OFDM in WiFi Channels

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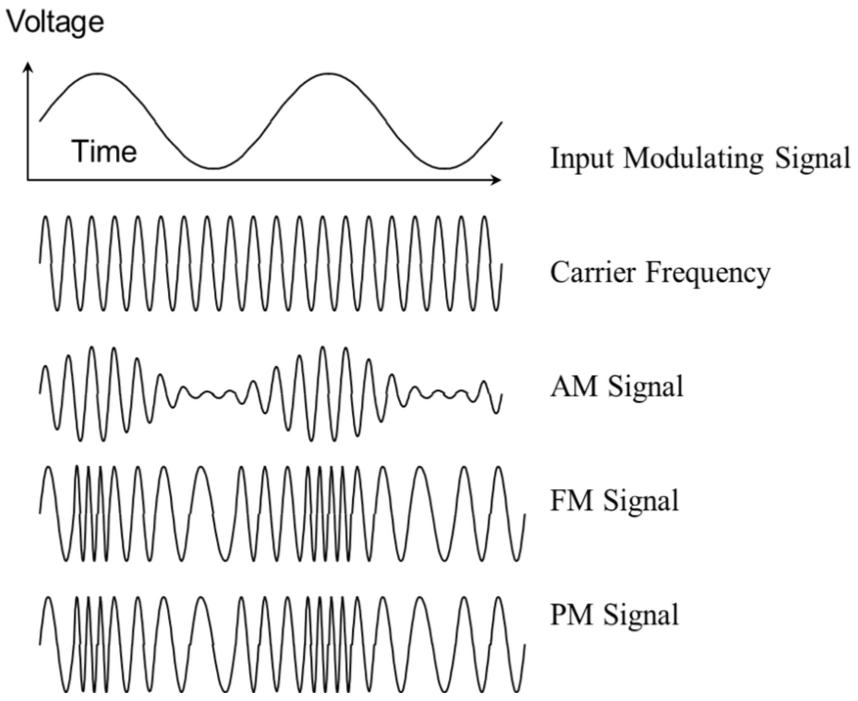
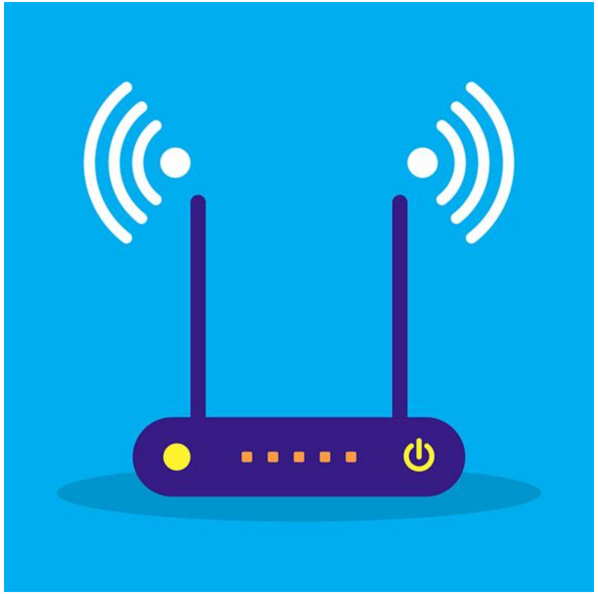
Introduction - Modulation

- Modulation refers to a carrier signal that may be varied so that some information can be embedded into carrier and transmitted over air or cable
    - Amplitude Modulation - AM Radio
    - Frequency Modulation - FM Radio/Audio
    - Phase Modulation - Data/WiFi
- The receiving end then demodulates the signal to recover the original message
- All telecommunication systems use some variation of these types of modulation/demodulation
    - “Modem” - modulates and demodulates



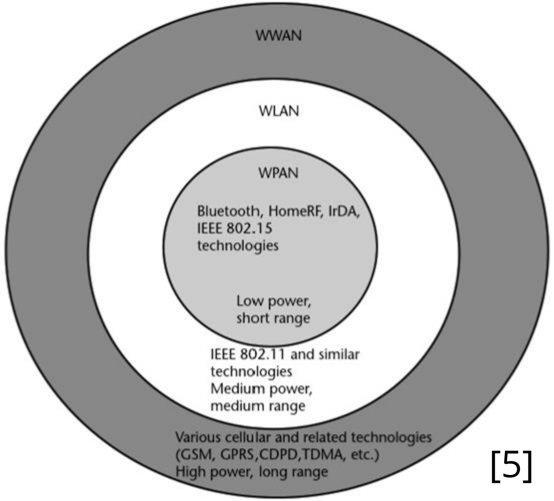
WiFi Background

- Wireless Fidelity
- Transmits and Receives data on two operating frequencies
    - 2.4GHz - covers further distance, slow speeds
    - 5GHz - less coverage, faster speeds
- Acts as mmWave radio communicator with devices
    - Non-iodized/low power radiation
    - safer than the sun’s uv rays
- IEEE defined 802 networking specifications
    - 802.3 - ethernet
    - 802.15 - bluetooth
    - 802.11 - WiFi
        - a,b,g,n,ac,ax - different data rates of transmission



IEEE 802.11 Standards

- IEEE has a wide range of standards for Wireless devices
- 802.11a (1999)
  - 5GHz, 54Mbps, 52 OFDM subcarriers
- 802.11b (1999)
  - 2.4GHz, 11Mbps, redundant today
- 802.11g (2003)
  - 2.4GHz, 54Mbps, OFDM
- 802.11n (2009)
  - 5GHz, 140-300Mbps, MIMO, WiFi-4
- 802.11ac (2013)
  - 5GHz, 500M-1Gbps, MIMO, WiFi-5



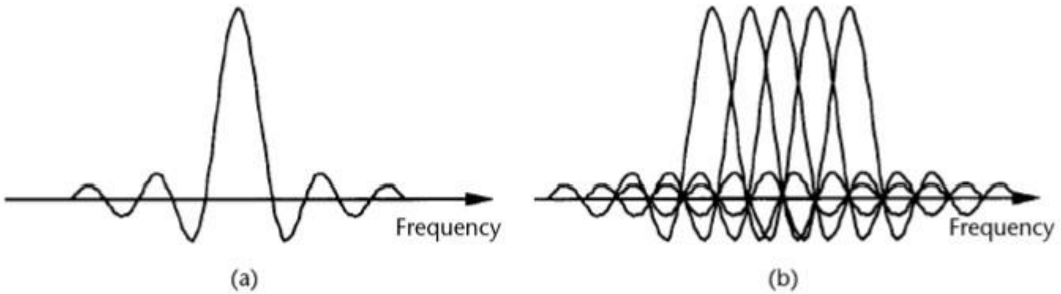
[5]

Version	Name	Frequency band	Bit rate (maximum theoretical)
IEEE 802.11 (legacy)	WLAN	2.4 GHz	1 Mb/s–2 Mb/s
IEEE 802.11a	WLAN (Wi-Fi)	5 GHz	54 Mb/s
IEEE 802.11b	WLAN (Wi-Fi)	2.4 GHz	11 Mb/s
IEEE 802.11g	WLAN (Wi-Fi)	2.4 GHz	54 Mb/s
IEEE 802.11n	WLAN (Wi-Fi)	2.4 / 5 GHz	300 Mb/s
IEEE 802.11ac	WLAN (Wi-Fi)	5 GHz	1 Gb/s (total for area) and 500 Mb/s (single station)
IEEE 802.11ad	WiGig	60 GHz (and backwards 2.4 / 5 GHz)	7 Gb/s
IEEE 802.15.1	Bluetooth	2.4 GHz	1 Mb/s
IEEE 802.15.3/3a	UWB	Various bands	10–500 Mb/s
IEEE 802.15.4	ZigBee	2.4 GHz, 915 MHz (America), 868 MHz (Europe)	250 kb/s
IEEE 802.16	WiMAX	10–66 GHz	120 Mb/s
IEEE 802.16a/e	WiMAX	2–11 GHz	70 Mb/s
IEEE 802.20	WMAN/WAN	3.5 GHz	1 Mb/s
IEEE 802.22	Wireless Regional Area Network	VHF/UHF TV bands	

[5]

Orthogonal Frequency Division Multiplexing

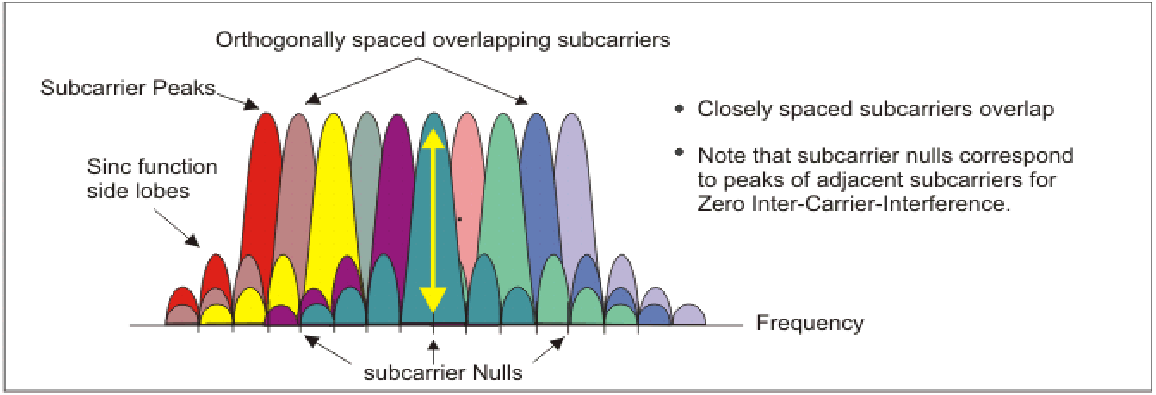
- OFDM is a special case of multicarrier transmission, where a single data stream is transmitted over a number of lower-rate subcarriers (SCs) [2]
- Can be seen as a modulation technique or a multiplexing technique. [2]
- Traditional format of sending data over a radio channel is sent serially
    - Relies on single channel and any interference on that single frequency can disrupt whole transmission [3]
- OFDM transmits data in parallel across various carriers - “substreams”
    - Reduces interference among symbols which increases symbol reception accuracy while maintaining the same throughput



Spectra of OFDM subchannel (a) and OFDM signal (b). [2]

Importance of Orthogonality

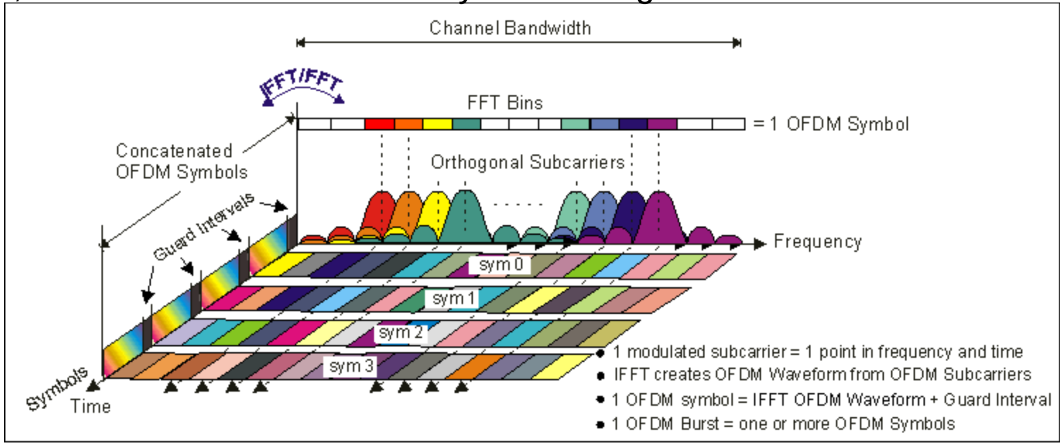
- Data bits (pulses) in the T.D. look like sinc function in F.D. from Fourier Transform
- Carriers are linearly independent (orthogonal) if the carrier spacing is a multiple of 1/T or sampling frequency
  - Where T is the period of the baseband sampling frequency
- Peaks of subcarriers line up with nulls of adjacent subcarriers - orthogonality
- Receivers acts as a bank of demodulators, calculates correlation values with center frequency of each SC and can recover the transmitted data with no cross talk.



OFDM Signal Frequency Spectra [7]

Symbols and Cyclic Prefix (Guard Intervals)

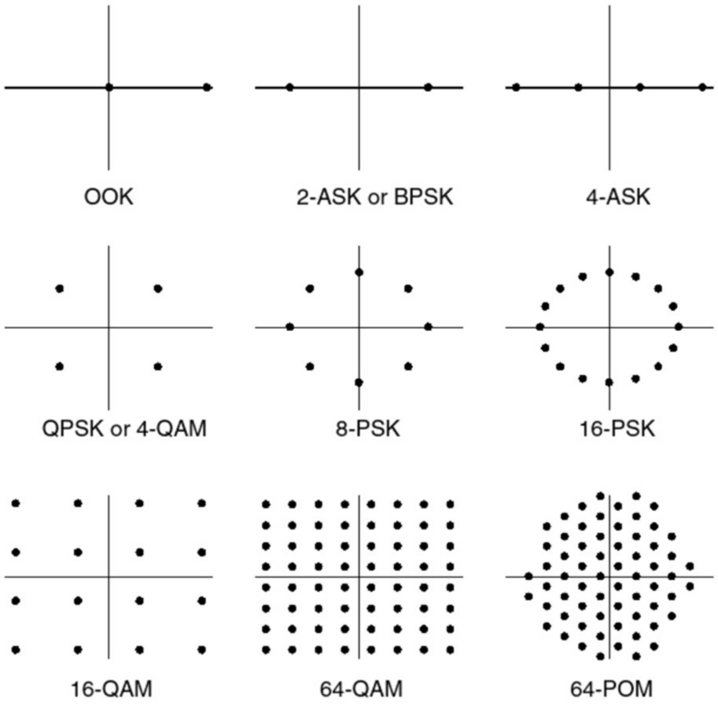
- Symbol - the time period in which a group of data bits are mapped to an analog pulse shape and modulated onto the carrier
- Symbol rate - frequency at which groups of data bits are modulated onto the carrier
- Number of subcarriers divided by Sampling frequency = Period of One OFDM symbol
- Cyclic Prefix - the space between symbols, added to the front of each symbol during transmission
    - Consecutive OFDM symbols spaced sufficiently to avoid multipath
    - Convolution of transmitted symbols with channel is circularly symmetric, ensures orthogonality



Frequency-Time Representative of an OFDM signal [7]

ASK & PSK

- Amplitude Shift Keying (ASK) - map digit bits to an analog carrier signal
  - 1 being a positive amplitude
  - 0 being a negative amplitude
- Phase Shift Keying (PSK) - modulate digital data to a carrier signal by applying data-dependent phase shifts
  - Equivalent to 2-ASK by using 180° phase shifts
  - Binary Phase Shift Keying
- Quaternary Phase Shift Keying (QPSK) - four different possible phase shifts applied to carrier signal
  - 2 bits per symbol
- Quadrature Amplitude Modulation (QAM) - combo of ASK/PSK
  - Possible constellation points arranged in polar coordinates
  - 4-QAM - 2 bits form 4 possible constellation points
  - 16-QAM - 4 bits form 16 possible constellation points



Polar diagrams for different amplitude and phase modulation schemes. [5]

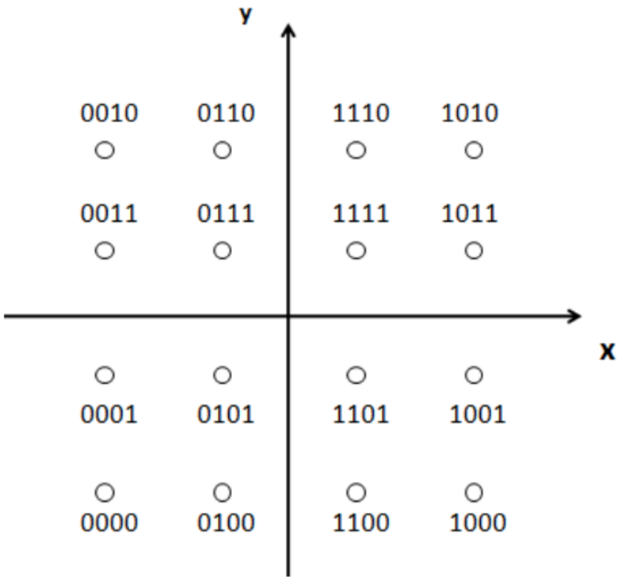
OFDM Modulation

OFDM transmitter maps the message bits into a sequence of PSK or QAM symbols

- 16-QAM, 64-QAM, 256-QAM

QAM modulation scheme acquires higher data rate, that is, higher bandwidth efficiency, by sacrificing power utilization.

- Higher SNR to maintain low bit error rate



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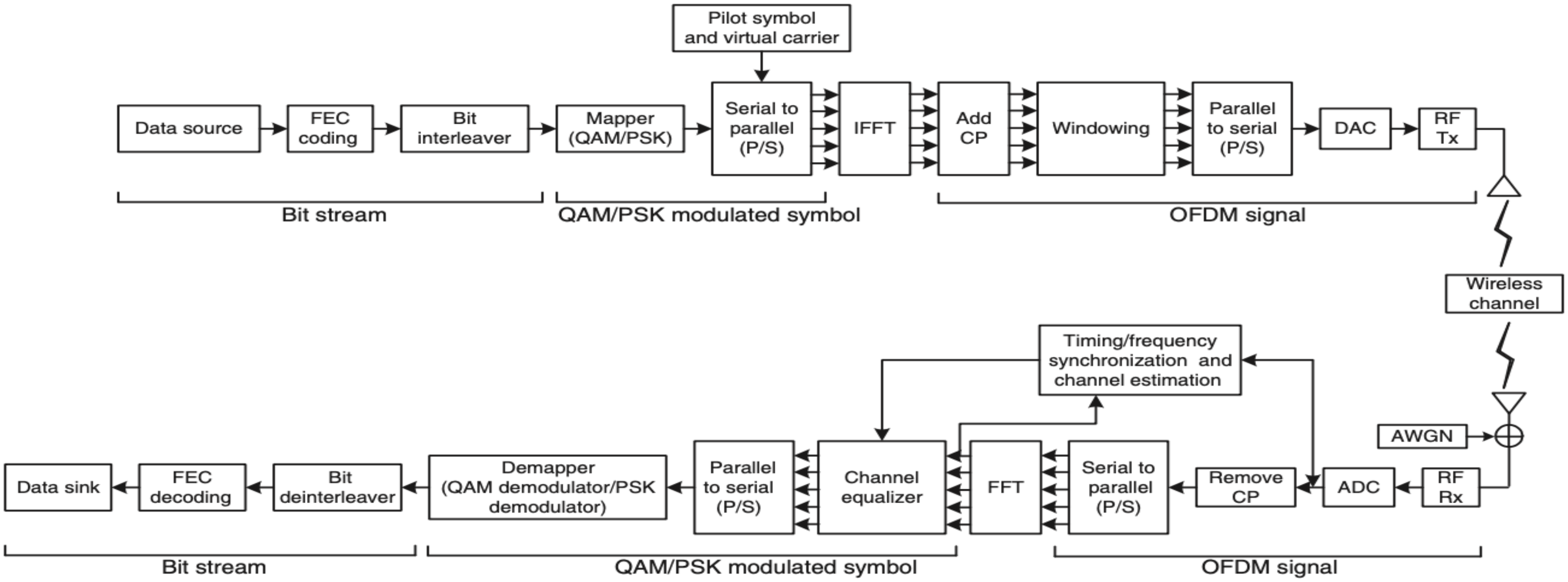
OFDM Architecture



[8]

Advantages of OFDM

- Immunity to Selective Fading
  - Resistant to frequency selective fading than SC systems
  - Divides the overall channel into multiple narrowband signals affected individually
- Resilience to Interference
  - Bandwidth limited interference won't affect all the sub-channels
  - Not all data will be lost like SC would
- Spectrum Efficiency
  - Orthogonal subchannels allow them to be overlapping without sidelobe interference
  - Saves room within bandwidth and receiver can equalize individual subchannels easily

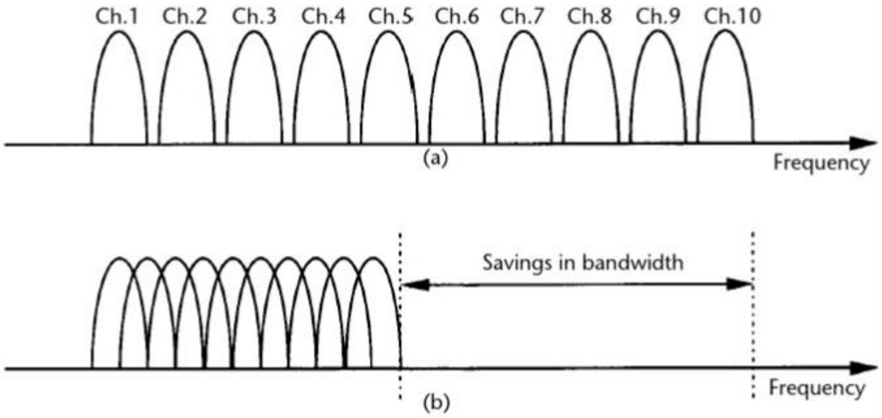


Figure 1.10 Concept of the OFDM signal: (a) conventional multicarrier technique, and (b) orthogonal multicarrier modulation technique.

[3]

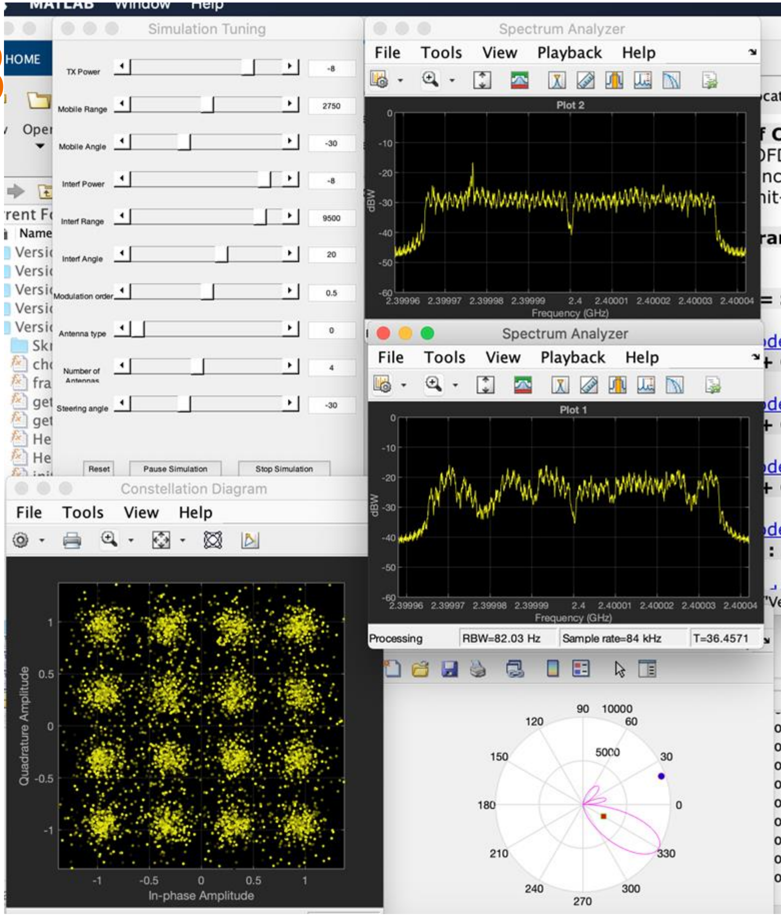
Disadvantages of OFDM

- High Peak-to-Average-Power ratio (PAPR)
  - Noisy amplitude variation and relatively large dynamic range
  - Impacts the RF amplifier efficiency
  - Amplifiers need to be linear and accommodate for large amplitude variations
- Sensitive to Doppler Shift
  - Transmitter is moving in relation to the receiver
  - Movement shifts frequency of the signal, thus frequency perceived by receiver differs than original
- Loss in efficiency due to addition of cyclic prefix (guard interval)

Summary

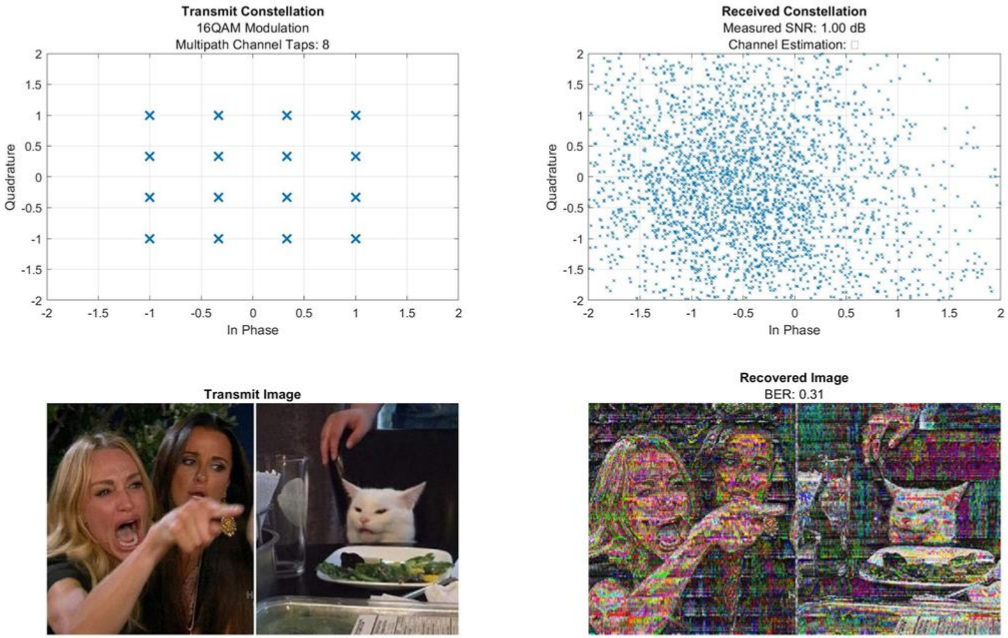
- OFDM is the fundamental building block for many modulation schemes that are widely used in wireless communications today.
  - WiFi, Mobile communications (LTE), PWAN
- Provides a reliable signal and higher resilience against interference, fading and other complexities that happen with wireless channels.
- Allows for the reliable high speed data that has become normal for the wireless devices that are used today.

Simulated Channels using MATLAB



Matlab Example - 16QAM

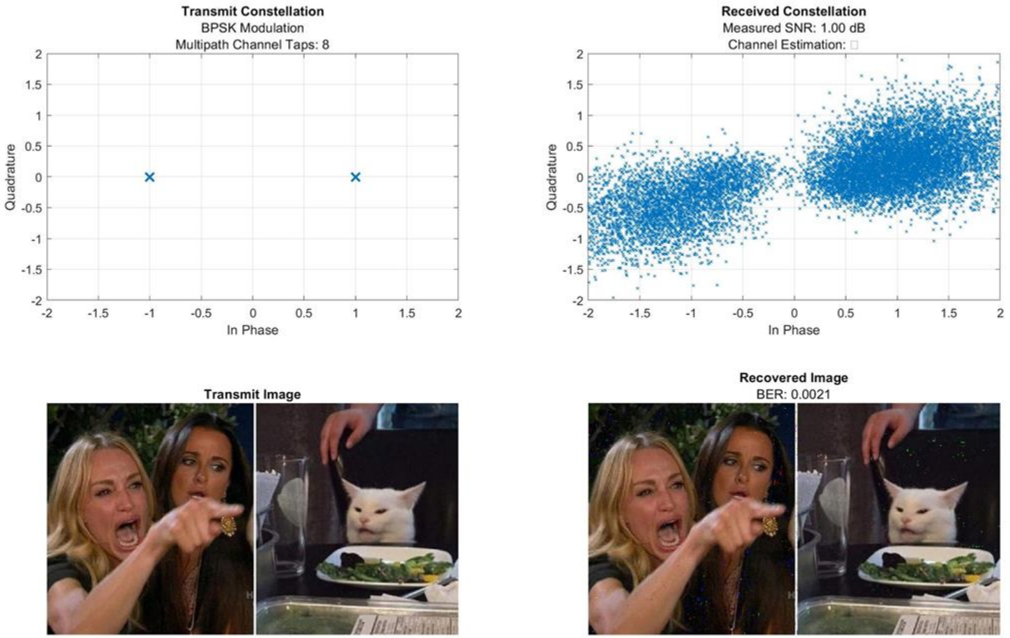
- Want to send a meme to your friend who's on same WiFi
- Transmission of image vs the received image for a 16QAM modulation with desired SNR of 20dB
- BER is 31%



Code generated from [9]

Matlab Example - BPSK

- Due to wide variability in noise tolerance from 16QAM, if instead used BPSK modulation with same SNR of 20 dB
- BER is about .0021%



Code generated from [9]

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Thank You!