Chapter 3

Wireless Network Principles

Wireless Basics

Wireless technology is used in many types of communication. We use it for networking because it is cheaper and more flexible than running cables. While wireless networks can be just as fast and powerful as wired networks, they do have some drawbacks. Wireless signals, wireless devices, Wi-Fi modes, Wi-Fi signals, power and receiver sensitivity and antennas are some of the concepts to be considered in wireless networking.

Wireless signal- Wireless signals are important because they can transfer information -- audio, video, our voices, data -- without the use of wires, and that makes them very useful.

Wireless signals are **electromagnetic waves** travelling through the air. These are formed when electric energy travels through a piece of metal, for example a wire or antenna and waves are formed around that piece of metal. These waves can travel some distance depending on the strength of that energy.

Frequency allocation and Regulation

Frequency allocation is also called spectrum allocation. Spectrum allocation is the process of regulating the use of the electromagnetic spectrum and dividing it among various and sometimes competing organizations and interests. This ensures that there is little competition when using a specific frequency band, which can cause interference if the same frequency band is used for different and unregulated purposes. This regulation is controlled by various governmental and international organizations. Spectrum allocation came to be because of the emerging and convergence of wireless telecommunications technology which created huge demands on the radio frequency spectrum for various services such as high-speed data transfer and communication. Spectrum allocation is done to prevent major interference and chaos in the airwaves, which would serve no one at all.

Some standardization organizations working on spectrum allocation and regulation:

- European Conference of Postal and Telecommunications Administrations (CEPT)
- International Telecommunication Union (ITU)

- Inter-American Telecommunication Commission (CITEL)

Types of spectrum allocation

- No one may transmit — Spectrum band is reserved for a specific use such as radio astronomy so that there is no interference with radio telescopes
- Anyone may transmit — As long as transmission power limits are respected
- Only licensed users/organizations of the specific band may transmit — Examples are cellular and television spectrums as well as amateur radio frequency allocations

Antenna

An antenna is a transducer that converts radio frequency (RF) fields into alternating current or vice versa. There are both receiving and transmission antennas for sending or receiving radio transmissions. Antennas play an important role in the operation of all radio equipment. They are used in wireless local area networks, mobile telephony and satellite communication.

Antennas have an arrangement of metallic conductors with an electrical connection to receivers or transmitters. Current is forced through these conductors by radio transmitters to create alternating magnetic fields. These fields induce voltage at the antenna terminals, which are connected to the receiver input. In the far field, the oscillating magnetic field is coupled with a similar oscillating electric field, which defines electromagnetic waves capable of propagating the signal for long distances.

Several varying types of antennas exist for Wi-Fi, each with a specific purpose for how and when they should be used. Different types of antennas can be found anywhere from small office settings to outdoor camping grounds. While there are many types of antennas, all of them have the same purpose: producing radio waves to send information through the air. The three main antenna types are omnidirectional, semi-directional, and highly directional.

Radio waves are electromagnetic waves that carry signals through air at the speed of light without any transmission loss. Antennas can be omni-directional, directional or arbitrary.

Omnidirectional - Omnidirectional antennas are designed to radiate a signal in all directions. Although it is impossible under the basic laws of physics for an antenna to perfectly radiate a signal in all directions at equal strength, an antenna of this type is an attempt to provide general coverage in all directions. This is the most common type found for client adapters and access points, as in these situations, good coverage in a general spherical area around the antenna is desirable.

Semi directional - Semi-directional antennas are designed to direct the RF signal in a specific direction for point-to-point communication. Semi-directional antennas are used for short to medium distance communication indoors or outdoors. A good way to think of how the semi-directional antenna radiates RF is to think of it as a street lamp shining down on the street. It is common to use semi-directional antennas in a campus like environment since they can provide a network bridge between two buildings.

Highly-directional - Highly directional antennas are used for long distant point-to-point communication. They are used to bridge networks between two buildings that are far apart. Because these antennas are high gain, they provide the most focused and narrow beam width. Instead of a street light shining down, it is more of a spotlight shining in a specific direction. The two main highly directional antennas are Parabolic (Dish) and Grid. Dish antennas look similar to the TV dish antennas that you would find in a home but are often much larger in size. Grid antennas can also vary in size, but they look like a grill and are designed for outdoor environments with higher winds.

Signal Propagation

This is the movement of radio waves from a transmitter to a receiver. When the waves travel (propagate) from one point to another, they are, like light waves, affected by different phenomena such as light reflection, absorption, or scattering. The propagation channel has the most impact on the design of a wireless receiver. The wireless channel causes the transmitted signal to lose power as it propagates from the transmitter to the receiver. Reflections, diffraction, and scattering create multiple propagation paths between the transmitter and the receiver, each with a different delay. The net result is that wireless propagation leads to a loss of received signal power as well as the presence of multipath, which creates frequency selectivity in the channel.

Mechanisms of Propagation

In a wireless communication system, a transmitted signal can reach the receiver via a number of propagation mechanisms. When a signal reaches the receiver from the transmitter in a single path, without suffering any reflections, diffractions, or scattering, this is known as propagation along the *line-of-sight* (LOS) path. An LOS component has the shortest time delay among all the received signals and is usually the strongest signal received.

In *non-line-of-sight* (NLOS) propagation, a signal transmitted into a wireless medium reaches the receiver via one or more indirect paths, each having different attenuations and delays. When a transmitted signal travels through communication paths other than the LOS path to reach the receiver, it is said to have undergone NLOS propagation. NLOS propagation is responsible for coverage behind buildings and other obstructions. The main NLOS propagation mechanisms are reflection, scattering, and diffraction.

Reflection occurs when a wave impinges on an object that is smooth, which means that any protrusions have dimensions much larger than a wavelength. Reflection is accompanied by refraction (transmission of the wave through the object). The strengths of the reflected and refracted waves depend on the type of material.

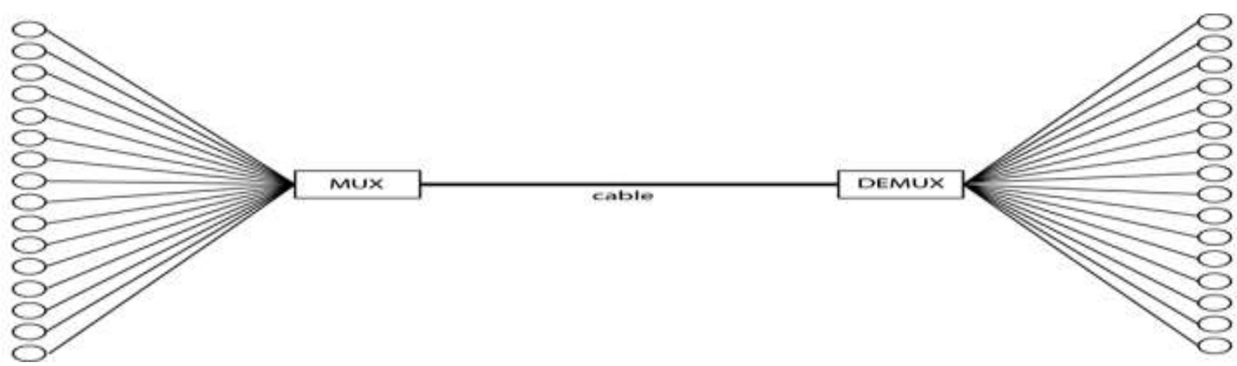
Scattering is what happens when a wave impinges on an object that is rough or has irregularities with dimensions on the order of the wavelength. It is similar to reflection but results in a smearing of the signal around the angle of reflection. This leads to a larger loss of energy as the signal is spread over a wider area. It also results in multiple paths arriving at the receiver from a similar location with slight differences in delay.

Diffraction is the "bending" of waves around sharp corners. Important examples of diffraction include waves bending over the tops of buildings, around street corners, and through doorways. Diffraction is one of the main ways that it is possible to provide cellular coverage in cities and is one reason why lower frequencies, say less than 3GHz, are considered beachfront property in the world of cellular spectrum.

Multiplexing

Multiplexing, or *muxing*, is a way of sending multiple signals or streams of information over a communications link at the same time in the form of a single, complex signal. When the signal reaches its destination, a process called *demultiplexing*, or *demuxing*, recovers the separate signals and outputs them to individual lines. Multiplexing is a method used by networks to consolidate multiple signals (digital or analog) into a single composite signal that is transported over a common medium, such as a fiber optic cable or radio wave. When the composite signal reaches its destination, it is demultiplexed, and the individual signals are restored and made available for processing.

The individual network signals are input into a multiplexer (mux) that combines them into a composite signal, which is then transmitted through a shared medium. When the composite signal reaches its destination, a demultiplexer (demux) splits the signal back into the original component signals and outputs them into separate lines for use by other operations.



Organizations implement multiplexing on their networks for two reasons:

- To enable network devices to communicate with each other without needing a dedicated connection between each device pair.
- To better utilize scarce or expensive network resources.

Types of multiplexing

Organizations can select from multiple forms of multiplexing. Their choices will depend in large part on the types of signals being transmitted (analog vs. digital) and the media used to carry those transmissions, such as coaxial cable, fiber optic cable or microwave link. The following is an overview of several common multiplexing techniques.

Frequency-division multiplexing (FDM). In FDM, the total bandwidth is divided to a set of frequency bands that do not overlap. Each of these bands is a carrier of a different signal that is generated and modulated by one of the sending devices. The frequency bands are separated from one another by strips of unused frequencies called the guard bands, to prevent overlapping of signals.

The modulated signals are combined together using a multiplexer (MUX) in the sending end. The combined signal is transmitted over the communication channel, thus allowing multiple independent data streams to be transmitted simultaneously. At the receiving end, the individual signals are extracted from the combined signal by the process of demultiplexing (DEMUX).

Wavelength-division multiplexing (WDM) - In WDM, the optical signals from different sources or (transponders) are combined by a multiplexer, which is essentially an optical combiner. They are combined so that their wavelengths are different.

The combined signal is transmitted via a single optical fiber strand. At the receiving end, a demultiplexer splits the incoming beam into its components and each of the beams is send to the corresponding receivers. Conceptually, WDM is similar to FDM, except that FDM is described in terms of frequencies (radio or television broadcasting) whereas WDM is specific to wavelengths. The WDM approach is more common in telecommunication systems and computer networks that use laser systems to send light signals over fiber optic cables.

Time-division multiplexing (TDM) - In TDM, the data flow of each input stream is divided into units. One unit may be 1 bit, 1 byte, or a block of few bytes. Each input unit is allotted an input time slot. One input unit corresponds to one output unit and is allotted an output time slot. During transmission, one unit of each of the input streams is allotted one-time slot, periodically, in a sequence, on a rotational basis. This system is popularly called round-robin system. TDM operates at the temporal level, unlike FDM and WDM, which operate at the frequency or wavelength level. Although TDM has its roots in telegraphy, it is now commonly used in digital telephony to transmit multiple conversations across a common medium.

Code-division multiplexing (CDM)- Code division multiplexing (CDM) is a multiplexing technique that uses spread spectrum communication. In spread spectrum communications, a narrowband signal is spread over a larger band of frequency or across multiple channels via division. It does not constrict bandwidth's digital signals or frequencies. It is less susceptible to interference, thus providing better data communication capability and a more secure private line. When CDM is used to allow multiple signals from multiple users to share a common communication channel, the technology is called Code Division Multiple Access (CDMA). Each group of users is given a shared code and individual conversations are encoded in a digital sequence. Data is available on the shared channel, but only those users associated with a particular code can access the data. Generally, in code division multiplexing, a sequence of bits called the ***spreading code*** is assigned to each signal to distinguish one signal from another. The spreading code is combined with the original signal to produce a new stream of encoded data, which is then transmitted on a shared medium. A demux that knows the code can then retrieve the original signals by subtracting out the spreading code, a process called *dispreading*. CDM is widely used in digital television and radio broadcasting, in 3G mobile cellular networks, 4G and 5G . CDM can also support multiple signals from multiple sources, a technique known as ***code-division multiple access***.

Space-division multiplexing (SDM). Signal paths are spatially separated through the use of multiple conductors, such as optical fibers or electrical wires. The conductors are bundled into a single transport medium but are physically separated, with each conductor handling a transmitted channel. Individual conductors can be further multiplexed through the use of FDM, TDM or other techniques. SDM is often used in submarine cable systems to help increase capacity, but it can also be used for wireless communications.

Polarization-division multiplexing (PDM). Incoming electromagnetic signals are polarized into orthogonal channels that are transmitted through a common medium. PDM is frequently used in fiber optics communications, as well as radio and microwave transmissions. For example, satellite TV providers often use PDM to deliver TV signals to satellite dishes.

Modulation

Modulation is the process of converting data into electrical signals optimized for transmission. Modulation is the process of converting data into radio waves by adding information to an electronic or optical carrier signal. A carrier signal is one with a steady waveform constant height, or amplitude, and frequency. There are three aspects of a signal that can be modulated; amplitude, frequency, and phase. The amplitude is the power or intensity of the signal, the frequency is how often the signal repeated itself, and the phase describes where in the cycle the waveform is with respect to time.

Types of modulation

There are two types of modulation: Analog modulation and digital modulation.

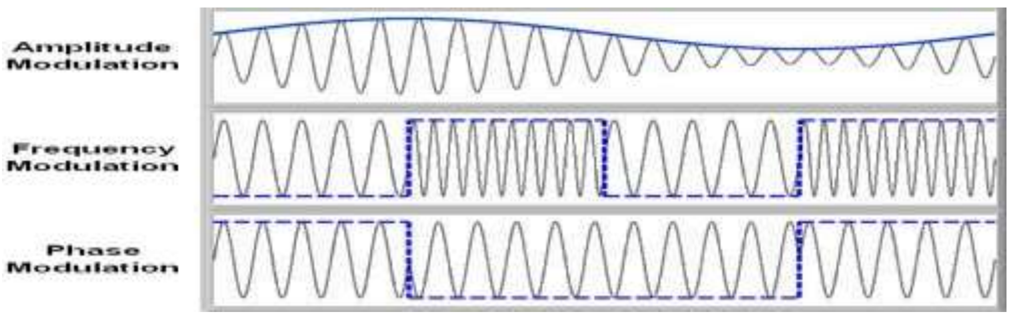
Analog modulation

Analog modulation refers to the process of transferring an analog baseband (low frequency) signal, like an audio or TV signal over a higher frequency signal such as a radio frequency band. The three parameters modulated in analog modulation: amplitude, frequency and phase.

Amplitude Modulation- Amplitude modulation was developed in the beginning of the 20th century. It was the earliest modulation technique used to transmit voice by radio. This type of modulation technique is used in electronic communication. In this modulation, the amplitude of the carrier signal varies in accordance with the message signal, and other factors like phase and frequency remain constant. This type of modulation requires more power and greater bandwidth; filtering is very difficult. Amplitude modulation is used in computer modems, VHF aircraft radio, and in portable two-way radio an others.

Frequency Modulation- In this type of modulation, the frequency of the carrier signal varies in accordance with the message signal, and other parameters like amplitude and phase remain constant. This type of modulation is commonly used for broadcasting music and speech, magnetic tape recording systems, two-way radio systems and video transmission systems. When noise occurs naturally in radio systems, frequency modulation with sufficient bandwidth provides an advantage in cancelling the noise.

Phase Modulation- In this type of modulation, the phase of the carrier signal varies in accordance with the message signal. the phase of the carrier signal is varied in correspondence with the amplitude of the modulating signal by maintaining amplitude and frequency at constant. When the phase of the signal is changed, then it affects the frequency. So, for this reason, this modulation is also comes under the frequency modulation. Generally, phase modulation is used for transmitting waves. It is an essential part of many digital transmission-coding schemes that underlie a wide range of technologies like GSM, Wi-Fi, and satellite television.



Digital Modulation

For a better quality and efficient communication, digital modulation technique is employed. The main advantages of the digital modulation over analog modulation include available bandwidth, high noise immunity and permissible power. In digital modulation, a message signal is converted from analog to digital message, and then modulated by using a carrier wave.

The carrier wave is switched on and off to create pulses such that the signal is modulated. Similar to the analog, in this system, the type of the digital modulation is decided by the variation of the carrier wave parameters like amplitude, phase and frequency. The most important digital modulation techniques are based on keying such as Amplitude Shift Keying, Frequency Shift Keying and Phase Shift Keying.

In an Amplitude shift keying, the amplitude of the carrier wave changes based on the message signal or on the base-band signal, which is in digital format. It is sensitive to noise and used for low-band requirements. In frequency shift keying, the frequency of the carrier wave is varied for each symbol in the digital data. It needs larger bandwidths. Similarly, the phase shift keying changes the phase of the carrier for each symbol and it is less sensitive to noise.

Demodulation

Demodulation is the reverse process (to modulation) to recover the message signal at the receiver. Is the act of extracting digital data from the signal once it reaches its destination. A common example of a demodulating device is a modem. The difference between modulation and demodulation can be shown as follows.

Modulator	Demodulator
Data is collected and modified into the carrier	Data is recovered
Carried out on the sender's side.	Takes place on the receiver's side.
Original message signal is mixed with a carrier wave	Original information signal is created by separating carrier signal from message signal
Modulation is done to transmit data over long distance	Demodulation process prevents the signal from being modified

Media Access Control

A media access control is a network data transfer policy that determines how data is transmitted between two computer terminals through a network cable. The media access control policy involves sub-layers of the data link layer 2 in the OSI reference model. The essence of the MAC protocol is to ensure non-collision and eases the transfer of data packets between two computer terminals. A collision takes place when two or more terminals transmit data/information simultaneously. This leads to a breakdown of communication.

Media Access Control Methods

The network channel through which data is transmitted between terminal nodes to avoid collision has three various ways of accomplishing this purpose. They include:

- Carrier sense multiple access with collision avoidance (CSMA/CA)
- Carrier sense multiple access with collision detection (CSMA/CD)
- Demand priority
- Token passing

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) - is a media access control policy that regulates how data packets are transmitted between two computer nodes. This method avoids collision by configuring each computer terminal to make a signal before transmission. The signal is carried out by the transmitting computer to avoid a collision. Multiple access implies that many computers are attempting to transmit data. Collision avoidance means that when a computer node transmitting data states its intention, the other waits at a specific length of time before resending the data. CSMA/CA is data traffic regulation is slow and adds cost in having each computer node signal its intention before transmitting data. It used only on Apple networks.

Carrier Sense Multiple Access with Collision Detection (CSMA/CD) - Carrier sense multiple access with collision detection (CSMA/CD) is the opposite of CSMA/CA. Instead of detecting data to transmit signal intention to prevent a collision, it observes the media to detect the signal before transmitting. Collision detection means that when a collision is detected by the media access control policy, transmitting by the network stations stops at a random length of time before transmitting starts again. It is faster than CSMA/CA as it functions in a network station that involves fewer data frames being transmitted. CSMA/CD is not as efficient as CSMA/CA in preventing network collisions. This is because it only detects huge data traffic in the network cable. Huge data traffic increases the possibility of a collision taking place. It is used on the Ethernet network.

Demand Priority- The demand priority is an improved version of the Carrier sense multiple access with collision detection (CSMA/CD). This data control policy uses an 'active hub' in regulating how a network is accessed. Demand priority requires that the network terminals obtain authorization from the active hub before data can be transmitted. Another distinct feature of this MAC control policy is that data can be transmitted between the two network terminals at the same time without collision.

Token Passing- This media access control method uses free token passing to prevent a collision. Only a computer that possesses a free token, which is a small data frame, is authorized to transmit. Transmission occurs from a network terminal that has a higher priority than one with a low priority. Token passing flourishes in an environment where a large number of short data frames are transmitted. This media access control policy is highly efficient in avoiding a collision. Possession of the free token is the only key to transmitting data by a network node. Each terminal holds this free token for a specific amount of time if the network with the high priority does not have data to transmit, the token is passed to the adjoining station in the network.

Classifications of Wireless Networks

There are four basic types of wireless networks. Those are:

- Wireless LAN
- Wireless MAN
- Wireless PAN
- Wireless PAN

Wireless LAN- Wireless LAN (WLAN) technology provides internet access within a building or a limited outdoor area. First used within offices and homes, WLAN technology is now also used in stores and restaurants. A wireless local area network (WLAN) links two or more devices over a short distance using a wireless distribution method, usually providing a connection through an access point for Internet access. The use of spread-spectrum technologies may allow users to move around within a local coverage area, and still remain connected to the network.

Wireless MAN- Wireless metropolitan area networks have been installed in cities worldwide to provide access for people outside an office or home network. These networks cover a wider area than office or home networks, but the principles are the same. Several Wireless LANs are connected together in Wireless MAN.

Wireless PAN- Wireless personal area networks cover a very limited area -- typically a maximum of 100 meters for most applications using protocols like Bluetooth and

ZigBee. Bluetooth enables hands-free phone calls, connects a phone to earpieces or transmits signals between smart devices. Zigbee connects stations along an IoT network.

Wireless WAN- Wireless WANs use cellular technology to provide access outside the range of a wireless LAN or metropolitan network. These networks enable users to make phone calls to others connecting either through a wireless WAN or a wired telephone system. Users can also connect to the internet to access websites or server-based applications.