagnetic spectrum is more efficient than with other technologies), resistance to RF interference, and lowered multipath distortion.

The spectral efficiency is achieved by effectively transmitting multiple modulated signals as closely together as possible in relation to the frequencies used. The goal is to keep these modulated signals orthogonal so that they do not cause large amounts of interference with each other.

RF interference is less of a problem for the same basic reasons that it is a lesser problem in spread spectrum systems. The signal is spread across a wider frequency bandwidth than it needs, though OFDM spreads the signal differently.

Multipath distortion is also reduced for this reason. OFDM systems implement error correcting so that any subcarriers experiencing interference are "balanced out" by the other subcarriers through a sort of parity algorithm similar to that used in fault tolerant hard drive systems.

OFDM is not only used in WLAN technology, but is also used in asymmetric digital subscriber lines (ADSL) and in IEEE 802.16−also known as WiMAX. OFDM is similar to its namesake FDM (frequency division multiplexing), but OFDM is more focused on reducing interference between subcarriers than on perfecting the signal quality of each subcarrier.

OFDM reduces crosstalk between subcarriers even though the sub carriers overlap in the spectrum used. Crosstalk is a negative impact of one frequency or channel's signal on another frequency or channel's signal. The crosstalk is reduced through the orthogonality of the OFDM communication channels.

IEEE 802.11n

Like OFDM today, IEEE 802.11n is not planned to use spread spectrum technology as its primary communications mechanism. Instead, it is expected to use a modified version of OFDM that is currently referenced as High Throughput−OFDM (HT−OFDM).

The current draft for IEEE 802.11n, which defines the HT−OFDM PHY, will be based on the current OFDM PHY specified in Clause 17 of the IEEE 802.11a amendment. The draft calls for up to four spatial streams using 20 MHz of bandwidth each or up to four spatial streams using 40 MHz of bandwidth each.

The latter would result in data rates of up to 600 Mbps. The draft also states that the IEEE 802.11n PHY will operate in one of three modes:non−HT mode, HT mixed mode, and Greenfield mode. *Non−HT mode* calls for wireless communications using either OFDM or ERP−OFDM, depending on whether the 5 or 2.4 GHz spectrum is used, respectively.

The *HT mixed mode* allows for communications that are compatible with non−HT devices (OFDM or ERP−OFDM). Both non−HT and HT mixed modes are required.

Greenfield mode is optional and can be thought of as HT−only. This would be much like placing today's IEEE 802.11g devices in "g−only" mode.

The access points developed to support HT−OFDM must support both non−HT and 20 MHz HT to be considered IEEE 802.11n compliant in the current draft.

This means that the access point will have to support backward compatibility with IEEE 802.11g and IEEE 802.11a as well as one to four spatial streams 20 MHz wide using HT−OFDM. With this constraint, down−level stations such as IEEE 802.11g−compatible laptops will be able to communicate with the IEEE 802.11n access points.

A station claiming to be IEEE 802.11n compliant will have to be able to support non−HT mode and 20 MHz HT mode with one spatial stream. This, again, means the station will be able to communicate with older IEEE 802.11a or IEEE 802.11g equipment as well as newer IEEE 802.11n equipment.

How Spread Spectrum Technology Works

In order to more fully understand the functionality of spread spectrum technology, you will need to learn about two important concepts: modulation and coding.

Modulation

Modulation is defined as the process of manipulating a carrier signal so that it can represent intelligent information. There are multiple kinds of modulation, but they fall into two general categories: digital modulation and analog modulation. WLAN technologies use digital modulation only, and that is the modulation type that will be covered here.

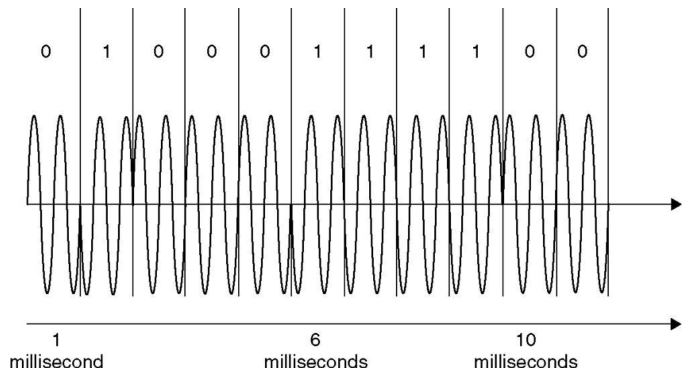
An RF signal can be modulated by manipulating the frequency, phase, or amplitude. Amplitude modulation is not sufficient alone for WLAN technologies, since the amplitude is often affected by interference. This leaves frequency and phase modulation, and newer WLAN technologies use different kinds of phase modulation to achieve communications. Frequency modulation is also used though it is less common today.

RF signals are modulated so that they can represent 0s and 1s. As long as a 0 or 1 can be represented, any computer information can be transferred on the signal.

Consider the following very simple example. Assume that two devices are configured to read signals at 1−millisecond intervals and that a change in phase would indicate a change in bit representation.

In other words, every time the phase changes, we toggle the bit. If there is no phase change, the devices assume the bit should stay the same as it was during the last 1−millisecond interval.

Therefore, once communications are established and a starting bit (let's say 0) is defined, any sequence of bits can be transmitted going forward. Let's further say that when actual data communications are about to begin, there is always a flip from 0 to 1 to 0 so that the receiving device knows to begin processing the next phase changes as information.



In this example, as depicted in above, the sending alert which you could refer to as a Preamble is sent first as 180−degree phase shifts from 0 to 1 and then back to 0. Next, two 0s are sent, so there is no phase shift, and these two 0s are followed by four 1s, indicated by a phase shift at millisecond 6. Finally, another phase shift at millisecond 10 indicates that the transmission should now represent a 0, and the two 0s end the eight bit binary number that was transmitted.

This phase shifting algorithm is often called the *keying* mechanism of the modulation, and the time window is called the *symbol* or *symbol period.* Technically, the symbol is the smallest unit of data transmitted at one time. For example, BPSK modulation transmits one bit at a time, whereas 16 quadrature amplitude modulation (16−QAM) transfers four bits at a time.

The most common type of modulation used in WLANs is one of many varieties of phase shift keying. *Phase shift keying* works similar to the fictional example above.

FHSS Modulation

FHSS systems, which meet the specifications of the IEEE 802.11 standard, use a form of modulation known as *Gaussian frequency shift keying (GFSK).* Both two level and four−level GFSK (2GFSK and 4GFSK) are supported by the standard for 1 and 2 Mbps data rates, respectively. Do not confuse the modulation scheme with the hopping sequence.

When the FHSS device hops to a frequency, it will use GFSK modulation to communicate on that frequency. When it hops to the next frequency, it will use the same modulation. The modulation scheme and the hopping sequence are two different concepts, though they are often confused because of the use of the word frequency in the modulation scheme title.

Frequency shift keying (FSK) has been used as a modulation technique for many years. Early modems used on standard telephone landlines used a form of FSK.

As you can infer from the modulation name, this modulation technique does use the frequency as the manipulated characteristic of the RF signal to impress data on the wave. GFSK, as it is implemented in IEEE 802.11, uses either two frequencies (2GFSK−sometimes called binary or 2−ary GFSK) or four frequencies (4GFSK−sometimes called 4−ary GFSK) to encode the information onto the signal.

Because most interference causes a reduction in amplitude and not a change in frequency, FSK is resistant, though not immune, to interference based corruption. GFSK is a modulation technique where the data is first passed through a Gaussian filter in the base band and then modulated with frequency modulation.

DSSS Modulation
DSSS systems use differential phase shift keying (DPSK) to modulate information onto carrier signals. The actual phase of the waveform (RF wave used for signaling) does not matter because it is a phase shift or change in phase that encodes information. Like FSK, phase shifting modulation schemes are resistant to interference because the phase is not usually impacted by interference.

This first kind of DPSK used in DSSS systems, called *differential binary phase shift keying(DBPSK),* provides a data rate of 1 Mbps.

The second kind of modulation used in DSSS systems is *differential quadrature phase shift keying (DQPSK).* As you can probably guess from the name, this phase shifting technique uses four different shifts to represent four different values.

Phase Shift in	Degrees Value
0	00
90	01
180	11
270	10

Using a four shift modulation scheme allows for faster data rates, and this is why DQPSK is used when communicating at 2 Mbps; however, DQPSK is more sensitive to multipath interference than DBPSK. For this reason, IEEE 802.11 equipment may have to be throttled back to 1 Mbps in high−multipath environments.

HR/DSSS Modulation
HR/DSSS uses a combination of DQPSK and complementary code keying (CCK) for modulation.

Either four or eight bits are encoded in each symbol period. Four bits are used for 5.5 Mbps communications, and eight bits are used for 11 Mbps. In either case, two bits are always modulated using DQPSK, and the remaining bits are modulated using CCK. Since CCK is more of an encoding or coding mechanism.

OFDM Modulation
OFDM systems, such as IEEE 802.11a and 802.11g, use different modulation techniques depending on the data rate. Modulations include DBPSK, DQPSK, 16−QAM, and 64−QAM.

Modulation Scheme	Data Rate (Mbps)
DBPSK	6
DBPSK	9
DQPSK	12
DQPSK	18
16−QAM	24
16−QAM	36

64−QAM	48
64−QAM	54

When describing QAM modulation, the number before the modulation type represents the number of possible phase shifts that the modulation supports. For example, 16−QAM supports 16 possible phase shifts, whereas 64−QAM supports 64 possible phase shifts.

Coding

Before information is modulated onto RF carrier signals, it is encoded with different coding schemes. These coding schemes provide resilience to the communications process in that they spread the data using pseudorandom numbers (PN) that allow for error correction on the receiving end.

FHSS Coding

The only *coding* employed in FHSS systems is the hopping sequence, which will be covered later. In the past, many considered this to be an element of security, since devices communicating on the FHSS network would have to know the hopping sequence; however, due to standardization, this feature of FHSS systems can no longer be considered a security feature.

DSSS Coding

Unlike FHSS systems, DSSS systems do encode the information to be transferred. Redundant information is added to the information to be transferred through a process known as *processing gain.*

Each data bit is processed mathematically against a fixed−length binary number known as a pseudorandom number, or PN. The mathematical operation performed, called XOR'ing, results in a much larger amount of data than the original bit. The IEEE requires a processing gain of 11 for DSSS systems, **which results in an 11 bit chunk of information for every single bit of actual data.**

The resulting 11 bit chunk is called a *chip.* This chip is still just a binary number, but it is important that you understand the terminology so that you can understand various documents and reference materials such as the IEEE standards themselves.

The specific code that is used as a PN code is known as the *Barker sequence* or the *chipping code.* This code is equal to 10110111000 and is referenced as +1 −1 +1 +1 −1 +1 +1 +1 −1 −1 −1 in the IEEE standards. This means that the bit value of 0 is transmitted as 01001000111 and the bit value of 1 is transmitted as 10110111000. This encoding occurs before the data is modulated, and in the end, the actual data is never modulated onto the carrier signal. Instead, the result of XOR’ing each signal bit against the Barker sequence is modulated.

This result (11 chips) is also known as the *Barker code.* By transferring this calculated information (the chips) instead of the original bits, the standards make it possible to recover from interference problems. For example, if the receiver is missing some of the information due to corruption, it can still determine the value of the original bit. Imagine that the receiver has received 0???1000?11. The receiver will be able to infer the actual bit that was intended. How can it do this? Because only a 0 bit would have a chipping code that starts with a 0, then three values, then a 1000, then some value, and then an 11.

HR/DSSS Coding

CCK is used in HR/DSSS implementations such as IEEE 802.11b and is much more complicated than the processing gain used in IEEE 802.11 systems.

First, CCK uses a PN code that results in a processing gain of 8 instead of 11. This 8−chip sequence results in 1.375 million codes per second instead of the 1 million codes per second in DSSS systems.

Eleven million chips per second are processed by both DSSS and HR/DSSS, but HR/DSSS uses the shorter 8−chip PN code, and this provides the higher rate of total codes per second. Of course, with a higher rate of codes per second, you reduce the amount of resilience against interference.

This is why you can only maintain 11 Mbps when the two communicating devices are closer together, and that's why they fall back to lower data rates as they get farther apart. Increasing the chipping code size increases the resilience against interference.

The second difference between CCK and Barker sequencing is that CCK uses different PN codes for different bit sequences. Whereas the Barker sequence is always 10110111000, the CCK 8−chip sequence is calculated according to the data being encoded.

The data being encoded is encoded in 8−bit chunks at 11 Mbps and 4−bit chunks at 5.5 Mbps. There is a one−to−one relationship (complementary) that exists between every possible 8 bits of actual data and the 8−chip sequence that is calculated to represent that data. The same is true for the 4−bit data when it is encoded. Once the data is encoded with CCK, it is modulated onto the carrier signals, using DQPSK.

OFDM Coding

OFDM systems support a type of coding known as *convolution coding.* Convolution coding is not actually part of OFDM but is an IEEE 802.11a/g−supported forward error correction mechanism that provides error correction to OFDM communications.

Convolution coding adds extra information to the transmitted data that is comparable to the parity data used to provide fault tolerance in storage systems.

If an OFDM subcarrier is experiencing interference, the receiving device can regenerate the original data using the parity type information that has been added to the data before transmission.

To understand how convolution coding operates, consider the following situation. Imagine you want to store and send two numbers: the number 13 and the number 47.You would send the number 60 (47 + 13) along with these two numbers.

Now, assume the receiver is only able to receive the number 13 and the number 60 with a flag that informs the receiver that the number 60 is the recovery code. If the receiver knows the proper algorithm (recovery code−number received = number missing), it can regenerate the number 47 even though it did not properly receive that transmission.

This is an oversimplification, but it should help you understand how convolution coding works, particularly if you are not familiar with parity bits and storage based fault tolerance. As stated earlier, DSSS systems use a technique known as processing gain; the higher the processing gain, the lower the data rate, but the higher the interference resistance.

In convolution coding systems, higher convolution coding ratios (compared to the actual information) equal lower data rates and lower convolution coding ratios equal higher data rates.

Spectrum Fundamental Concepts

So far in this chapter, you've been introduced to the general concept of spread spectrum and the specific spread spectrum and other modulation techniques that are specified within the IEEE 802.11 standards and amendments. In this final section of the chapter we will cover:

- Dwell Time and Hop Time for FHSS Systems
- Carrier Frequencies, Channel Centers, and Widths
- Colocation
- Throughput Versus Data Rate
- Bandwidth
- Communication Resilience

Dwell Time and Hop Time

FHSS systems include characteristics that are not included in any of the other modulation and communication technologies used within the IEEE 802.11 standard or the amendments.

These characteristics include dwell time, hopping sequences, and hop time. These characteristics come together to make up how the FHSS system will function and the actual data throughput that will be available.

Dwell Time

The amount of time spent on a specific frequency in an FHSS hopping sequence is known as the *dwell time.* These channels, 1 MHz of bandwidth each, provide 79 optional frequencies on which to dwell for the specified length of the dwell time.

Hopping Sequence

The *hopping sequence* is the list of frequencies through which the FHSS system will hop according to the specified dwell time. This hopping sequence is also known as a hopping pattern or hopping set.

The IEEE 802.11 standard, section 14.6.5, states that 1 MHz channels should be used. These channels exist between 2.402 and 2.480 GHz in the United States and most of Europe.

Every station in a Basic Service Set must use the same hopping sequence. Every station must also store a table of all the hopping sequences that are used within the system.

These hopping sequences must have a minimum hop size of 6 MHz in frequency. In other words, if the device is currently communicating on the 2.402 GHz frequency, it must hop to 2.408 GHz at the next hop at a minimum.

Hop Time

The completion of any action oriented task, whether performed by a computer or a human, requires some duration of time. Since hopping from one frequency to another is an action, it takes some duration of time. The duration of time required to hop from one frequency in the hopping sequence to the next is called the *hop time.*

Hop times are measured in microseconds (μs) and are commonly rated at 200–300 μs. Even though these durations are drastically short, they can add up to an impacting amount of time, given enough hops over a long enough duration of time; however, many consider these small measures of time inconsequential.

The reality is that no station can transmit during the hop time; therefore, the hop time must be considered as overhead. This is where dwell times and hop times begin to impact one another.

A longer dwell time means fewer hops and therefore less overhead. This would lead you to think that an infinite dwell time would be best, since it would involve no hop time overhead; however, an infinite dwell time is effectively narrowband communications.

To prevent this, the FCC/EMEA specifies that a maximum dwell time of 400 ms per carrier frequency in any 30−second window must be enforced.

If you do the math, you will quickly see that you will need at least 75 hops in a hopping sequence to make the math work. For example, 100 ms dwell times multiplied by 75 hops equals 7500 ms, or 7.5 seconds. If you multiply 7.5 times 4 (to achieve a total of 400 ms), you end up with just over 30 seconds due to the inclusion of hop time overhead.

Unlike DSSS systems, FHSS systems do not use channels continually. The FHSS systems use hopping sequences across multiple carrier frequencies, and these carrier frequencies are also sometimes called channels. The carrier frequencies are 1 MHz wide in FHSS systems. This means that every carrier frequency is centered on a channel from 2.402 to 2.480 GHz.

DSSS

The IEEE 802.11 standard calls for use of the 2.4 GHz ISM band ranging from 2.400 to 2.497 GHz. In the United States and Europe, the range from 2.4000 to 2.4835 GHz is specified as the total frequency space available.

The DSSS channels are 22 MHz wide, and the center of each channel is spaced 5 MHz from the closest channels.

The benefit of using channel numbers as a reference point becomes clear when you begin to have discussions about network configuration and colocation issues. It is much easier to say that you are going to use channels 1, 6, and 11 to provide wireless coverage in a conference facility than to say you are going to tune your radio to 2.412 GHz on the first device, 2.437 GHz on the second device, and 2.462 GHz on the third device. HR/DSSS uses the same channel structure as DSSS.

OFDM

IEEE 802.11a and IEEE 802.11g both use OFDM modulation. The 5 GHz U−NII bands are used with IEEE 802.11a, and the 2.4 GHz ISM band is used with IEEE 802.11g.

OFDM−IEEE 802.11a The frequency bands specified in the IEEE 802.11a standard are

♦ 5.150—5.250 GHz−Lower U−NII Band
♦ 5.250—5.350 GHz−Middle U−NII Band
♦ 5.725—5.825 GHz−Upper U−NII Band

These bands are each divided into four nonoverlapping channels for a total of 12 nonoverlapping channels available to IEEE 802.11a devices.

Most consumer and SOHO devices use the lower and middle bands, which provide a total of eight channels in these devices.

Remember that OFDM uses subcarriers, so each of these channels will have 52 subcarriers that actually transmit the data. Additionally, the 52 subcarriers are 300 kHz each.

A brief investigation reveals that the IEEE 802.11a OFDM technology uses 20 MHz of spacing between each channel. You would also know that the channels are 20 MHz wide.

Colocation

Once you understand the channels used by the different IEEE 802.11–based technologies, you can begin to consider the colocation abilities of these systems. *Colocation* refers to the ability to place multiple devices in an environment so that they will cause little or no interference to each other.

While the recommendations put forth in the IEEE standards for colocation do still result in some low levels of interference, they provide a functional guideline for implementing WLAN technology.

FHSS

FHSS systems can be colocated by using hopping sequences that result in infrequent simultaneous channel usage.

In other words, the hopping sequences will be arranged in such a way that there are very few times, if any, where two different service sets are trying to dwell on the same channel.

When they do land on the same channel, the interference will only last the length of one dwell time.

DSSS

The maximum number of **nonoverlapping** service sets that can be created using DSSS technology is three. The center channel frequencies must be spaced by 25 MHz in order to be considered nonoverlapping by the IEEE standards.

The reality is that there is still some level of overlap, but the interference is so minimal that it is not considered in most installations. In North America and most of Europe, the three nonoverlapping channels that can be used in the same service area simultaneously are **1, 6, and 11.**

You might have noticed that the nonoverlapping channels are spaced by five channels. This results in the ability to have any two channels, spaced apart by five channel numbers, function in the same service area without detrimental interference. For example, you could use channel 3 and channel 8, or you could use channel 2 and channel 7.

Of course, a channel spread of more than five will also provide nonoverlapping channels. In fact, it would provide the lowest real levels of interference.

If you need only two channels and they are available, channels 1 and 11 would be ideal.

MOST CUSTOMER DEVICES COMES WITH CHANNEL 1 OR 6 ACTIVATED!
If you are using older DSSS technologies at 2 Mbps, you can only provide 6 Mbps of total speed in a service area.

OFDM

Thanks to the higher data rates in OFDM, you can provide much more total speed. IEEE 802.11g (ERP–OFDM) can use the same three nonoverlapping channels as DSSS systems and can provide a total of 163 Mbps. IEEE 802.11a can use all eight nonoverlapping channels in the lower and middle U–NII bands for an aggregate speed of 432 Mbps in a service area.

Colocation Technologies Compared

Ultimately, the technology you choose to implement will impact the throughput available to networking applications.

However, the decision is never as simple as choosing the technology with the highest data rate and highest number of colocated service sets. This is because some technologies will lower their data rates before others.

For example, IEEE 802.11a devices will throttle back to a lower data rate at a shorter distance than IEEE 802.11g devices. This is because the receiving device cannot detect the signal as easily at a greater distance.

IEEE 802.11a devices use shorter antennas and are able to "pick up" less of the RF signal at the same point in space as an IEEE 802.11g device. The result is that, at 150 feet from the access point, you may have more bandwidth available to your network applications with three IEEE 802.11g devices than you would with five to eight IEEE 802.11a devices.

In most modern network installations, the choice will be between IEEE 802.11a (OFDM) and IEEE 802.11g (ERP) devices; however, this will change in the next few years as the IEEE 802.11n standard is ratified and those devices begin to infiltrate the market. It is important, however, that you still understand the basic functionality of FHSS and DSSS systems and HR/DSSS systems.

The FHSS and DSSS systems are disappearing quickly in the WLAN market, but the HR/DSSS systems are still very widely deployed.

Throughput Versus Data Rate

It is very important to distinguish between throughput and data rate. The data rate of a WLAN system is a component of the entire bandwidth that is available for communications between WLAN devices.

Much of this bandwidth and the time usage of the same is consumed by WLAN management data and redundant data in the WLAN signals. Because of this, the throughput of the system is always lower than the data rate.

Defined, *data rate* is the measurement of the total amount of data that can be transferred through the system, including intentionally transferred data and overhead data.

Throughput is defined as the amount of useful information that can be intentionally transferred through the system.

To make it simple, if you transfer a 50KB Microsoft Word document from one computer to another across a WLAN, much more than 50KB of network traffic will be generated. While the data rate may be 54 Mbps, you may find that throughput is as low as 20 to 28 Mbps.

Bandwidth

In the wireless world, *bandwidth* refers to the frequency space made available to the networking devices.

For example, an IEEE 802.11g channel is 22 MHz wide, so it has 22 MHz of bandwidth. However, it is not uncommon to hear the word "bandwidth" used to refer to the amount of "space" available for data transfer.

For example, it is common for many networking professionals to say they have 10 Mbps of bandwidth available on their network. This seems to have evolved over the years from an understanding that if you have more bandwidth (more frequency space), you can transfer more information.

This is true, in general; however, it is often better to refer to bandwidth in its most absolute sense, and that is the width of the frequency band that you are using, and then refer to data rates and throughput for the rest.

Communication Resilience

When it comes to communication resilience, FHSS and OFDM systems currently provide the best resistance to interference.

All of the technologies covered in this chapter provide some level of resilience, but the higher data rates and colocation abilities tend to make OFDM−whether in IEEE 802.11a or IEEE 802.11g−more appealing at this time.

FHSS is the most resilient but has the lowest data rates, being equal to the original DSSS. OFDM has the second highest level of resilience and the highest data rates while we wait for HT−OFDM in IEEE 802.11n.

Summary

PHY	Data Rates	Frequency Band	IEEE Standards Introducing the Technology	Maximum Colocated WLANs	Max Total Data Rate in a Service Area
FHSS	1 or 2 Mbps	2.4 GHz ISM	IEEE 802.11−1997	79 max, 12 practical	158 Mbps max, 24 Mbps practical
DSSS	1 or 2 Mbps	2.4 GHz ISM	IEEE 802.11−1997	2 or 3	6 Mbps
HR/DSSS	1, 2, 5.5, or 11 Mbps	2.4 GHz ISM	IEEE 802.11b−1999	3	33 Mbps
ERP	1, 2, 5.5, 11, 6, 9, 12, 18, 24, 36, 48, or 54 Mbps	2.4 GHz ISM	IEEE 802.11g−2003	3	162 Mbps
OFDM	6, 9, 12, 18, 24, 36, 48, or 54 Mbps	5 GHz U−NII	IEEE 802.11a−1999	19 in consumer or SOHO, 23 total	648 Mbps

Review Questions

1. In order to implement multiple WLANs in the same location using HR/DSSS systems, how many channels must separate the WLANs?

A. 1
B. 5
C. 6
D. 11

2. OFDM modulation techniques are applied at what layer of the OSI model?

A. Layer 4
B. Layer 2
C. Layer 6
D. Layer 1

3. If you were to install five OFDM WLANs in the same location, what aggregate data rate would be available to the service area, assuming the highest data rate could be achieved in each WLAN?

A. 55 Mbps
B. 10 Mbps
C. 270 Mbps
D. 128 Mbps

4. Which modulation technique is used by DSSS systems communicating at 2 Mbps?

A. DQPSK
B. DBPSK
C. 16−QAM
D. 64−QAM

5. How many channels are specified for use with DSSS?

A. 14
B. 12
C. 11
D. 8

6. How many channels are specified for use by the IEEE in the lowest two U−NII bands for OFDM technologies?

A. 4
B. 8
C. 11
D. 14

7. FHSS systems use what frequency range within the 2.4 GHz ISM band?

A. 2.400–2.4835 GHz
B. 2.400–2.485 GHz
C. 2.401–2.480 GHz
D. 4.435–2.485 GHz

8. If an IEEE HR/DSSS device is used, what are the supported data rates? (Choose all that apply.)

A. 54 Mbps
B. 11 Mbps
C. 2 Mbps
D. 36 Mbps

9. How many subcarriers are used in each OFDM channel to transmit data?

A. 14
B. 12
C. 52
D. 54

Answers

1. C. Six channels of separation are required for HR/DSSS systems, and 5 channels are required for DSSS systems.

2. D. The correct answer is Layer 1. The Physical layer is where wireless modulation takes place, and therefore, this is where OFDM modulation occurs.

3. C. The correct answer is 270 Mbps. Since there are five service sets communicating at 54 Mbps each, the aggregate would be 270 Mbps for the data rate.

4. A. The correct answer is DQPSK. DBPSK is used for 1 Mbps DSSS communications, and 16−QAM/64−QAM is used with OFDM technologies.

5. A. The correct answer is 14. While only 11 channels are used in North America, due to FCC regulations, 14 channels are specified in the standard.

6. B. The correct answer is 8. There are 12 total channels specified for IEEE 802.11a technologies. Four channels are specified in each of the three bands: lower, middle, and upper. There is also a fourth band, but the IEEE standards do not yet utilize it. This results in eight channels being available in the lower and middle bands.

7. A. The correct answer is 2.400−2.4835 GHz. FHSS systems use 1 MHz of bandwidth for each of 79 channels, starting with the first channel at 2.402 GHz and moving up sequentially to 2.480 GHz, but they exist within the boundaries of 2.400−2.4835 GHz.

8. B, C. The correct answers are 11 Mbps and 2 Mbps. IEEE 802.11b supports data rates of 11, 5.5, 2, and 1 Mbps. The data rates of 36 and 54 Mbps are supported by IEEE 802.11g and IEEE 802.11a technologies.

9. C. The correct answer is 52. Fifty−two subcarriers are used within each of the 12 OFDM channels used by IEEE 802.11a in the U−NII bands. Fifty−two subcarriers are also used within each of the 11 OFDM channels used by IEEE 802.11g in the ISM band. Only 48 of the 52 carry actual data.