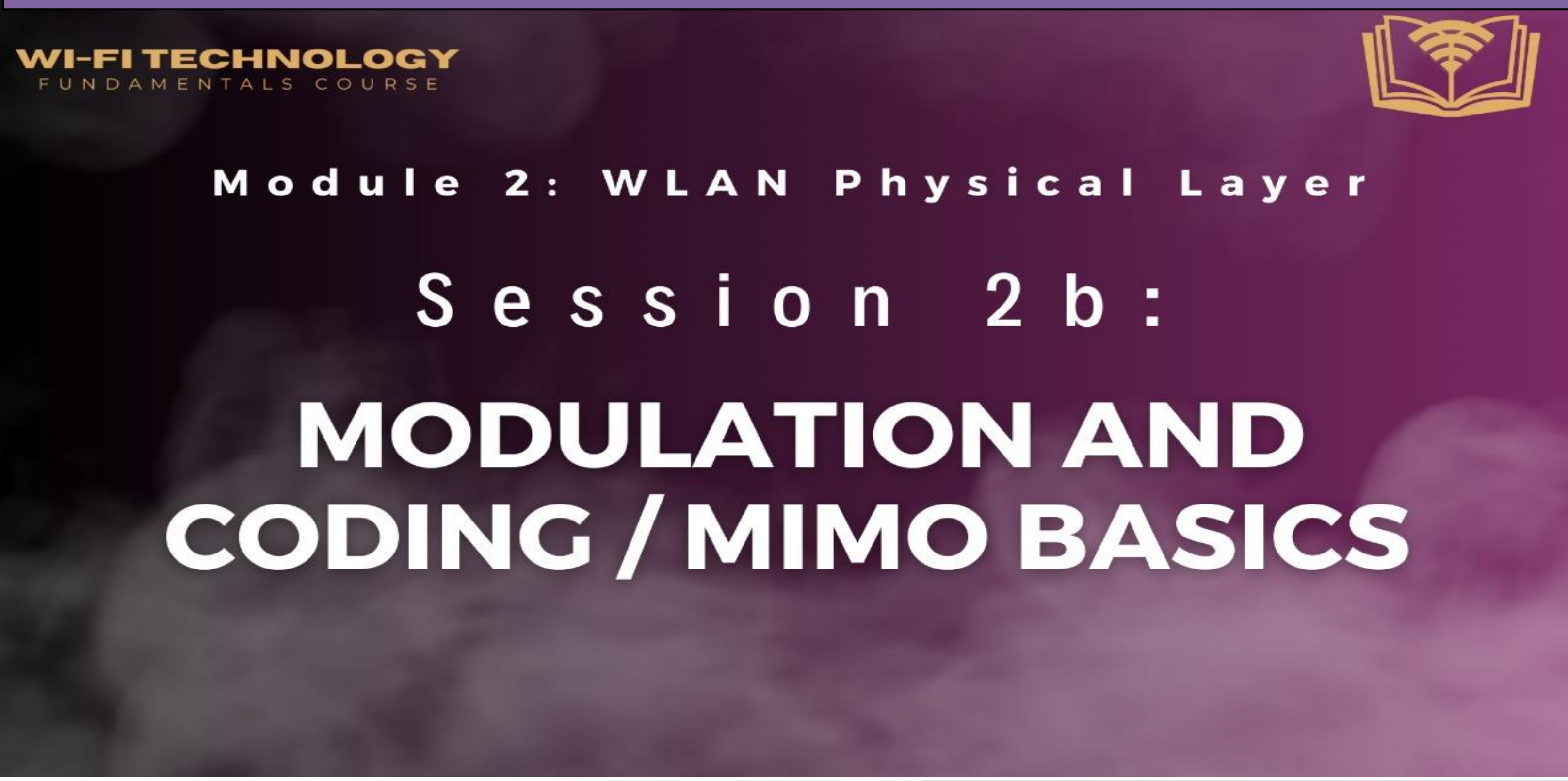
Class Notes



By
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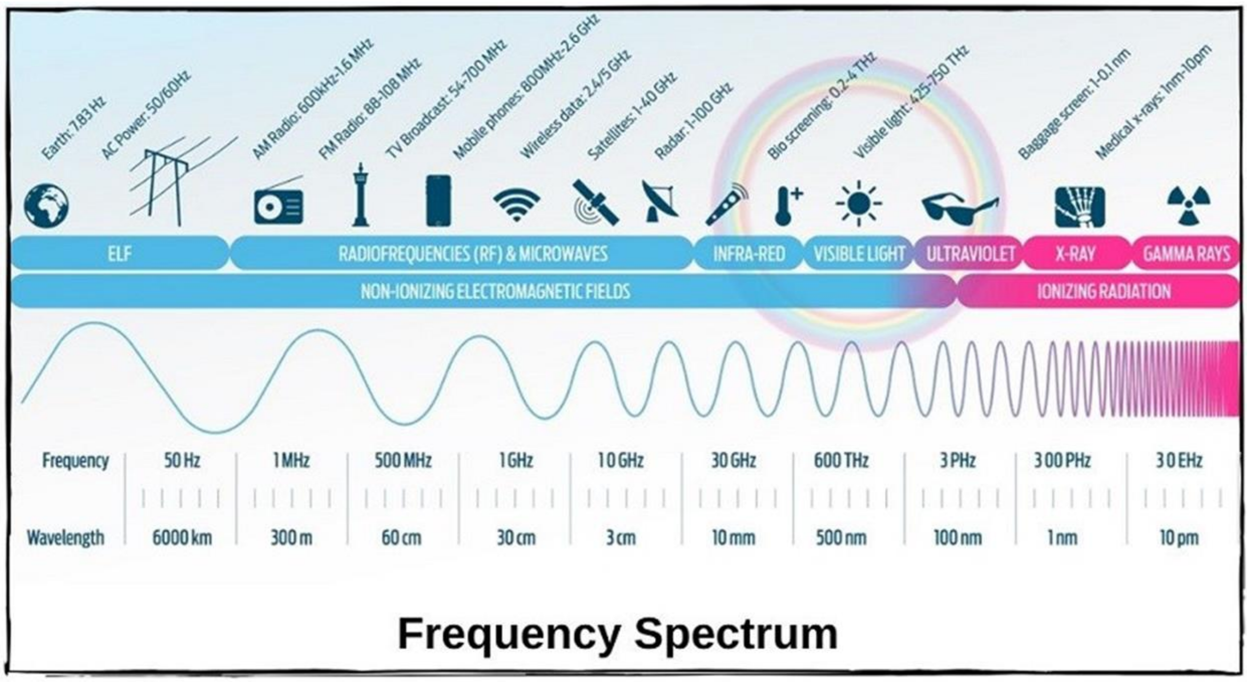
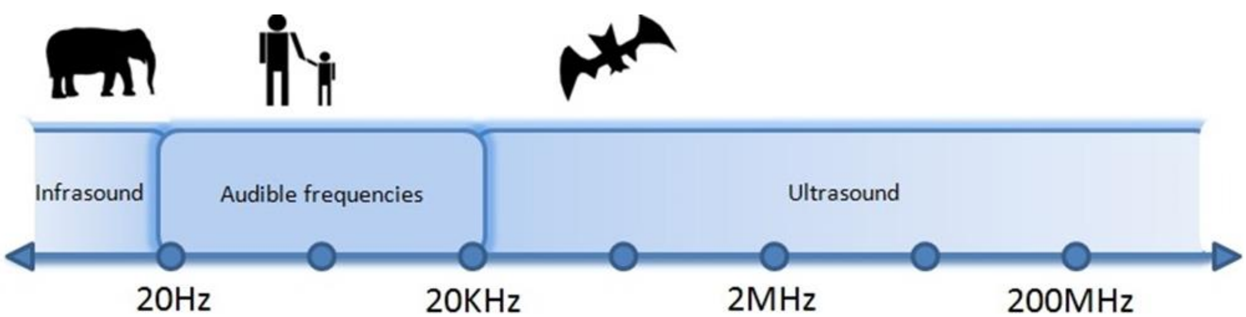
15th Oct 2023

Frequency Spectrum:





- The frequency spectrum encompasses a wide range of frequencies in which various types of wireless communication and transmission occur. In the context of Wi-Fi and human hearing, it's crucial to recognize that human hearing typically spans from 20 Hz (hertz) to 20,000 Hz. However, this represents only a small portion of the extensive frequency spectrum.

- Wi-Fi operates within the radio frequency segment of this broader spectrum. Specifically, Wi-Fi utilizes two primary frequency bands: the 2.4 GHz ISM (Industrial, Scientific, and Medical) Band and the 5 GHz Band.

- The 2.4 GHz ISM Band provides approximately 80 MHz of spectrum, divided into multiple channels, each with a width of roughly 22 MHz. These channels often overlap, potentially leading to interference between devices using adjacent channels.

- Conversely, the 5 GHz Band, spanning from 5.1 GHz to 5.8 GHz, offers non-overlapping channels. This makes it less prone to interference compared to the 2.4 GHz band. Additionally, this band offers higher data rates, enhancing Wi-Fi network performance.

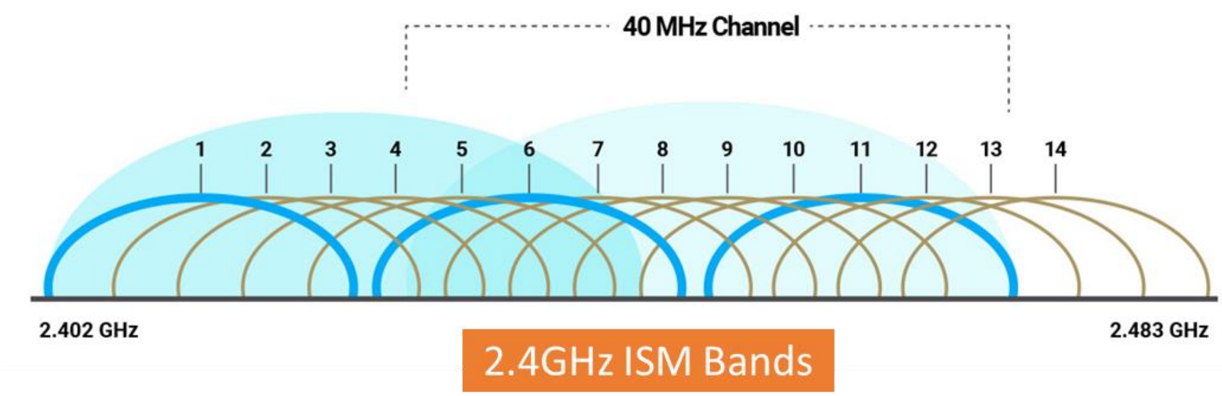
- A recent addition to Wi-Fi technology is the 6 GHz Band, which provides approximately 1.2 GHz of spectrum. This new band, associated with Wi-Fi 6E technology, unlocks the potential for even higher data rates and reduced interference.

- Each of these frequency bands possesses unique characteristics, including spectrum availability, range, and data rates. These distinctions play a crucial role in optimizing Wi-Fi network performance in various environments.

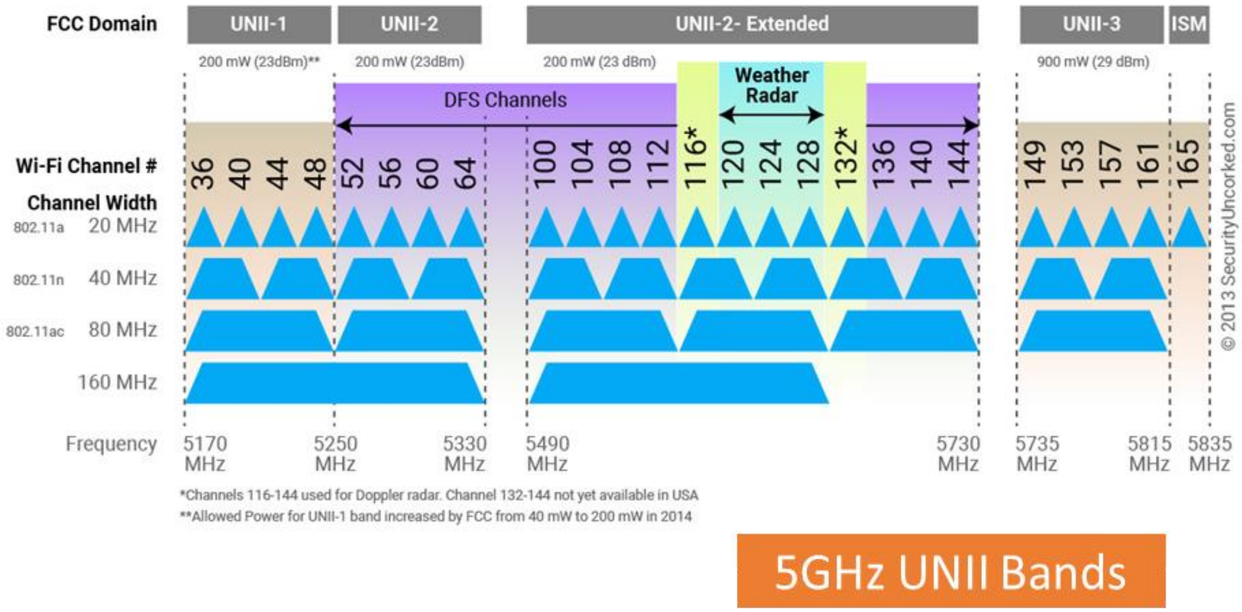
Wi-Fi Unlicensed Frequency:

- A fundamental aspect of Wi-Fi technology is its reliance on unlicensed frequency bands. This means that Wi-Fi users do not need to obtain specific licenses or pay fees to access and operate within these frequency ranges. Instead, governments allocate certain portions of the radio spectrum for unlicensed use, subject to specific regulatory guidelines.

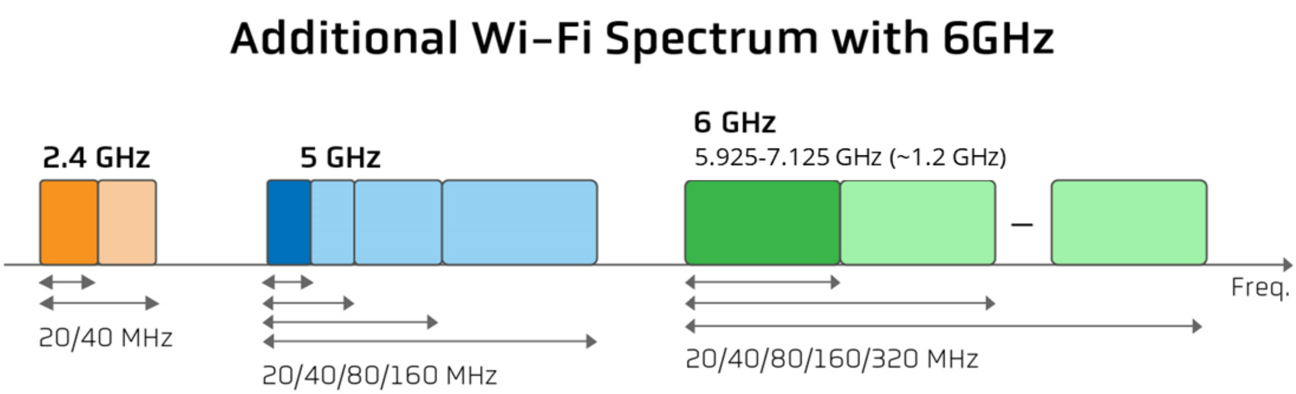
- The 2.4 GHz ISM Band, encompassing channels 1 through 11, falls under the unlicensed spectrum category. However, since it was one of the earliest frequency bands used for Wi-Fi, it has become somewhat congested. This band shares spectrum not only with Wi-Fi devices but also with other technologies such as Bluetooth, cordless phones, and baby monitors. Consequently, the 2.4 GHz band can experience interference and performance challenges, particularly in areas with a high concentration of such devices.



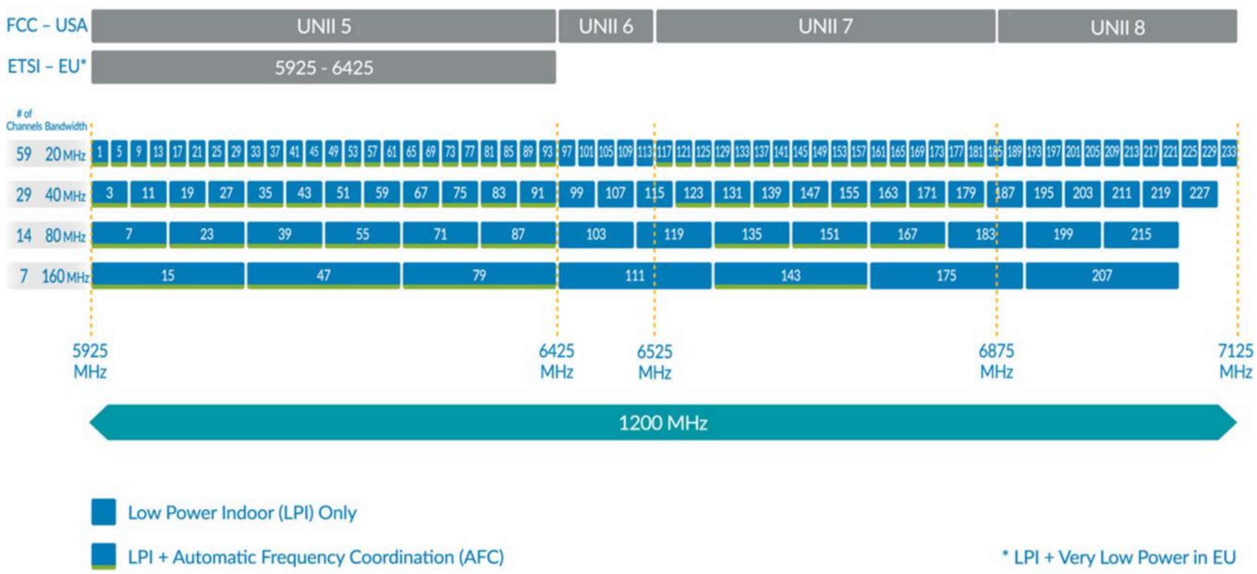
- In contrast, the 5 GHz Band provides a less crowded spectrum due to its higher frequencies. This results in a cleaner spectrum environment, delivering enhanced performance, especially in settings where interference is a concern.



- The 6 GHz Band, as the newest addition to the unlicensed spectrum, offers substantial advantages. With approximately 1.2 GHz of available spectrum, it provides ample room for Wi-Fi 6E technology, which leverages this extended spectrum to offer higher data rates and minimized interference. It's important to note that the availability of the 6 GHz Band for unlicensed use varies from one country to another.



6 GHz Channel Allocation:



- The 6 GHz Band's significance lies not only in its extensive spectrum but also in the way this spectrum is divided into channels. This allocation is crucial for optimizing the spectrum's use for Wi-Fi networks.

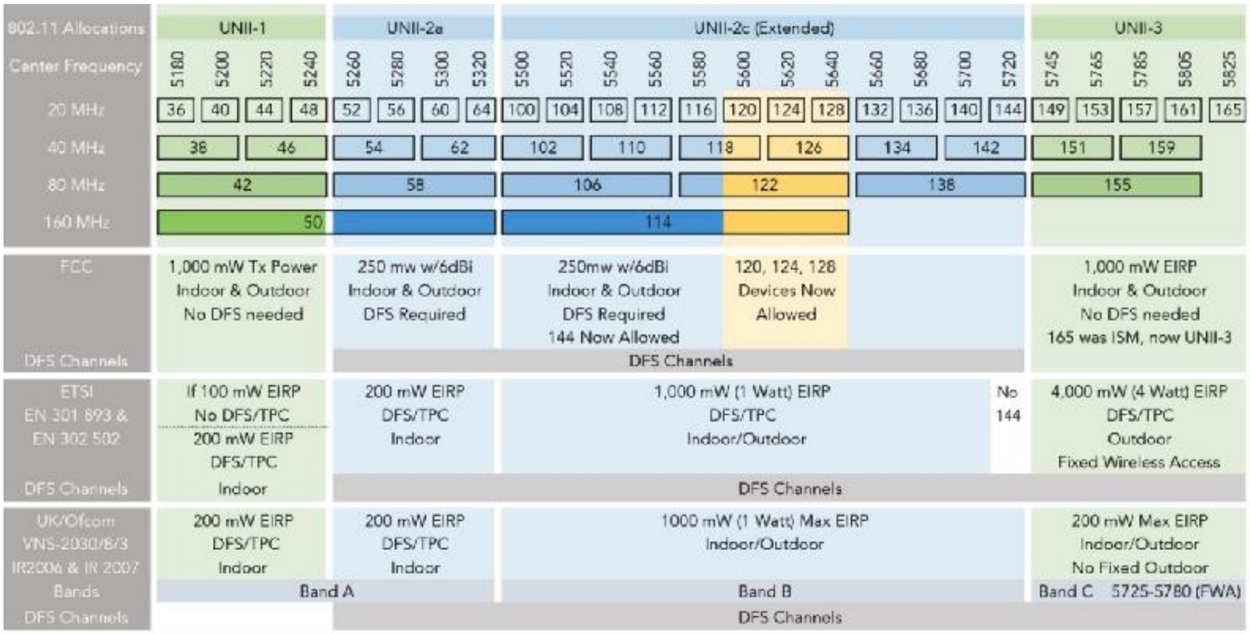
- Within the 6 GHz Band, numerous channels are available, each potentially allocated various bandwidths. Common channel widths include 20 MHz, 40 MHz, 80 MHz, and 160 MHz. This variety in channel widths provides flexibility in terms of data rates and the number of non-overlapping channels that can be utilized.

- For instance, when employing 20 MHz channels, it's possible to access approximately 59 non-overlapping channels. If 40 MHz channels are used, this number decreases to around 29. Moreover, it's essential to acknowledge that channel aggregation allows for wider channels, such as 80 MHz or 160 MHz. However, choosing broader channels results in fewer non-overlapping channels available for use.

- Each channel in the 6 GHz Band carries specific usage restrictions. Certain channels are exclusively designated for low-power indoor use, while others are meant for outdoor use only. Simultaneously, some channels are reserved for both indoor and outdoor applications. These designations ensure efficient and interference-minimized spectrum use across various applications and devices.

- Wi-Fi 6E technology harnesses the extended spectrum provided by the 6 GHz Band to deliver higher data rates and improved performance, particularly in scenarios where high-quality wireless connectivity is imperative.

UNII Bands Power Restrictions



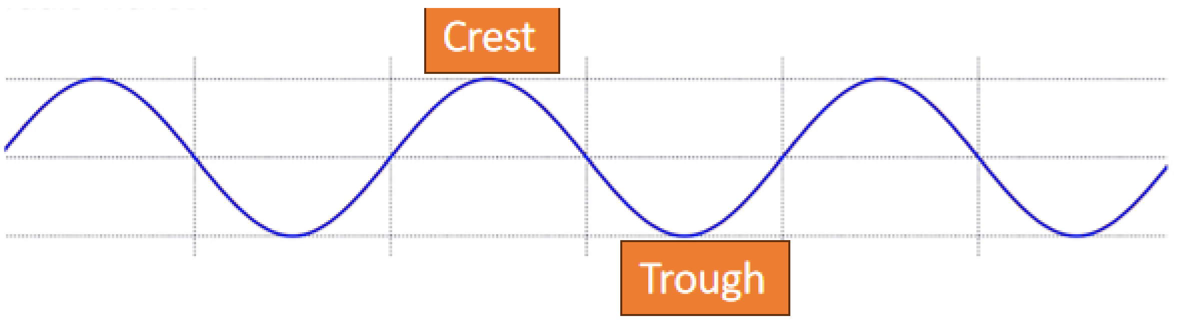
U-NII #	U-NII 5				U-NII 6		U-NII 7				U-NII 8	
Frequency Band	5925 <-----------------------------------> 6425 MHz				6425 <---> 6525 MHz		6525 <-----------------------------------> 6875 MHz				6875 <---> 7125 MHz	
Band Allocation	500 MHz				100 MHz		350 MHz				250 MHz	
e-CFR FCC Rule Part	Part 15.407(a)(4)-(8)				Part 15.407(a)(5), (6), (8)		Part 15.407(a)(4)-(8)				Part 15.407(a)(5), (6), (8)	
Phases	Phase 1 devices		Phase2 devices		Phase 1 devices		Phase 1 devices		Phase2 devices		Phase 1 devices	
Device (New Equipment Class)	Low Power Indoor AP (6ID), Subordinates (6PP), Indoor Clients (6XD), Dual Client (6CD)		Standard Power AP (6SP), Fixed (6FX) & Standard Clients (6FC), Dual Client (6CD)		Low Power Indoor AP (6ID), Subordinates (6PP), Indoor Clients (6XD), Dual Client (6CD)		Low Power Indoor AP (6ID), Subordinates (6PP), Indoor Clients (6XD), Dual Client (6CD)		Standard Power AP (6SP), Fixed (6FX) & Standard Clients (6FC), Dual Client (6CD)		Low Power Indoor AP (6ID), Subordinates (6PP), Indoor Clients (6XD), Dual Client (6CD)	
AP and Associated Clients	Low-Power Indoor AP	Client Connected to Low Power AP	Standard Power AP (AFC Controlled)	Client Connected to Standard Power AP	Low-Power Indoor AP	Client Connected to Low Power AP	Low-Power Indoor AP	Client Connected to Low Power AP	Standard Power AP (AFC Controlled)	Client Connected to Standard Power AP	Low-Power Indoor AP	Client Connected to Low Power AP
Maximum EIRP	30 dBm	24 dBm	36 dBm Additional rule for outdoor operation Max EIRP < 125 mW (21 dBm) at any elevation angle > 30° from horizon	30 dBm	30 dBm	24 dBm	30 dBm	24 dBm	36 dBm Additional rule for outdoor operation Max EIRP < 125 mW (21 dBm) at any elevation angle > 30° from horizon	30 dBm	30 dBm	24 dBm

Electromagnetic waves

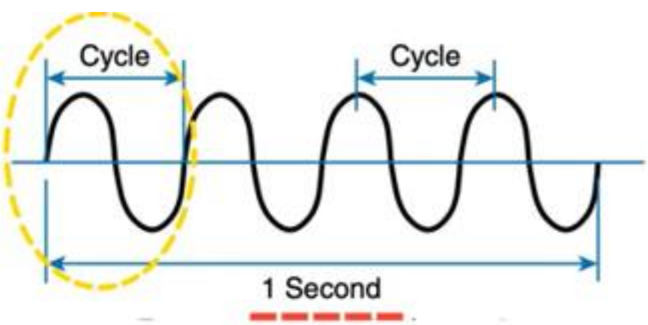
- When we transmit information from one point to another, whether it's through air, wires, or any other medium, the information travels in the form of waves. These waves play a crucial role in communication.
- The movement of information in the form of waves involves a concept known as frequency. Frequency is essentially the rate at which a wave completes one full cycle. A cycle, in this context, is one complete movement of a waveform from 0 degrees to 360 degrees in phase.

Frequency = Number of cycles per second

- **Hz**- standard unit of measurement used for measuring frequency.
- **1Hz** = 1 cycle per second



- Imagine a sine wave as an example. A cycle of a sine wave is the journey from the starting point (0 degrees) to the peak (90 degrees), down to the trough (180 degrees), and back to the starting point (360 degrees). This entire process is one cycle.



frequency = 4 cycles/second

4 hertz

- Frequency is defined as the number of cycles that occur in one second. If, for instance, this cycle repeats four times within a second, the frequency is said to be four cycles per second. This unit of frequency is measured in Hertz (Hz).

- So, when we refer to a wave having a frequency of four Hertz, it means that the cycle of that wave repeats four times in one second.

Unit	Abbreviation	Meaning
Hertz	Hz	Cycles per second
Kilohertz	kHz	1000 Hz
Megahertz	MHz	1,000,000 Hz
Gigahertz	GHz	1,000,000,000 Hz

- Kilohertz (kHz) is a thousand Hertz.
- Megahertz (MHz) is a million Hertz.
- Gigahertz (GHz) is a billion Hertz.

- So, when we say something is operating at 1 GHz, it means that the cycle repeats one billion times per second.

- For example, a device with a clock speed of 2.4 GHz means that its waveform cycles 2.4 billion times per second.

- Now talking about the radio waves, they operate within the frequency range of around 3 Khz to 300 Ghz. This broad spectrum accommodates various technologies, including TV and radio communication, satellite communication, radar, and wireless networks.

What is a wave?

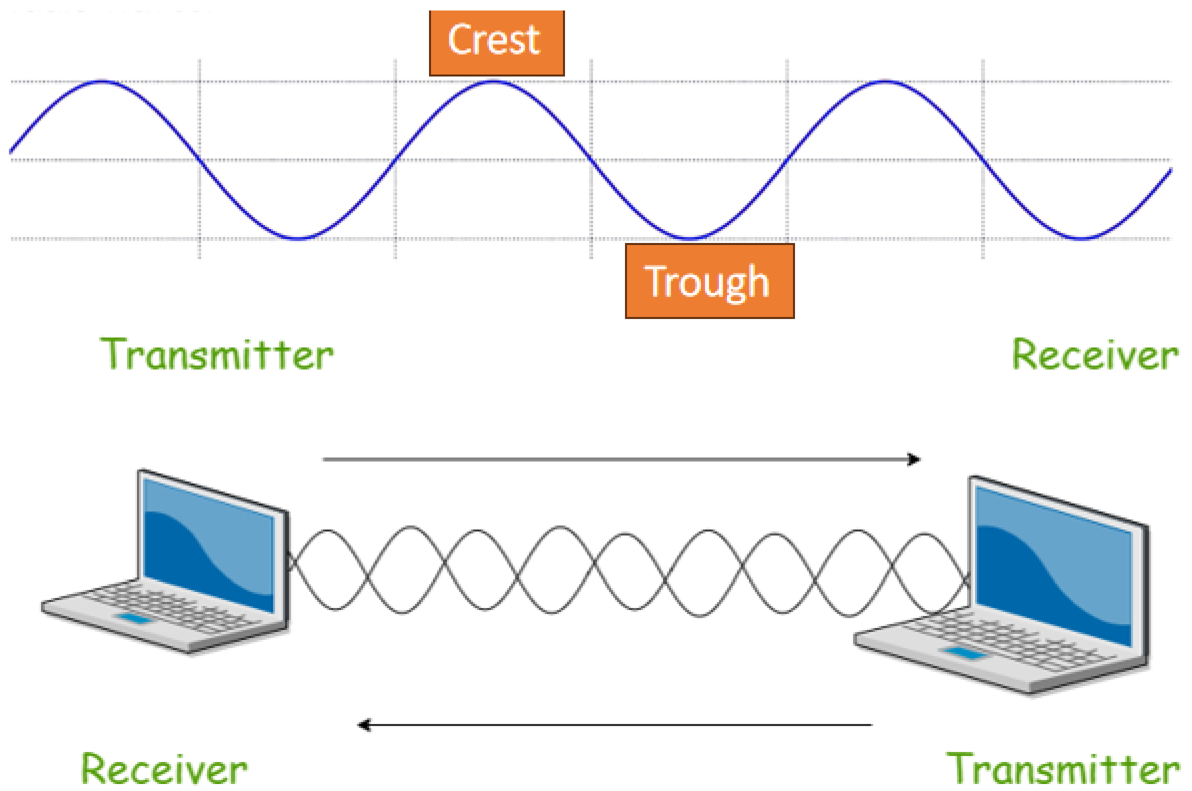
In essence, a **wave** is a traveling disturbance that carries energy from one point to another. When we talk about waves in the context of technology, we are essentially transferring information in the form of energy. This process involves sending ones and zeros from a transmitter to a receiver, constituting the basis of communication technologies like TV, radio, and wireless networks.

In the context of wireless communication, the terminology involves two key elements:

- **Wave:** The energy being transmitted from the transmitter to the receiver is termed as a wave.
- **Medium:** This refers to the substance or space through which the wave travels. In wireless communication, where there are no physical wires, the medium is often air. If, for example, the communication takes place underwater, then water becomes the medium.

The entire process of sending energy from the transmitter to the receiver is known as **propagation**. Whether it's through air, water, or any other medium, the signal moves through space, and this movement is the propagation of the wave.

Now, when we visualize a wave, it typically has two main components:
- **Crest:** The highest point of the wave.
- **Trough:** The lowest point of the wave.

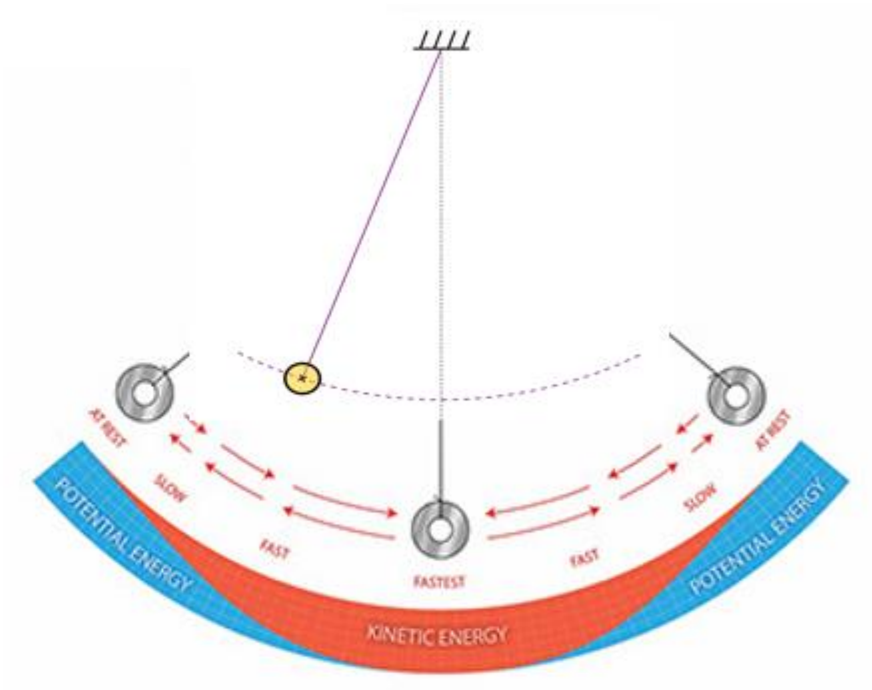


Signal energy or propagation

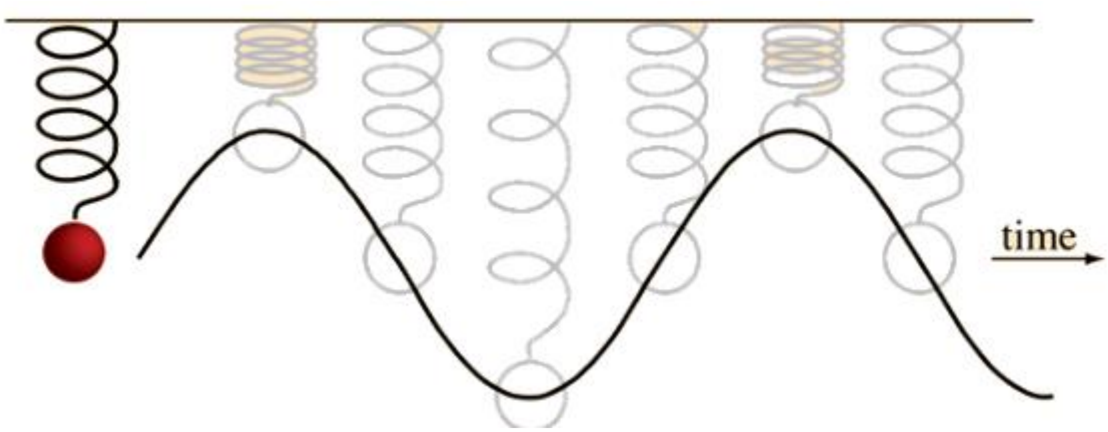
Why does energy travel in the form of a wave? Why can't it just go straight from one point to another? To answer this, let's look at a simple example,

- consider periodic motion, like that of a pendulum. As the pendulum swings back and forth, energy is constantly being converted between potential and kinetic energy. At the highest point, it possesses maximum potential energy, and at the lowest point, it has maximum kinetic energy.

- The oscillation continues, and over time, resistance in the medium, such as air, causes the pendulum to slow down.



- Similarly, if you were to use a spring, pulling it down and releasing it, the energy stored as potential energy propels the spring back and forth. Again, this process involves a constant conversion between potential and kinetic energy.



- When we are discussing signals and waves, it's not feasible for a signal to continuously move at the same speed due to various factors, including resistance. For example, in the case of a pendulum clock, an external energy source is required to sustain the motion because resistance gradually slows it down.

- So, the essence of why energy travels in the form of waves lies in the dynamic interplay between potential and kinetic energy, the impact of resistance, and the continuous cycle of energy conversion.

- Now, let's relate this to generating waves. Imagine dropping a water droplet into a pool. The energy generated travels as waves. As the waves propagate, they encounter resistance, causing them to slow down. The kinetic energy is then converted into potential energy, forming a continuous cycle of energy conversion.

Basics of an oscillator

- Electronic devices don't rely on dropping water droplets to generate waves, instead, they utilize circuits. At a very basic level, one key component is an **oscillator**. While the technology behind it is intricate and involves numerous components like transistors and resistors, we can simplify the concept to an **LC (inductor-capacitor) circuit.**

- An oscillator in an electronic circuit generates waveforms. The process is not as straightforward as a pendulum, but at its core, it involves creating a repetitive cycle of energy. The specifics delve into formulas, equations, and various electronic components, but the result is the generation of waveforms that carry information from one point to another.

- It achieves this by transmitting current between a capacitor, which stores electric fields, and an inductor, which stores magnetic fields.

- The process involves the continuous transfer of energy from the capacitor to the inductor and vice versa. The capacitor accumulates energy in the form of electric fields, which then charges the inductor. In the reverse order, the inductor returns and charges the capacitor.

- The constant shift in energy between the electric field and the magnetic field generates the waveforms.

- The sine wave is the natural waveform that results from this type of circuit

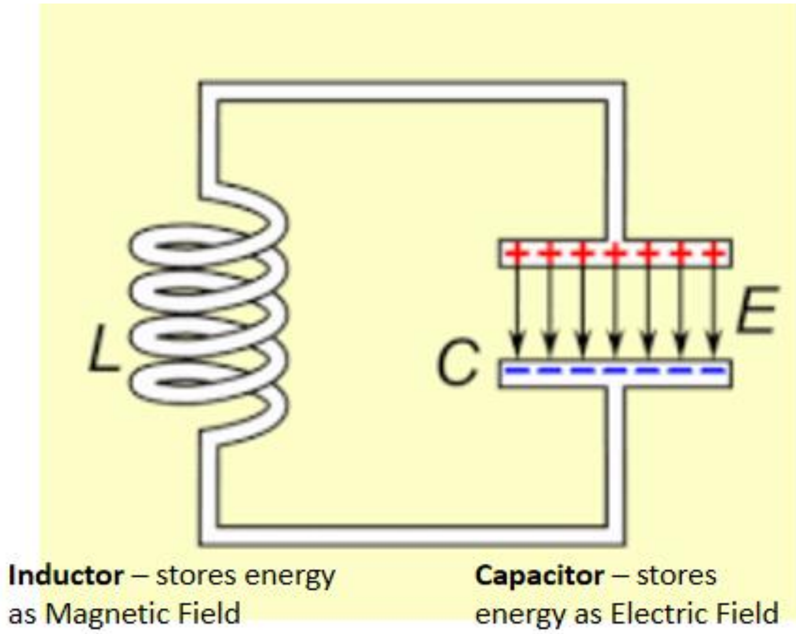
Now, to control the frequency of these waveforms, certain parameters in the circuitry can be adjusted. This control allows for the generation of periodic waveforms at varying frequencies.

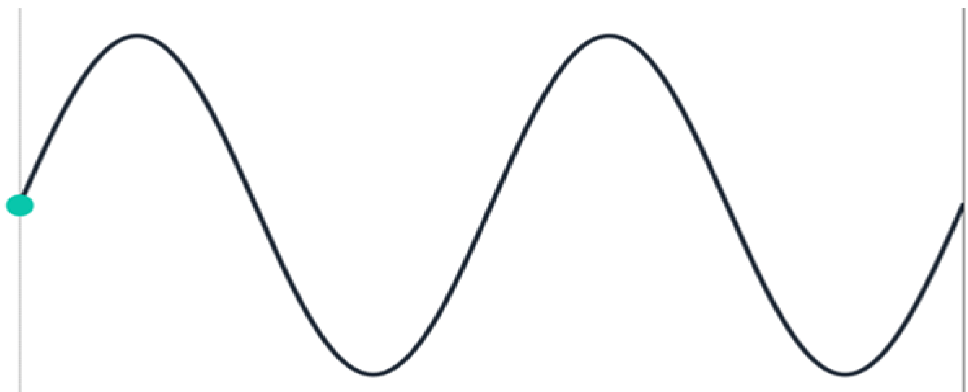
Moving on to the fundamental properties of periodic waveforms:

- **Frequency:** This is the number of cycles within one second. Higher frequencies result in shorter wavelengths, and lower frequencies have longer wavelengths.

- **Wavelength:** It is the distance between two similar points in a waveform, such as the crest of two periodic waves. Wavelength is inversely proportional to frequency.

- **Amplitude:** Amplitude represents the power level of the waveform. Higher amplitude indicates transmission at a higher energy level.





Properties of a Periodic Waveform:

1. Frequency: Frequency is a fundamental property of a periodic waveform. It represents the number of cycles within one second. Higher frequency waveforms have more cycles per second, while lower frequency waveforms have fewer cycles.

2. Wavelength: Wavelength is the distance between similar points in a waveform, such as the crest of two consecutive cycles. It is inversely proportional to frequency. Higher frequency waveforms have shorter wavelengths, while lower frequency waveforms have longer wavelengths.

3. Amplitude: Amplitude relates to the power level of the waveform. It represents the height of the waveform. Higher amplitude waveforms transmit at a higher energy level, while lower amplitude waveforms transmit at a lower energy level. For example, in sound, speaking at a higher volume produces higher amplitude sound waves.

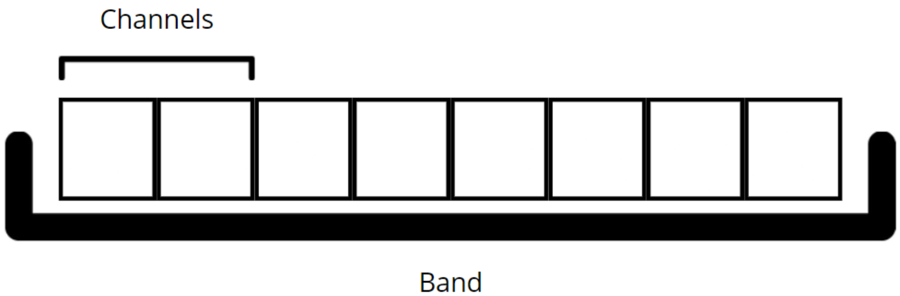
4. Phase: Phase is a relative property, representing the relationship between the positions, amplitudes, crests, and troughs of two waveforms. It involves measuring how one waveform's cycle aligns or shifts with respect to another waveform. Phase shifts are often expressed in degrees, with 0 degrees at the starting point of a waveform, 90 degrees at the first crest, 180 degrees at a midpoint, 270 degrees at the first trough, and 360 degrees for one complete cycle.

These properties define the characteristics of periodic waveforms and play a crucial role in signal generation, transmission, and communication systems.

What is channel bandwidth?

Channel:

Each frequency band is divided into smaller segments; these smaller segments are called "Channels". And the range that each channel covers is known as "Channel Width"

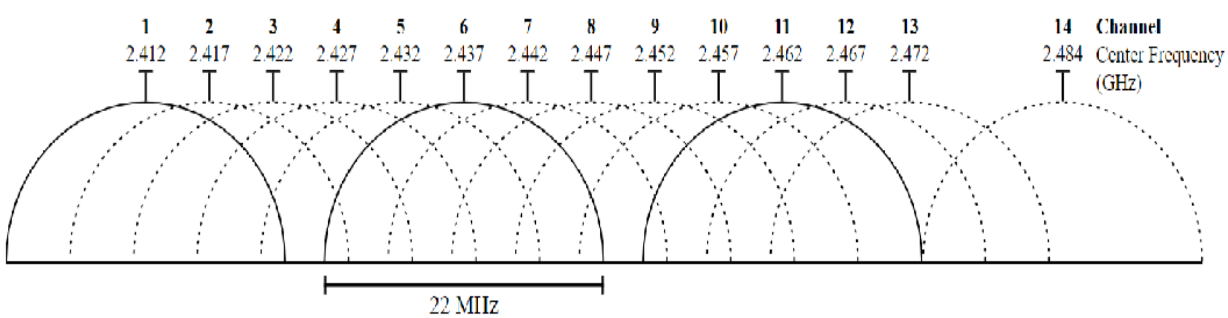


Bandwidth of a Channel:

A channel is the medium through which the signal carrying information will be passed. In terms of analog signal, bandwidth of the channel is the range of frequencies that the channel can carry. In terms of digital signal, bandwidth of the channel is the maximum bit rate supported by the channel. i.e., the maximum amount of data that the channel can carry per second.

Channel bandwidth refers to the range of frequencies available for transmitting data.
It is measured in Hertz (Hz), and common bandwidths include 20 MHz, 40 MHz, 80 MHz, 160 MHz, and 320 MHz.

Channel Bandwidth in the 2.4 GHz Spectrum:



The 2.4 GHz band covers a 100 MHz range from 2400 MHz to 2500 MHz.

In the 2.4 GHz spectrum, there are approximately 14 channels available for wireless communication. These channels are spaced apart to minimize interference.
Some of these channels are non-overlapping, meaning they don't interfere with each other.
For example, Channel 6 is approximately 22 MHz wide, making it a common choice for wireless communication.

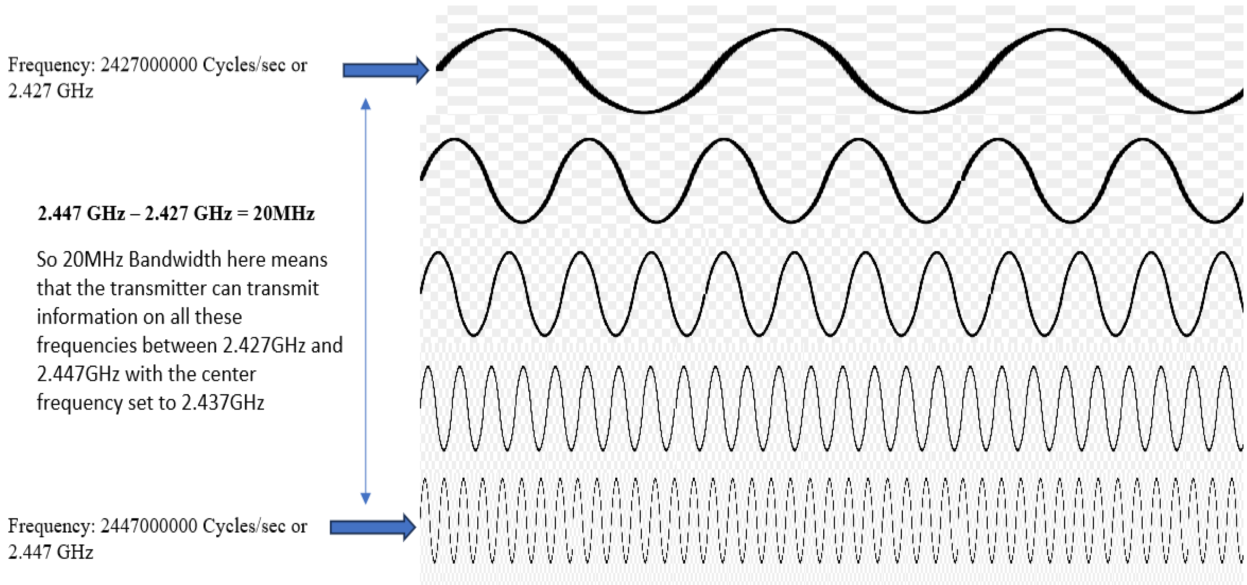
Understanding Channel Bandwidth:

Channel bandwidth determines how much information can be transmitted over a wireless link.
It defines the frequency range available for communication. A 20 MHz wide channel allows data transmission on frequencies between 2.42 GHz and 2.44 GHz.

Frequency is the number of cycles per second in a waveform, measured in Hertz.
A higher frequency wave has more cycles per second, which means it carries more information.
A 20 MHz channel means there are 20 million cycles per second available for data transmission.
Channel bandwidth encompasses a specific range of frequencies where data can be transmitted.

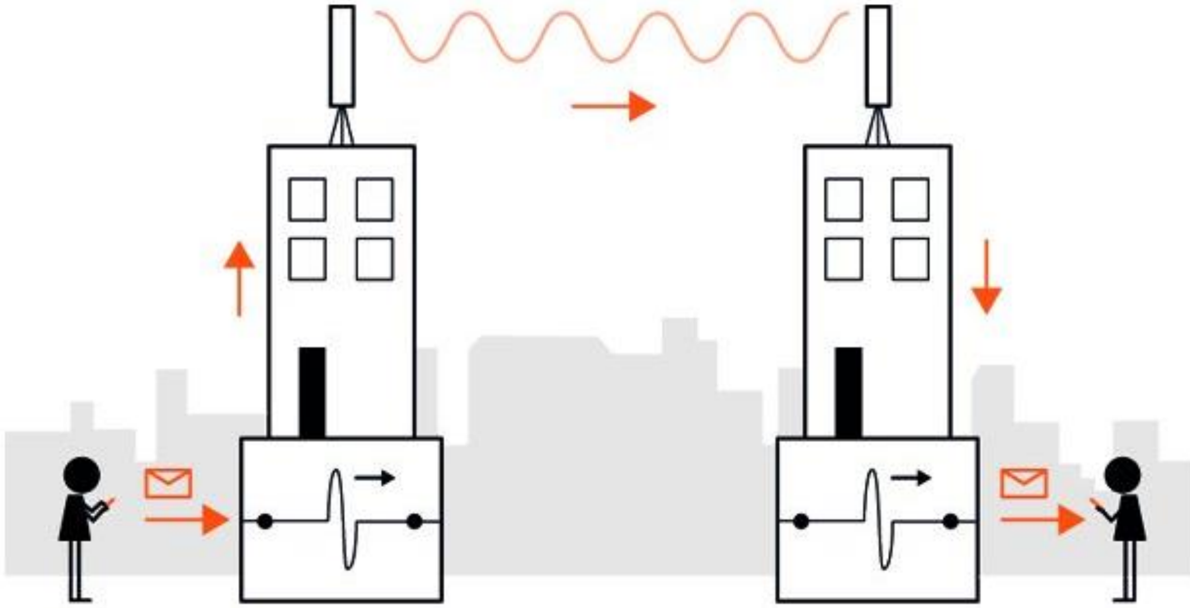
Significance of Channel Bandwidth:

Channel bandwidth is crucial for efficient data transmission and minimizing interference.
It ensures that multiple wireless devices can communicate simultaneously without causing excessive interference.
The choice of channel bandwidth affects the data transfer rate and the quality of the wireless connection.

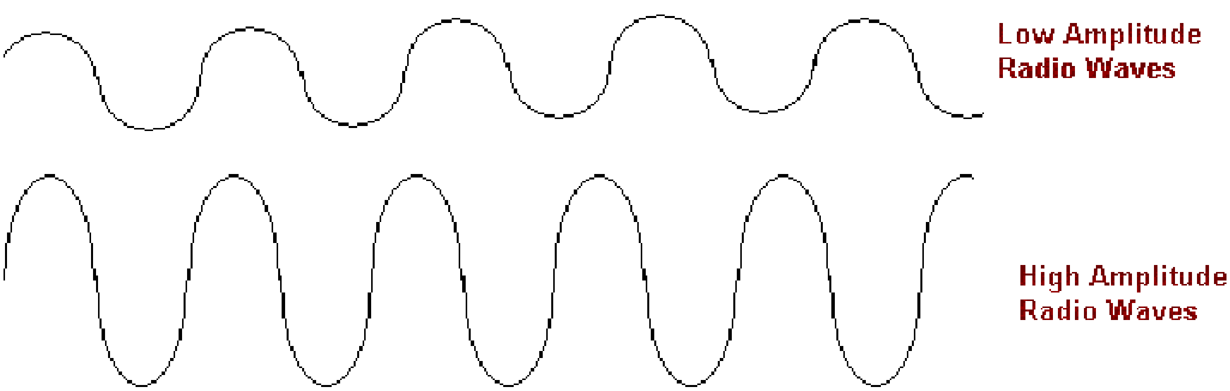


How Radio Waves Carry Information?

The basic principle behind how radio waves carry information is simple. Imagine, you have a sender and a receiver using radio waves to communicate. The sender, or transmitter, transforms the messages by adjusting the strength or speed of the radio waves, kind of like Morse code where dots and dashes represent letters. On the other side, the receiver is tuned to the same "language" and recognizes these changes. It then converts the encoded signal back into the original message, which could be anything from sounds to images or data. In simpler terms, one end tweaks the waves to hide the message, and the other end understands these tweaks and reveals the hidden information.

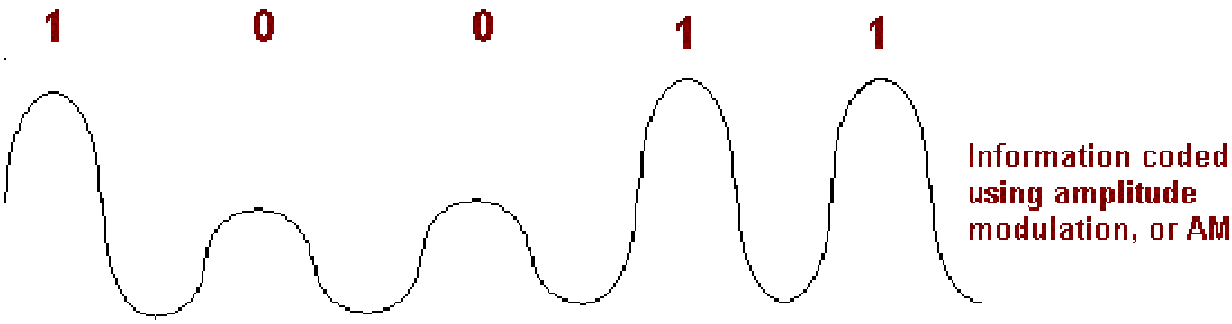


Using Amplitude for Data Transmission:



Amplitude refers to the height or strength of a wave.
It can be varied when transmitting a signal, similar to how one adjusts the volume when speaking.
To transmit binary data (1s and 0s), a higher amplitude represents '1,' while a lower amplitude represents '0.'

Agreement Between Transmitter and Receiver:

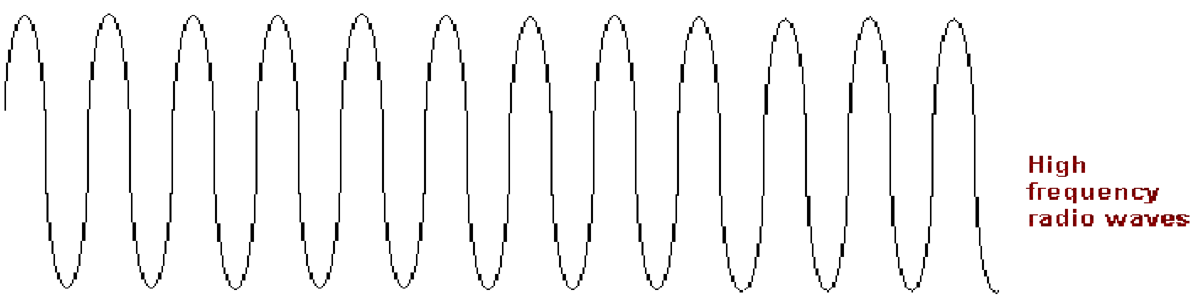


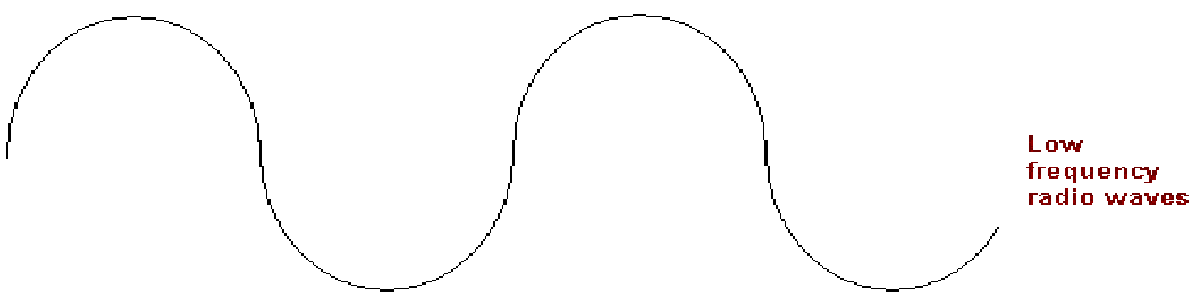
Successful communication depends on a mutual agreement between the transmitter and receiver.

The transmitter communicates to the receiver that high amplitude signifies '1,' and low amplitude signifies '0.'

The receiver decodes the signal based on these agreements.

Using Frequency for Data Transmission:



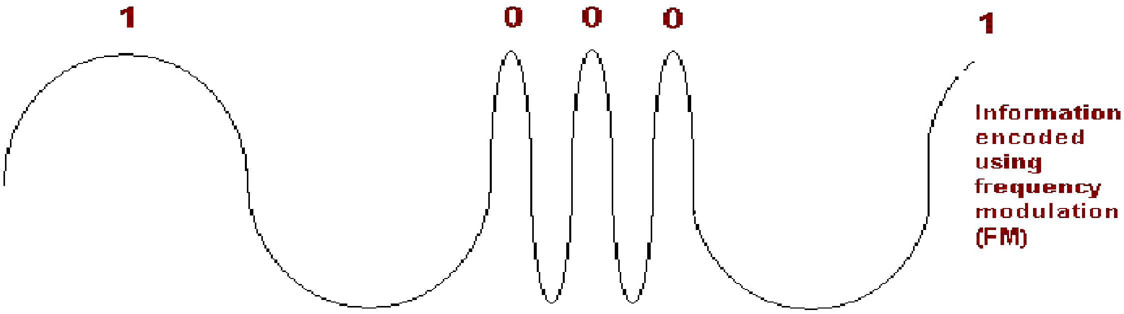


Frequency modulation is another way to convey information.

The frequency of a signal can be varied without changing its amplitude.

A lower frequency can represent '1,' and a higher frequency can represent '0.'

Importance of Agreement Between Transmitter and Receiver:



The transmitter communicates to the receiver that a lower frequency indicates '1,' while a higher frequency indicates '0.'
The receiver recognizes these frequency changes to decode the information.

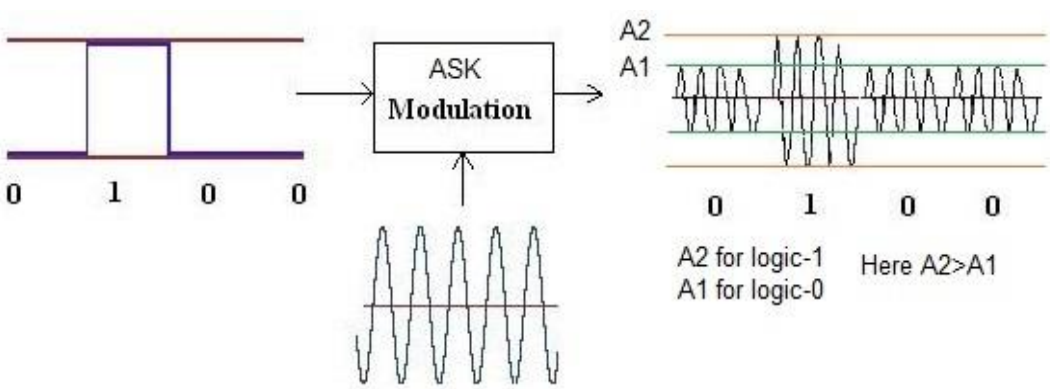
Modulation

Modulation is a fundamental concept in telecommunications that involves modifying properties of a carrier signal such as its amplitude, frequency, or phase to encode information. This information is often digital, in the form of binary sequences.It involves varying one or more properties of a periodic waveform to transmit information.

There are various forms of modulation, each designed to alter a particular characteristic of the carrier wave. The most commonly altered characteristics include amplitude, frequency, phase, pulse sequence, and pulse duration.

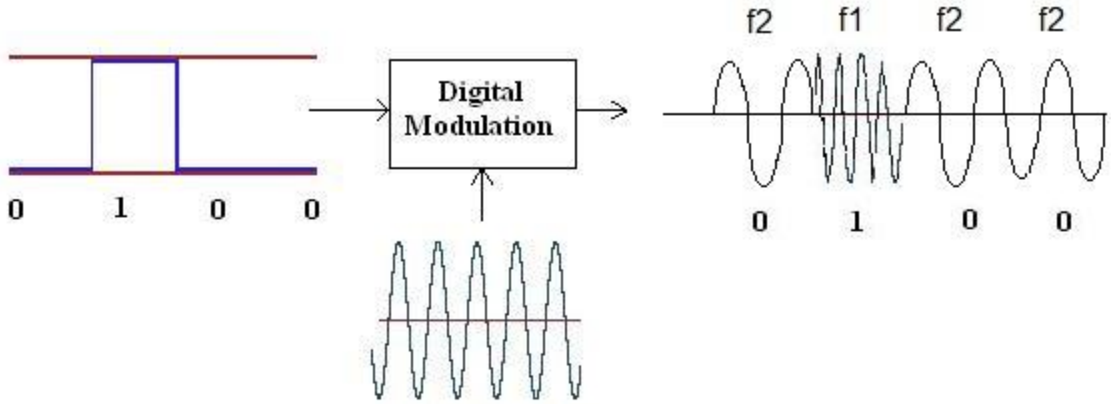
Amplitude Shift Keying(ASK):

The short form of Amplitude Shift Keying is referred to as ASK. It is the digital modulation technique. In this technique, amplitude of the RF carrier is varied in accordance with baseband digital input signal. As shown in the figure, binary 1 will be represented by a carrier signal with some amplitude while binary 0 will be represented by a carrier of zero amplitude(i.e. no carrier).



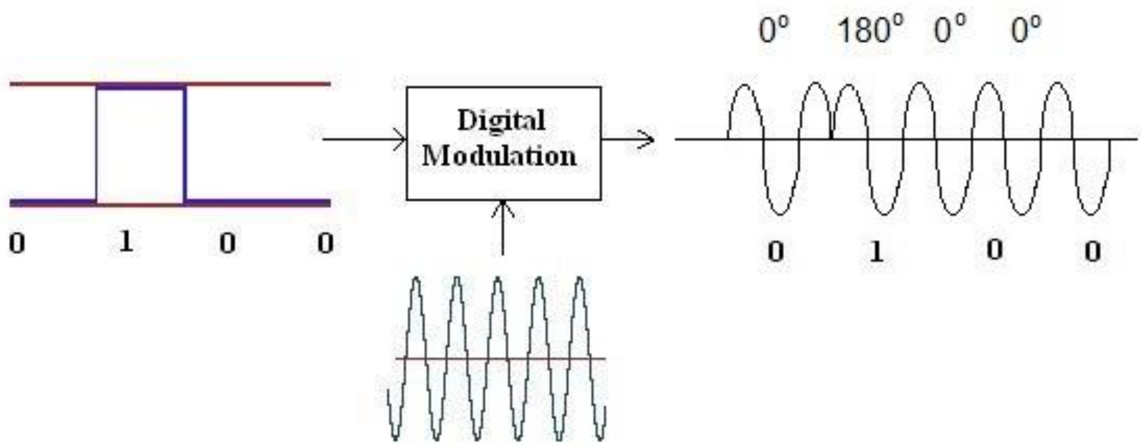
Frequency Shift Keying:

The short form of Frequency Shift Keying is referred to as FSK. It is also a digital modulation technique. In this technique, frequency of the RF carrier is varied in accordance with baseband digital input. As shown, binary 1 and 0 are represented by two different carrier frequencies. In the following figure binary 1 is represented by high frequency 'f1' and binary 0 is represented by low frequency 'f2'.



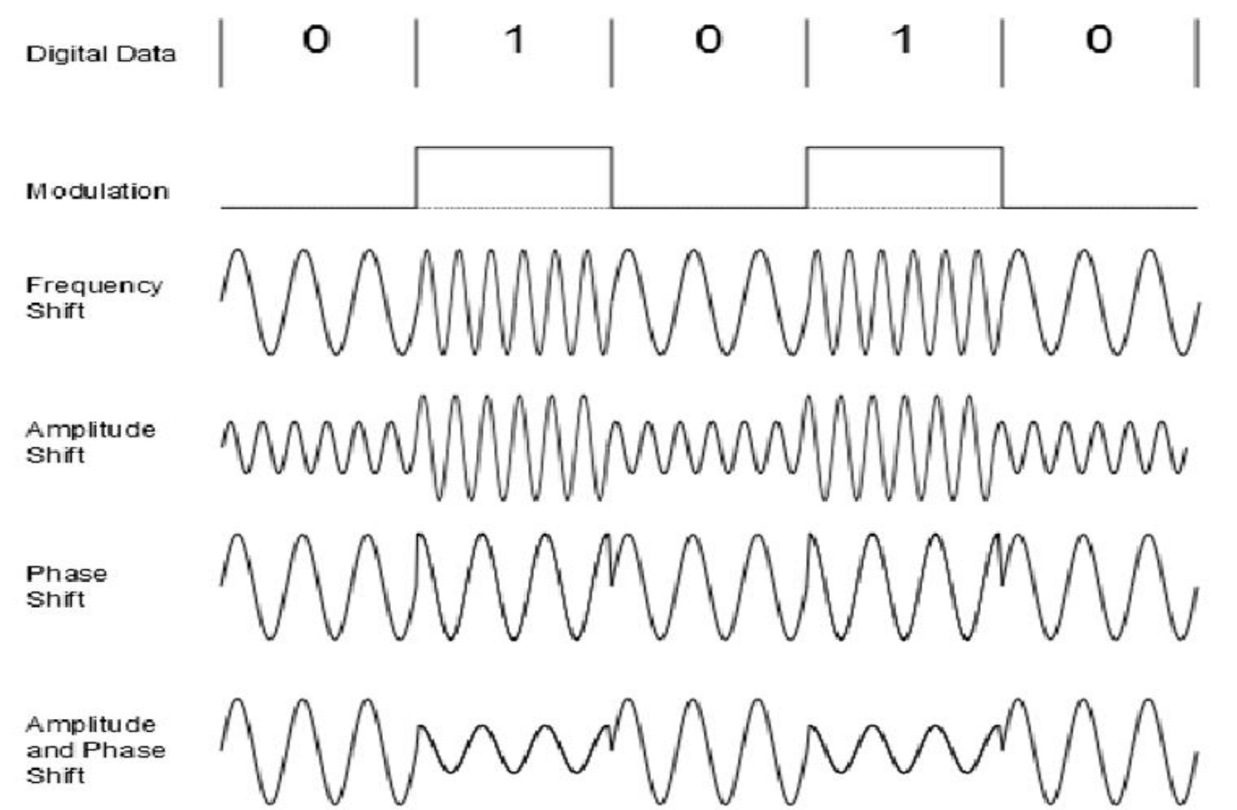
Phase Shift Keying:

The short form of Phase Shift Keying is referred to as PSK. It is a digital modulation technique where the phase of the RF carrier is changed based on digital input. Figure depicts Binary Phase Shift Keying modulation type of PSK. As shown in the figure, Binary 1 is represented by the 180 degree phase of the carrier and binary 0 is represented by the 0 degree phase of the RF carrier.



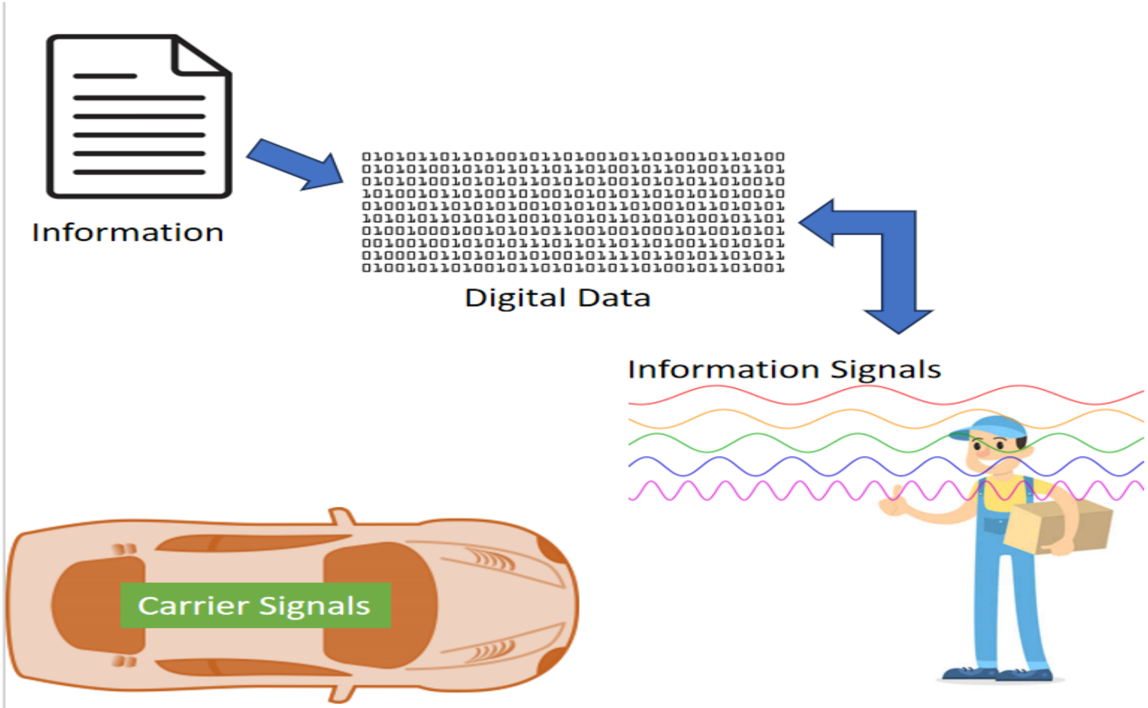
Quadrate Amplitude Modulation:

The full form of QAM is Quadrature Amplitude Modulation technique. It is a digital modulation technique. This modulation technique is a combination of both Amplitude and phase modulation techniques. For QAM, each carrier is ASK/PSK modulated. Hence data symbols have different amplitudes and phases.By changing both properties at once, it can transmit more information per signal.For example, a specific amplitude and phase combination can represent multiple bits of data, improving throughput.

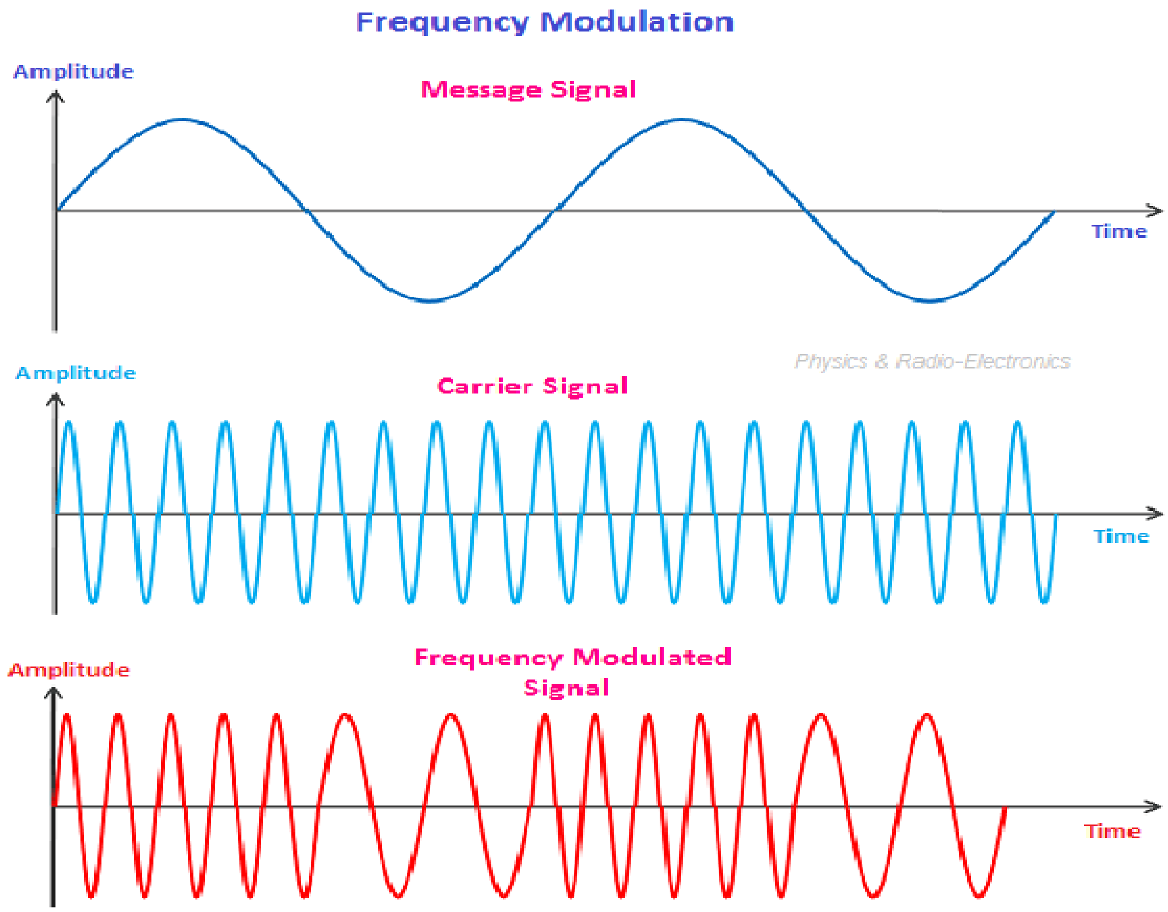


Information Signals and Carrier Signals

Information is in the form of “Ones” and “Zeros”.We have data in the form of ones and zeros, like a secret code.This data, known as the baseband signal, is at a low frequency and represents our "code."To send this data over long distances, we need a "carrier signal" at a much higher frequency. We imagine this like a person (the "carrier boy") carrying our information on top of a fast car (the "carrier signal").The carrier signal is like a highway for our data.To prevent different people from sending information at the same time and causing problems, each "carrier boy" uses a unique "car" (carrier signal).This is similar to tuning our radio to a specific channel to listen to a particular program.The process of putting our data on the carrier signal is called modulation.When we combine the baseband signal with the carrier signal, we get the actual signal that's sent through the air. This is how messages travel wirelessly.



This is the process of combining Information Signals with Carrier Signals.

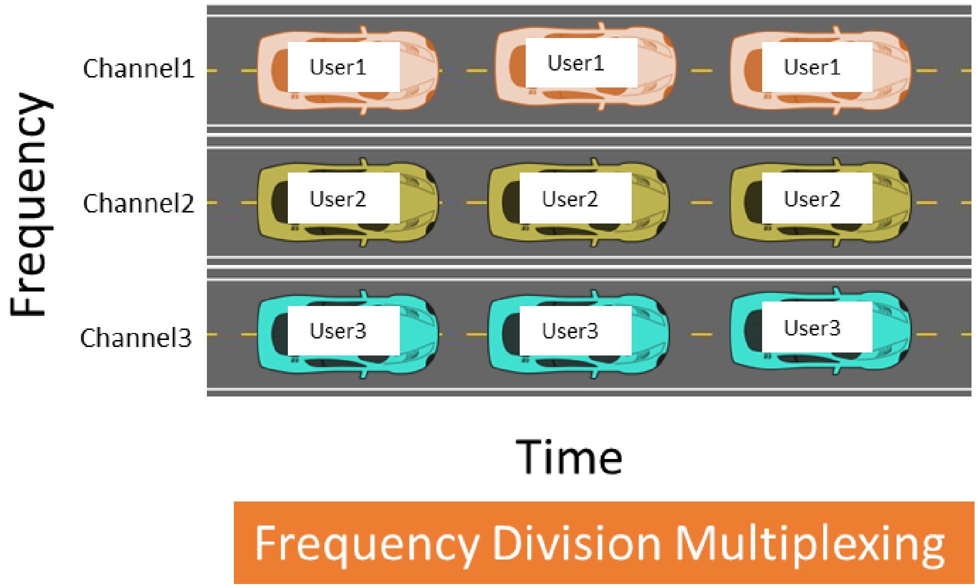


This is the output in the air that is acheived after combining Information Signal with Carrier Signal.

Different Multiple Access Techniques

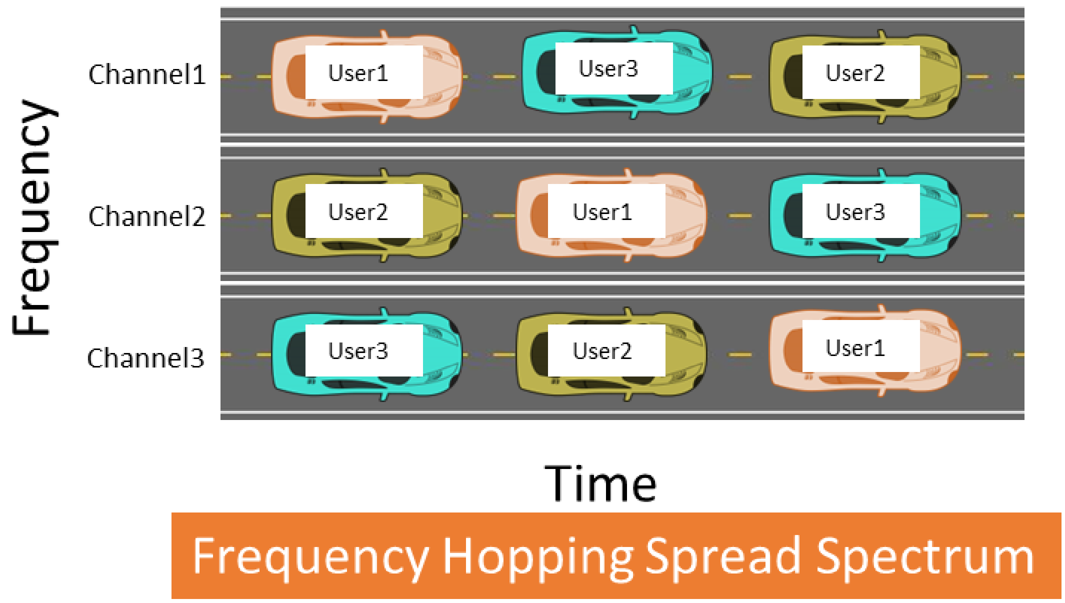
1. Frequency Division Multiplexing (FDM):

- Description: FDM is a technique that divides the available frequency spectrum into multiple channels, each with its carrier signal. Each user or channel is assigned a specific frequency band, and they communicate using that frequency.
- Characteristic: Each user has a dedicated frequency band, and they don't share the same frequency with others.
- Example: AM and FM radio use FDM, where different stations transmit on distinct frequency bands.



2. Frequency Hopping Spread Spectrum (FHSS):

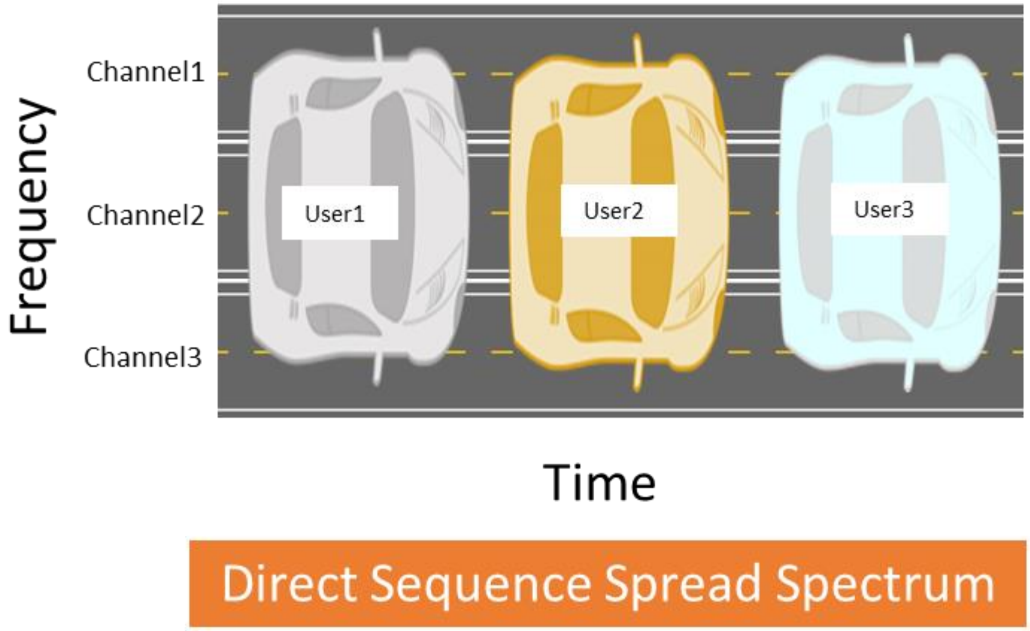
- Description: FHSS is a technique that enhances security by allowing users to hop between different frequencies at specific time intervals. Users change frequencies rapidly, making it difficult for eavesdroppers to intercept the signal.
- Characteristic: Rapid frequency hopping is used to transmit data securely.
- Example: FHSS is used in various wireless communication technologies, including some Wi-Fi and Bluetooth implementations.



3. Direct Sequence Spread Spectrum (DSSS):

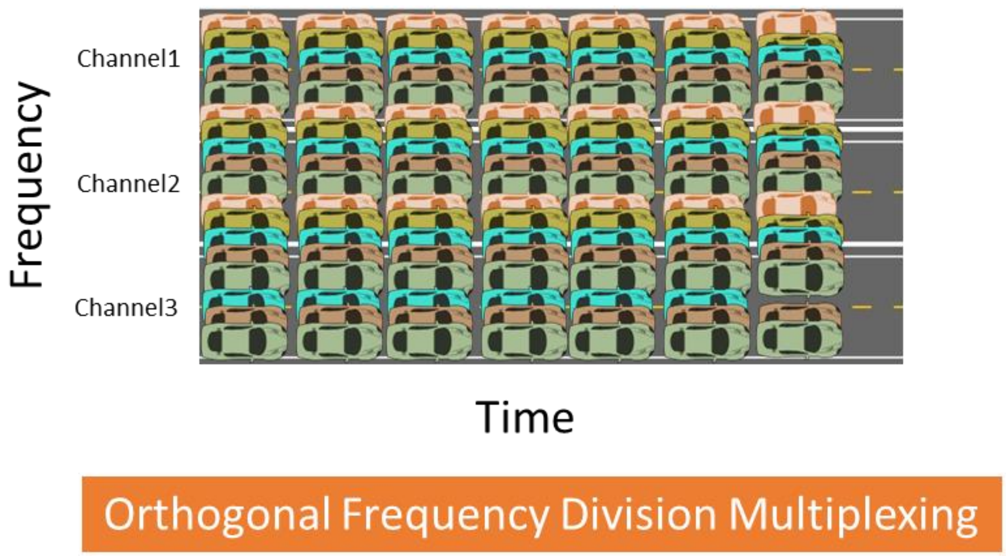
- Description: DSSS spreads the information over the entire available frequency band, making it more resistant to interference and jamming. It involves multiplying the information signal by a "spread code."
- Characteristic: Data is spread across a wide frequency band using a specific code.

- Example: DSSS is commonly used in technologies like CDMA (Code Division Multiple Access) in mobile communication and some wireless LAN standards.



4. Orthogonal Frequency Division Multiplexing (OFDM):

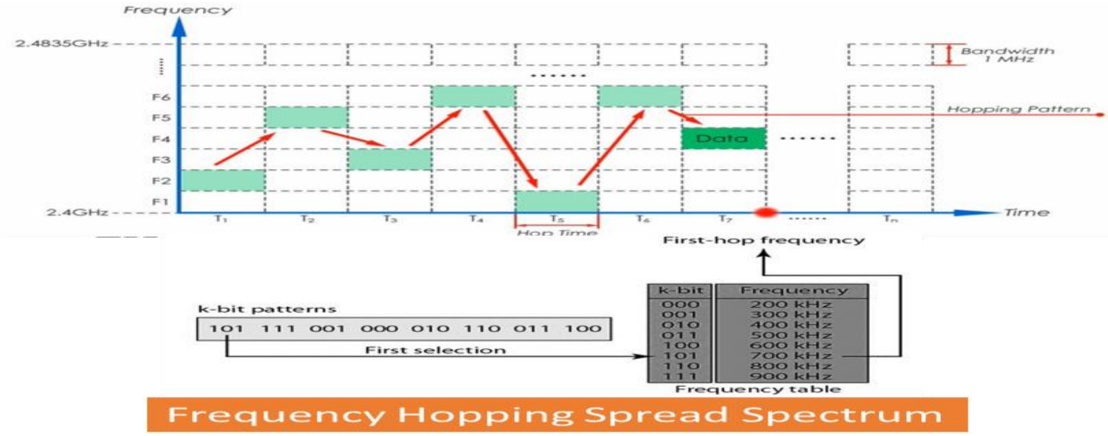
- Description: OFDM is a technique that divides a high-speed data stream into multiple lower-speed data streams, which are transmitted simultaneously on multiple subcarriers. These subcarriers are orthogonal, meaning they don't interfere with each other.
- Characteristic: OFDM uses multiple subcarriers that can be transmitted concurrently without interference.
- Example: OFDM is widely used in various communication systems, including DSL, Wi-Fi, and 4G/5G cellular networks.



What is spread spectrum?

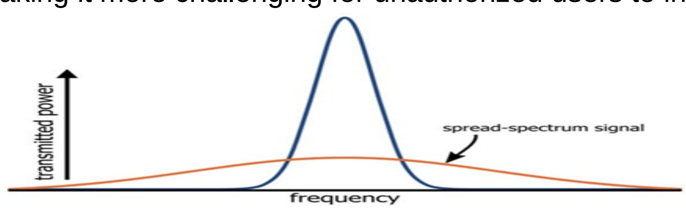
Spread Spectrum (SP Spectrum) refers to a technique used in wireless communication to spread the signal over a wider frequency band than the original signal bandwidth. It serves multiple purposes, including enhancing signal security, improving resistance to interference, and reducing the impact of narrowband interference.

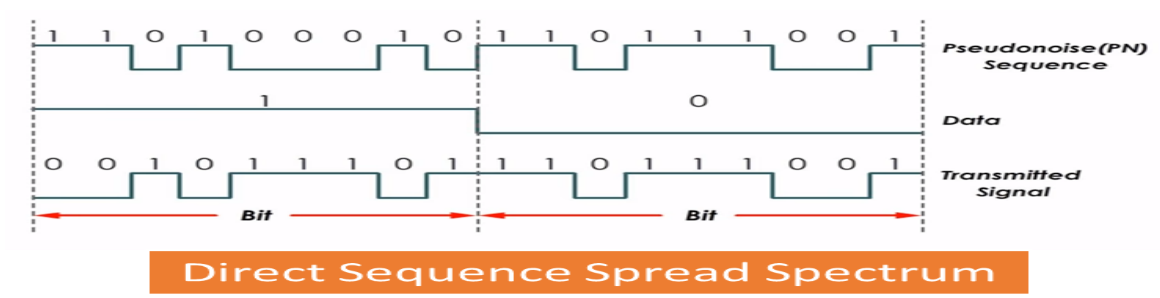
There are two primary methods used in Spread Spectrum:



1. Frequency Hopping Spread Spectrum (FHSS):

- In FHSS, a random pattern or code is applied to the base signal, causing it to hop between different frequencies over time.
- This hopping pattern is synchronized between the transmitter and receiver, allowing them to switch frequencies in coordination.
- The random frequency changes help combat interference and provide a degree of security, making it more challenging for unauthorized users to intercept the signal.





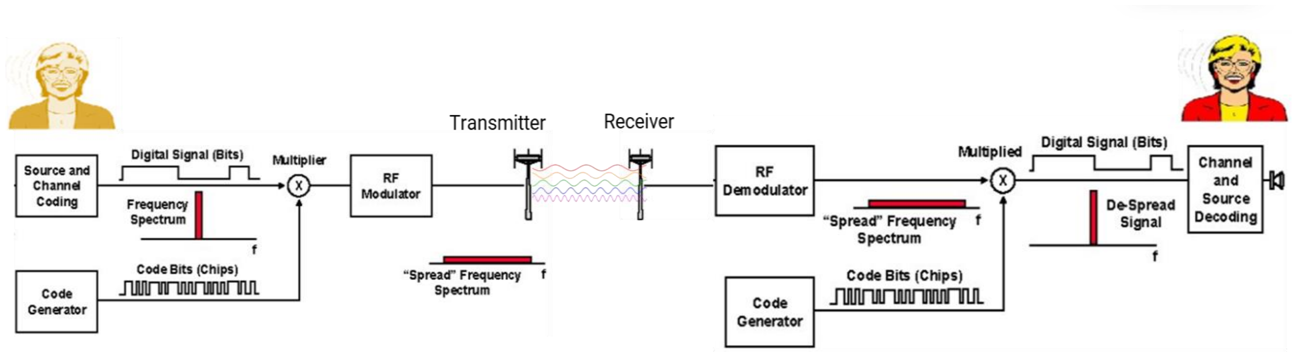
2. Direct Sequence Spread Spectrum (DSSS):

- In DSSS, a spreading sequence or code, such as a pseudorandom noise (PN) sequence, is used to spread the signal across a broader frequency spectrum.
- This technique involves multiplying the original signal by a PN sequence, which expands the bandwidth of the signal.

- Even though DSSS involves significant overhead (about 10 times) due to the spreading of information, it significantly enhances signal reliability and robustness against noise and interference.

While these methods result in lower data transmission rates due to the increased overhead, they greatly enhance the security and reliability of the transmitted signal, making them vital for applications where signal integrity and robustness are critical. Understanding these Spread Spectrum techniques provides a comprehensive insight into the principles underpinning wireless communication security and interference mitigation.

DSSS Transmit and Receive



Data Rate	Code Length	Modulation	Symbol Rate	Bits/Symbol
1 Mbps	11 (Barker Sequence)	BPSK	1 MSps	1
2 Mbps	11 (Barker Sequence)	QPSK	1 MSps	2
5.5 Mbps	8 (CCK)	QPSK	1.375 MSps	4
11 Mbps	8 (CCK)	QPSK	1.375 MSps	8

When implementing Direct Sequence Spread Spectrum (DSSS) technology, the transmission and reception processes involve several critical steps to ensure secure and reliable communication.
Transmitting Data:
1. Begin with the data in the form of ones and zeros that you want to transmit.
2. Use a code generator to spread the signal, expanding it across a wide frequency spectrum. This process involves multiplying the data by a specific code.
3. The spread signal is then modulated onto the carrier signal using an RF modulator.
4. The modulated signal is transmitted to the receiver.

Receiving and Decoding Data:
1. The receiver captures the transmitted signal and demodulates it to extract the base signal from the carrier signal.

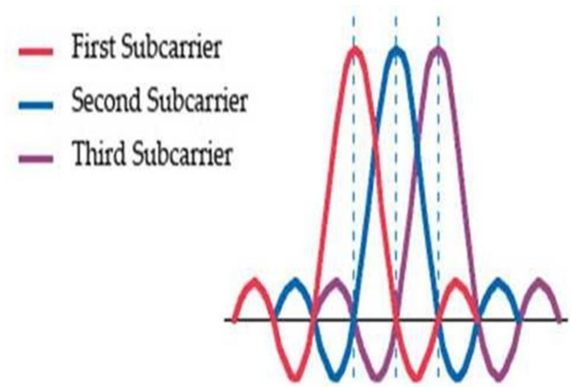
2. The opposite of the code generator, often referred to as a correlator, is employed to reverse the spreading process. It takes the spread signal and applies the original code to obtain the de-spreaded signal, essentially reconstructing the original data set.
3. The received data undergoes further processing and is then sent for interpretation or utilization.

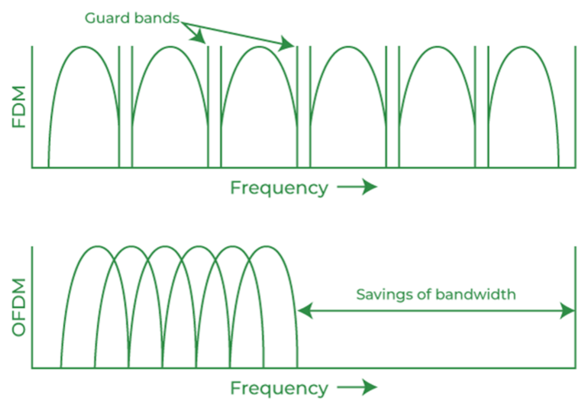
To achieve different data rates within the 802.11 standards (e.g., 1 Mbps, 2.5 Mbps, 2 Mbps, 5.5 Mbps, 11 Mbps), various techniques are utilized, including altering the code lengths and modulation rates:

- **Code Length Variation:** Using different code lengths, measured in chips or code bits, enables the manipulation of the amount of data encoded, thereby facilitating diverse data rates. Shorter code lengths result in higher throughput, allowing for increased data rates.
- **Modulation Rate Variation:** Modulation techniques, such as BPSK (Binary Phase Shift Keying) and QPSK (Quadrature Phase Shift Keying), play a vital role in achieving different data rates. By employing complex modulation methods, the data rate can be adjusted to meet specific requirements.

Understanding these fundamental steps and the variations in code lengths and modulation rates sheds light on how DSSS achieves different data rates, contributing to a more comprehensive grasp of the intricacies of wireless communication.

Orthogonal Frequency Division Multiplexing (OFDM)





Exploring OFDM (Orthogonal Frequency Division Multiplexing) is crucial to understanding the evolution of wireless networking. As networks evolved, there was a shift in the approach to efficiently utilize available frequency spectrum, making OFDM a significant advancement. OFDM differs from earlier multiplexing methods like frequency hopping and direct sequence spread spectrum.

Let's simplify how OFDM works and why it's essential:

Transition to OFDM:

- Early wireless standards, like 802.11b, did not prioritize high data rates as we do today. The focus was on low data rates, where techniques like frequency hopping and direct sequence spread spectrum were adequate.
- As the demand for higher data rates grew, it became clear that using the spectrum more efficiently was necessary to achieve greater throughput.

Spectral Efficiency with OFDM:

- OFDM is a key solution to improve spectral efficiency. Spectral efficiency means using the available spectrum more efficiently to transmit more data.
- The amount of spectrum available remains constant. For instance, a 20 MHz channel is still 20 MHz, whether in 802.11b or modern standards like 802.11n, 802.11ac, and 802.11ax.
- Spectral efficiency means packing more information into the same amount of spectrum, effectively transmitting more data within the available frequencies.

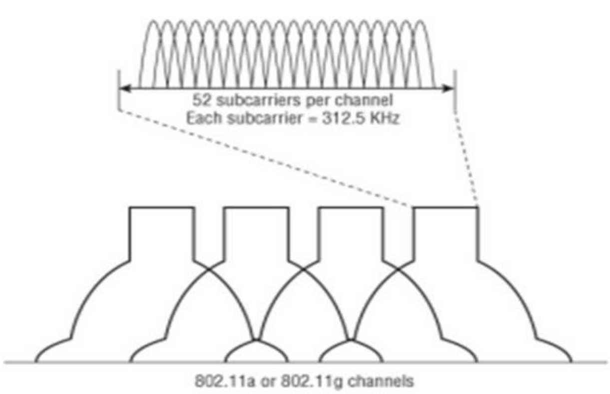
How OFDM Works:

- OFDM achieves spectral efficiency by dividing the available spectrum into smaller subcarriers.
- Traditional frequency division multiplexing (FDM) allocates specific non-overlapping frequencies to different users, separated by guard bands.
- OFDM takes a different approach: it overlaps subcarriers, maximizing the use of available bandwidth.
- The key to successful transmission with overlapping subcarriers is the orthogonal nature of the waveforms.
- When one subcarrier reaches its peak energy level, adjacent subcarriers are at zero energy.
- This orthogonality minimizes interference, allowing multiple subcarriers to transmit concurrently without disrupting each other.

The term "Orthogonal Frequency Division Multiplexing" precisely captures this concept. It's about dividing frequency and multiplexing data in an orthogonal (non-interfering) manner.

OFDM has become the foundation for many modern wireless technologies, as it significantly improves spectral efficiency and allows us to achieve higher data rates within the same spectrum.

Basic OFDM Data Rates for 802.11a/b



Modulation	Coded bits per sub-carrier	Coded bits per OFDM symbol	Coding rate	Data bits per OFDM symbol	Data rate for 20MHz channel
BPSK	1	48	1/2	24	6 Mbps
BPSK	1	48	3/4	36	9 Mbps
QPSK	2	96	1/2	48	12 Mbps
QPSK	2	96	3/4	72	18 Mbps
16-QAM	4	192	1/2	96	24 Mbps
16-QAM	4	192	3/4	144	36 Mbps
64-QAM	6	288	2/3	192	48 Mbps
64-QAM	6	288	3/4	216	54 Mbps

In the context of 802.11g and 802.11a standards, OFDM is employed to efficiently utilize the available 20 MHz channel. Here's how it works:

Breaking Down the Spectrum:

- With OFDM, the 20 MHz channel is divided into 52 subcarriers, each approximately 300 kHz wide.
- Instead of transmitting data on a single carrier, information is sent in parallel across all these subcarriers. This is akin to multiple lanes on a highway, allowing more data to be transmitted simultaneously.

Spectrum Efficiency:

- The key to OFDM's effectiveness is packing these subcarriers closely together while making them orthogonal (non-interfering) to each other.
- This means that when one subcarrier is at its peak energy level, the others are at zero energy, minimizing the risk of interference.
- By using the spectrum in this manner, it becomes significantly more efficient, allowing for the transmission of a greater amount of data within the same 20 MHz channel.

Increasing Data Rates:

- This efficient use of the spectrum facilitates higher data rates. While 802.11b offered data rates of 1 Mbps or 2 Mbps, standards like 802.11g and 802.11a saw substantial improvements, with data rates reaching 6 Mbps, 9 Mbps, 12 Mbps, and beyond.
- Achieving higher data rates isn't solely about subcarrier packing; it also involves varying coding rates, modulation types, and other factors. These adjustments contribute to reaching even higher data rates.

Overall, OFDM serves as a foundational technology that allows for a more efficient use of the available spectrum. It's a pivotal element in achieving higher data rates and enhancing the performance of wireless networks.