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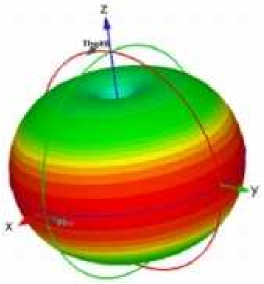
Seminar 2

Physics of 802.11 wireless networks



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Abstract

This document describes the basic physics principles of 802.11 networks. It will cover the theoretical aspects such as Maxwell equations of electromagnetic fields as well as the practical implementation of these concepts when building 802.11 networks. In everyday usage of 802.11 wireless networks the approach is mostly empirical and the physical concepts are most of the time hidden. The purpose of this document is to shed some light into these concepts as to help the wireless LAN engineer better understand the behavior of the network.

Contents

1 Introduction

802.11 wireless networks use electromagnetic waves to transmit data between devices. These waves are best described by Maxwell equations. There's a wide spectrum of EM waves that includes visible light, infrared, ultraviolet and radio waves among other. Inside this spectrum in the radio band we find some unlicensed bands that are available to everybody for any type of usage. This unlicensed part of the radio spectrum is used by 802.11 networks.

There are many protocols that regulate 802.11 data transmission. These protocols are developed and ratified by the IEEE organization and help manufacturers build devices that can communicate with each other. These protocols dictate the frequency bands used, modulation, security algorithms, data rates, etc. The most widely know protocols of this family are 802.11b, 802.11g and 802.11a which allow a maximum data rate of 54Mbps. A new protocol is being developed know as 802.11n which could provide for 10 times faster connections. In 802.11b, g and a protocols we use 2 types of modulation techniques: direct sequence spread spectrum (DSSS) and orthogonal frequency division multiplexing (OFDM). DSSS is used for slower data rates that are described by 802.11b and OFDM for the higher data rates introduced by 802.11g and a.

The way we transmit data from the wired network to the wireless client is by using a device called access point. An access point has a transmitter and antennas that actually bridge the signal to the air. Antennas have the task of transmitting the data to the client. For this task antennas are optimized to cover the maximum area possible. Some antennas radiate in all directions equal (omnidirectional) and others have a distinct directional pattern. The most common type of antenna we encounter is the dipole which is omnidirectional. A very good example of directional antennas is the Yagi antenna which is used for both indoor and outdoor deployment. While antennas try to transmit the signal as far as possible to the client we also encounter many barriers: attenuation, multipathing and interference. Sometimes these obstacles can be eliminated by a good implementation of the network but not always.

2 Electromagnetism

Maxwell equations are the basis for understanding all electromagnetic phenomena. All electrical and electronic devices available today are possible because we have these basic physics concepts to help us. Maxwell equations explain the relation between electric and magnetic field. In wireless networks, apart from the electronics involved, these equations explain the phenomena of electromagnetic waves that make wireless communications possible.

2.1 Maxwell equations

Maxwell equations are the core of 802.11 wireless technology. We will write them in their differential form:

$$\nabla \cdot \vec{D} = \rho \qquad (1) \qquad\qquad \nabla \cdot \vec{B} = 0 \qquad (3)$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad (2) \qquad\qquad \nabla \times \vec{H} = \vec{j} + \frac{\partial \vec{D}}{\partial t} \qquad (4)$$

In these equations we have the following quantities:

$\vec{E}$: electric field intensity

$\vec{D}$: electric field density

$\vec{H}$: magnetic field intensity

$\vec{B}$: magnetic field density

ρ : electric charge density

j : electric current density

We also know the relation between intensity and density for both fields:

$$\vec{D} = \varepsilon \varepsilon_0 \vec{E} \qquad (5)$$

$$\vec{B} = \mu\mu_0\vec{H} \tag{6}$$

2.2 Electromagnetic waves

From the Maxwell equations and with the condition that $\rho = 0$ and $\vec{j} = 0$ we can derive the wave equations for the electrical and magnetic fields in matter.

$$\nabla^2\vec{E} = \varepsilon\varepsilon_0\mu\mu_0\frac{\partial^2\vec{E}}{\partial t^2} \tag{7}$$

$$\nabla^2\vec{B} = \varepsilon\varepsilon_0\mu\mu_0\frac{\partial^2\vec{B}}{\partial t^2} \tag{8}$$

We see that the speed with which the electromagnetic wave propagates in matter is c where $c^2 = (\varepsilon\varepsilon_0\mu\mu_0)^{-1} = c_0^2/n^2$. Here $c_0 = (\sqrt{\varepsilon_0\mu_0})^{-1}$ is the speed of the wave in vacuum also know as the speed of light and $n = \sqrt{\varepsilon\mu}$ is the index of refraction.

The general solution for these equations is a superposition of plane waves:

$$\vec{E}(\vec{r},t) = \sum_{\vec{k},\omega}\vec{E}_0(\vec{k},\omega)e^{i(\vec{k}\cdot\vec{r}-\omega t)} \tag{9}$$

$$\vec{B}(\vec{r},t) = \sum_{\vec{k},\omega}\vec{B}_0(\vec{k},\omega)e^{i(\vec{k}\cdot\vec{r}-\omega t)} \tag{10}$$

where $\omega^2 = k^2c^2$.

From the above equations we can deduce the following relation:

$$\vec{k}\times\vec{E}_0(\vec{k},\omega) = -\omega\vec{B}_0(\vec{k},\omega) \tag{11}$$

This is the most important property to remember about the EM wave: the vectors $\vec{E}$, $\vec{B}$ and $\vec{k}$ are all perpendicular to each other (figure 1). The wave propagates in the direction of vector $\vec{k}$ with speed c. The EM wave can be characterized by its frequency ν or wavelength λ: $c = \frac{\omega}{k} = \frac{\omega}{2\pi}\frac{2\pi}{k} = \nu\lambda$

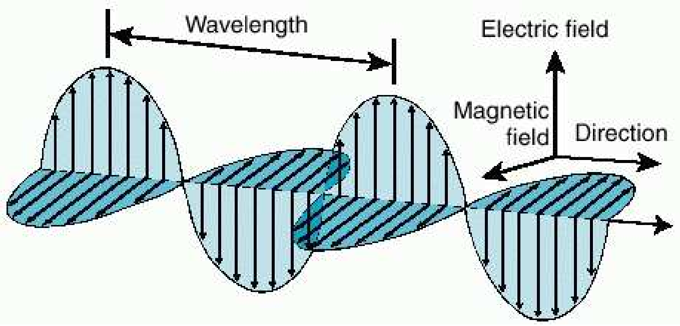


Figure 1: The EM wave

3 The electromagnetic spectrum

802.11 networks use electromagnetic waves with a specific frequency. The EM spectrum ranges from the very low (long radio waves) to the very high frequencies (gamma rays)(figure 2). The frequency band from 3kHz up to 300GHz is called the Radio wave band or RF band (figure 3). 802.11 networks use EM waves with frequencies from this part of the spectrum.

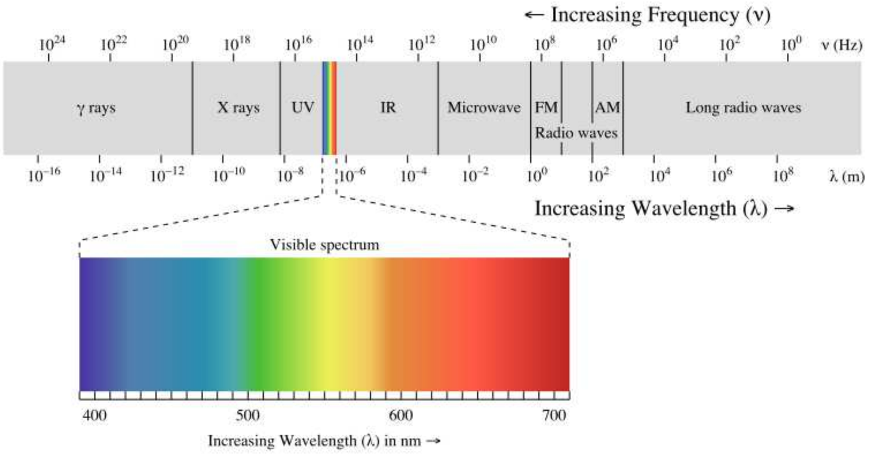


Figure 2: The electromagnetic spectrum [5]

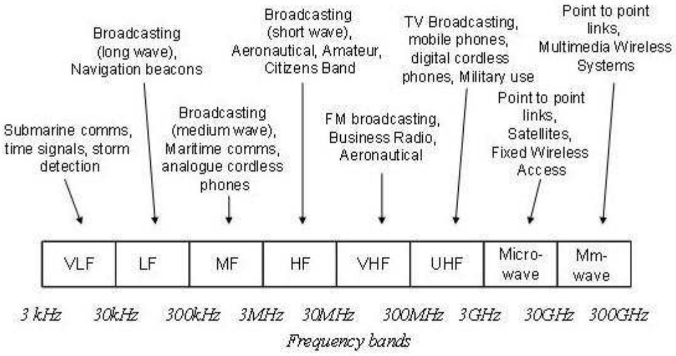


Figure 3: The RF band and its usage [5]

The RF band is not completely open for use by any individual or vendor. Most of the RF band is licensed and anybody who wishes to use these frequencies needs to apply for a license. Examples of this are the broadcast license and WiMAX license.

There are three unlicensed bands: 900 MHz, 2.4 GHz, and 5.7 GHz (figure 4). Frequencies for these bands are as follows:

- 900-MHz band: 902. to 928. MHz
- 2.4-GHz band: 2.400 to 2.483 GHz (in Japan extends to 2.495 GHz)
- 5-GHz band: 5.150 to 5.350 MHz, 5.725 to 5.825 MHz, with some countries supporting middle bands between 5.350 and 5.825 MHz.

802.11 networks use frequencies that are unlicensed. Vendors can therefore design products that use these frequencies and users can freely build networks. This freedom however comes at a price because anybody can use these frequencies for any purpose. Networks using unlicensed frequency bands are susceptible to interference from a variety of sources. 802.11b/g networks operate in the 2.4GHz band and the most common sources of interference for these networks are microwave ovens, cordless phones and bluetooth devices. 802.11a networks operate in the 5GHz band which is also used by satellites and radars. In this last case a protocol (802.11h) was created to avoid interference from 802.11a with radar transmissions.

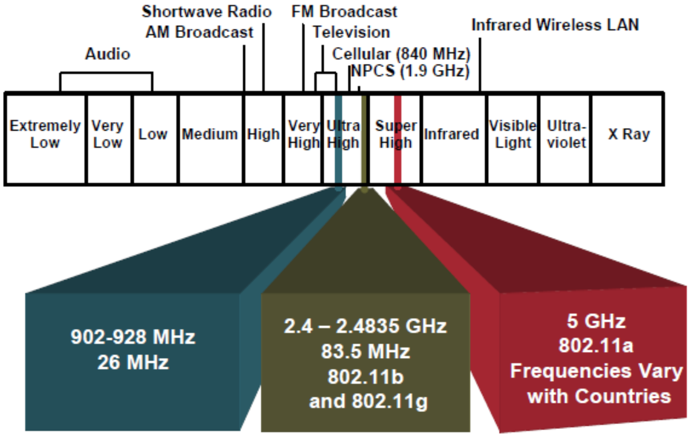


Figure 4: Unlicensed frequency bands [1]

4 802.11 protocols

In the world of networking a protocol is a set of rules that determine the format and transmission of data. A protocol defines all aspects necessary for devices to communicate without problems. These can include physical properties (voltage, power, frequencies, etc.), logical interpretation of signals (number of bits, fields in a packet, etc) and behaviour of devices (retries, beacons, etc). 802.11 wireless networks comprise a wide set of protocols that regulate them. I will briefly discuss the most important protocols of this set.

4.1 802.11b and 802.11g

As mentioned before these protocols use the 2.4 GHz frequency band. 802.11b allows a maximum troughput of 11 Mbps and was ratified by the IEEE organization in 1999 (for more information about IEEE you can visit www.ieee.com). 802.11g allows a maximum troughput of 54 Mbps and was ratified in 2003. Keep in mind that the wireless network is a shared medium and only one device can speak at a time. 802.11g defines backward compatibility with 802.11b devices which means that a network can include both types of devices. The maximum transmit power output allowed for a device is 100mW. According to these protocols the 2.4 GHz frequency band is divided into channels. Each of these channels is 22 MHz wide. In North America (FCC regulation) there are 11 allowed channels, in Europe (ETSI regulation) there are 13, in Japan there are 14. However not all of these channels can be used simultaneously. Only three channels are non-overlapping (figure 5). If we use three 802.11g access points each on a different channel we can get a troughput of 162 Mbps. In a larger environment with many transmitters we can minimize interference between them by assigning different channels to adjacent units.

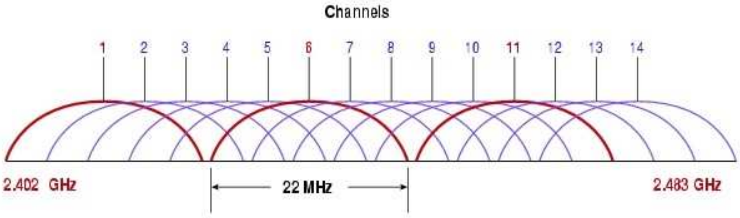


Figure 5: 802.11b and 802.11g channels [1]

4.2 802.11i

This protocol dictates only security rules. The protocol includes among other algorithms for authentication of devices and encryption of data. This protocol is also know as WPA2 (Wi-Fi Protected Access 2).

4.3 802.11a

This protocol uses the 5 GHz frequency band. It provides the same maximum troughput as 802.11g (54 Mbps) and was ratified by the IEEE in 1999. Regulations for 802.11a vary from country to country since this frequency band is used by military, radars, satellites, etc. Some countries don't allow 802.11a networks while others limit the usage to only some channels. The 5GHz unlicensed band is divided into 3 frequency bands: UNII-1, UNII-2 in UNII-3 (figure 6). 802.11a divides each of these bands into four non-overlapping channels which gives a total of 12 channels. By ETSI standards only UNII-1 and UNII-2 channels are allowed. The total bandwidth we can achieve using 8 access points is 648 Mbps.

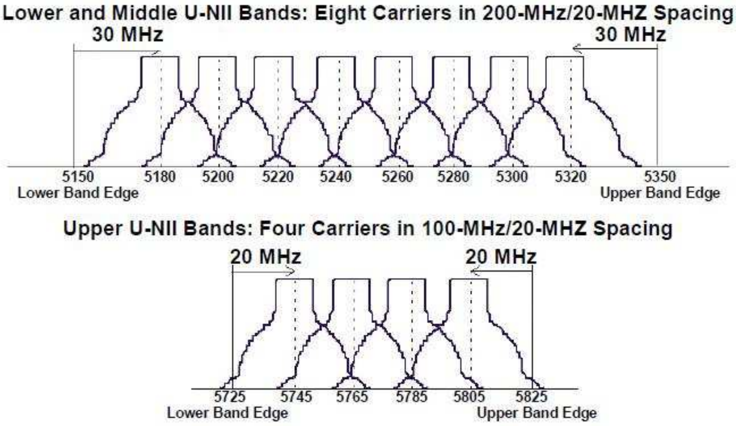


Figure 6: 802.11a channels [1]

4.4 802.11n

This is the latest protocol being developed by the IEEE. It's the next step regarding data troughput. Although many manufacturers claim to have 802.11n compliant products the actual protocol has not yet been ratified. The currently available devices are 802.11n draft 1 or 2 compliant only. The protocol allows for a maximum of 600 Mbps troughput depending on the implementation. This protocol will include the following improvements:

- Use of both 2.4 GHz and 5 GHz frequency bands.
- Channel bonding which agregates two 20 MHz channels into one 40 MHz channel. This allows for a higher data rate but decreases the number of channels available.
- MIMO (multiple input multiple outpu) technology which utilizes multipath signals to the advantage of the wireless network. In a non-MIMO based 802.11a/b/g network, multipath signals were perceived as interference degrading a receiver's ability to recover the message information in the signal. MIMO uses the multipath signal's diversity to increase a receiver's ability to recover the message information from the signal. With MIMO the signal is transmited by multiple antennas and received also by multiple antennas.

5 How is data transmitted?

Now that we know what type of waves are used in 802.11 networks the following questions arise: how is data transmitted over the EM waves? what determines the throughput we can achieve? how does noise influence the transmission? how does the network handle the loss of bits? The answer to these questions is modulation. Different types of modulations achieve different data rates.

As a receiver moves farther from a transmitter, the signal gets weaker, and the difference between the signal and noise decreases. At some point, the signal cannot be distinguished from the noise, and loss of communication occurs. The amount of compression (or modulation type) at which the signal is transmitted determines the amount of signal necessary to be clearly received through the noise. As transmission or modulation schemes (compression) become more complex and data rate goes up, immunity to noise decreases, and coverage goes down. In 802.11 networks when the signal becomes too weak to receive data at a given data rate the transmitter switches to a slower connection. However at some point even the slowest data rate (1 Mbps) can not be sustained and connection is lost.

5.1 Modulation

There are many types of modulation techniques that are used to compress data. This is because there are many ways in which the EM wave can be modulated (figure 7).

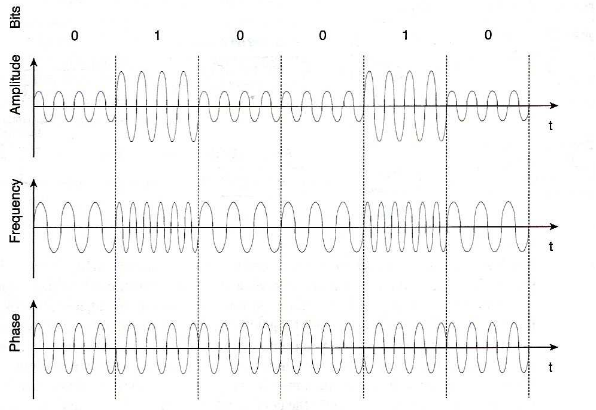
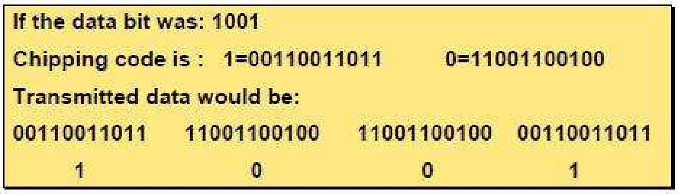


Figure 7: Modulation examples [4]

5.1.1 DSSS

802.11b protocol uses DSSS (Direct Sequence Spread Spectrum) modulation techniques. Spread-spectrum techniques take a modulation approach that uses a much higher than necessary spectrum bandwidth to communicate information at a much lower rate. Each bit is replaced or spread by a wideband spreading code. This modulation has the ability to operate in low signal-to-noise ratio (SNR) conditions. The spreading sequence converts a data bit into chips (figure 8). This results in greater immunity to radio frequency interference. A feature of these codes is that the receiver could actually miss several bits and the software would still be able to identify that the code was intended to be a 1 or a 0. If there were an interfering signal, the unit would still be able to get the data through without loss of data or reduction in throughput or performance.



If the data bit was: 1001

Chipping code is : 1=00110011011 0=11001100100

Transmitted data would be:

00110011011	**11001100100**	**11001100100**	**00110011011**
1	**0**	**0**	**1**

Figure 8: Spreading or chipping sequence [1]

Example: A bit received that was a 01111011011 would, when compared to a 1, be two bits different. Compared to a 0, it would be 9 bits different. Therefore, that received bit should represent a 1. More than 5 data bits would have to be inverted to change the value, which means that more than half the signal would have to be lost before the original message would be impossible to reconstruct.

Each data bit becomes a string of chips (chipping sequence) transmitted in parallel across a wide frequency range. The chips are spread over the frequency band which in this case is 22 MHz wide (figure 9).

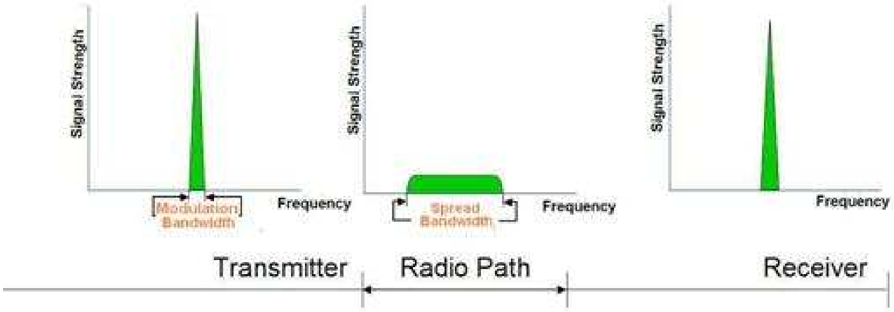


Figure 9: Direct Sequence Spread Spectrum [12]

The modulator converts the spread binary signal into an analog waveform through the use of different modulation types, depending on which data rate is chosen:

- Binary Phase Shift Keying (BPSK): BPSK uses one phase to represent a binary 1 and another to represent a binary 0 for a total of two bits of binary data. This technique is used to transmit data at 1 Mbps.
- Quadrature Phase Shift Keying (QPSK): With QPSK, the carrier undergoes four changes in phase and can thus represent four binary bits of data. This technique is used to transmit data at 2 Mbps.
- Complementary Code Keying (CCK): CCK uses a complex set of functions known as complementary codes to send more data. One of the advantages of CCK over similar modulation techniques is that it suffers less from multipath distortion. This technique is used to transmit data at 5.5 and 11 Mbps.

5.1.2 OFDM

Orthogonal Frequency Division Multiplexing is the modulation technique used by 802.11a and 802.11g. OFDM works by breaking one high-speed data carrier into several lower-speed sub-carriers, which are then transmitted in parallel. Each high-speed carrier is 20 MHz wide and is broken up into 52 subchannels, each approximately 300 kHz wide. OFDM uses 48 of these subchannels for data, while the remaining four are used for error correction (figure 10).

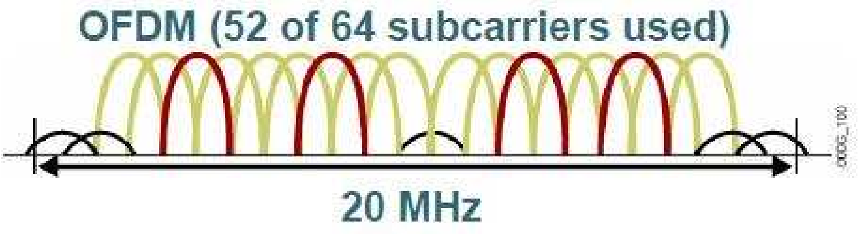
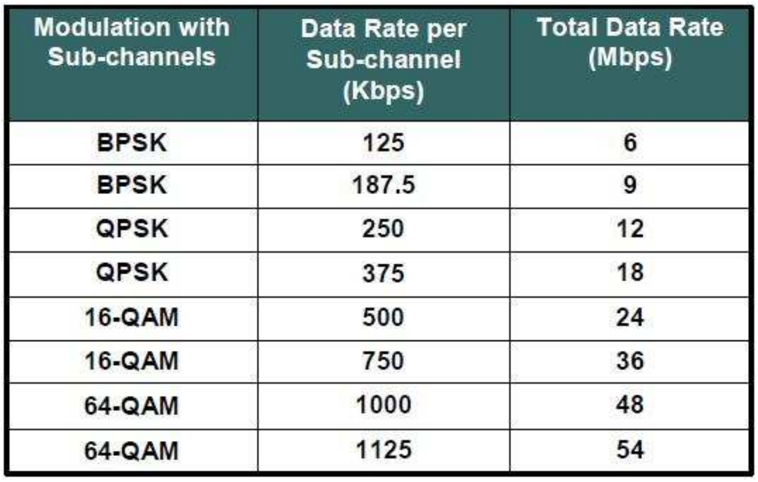


Figure 10: Orthogonal Frequency Division Multiplexing [1]

Each sub-channel in the OFDM implementation is about 300 kHz wide. At the low end of the speed gradient, BPSK is used to encode 125 kbps of data per channel, resulting in a 6000-kbps, or 6-Mbps, data rate. Using QPSK, you can double the amount of data encoded to 250 kbps per channel, yielding a 12-Mbps data rate. And by using 16-state quadrature amplitude modulation (16-QAM) encoding 4 bits per cycle, you can achieve a data rate of 24 Mbps. The 802.11a standard specifies that all 802.11a-compliant products must support these basic data rates. The standard also lets the vendor extend the modulation scheme beyond 24 Mbps. Data rates of 54 Mbps are achieved by using 64-state quadrature amplitude modulation (64-QAM), which yields 8 bits per cycle or 10 bits per cycle, for a total of up to 1.125 Mbps per 300-kHz channel. With 48 channels, this results in a 54-Mbps data rate 11. Remember, the more bits per cycle (hertz) that are encoded, the more susceptible the signal is to interference, and ultimately the shorter the range, unless power output is increased.



Modulation with Sub-channels	Data Rate per Sub-channel (Kbps)	Total Data Rate (Mbps)
BPSK	125	6
BPSK	187.5	9
QPSK	250	12
QPSK	375	18
16-QAM	500	24
16-QAM	750	36
64-QAM	1000	48
64-QAM	1125	54

Figure 11: OFDM subchannel modulation types [1]

802.11g uses both DSSS and OFDM modulation for backward compatibility with 802.11b devices. It uses OFDM for 802.11g data rates (54, 48, 36, 24, 18, 12, 9, and, 6 Mbps) and DSSS for 802.11b data rates (11, 5.5, 2, and, 1 Mbps).

6 802.11 antennae

The most vital piece of equipment in a 802.11 network is the **access point**. This is the device that serves as a bridge between the wireless and the wired network. It has all the logic and the transmitter necessary for radiating the EM waves. The architecture of an access point itself will not be covered in this document. The radiating element of an access point are the antennas attached to it. In this section we will discuss common antennae and their properties.

6.1 Basic Definitions

We often define antennae and antenna terminology in terms of a transmitting antenna, but all the definitions apply to receiving antennae as well. In fact, an antenna's properties are the same in either operating mode. This is true because Maxwell's equations are symmetric with respect to time.

When reading antenna specifications the most common unit we find is dB $= 10\log_{10}\frac{P_1}{P_0}$. The three dB units we usually encounter are:

- dBm where we compare power to 1mW
- dBi where antenna gain is compared with an isotropic radiator
- dBd where antenna gain is compared to a dipole antenna

Antenna gain is the amount of increase in energy that an antenna *appears* to add to an RF signal. The gain of an antenna (in any given direction) is defined as the ratio of the power gain in a given direction to the power gain of a reference antenna in the same direction. It is standard practice to use an isotropic radiator as the reference antenna in this definition. To convert any number from dBd to dBi, simply add 2.14 to the dBd number. Note that when a single number is stated for the gain of an antenna, it is assumed that this is the maximum gain (the gain in the direction of the maximum radiation).

In RF, you have to give up something to gain something else. In antenna gain, this comes in the form of coverage angle, known as beamwidth. Beamwidth is defined as the area or angle in which the majority of the signal is transmitted. As the gain of an antenna goes up, the beamwidth angle goes down, allowing further distances to be achieved (at the expense of other directions).

The **3-dB beamwidth** (or half-power beamwidth) of an antenna is typically defined for each of the principal planes. The 3-dB beamwidth in each plane is defined as the angle between the points in the main lobe that are down from the maximum gain by 3 dB. This is shown in figure 14 in the following section. The 3-dB beamwidth in the plot in this figure is shown as the angle between the two blue lines in the polar plot. In this example, the 3-dB beamwidth in this plane is about 37 degrees. Antennae with wide beamwidths typically have low gain and antennae with narrow beamwidths tend to have higher gain. Remember that gain is a measure of how much of the power is radiated in a given direction. So an antenna that directs most of its energy into a narrow beam (at least in one plane) will have a higher gain.

Most antennae available are described as **vertically polarized**. This means that the EM wave is linearly polarized and the electric field is oriented vertically if the antenna is placed upright. Some antennae have markings showing in which direction the wave is polarized and therefore how the antenna should be mounted. Antennae with the same polarization provide the best transmission/reception path. When mounting antennae we need to be careful about orientation to avoid placing the transmitting and receiving antennae with perpendicular polarizations.

6.2 Isotropic antenna

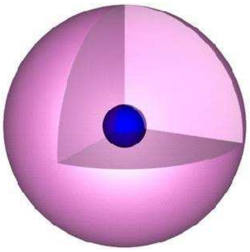


Figure 12: The theoretical isotropic antenna [13]

All antennae are measured against what is known as an isotropic antenna, which is a theoretical antenna. This is the basis for all other antennae. The coverage of an isotropic antenna extends in all directions equally. It has a perfect 360° vertical and horizontal beamwidth.

6.3 Antenna patterns

The radiation pattern or antenna pattern is the graphical representation of the radiation properties of the antenna as a function of space. That is, the antenna's pattern describes how the antenna radiates energy out into space (or how it receives energy). It is important to state that an antenna radiates energy in all directions, at least to some extent, so the antenna pattern is actually three-dimensional. It is common, however, to describe this 3D pattern with two planar patterns, called the principal plane patterns. These principal plane patterns can be obtained by making two slices through the 3D pattern through the maximum value of the pattern or by direct measurement. It is these principal plane patterns that are commonly referred to as the antenna patterns.

In discussions of principal plane patterns or even antenna patterns, you will frequently encounter the terms **azimuth** plane pattern and **elevation** plane pattern. The term azimuth is commonly found in reference to "the horizontal" whereas the term elevation commonly refers to "the vertical". When used to describe antenna patterns, these terms assume that the antenna is mounted (or measured) in the orientation in which it will be used. In figure 13, the x-y plane ($\theta = 90°$) is the azimuth plane. The elevation plane is then a plane orthogonal to the x-y plane, say the y-z plane ($\phi = 90°$). The antenna patterns (azimuth and elevation plane patterns) are frequently shown as plots in polar coordinates. This gives the viewer the ability to easily visualize how the antenna radiates in all directions as if the antenna was mounted already.

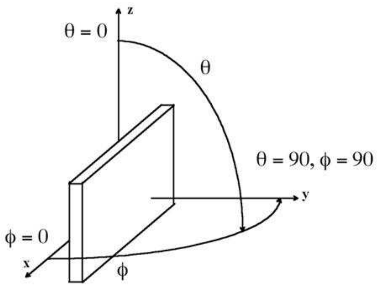
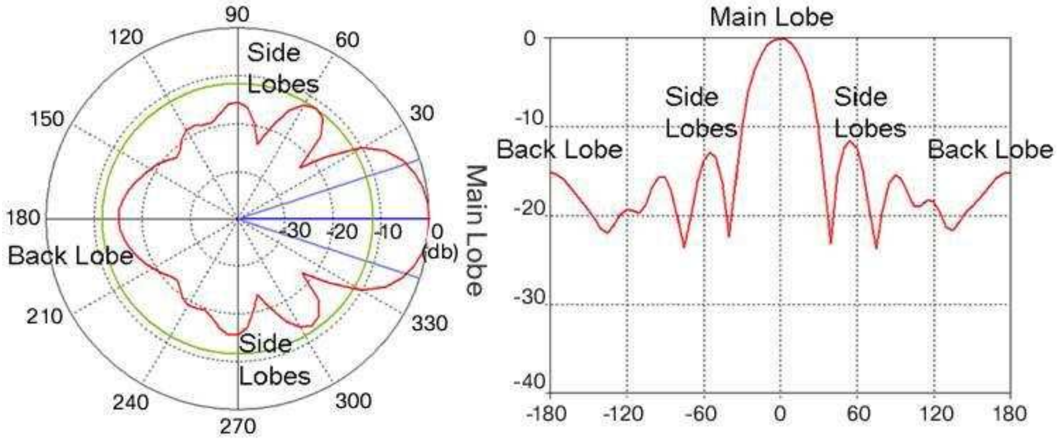


Figure 13: Antenna measurement coordinate system [10]

In figure 14 we can see two different representations of radiation patterns. The quantity plotted is antenna gain in all directions with respect to the maximum gain (at 0°). The figure shows the different lobes of the antenna as well as the 3dB-beamwidth.



(a) Pattern in Polar Coordinates

(b) Pattern in Cartesian Coordinates

Figure 14: Radiation patterns [10]

6.4 Antenna types

There are many different types of antennae. In this section I will describe some of the most common antennae used in 802.11 networks.

(b) Ceiling Mount Omni

(c) Yagi

(a) Dipole

(e) Patch

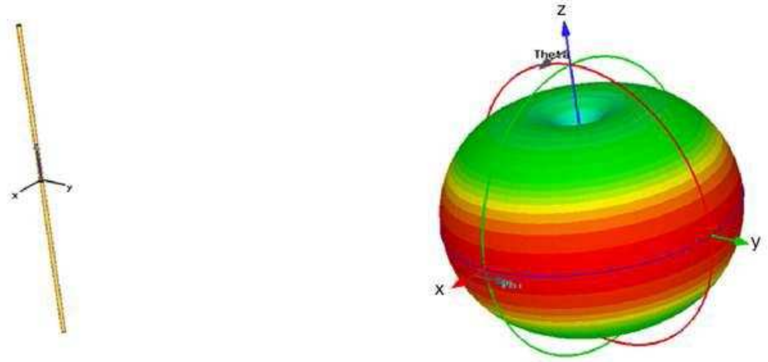
(d) Diversity Patch

Figure 15: Various antennae commonly found in WLAN systems [10]

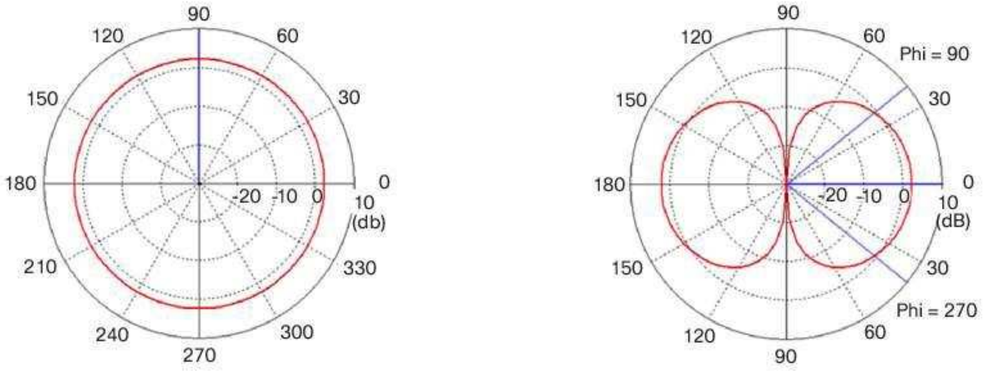
6.4.1 Dipole

A dipole antenna most commonly refers to a half-wavelength ($\lambda/2$) dipole. The physical antenna (not the package that it is in) is constructed of conductive elements whose combined length is about half of a wavelength at its intended frequency of operation. This is a simple antenna that radiates its energy out toward the horizon (perpendicular to the antenna). The patterns shown in figure 16 are those resulting from a perfect dipole formed with two thin wires oriented vertically along the z-axis. The resulting 3D pattern looks kind of like a donut or a bagel with the antenna sitting in the hole and radiating energy outward. The strongest energy is radiated outward, perpendicular to the antenna in the x-y plane. The azimuth plane pattern is formed by slicing through the 3D pattern in the horizontal plane, the x-y plane in this case, just as you would slice through a bagel. Notice that the azimuth plane pattern is non-directional, that is, the antenna radiates its energy equally in all directions in the azimuth plane. The dipole antenna is therefore **omnidirectional**. The elevation plane pattern is formed by slicing the 3D pattern through an orthogonal plane (either the x-z plane or the y-z plane).

The gain of the half-wave dipole is approximately 2.2 dBi. The value of 2.2 dBi is achieved at the horizon in the elevation plane and everywhere in the azimuth plane. Note that the azimuth plane pattern is a circle passing through the gain value of 2.2 dBi at all angles. From the elevation plane pattern we see that the dipole antenna has an elevation plane beamwidth of 78-degrees as indicated on the pattern in figure 16-d by the two blue lines. Given these antenna patterns, you can see that a dipole antenna should be mounted so that it is vertically oriented with respect to the floor or ground. This results in the maximum amount of energy radiating out into the intended coverage area. The null in the middle of the pattern will point up and down. Indoors, this typically is not a concern because of the close proximity of the ceiling and all the multipath present in the indoor environment.



(a) Dipole Antenna Model (b) Dipole 3D Radiation Pattern



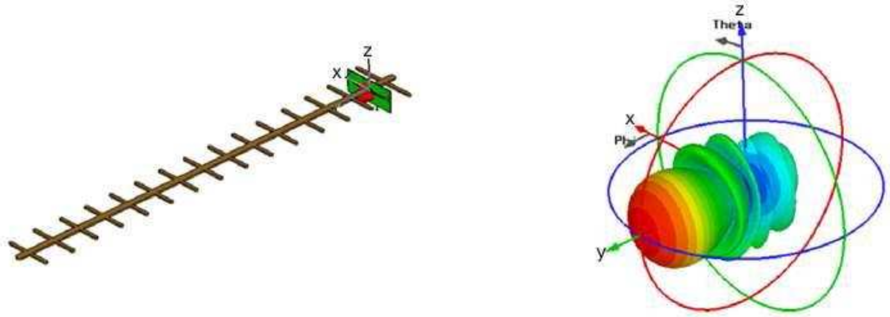
(c) Dipole Azimuth Plane Pattern (d) Dipole Elevation Plane Pattern

Figure 16: Dipole antenna and its patterns [10]

6.4.2 Yagi

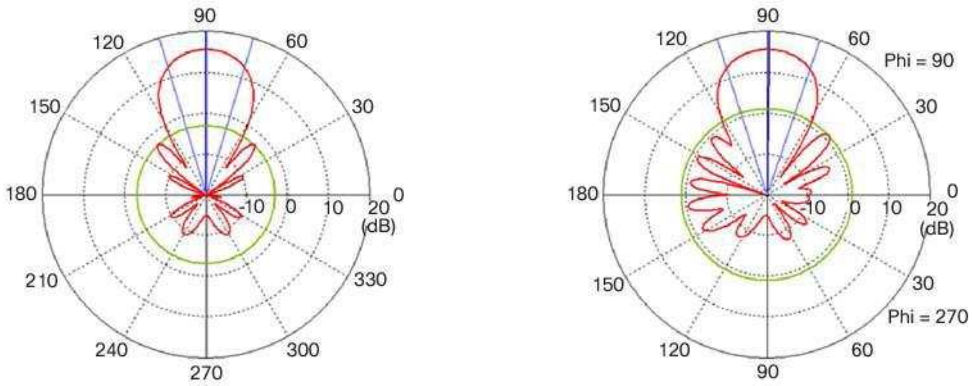
Directional antennas are used for coverage as well as point-to-point links. They can be patch antennas, dishes, horns or a whole host of other varieties. They all accomplish the same goal: radiating their energy out in a particular direction. One example of this is the Yagi antenna (named after Hidetsugu Yagi which co-invented the antenna together with Shintaro Uda).

A Yagi antenna is formed by driving a simple antenna, typically a dipole or dipole-like antenna, and shaping the beam using a well-chosen series of non-driven elements whose length and spacing are tightly controlled. The Yagi shown here in figure 17 is built with one reflector (the bar behind the driven antenna) and 14 directors (the bars in front of the driven antenna). This configuration yields a gain of about 15 dBi with azimuth and elevation plane beamwidths that are basically the same, around 36 degrees. That is a common feature of Yagi antennas. Many times these antennas are designed so that they can be rotated for either horizontal or vertical polarization, so having the same 3-dB beamwidth in each plane is a nice feature in those instances.



(a) Yagi Antenna Model

(b) Yagi Antenna 3D Radiation Pattern



(c) Yagi Antenna Azimuth Plane Pattern

(d) Yagi Antenna Elevation Plane Pattern

Figure 17: Yagi antenna and its patterns [10]

7 Signal degradation

All types of wireless networks experience signal degradation. There are many reasons why a signal that travels from a transmitter to a receiver loses its signal strength. Since a signal from an antenna radiates in all directions we lose power first of all due to the distance between the transmitter and the receiver. The power radiated by the transmitter is dissipated in all directions. In an ideal isotropic antenna this means that the power of the signal falls as $1/r^2$ where r is the distance to the transmitter. In a real antenna we find some directions with higher gain and in those directions the power is higher than in an isotropic antenna. But still the power falls with distance. This is something that can't be avoided. We trade antenna gain for coverage which simply means that some antennas will have better range. The level of the signal is usually know as RSSI (Radio Signal Strength Indicator) (figure 18).

There are however other causes for power loss and signal degradation that can be avoided or at least mitigated. The most common quantity we use to determine how good the signal is at a given point is the SNR (signal to noise ratio) (figure 18). With higher data rates and more complex modulation techniques we need a higher SNR to be able to understand the transmission. The RSSI and SNR quantities are included in 802.11 packets and can be used by the devices to improve connection by changing the modulation or maybe boosting power levels.

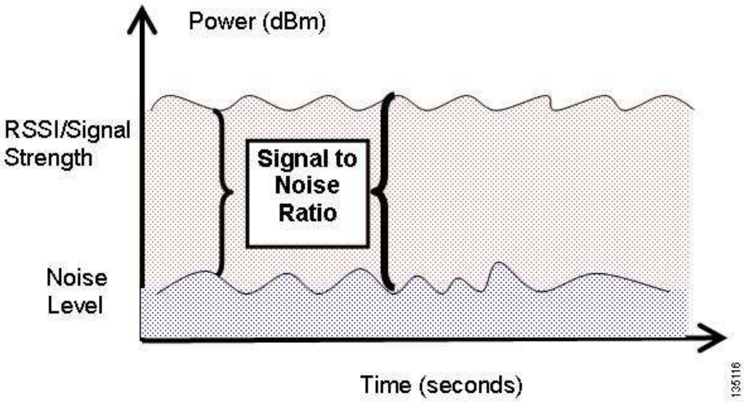


Figure 18: SNR and RSSI concepts [6]

7.1 Attenuation

Attenuation is the loss in amplitude that occurs whenever a signal travels through wire, free space or an obstruction. When a radio wave reaches an obstacle, some of its energy is absorbed and converted into another kind of energy, while another part is attenuated and continues to propagate (and another part may be reflected). The amount of energy absorbed depends mainly on the frequency of the EM wave and the material of the obstacle. For 802.11 networks we have here some very rough estimates for some common construction elements:

Plasterboard wall	3dB
Glass wall with metal frame	6dB
Cinder block wall	4dB
Office window	3dB
Metal door	6dB
Metal door in brick wall	12.4dB

Table 1: Attenuation for some common construction elements [14]

7.2 Multipathing

Multipath reflection occurs when reflections cause more than one copy of the same transmission to arrive at the receiver at slightly different times. These reflected signals sometimes cause problems at the receiver by partially canceling the direct signal, effectively reducing the amplitude. The link throughput slows down because the receiver needs more time to either separate the real signal from the reflected echoes or to wait for missed frames to be retransmitted.

7.3 Fresnel zones

For outdoor links (point to point or point to multipoint) is very important to have a clear line of sight between the antennas. In this type of deployment we usually have directional antennae. But how do we decide line of sight? A wireless line of sight typically requires visual line of sight plus additional path clearance to account for the spreading of the wireless signal. The shorter the wavelength of an electromagnetic wave, the less clearance it needs from objects that it passes as it travels between two points. The amount of clearance required for obstacles is expressed in terms of Fresnel zones. Fresnel zones consist of series of concentric ellipsoid surfaces that surround the straight-line path between the transmitter and receiver. The first Fresnel zone is defined as the surface containing every point for which the distance from the transmitter to any reflection point on the surface and then on the receiver is one half-wavelength longer than the direct signal path. As radio signals travel through free space to their intended target, they may encounter an obstruction in the Fresnel area, degrading the signal. Figure 19 illustrates the Fresnel zone between two antennas. As long as 60 percent of the first Fresnel (F1) zone is clear of obstructions, the link behaves essentially the same as a clear freespace path.

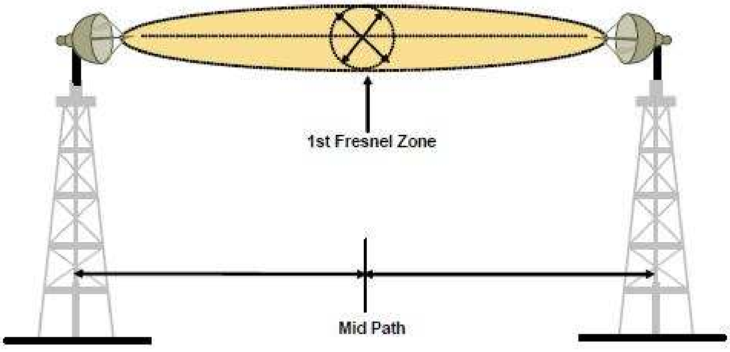


Figure 19: 1st Fresnel zone [6]

7.4 Interference

Since the frequency bands used in 802.11 is unlicensed there are many devices that can cause interference. Among the most common sources of interference are microwave ovens, bluetooth devices, radar and cordless phones. The only way we can avoid the sources of interference is by changing the frequency channel. Some products are able to do this automatically but this is not covered by 802.11 protocols. Sometimes even changing the channel doesn't help because the source of interference is occupying a band too wide.

8 Conclusion

Implementation of 802.11 networks is a very empirical work. The first steps are usually determining the type of network to be implemented (5 GHz or 2.4 GHz, point-to-point or client coverage, high or lower throughput, etc.). The most important task to ensure a good RF coverage and a resilient network is the **site survey** of the building or area to cover. The site survey consist of testing different access points and antennae to understand the RF properties of the area and to select the right equipment. The site survey is therefore an empirical way to predict how will EM waves travel. In a real world situation is almost impossible to predict this using a theoretical model. However, the theoretical model can be of great assistance to understand the results of the coverage measurements. A good knowledge of the physical properties described in this document can help us avoid interference, multi-pathing, attenuation of the signal and other problems usually encountered in 802.11 networks.

The protocols presented in this document reflect the current status of 802.11 networks. Improvements and upgrades are constantly being introduced and therefore also new protocols are developed to standardize equipment. 802.11n is the next protocol to be ratified and it will provide for higher data rates and a more resilient wireless network. Physicists and engineers work every day to develop new and better technologies and products.

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