Wireless LAN RF Principles

CISCO

WLAN-RF-Principles-1

Overview

In order to fully understand the 802.11 technology, it is necessary to have a clear concept of how wireless works at the first layer of the OSI model. At the heart of the physical layer is radio frequency (RF) communications. This lesson will give you the tools to understand what happens when a device sends a wave.

Objectives

Upon completing this lesson, you will be able to describe the principles of Wireless LANs RF. This ability includes being able to meet these objectives:

Describe the concept of wavelength

Describe the concept of wireless spectrum

Describe frequency

Describe the concept of amplitude

Describe Free Path Loss Model

Describe absorption

Describe reflection

Describe multipath

Describe scattering

Describe refraction

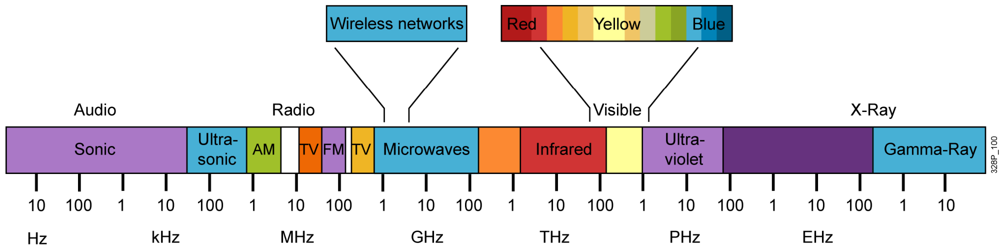
Describe Line Of Sight (LOS)

Describe the Fresnel zone

Describe RSSI and SNR

Wireless Spectrum

- Wireless networks use RF signals
- RF are electromagnetic waves
- Spectrum defines waves sizes, grouped by categories
- Wireless network radio range is in the microwave segment



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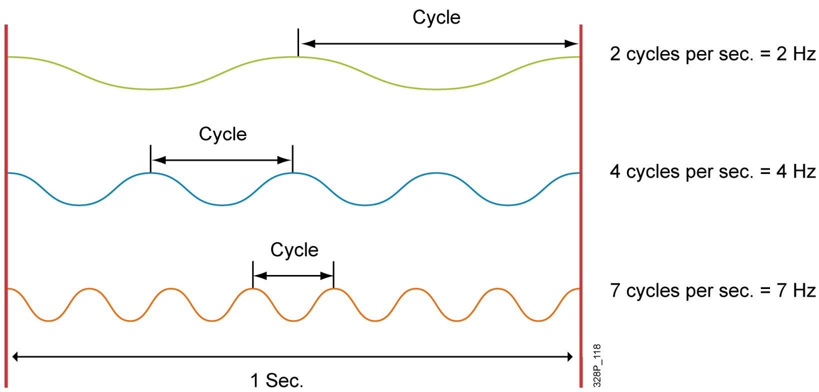
Many devices use radio waves to send information. A radio wave can be defined as an electromagnetic field radiated from a sender. It propagates to a receiver that receives its energy. Light is an example of electromagnetic energy. The eye can interpret it to send its energy to the brain, which will in turn transform it into impressions of colors.

Different waves have different sizes, expressed in meters. Another unit, Hertz (Hz), expresses how often a wave occurs per second. Waves are grouped by category, each group matching a size variation. The lower sized waves are in the sonic category, the highest in the Gamma ray group.

Humans utilize the waves that a human body can not perceive to send information. Depending on the type of information to send, certain wave groups are more efficient than others in the air. They are said to have different properties. Over the years, different needs and different regulations necessitated the creation of different subgroups.

Frequency



- The frequency determines how often a signal is seen
- 1 cycle per second is 1 Hertz
- Low frequency travel farther in the air than higher frequencies

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The wave is always sent at the speed of light as it is a magnetic field. This means that it will take a shorter or longer time to travel one cycle: if a signal wavelength is 5 millimeters long, it will take less time to travel a cycle than if it is 400 meters long, as the speed is the same in both cases. The natural consequence of this difference will be that, as the longer signal takes more time to travel one cycle, there will be less of its cycles in one second than of the first one.

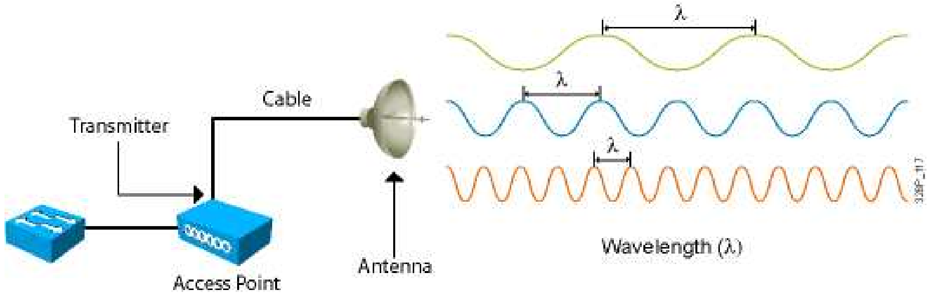
There is a direct relationship between the **frequency** (how often it is seen) of a signal and the **wavelength** (the distance the signal travels in one cycle) of the same signal: the shorter the wavelength, the more often the signal will repeat itself over a given time, therefore the higher its frequency.

When the signal occurs once a second, it is said to be a one **Hertz** signal. A signal occurring ten times a second is a 10 Hertz (**Hz**) signal; a million times a second is a Megahertz (**MHz**). A billion times a second is a Gigahertz (**GHz**). This plays a role in wireless networks, as signals of lower frequencies are less affected by the air than those of higher frequencies.

This is something which can be seen in everyday life: when a car approaches playing loud music, the first sounds heard are the drums and bass. This is due to the fact that lower frequencies travel further than the higher ones without being affected by the air.

Wireless networks use the 2.4 GHz band and the 5 GHz band. It is therefore said that the 5 GHz band allows smaller coverage than the 2.4 GHz one, and less than the frequencies used for GSM, on 900 MHz.

Wavelength



- The signal generated in the transmitter is sent to the antenna
- The electrons movement generate an electric field which is a wave
- The size of the cycle pattern is called the wavelength

An RF signal starts with an electrical alternating current (AC) signal generated by a transmitter. This signal is sent through a cable to an antenna where it will be "radiated" in the form of an electromagnetic wireless signal. Changes of electron flow in an antenna, otherwise known as current, produce changes in the **electromagnetic fields** around the antenna and transmit **electric and magnetic fields**.

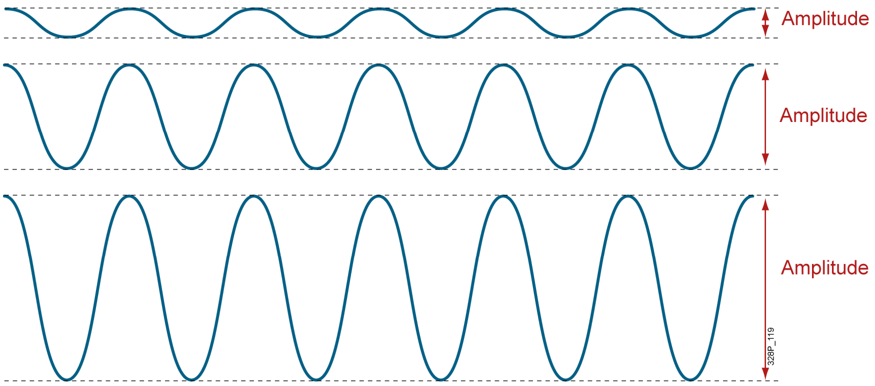
An alternating current is an electrical current with a direction that changes cyclically. The shape and form of an AC signal—defined as the waveform —is what is known as a sine wave. This shape is the same as the signal radiated by the antenna.

The wave sent has a certain size. In other words, from one point of the cycle to the same point in the next cycle, there is a physical distance called **wavelength**. Wavelength, usually represented by the Greek symbol λ (lambda), is the physical distance covered by the wave in one cycle.

Wavelength distance is very important as it will determine some properties of the wave: some environments and obstacles will affect the wave, but the impact will be high or low depending on the wavelength and the obstacle encountered. This phenomenon is covered in more detail later in this lesson.

Some AM radio stations will use a wave 400 or 500 meters long. Wireless networks use a wave a few centimeters long. Some satellites use waves about one millimeter long.

Amplitude



- Amplitude is the vertical distance, or height, between crests
- For the same wavelength and frequency, different amplitude can exist
- It represents the quantity of energy injected in the signal
- This value is usually regulated as it can affect the receivers

Another important factor affecting how a wave is sent is **amplitude**. Amplitude can be defined as the strength of the signal. From a graphical perspective, it is represented as the distance between the higher and lower crest of the cycle.

The Greek symbol γ (gamma) is the common representation of amplitude. It also affects the signal because it represents the level of energy injected in one cycle. The more energy injected, the higher the amplitude.

An easy way to represent this concept is to play the children's game where a rope is tied to something solid, such as a wall. The player then shakes the free end of the rope, and this creates a wave on the rope. It requires more energy to generate a big wave than a small one.

The amplitude can be increased: this is called amplification. Amplification can be active, via an increase of applied power, or passive, by focusing the energy in one direction, through the use of an antenna. Amplitude can also be decreased, which is called attenuation.

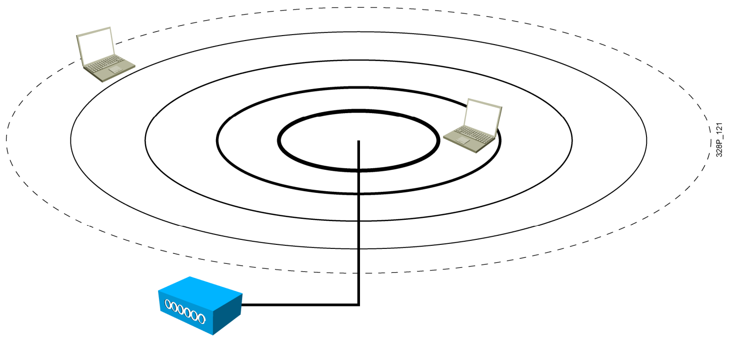
Finding the right amplitude for a signal is a delicate exercise: the signal will weaken as it moves away from the emitter. If the signal is too weak when arriving at the receiver, it will be unreadable, but if it is too strong it will require too much energy to be generated (i.e. will be very costly), and may be too strong for the receiver and could damage it.

This is another game children play, where they shout at each other. If they are too far away, they may not hear each other. But if they are too close and shout too loud, they may deafen each other. This demonstrates that there is an appropriate volume for the usual distance of a normal conversation.

There are regulations that define which are the right amounts of power for each type of device, depending on the usual expected distance, to avoid this type of issue.

Amplitude can be modified dynamically by the transmitter; this is called amplitude modulation, or AM. Some radio stations use this to encode the information they send to a radio receiver. Others prefer to change the frequency of the signal to encode the information; this is called frequency modulation, FM.

Free Path Loss



- As the wave spreads away from the emitter, it gets weaker:
  - The quantity of energy declines as the distance increases: the available quantity of energy available on each point of the circle is less as the circle is larger; the receiver catches only part of this energy
- Determining a range is determining the energy loss depending on the distance

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A radio wave emitted by an access point will be radiated in the air. If the antenna is said to be omnidirectional, the signal will be emitted in all directions, just like when throwing a stone in water, waves radiate in all directions from the point where the stone touched the water. If the antenna is directional, the beam will be more focused.

But as it travels away from the access point, it will be affected by the obstacles it encounters on the way. Depending on the type of obstacle, the effect will be different.

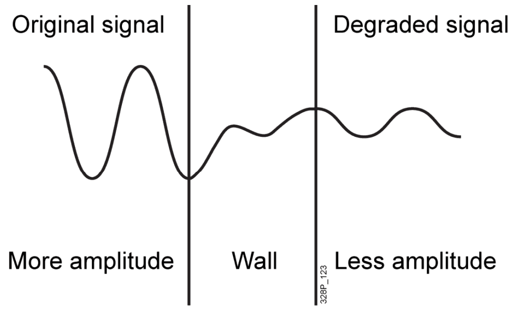
Even without encountering any obstacle, the first affect of wave propagation is strength attenuation. The attenuation of the signal strength on its way between a sender and a receiver is called **Free Path Loss**. The word "free" in the expression refers to the fact that the loss of energy is simply due to the distance, not to an obstacle blocking the signal. This word is very important as RF engineers also talk about Path Loss which takes into consideration other sources of loss.

Keep in mind that what causes free path loss is not the distance itself: there is actually no physical reason why a signal would be weaker further away" The cause of the loss is actually the combination of two effects:

> The sender is one point, and the signal is sent around itself. The energy has to be distributed over a larger area (a larger circle), but the amount of energy originally sent does not change. Therefore, the amount of energy available on each point of the circle is higher if the circle is small (less points) than large (more points among which the energy has to be divided)
>
> The receiver is not exactly one point, and will receive an amount of energy depending on its size: a large antenna will collect more points of the circle than a small one. But the antenna will never be able to pick up more than a portion of the signal originally sent; the rest of the energy sent will be lost

The combination of both factors causes free path loss. But if energy could be emitted towards a single direction, and if the receiver could catch 100% of that sent signal, there would not be any loss at any distance as there would be nothing along the path to absorb any of the signal strength.

Absorption



- Absorption takes energy from the wave
- This energy is dissipated in heat in the obstacle
- When 100% of the energy is taken, the wave stops
- The effect of absorption is to reduce amplitude
- The signal is therefore less powerful, but keeps the same wavelength and frequency

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As the signal travels away from the access point, it will lose energy not only as free path loss but even more as passing through different types of material. Each material will take part of the energy just like the copper cable. In the air, dust and humidity (water drops) will be warmed up by the signal, thus weakening it.

The signal also encounters other materials, such as walls. As the density of an obstacle is usually higher than the air, a higher proportion of the wave energy is lost while crossing the obstacle. This is called **absorption**.

This is something which can be seen in everyday life: when hearing conversations of people in another room, the voices are softer than they would be if people were talking at the same distance without the wall, because the wall absorbs part of the wave energy. The wave received by an ear has the same frequency and wave length as originally emitted, but its amplitude (strength) is lower.

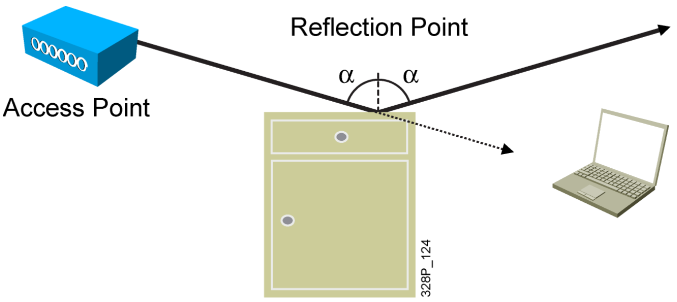
If the absorption is high, i.e. 100%, then the whole wave stops inside the obstacle. If it is less than 100%, only part of each gets to the receiver. If it is too weak, then the receiver may not be able to understand what was sent, and will just hear “noise.”

Absorption plays a very important role in wireless networks as all buildings are full of obstacles! But not all obstacles will absorb the signal in the same way: a concrete wall will absorb most of the signal energy, while a plaster wall will only absorb a portion.

A common scenario sees a site survey conducted to position access points while the building is empty. When the furniture is brought in to the building, the wireless network suddenly is not as efficient as it was before: new obstacles change the pattern.

Crowds also have an effect: a site survey is done to cover the area of a fair. When the fair effectively starts, the coverage may be reduced as the human body is full of water, which absorbs the signal.

Reflection



- Part of the energy is reflected
- Part may be transmitted
- The angle of reflection is the same as the initial angle
- Reflection depends on the material roughness relative to the wavelength and the angle
- Amplitude has no impact

Absorption has to be taken into consideration when designing a wireless network, but there is also another major phenomenon that affects wireless signals: **reflection**.

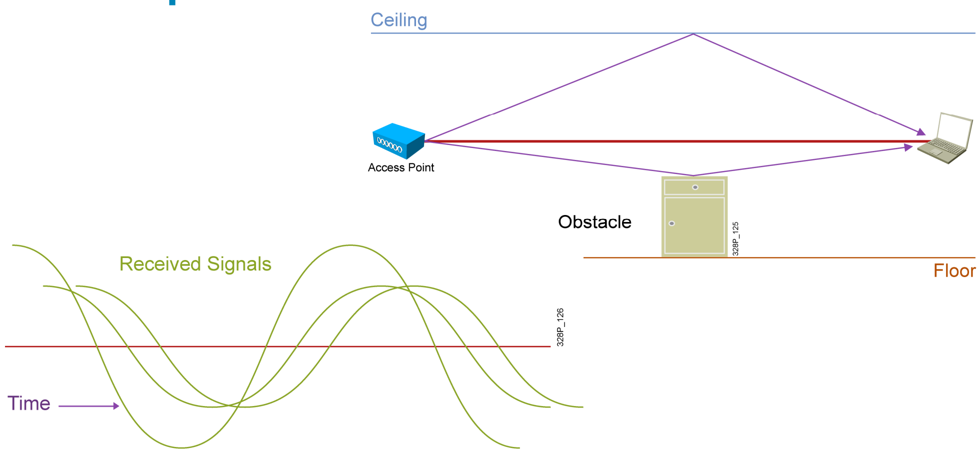
The effect of a signal hitting an obstacle depends on the nature of the obstacle. For example, porous materials will absorb part of the energy, and rough materials (where rough is relative to the wavelength) tend to reflect it, with an angle equal to the one at which it was received. Rough here refers to the surface texture. A flat surface reflects the signal because the wave tends to bounce uniformly on it; a more irregular texture, therefore "rough", would partly reflect the signal and partly absorb it.

The quantity of energy that will be absorbed, and then either transmitted through the material to the other side of the obstacle or reflected back is dependent on the angle at which the wave was received and the type of obstacle. For example, metal cabinets will reflect more than carpet or plaster.

A given obstacle may not be a source of reflection for a signal at one frequency, but may be a high source of reflection for the same signal sent at another frequency. Reflection also depends on the frequency: "rough" is relative to the wavelength.

Reflection will then depend on the angle at which the signal is received. This also relates to "roughness." The intensity of the reflection off a window will differ according to whether a signal is received at an acute angle or if it hits at a low angle.

Multipath



- Occurs when the signal reflects on surfaces and arrives to the receiver at different times
- Delayed multiple copies of the same signal hit the receiver
- Depends on the wavelength and the position of the receiver

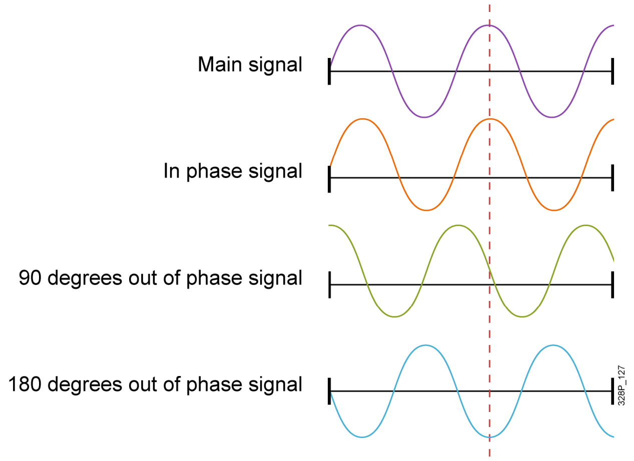
A major effect of reflections on wireless networks is called **multipath**. When a signal is sent as a wave, one portion of the wave will travel in a straight line from the sender to the receiver. This part is the main signal. But part of the same wave will hit obstacles and be reflected, some of it towards the same receiver. It will reach the same destination but slightly later, as this second wave has to travel a longer distance, because it does not travel in straight line. The effect is that the first wave, the main signal, will get mixed up with its own reflection.

This can cause major problems in wireless networks. The first effect is that the received signal is distorted and more difficult to understand. If the alteration is too great, the receiving station may not be able to understand the signal at all, even if the sender is close and the signal strength good enough.

The second effect is that the signal may actually be weaker than it should be. This refers to the notion of **out of phase** resulting in downfade. **Phase** relates to the relationship between two signals at the same frequency. A wave has its amplitude, which is the height of the crests. Downfade occurs when the difference between the primary wave and secondary wave signal is 121 to 179 degrees.

If a signal is received twice exactly at the same time between the primary and secondary waves, the receiver will get twice the positive energy (positive crest) at the same instant, then twice the negative energy (negative crest) at the same instant. The result is that both waves will add up to twice the amplitude (energy) than one single wave. Both signals are said to be **in phase** resulting in upfade. While the final received signal level can never be stronger than the original transmitted signal. However, it is stronger than it would originally have been at reception without upfade. The upfade occurs when the difference between primary and secondary wave signal is 0 to 120 degrees.

Multipath: Phase



- 2 signals are in phase when their cycles crests coincide
- Being out of phase weakens both signal or cancel them if amplitude and wavelength are the same

But if both signals are not sent at exactly the same time, the receiver may get the first positive crest, then as it receives the first subsequent negative crest, it may receive the second positive crest, receiving a positive signal to which the same exact negative signal is added results in a neutral signal, or no signal at all.

This is something that can be seen in everyday life: when using a noise cancellation headset. This device usually contains an electronic system that detects, or captures, the surrounding noise as it gets close to the ear, and dynamically plays the opposite wave, with the same amplitude: the result is silence.

The signals are said to be **out of phase** resulting in nulling, with an angle of 180 degrees. 180 degrees angle means that when the high crest of the first signal reach the end point, the low crest of the second signal reach the same end point, at the very same time. They are exactly the opposite, and the receiver gets no signal (if both signals have the same amplitude and wavelength).

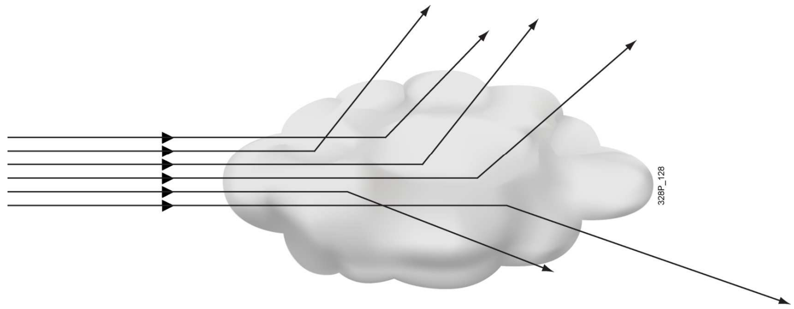
Most of the time, the difference between both signals is not 180 degrees, which means that the receiver does receive a signal, but the original signal is jammed by the second one, or the third, or more, depending on how many reflected signals make it to the point where the receiver is.

Physical position is another key issue. When the source of reflection is a flat metallic ceiling, reflection may occur in most places. But when it is a smaller obstacle, reflection will depend on the relative positions of the sender and the receiver… and on the wavelength: a signal emitted with a longer wavelength will not hit the obstacle at the exact same position, and will therefore not bounce in the same way. The result is that a given signal at a given frequency may be very badly affected by reflections at a given position, while it will not be affected at all a few centimeters away (remember that the Wi-Fi wavelengths are a few centimeters long).

This is something that can be seen in everyday life: as a car pulls up to a stop sign, the driver may notice static on the radio. But as they move forward a few inches or feet, the station starts to come in more clearly. By rolling forward, the antenna moves away slightly from the point where the multipath signals converge

Another result is that a signal at a given frequency may be very badly affected by reflections at any given position, while it will not be affected at all when at the same position but using another frequency.

Scattering



- Occurs when micro particles deviate the wave in multiple directions
- Affects shorter wavelengths more than longer ones
- Can weaken the signal or block it

Reflection relates to major obstacles, but it also occurs in the air itself. If the radio wave and the air particles could be seen, it would show that some of them, such as dust or micro drops of water (humidity), would affect the wave. These multiple reflections are described as **Scattering**.

Scattering will affect signal quality as the received result will be weaker (because part of it was reflected in other directions along the path) and more diffuse (as many of these micro reflections may hit the receiver).

The causes of scattering are not only dust and humidity, but can also be any other type of droplets, bubbles, density fluctuations, roughness of the surface on which a reflection may occur (part of the signal will be reflected in one main direction, part of it in many directions, thus scattered), or cells in organisms (such as the human body).

Here, again, the effect of scattering will depend on the frequency. When crossing the same environment, some frequencies will be highly scattered while some others will be mostly unaffected.

Scattering can have two effects in wireless networks:

The first effect is a degradation of the wave strength and quality at the receiver. It is usually easy to predict, as it is relatively consistent in the atmosphere. It is more complex to determine in non-heterogeneous environments, for example: in long range radio links crossing highly polluted urban air.

The second effect occurs when crossing uneven environments, such as tree leaves, or when reflecting off uneven surfaces such as moving water or a rocky terrain. The effect on the wave at the receiver will be harder to predict as it will depend on how the reflections occurred.

Refraction

- Occurs when the wave passes from one medium to another: direction change
- Minor effects on indoor networks
- Can have high impacts on outdoor long range links

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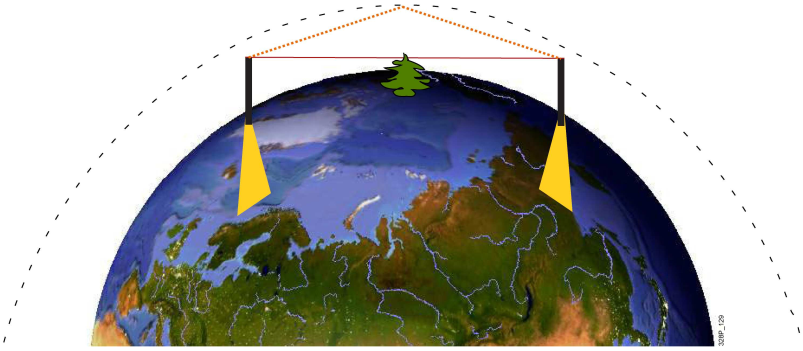
A final effect on a wave is **refraction**. Refraction occurs when the wave changes direction. This usually happens when a wave passes from one medium to another.

This effect can be seen when looking at a spoon or a straw in a glass: it looks as if it was cut instead of being a continuous straight object inside and outside the glass. The light goes through the liquid and the glass itself and gets refracted. The change of direction in the light beam creates this illusion.

Refraction can only have minor effects on indoor networks. It may affect more long range wireless links that cross areas of the atmosphere with different densities and humidity. Drier air will typically bend the signal away from the earth, while more humid air will bend it towards the earth.

Line of Sight



- Necessary for good signal transmission
- Earth curvature plays a role in outdoor links from a few miles (depends on transmitter and receiver elevation
- Visual obstacles may or may not prevent radio line of sight

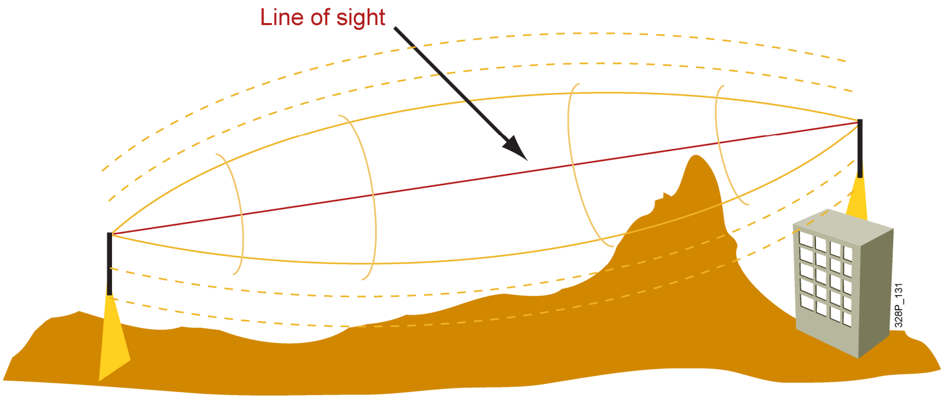
As a signal travels in a straight line towards a receiver, it will be received in good condition if there is clear line of sight between the sender and the receiver. If there is an object in the path of the wave, such as a tree or a building, then the attenuation (absorption) and other phenomena will prevent communications from occurring.

For an outdoor link beyond certain distances, the curvature of the earth will also play a role: for a typical 6-foot (183 cm) person, the horizon appears at about 6 miles (about 10 km). Its disappearance is determined by the height of the observer. If there are two 10-foot (3 meters) structures, the top of one will have a line-of-sight to the other up to about 16 miles (26 km), but it will have minimum clearance at the horizon point.

This is why it is said that a signal will be received in good condition if the receiver is in the line of sight of the sender. But the line of sight mentioned here is the **radio line of sight** more than the visual line of sight. They are often close concepts, but there may be no line of sight, because the antenna is hidden behind a light object such as roof tiles, and yet there will still be radio line of sight because the signal reaches the receiver in a condition good enough for it to be decoded. In some extreme conditions, the signal may reflect on an object or the atmosphere and be received in a place from which the sender could not be seen.

Fresnel Zone

- Determines an area around radio line of sight where reflections have most negative impact on the signal
- Should be at least 60% free from obstacles



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The radio line of sight, even when it matches the model of straight line or visual line of sight, is actually more than a simple line. If there are obstacles, not on the path itself (understood as a direct line between the sender and the receiver) but close to the path, the radio waves reflecting off those objects may arrive out of phase with the signals that travel directly to the receiver, which will then reduce the power of the received signal or arrive in or out of phase. Objects and their reflections most commonly decrease the signal.

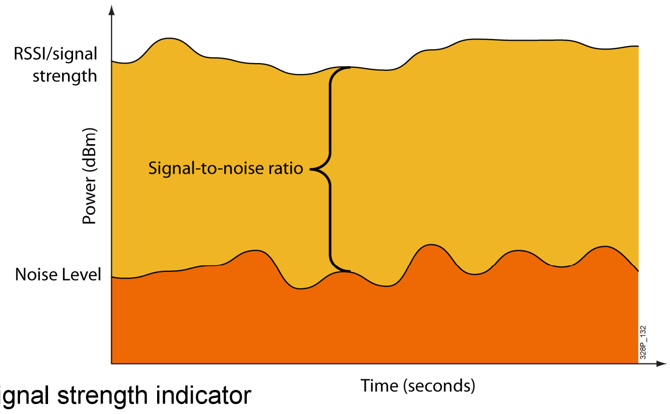
One way to mitigate these interferences is to ensure a minimum distance between the direct line of the signal and the closest obstacle; but how do we calculate what this "minimum distance" should be? It depends on the distance between the two points and the frequency of the signal, as individual frequencies will be affected differently by travel through the air and by reflections.

Augustin Fresnel (pronounced *fray-NELL)*, a 19th century physicist, provided a method to calculate where reflections will be in phase and out of phase around the direct line between the sender and the receiver. He created the corresponding "zones." In the first zone, closest to a direct line, reflections will cause signals that will be 0 to 90 degrees out of phase, thus negatively impacting the signal. In the second zone, which stands around the first one, they will be 90 to 270 degrees out of phase, and in the third zone, they will be 270 to 450 degrees out of phase and so on. Odd numbered zones are constructive and even numbered zones are destructive to the signal strength.

Theoretically, there are an infinite number of zones, but the area of main concern is the first zone. It should be kept largely free from obstructions to avoid interfering with radio reception. However, some obstruction may be acceptable, but it is said that at least 60% of this first zone should be free from any interference; 80% free is recommended.

The Fresnel zone mostly affects outdoor links, when indoors; distances are usually too short for it to be a major issue.

RSSI and SNR



- RSSI is the signal strength indicator
- dBm value transformed from a a vendor dependent grading coefficient
- Usually negative value, the closer to 0 the better
- SNR is signal strength relative to noise level
- The higher the better

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As the RF wave may have been affected by obstacles in its path, it is important to determine how much signal will be received by the other endpoint. If sender and receiver are compatible devices (e.g. two bridges, or an access point and a client WLAN adapter) the signal will probably not be too strong but it can be too weak to be heard or detected as an actual signal by the receiver.

The value that indicates how much power is received is called **Received Signal Strength Indicator (RSSI)**. It is usually expressed in **dBm** (a unit of relative power measurement against milliwatt).

Calculating the RSSI is a complex problem since the receiver does not know how much power was originally sent. RSSI, therefore, expresses a relative value determined by the receiving card while comparing received packets to each other.

The RSSI is, in fact, a grade value, which can range from 0 (no signal or no reference) to 255 max. But many vendors use a maximum value lower than 255 (for example 100 or 60). The value is relative because a magnetic and electric field will be received, and a transistor will transform them into electric power; current is not directly received. How much electric power can be generated depends on the received field as well as the circuit that transforms it into current.

From this grade value an “equivalent dBm” is displayed, which here, again, depends on the vendor. If a vendor determined that RSSI for a card would range from 0 to 100, 0 being represented as -95 dBm and 100 as -15 dBm, and if another one determined that 0 to 60 would be used, 0 being – 92 dBm and 60 being – 12 dBm, you could not really compare powers when reading RSSI = - 35 dBm on one vendor and RSSI = -28 dBm on the second vendor.

Therefore, RSSI is not a means of comparing cards, but more a way to help understand, card by card, how strong a received signal is relative to itself in different locations. This is useful for troubleshooting or when comparing same vendor cards values. On Cisco cards the utility will also display a grading of the RSSI (such as good, poor, etc).

Measuring the strength of the signal is one metric. Another important metric is the **SNR**, or **signal-to-noise ratio**. SNR determines how much stronger the signal is than the surrounding noise; the higher the SNR, the better.

As the SNR is built on the RSSI (it compares RSSI level to noise level), it is also a relative value. It determines the ability of the receiver to read the received signal and decode its zeros and ones. This is why the SNR is generally seen as more universal than the RSSI.

A good SNR depends on the RSSI. In other words, a relatively low SNR is acceptable if the environment is globally quiet, but it takes a higher SNR in a noisy environment.

Summary

- The wireless spectrum expresses the range of radio waves
- Frequency is how often the same cycle repeats per second
- Wavelength is the distance of the same points in a signal cycle
- Amplitude is how strong the signal is, and how high the wave
- Once radiated, some energy will be lost as the signal spreads, incurring Free Path Loss
- As the signal goes through obstacles, absorption weakens it
- It can also bounce on objects, which is reflection

Summary (cont.)

- When reflection occurs and several signals arrive at the receiver, a multipath issue occurs
- Scattering occurs when the signal is reflected in many directions by small obstacles
- Refraction occurs when the signal goes from one medium to another and changes direction
- For a signal to be transmitted in good conditions, radio line of sight should exist between endpoints
- Around the line of sight, a zone, the first Fresnel zone, should be mostly free from obstacles
- RSSI will determine received signal strength and SNR the signal-to-noise ratio at the receiver