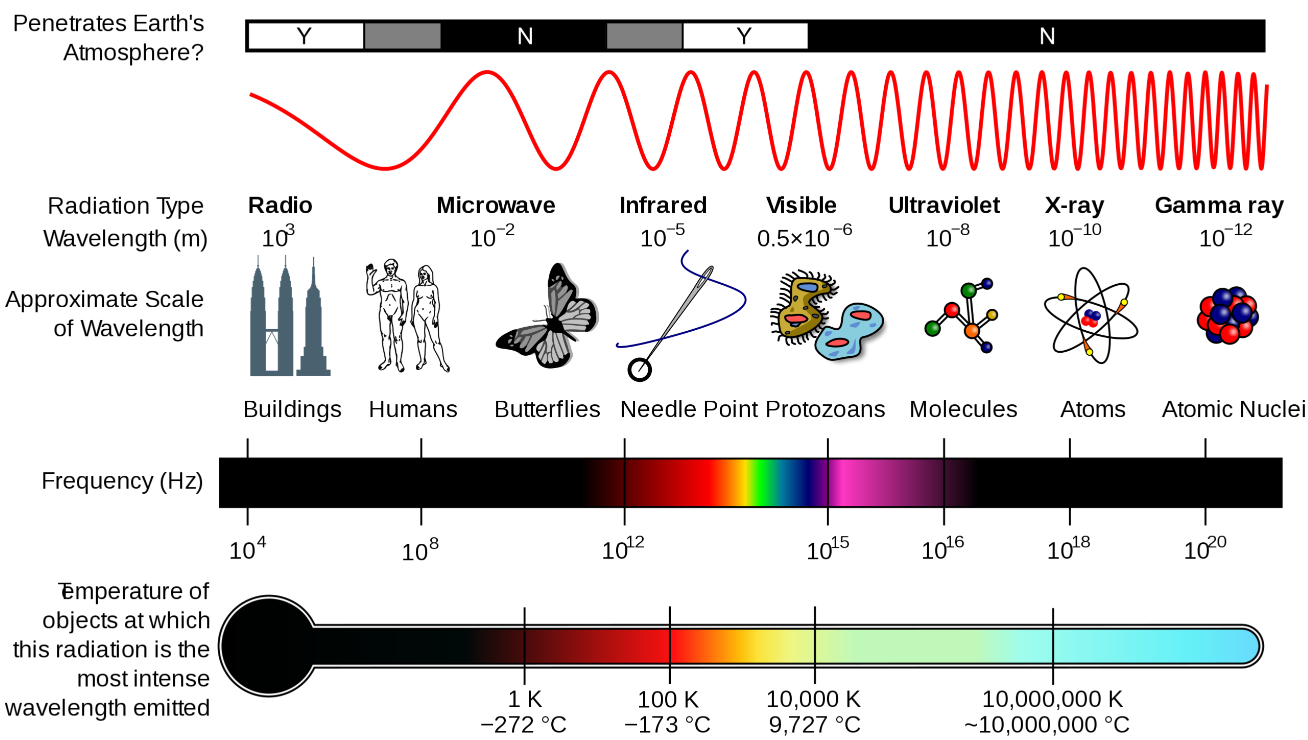
RF Explained - Waves, Math, WiFi

In this first article, we will understand the basis of my project on 'using Channel State Information for Robot Perception tasks'. And the basis is very simple, such that it only requires a revision of high school math and physics concepts!

So let's get started

What are RF waves?

These are basically electromagnetic waves ranging from 20KHz to 300GHz frequency range. According to my best friend Wikipedia, **Radio waves** are a type of electromagnetic radiation with wavelengths in the electromagnetic spectrum longer than infrared light. Following is the EM Spectrum for better visualization.



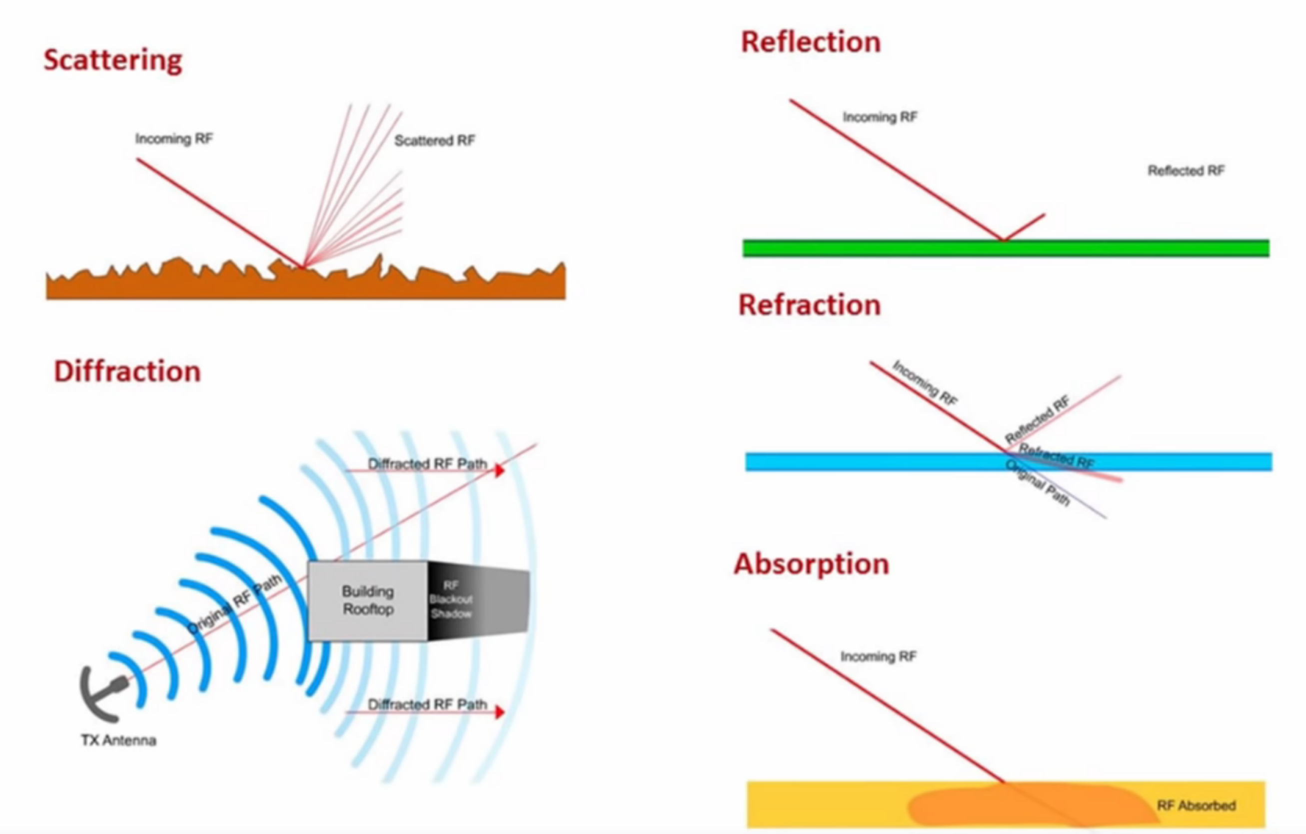
And just like any other wave radio waves also have peculiarities to define and identify them using common wave conventions - wavelength, amplitude, frequency, phase, modulation.

Wave Properties

There are 7 important properties of waves:

1. Attenuation: Gradual loss in power
2. Amplification: power gain, externally
3. Reflection
4. Refraction
5. Absorption
6. Scattering
7. Diffraction

Isn't a picture worth a thousand words? the following image shows these properties which I know you'll be able to easily recall once you see them!



RF Measurements and Math

Now let's just quickly recall the math we studied related to waves. remember Decibels?? Basically there are only two things:

1. Relationship between Watts and dBm.
2. Relationship between dB and dBm.

All the EM waves have some amount of power in them, and their interaction with any material is characterized by their power and frequency. Watts (W) is the basic unit of power measurements but waves are weak! and thus they are generally measured in milliwatts (mW). This gives us absolute measure of the power.

Further, to simplify the notation, scientists and researchers came up with another unit which can be understood in absolute as well as relative terms --> Decibels (dB)

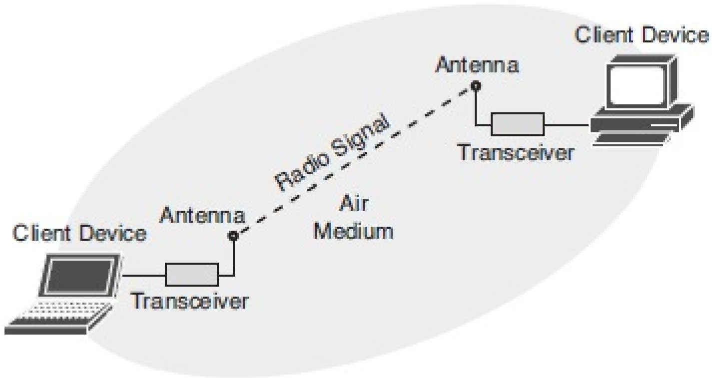
Following table shows how these units relates with each other:

Rule	Explanation	Percentage of Power Lost/ Gained	Current Power Level	Example
-3 dB	Half the watt value	50% lost	Half of original	100 mW - 3 dB = 50 mW
+3 db	Double the watt value	100% gained	Double the original	10 mW + 3 dB = 20 mW
-10 dB	Decrease watt value to one tenth of original	90% lost	One-tenth of original	300 mW -10 dB = 30 mW
+10 dB	Increase the watt value by ten-fold	1,000% gained	Ten times the original	10 mW + 10 dB = 100 mW

But why are we doing this?

We are doing this because we care about WiFi CSI and guess what type of waves are used in WiFi? --> Yes, Radio waves: broadly speaking 2.4GHZ and 5GHz frequency ranges.

Following image illustrates a basic RF system that enables the propagation of radio waves.



The transceiver and antenna can be integrated inside the client device or can be an external component. The transmission medium is primarily air, but there might be obstacles, such as walls and furniture.

RF Transceiver

A key component of a WiFi is the RF transceiver, which consists of a transmitter and a receiver. The transmitter transmits the radio wave on one end of the system (the "source"), and the receiver receives the radio wave on the other side (the "destination") of the system. The transceiver is generally composed of hardware that is part of the wireless client radio device (sometimes referred to as a client card).

Next figure shows the basic components of a transmitter and receiver.

A process known as *modulation* converts electrical digital signals that represent information (data bits, 1s and 0s) inside a computer into radio waves at the desired frequency, which propagate through the air medium. Refer to the section "RF Modulation" for details on how modulation works. The amplifier increases the amplitude of the radio wave signal to a desired transmit power prior to being fed to the antenna and propagating through the transmission medium (consisting primarily of air in addition to obstacles, such as walls, ceilings, chairs, and so on).

RF Receiver

At the destination, a receiver detects the relatively weak RF signal and demodulates it into data types applicable to the destination computer. The radio wave at the receiver must have amplitude that is above the receiver sensitivity of the receiver; otherwise, the receiver will not be able to "interpret" the signal, or decode it. The minimum receiver sensitivity depends on the data rate. For example, say that the receiver sensitivity of an access point is −69 dBm for 300 Mbps (802.11n) and −90 dBm for 1 Mbps (802.11b). The amplitude of the radio wave at the receiver of this access point must be above −69 dBm for 300 Mbps or above −90 dBm for 1 Mbps before the receiver will be able to decode the signal.

MIMO and OFDM - WiFi 802.11n/ac

With fancy tech like WiFi, comes some fancy methods too!

For the latest WiFi techniques we do not work with a single wave passing between Tx and Rx. Instead we have a range of intuitively spaces waves being transmitted between Tx and Rx. This is done in such a manner that these waves do not interfere with each other and hence do not create problems even when transmitted together!

According to my friend Wikipedia, multiple-input and multiple-output, or MIMO is a method for multiplying the capacity of a radio link using multiple transmission and receiving antennas to exploit multipath propagation. MIMO has become an essential element of wireless communication standards including IEEE 802.11n+ (WiFi). Greg Raleigh and V. K. Jones founded Airgo Networks in 2001 to develop MIMO-OFDM chipsets for wireless LANs.

And OFDM is the secret behind the recipe of effective communication through MIMO. Basically, In OFDM, multiple closely spaced orthogonal subcarrier signals with overlapping spectra are transmitted to carry data in parallel.

These are the advantages of OFDM over old methods:

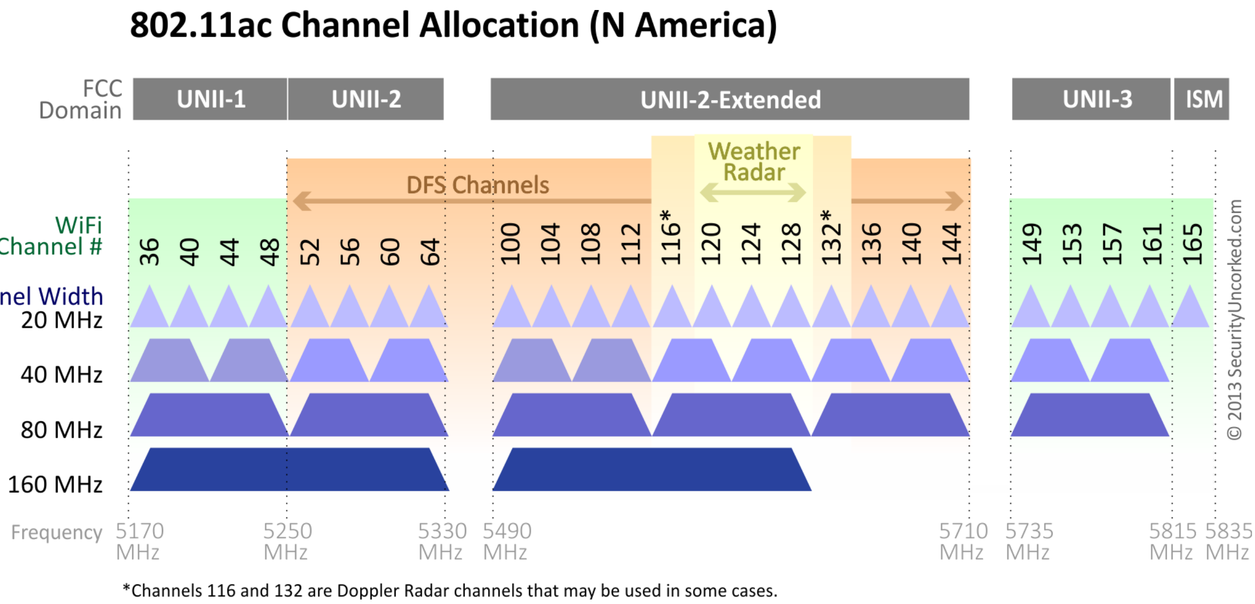
- High spectral efficiency as compared to other double sideband modulation schemes, spread spectrum, etc.
- Can easily adapt to severe channel conditions without complex time-domain equalization.
- Robust against narrow-band co-channel interference
- Robust against intersymbol interference (ISI) and fading caused by multipath propagation
- Efficient implementation using fast Fourier transform
- Low sensitivity to time synchronization errors
- Tuned sub-channel receiver filters are not required (unlike conventional FDM)
- Facilitates single frequency networks (SFNs) (i.e., transmitter macrodiversity)

Channels and Carrier

So now all the properties we recalled for a EM wave, are applicable to a single sub-carrier wave. A carrier is a waveform (usually sinusoidal) that is modulated with an information-bearing signal for the purpose of conveying information. The purpose of the carrier is usually either to transmit the information through space as an electromagnetic wave (as in radio communication), or to allow several carriers at different frequencies to share a common physical transmission medium by frequency division multiplexing

Whereas, A channel is used to convey an information signal, for example a digital bit stream, from one or several senders (or transmitters) to one or several receivers. A channel has a certain capacity for transmitting information, often measured by its bandwidth in Hz or its data rate in bits per second.

In WiFi there are a huge number of channels available, depending on the frequency and width of the band used (20, 40 or 80MHz). Following image depicts this range of channels in WiFi 6.



More Wiki!! - So that you can understand better!

- SNR
- RSSI
- CSI
- Fresnel Zone

References

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GTHill Wifi Channel

WiFi Networking: Radio Wave Basics

CWNA Guide to Wireless LANs, Second Edition

What is 802.11ax Wi-Fi, and will it really deliver 10Gbps?