Wi-Fi

What is Wi-Fi?

- A name for local area wireless computer networking technology
- Based on IEEE 802.11 standards on Wireless Local Area Networks (WLANs)
- Used as a synonym for WLAN (Wireless LANs)

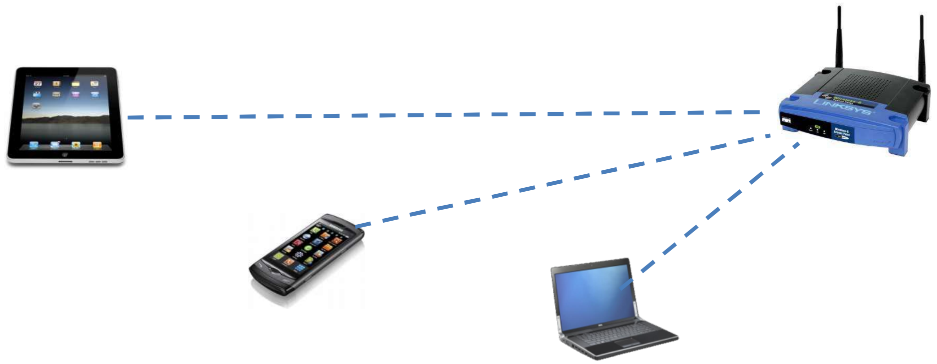
IEEE 802.11 standards

- Defines physical and data link layer techniques

- Physical layer
  - Modulation, coding techniques

layer1,2는 미디어가 뭐냐에 따라서 달라짐
근데 layer3부터는 상관없어짐
wifi는 무선이니까 layer1,2에서 정의하고 layer3에서는 유선이랑 같이 취급

- Data link layer
  - Medium access control



802.11 standards: The main stream

- Legacy 802.11 (1997)
  - 900MHz band, 2 Mbps
  - Frequency hopping spread spectrum (FHSS)
    - Patented by Hollywood star Hedy Lamarr

- 802.11b (1999)
  - 2.4GHz band, 11Mbps
  - Direct sequence spread spectrum (DSSS)
- 802.11a (1999)
  - 5GHz band, 54Mbps
  - Orthogonal frequency division multiplexing (OFDM)

802.11 standards: The main stream

- 802.11g (2003)
  - 2.4GHz band, but OFDM and 54Mbps
  - compatible with 802.11b

- 802.11n (2009)
  - 2.4GHz and 5GHz band
  - OFDM
  - up to 600Mbps with 40MHz channel, 4x4 MIMO

안테나 여러개

- 802.11ac (2014)
  - Gigabit throughput
  - Wider RF bandwidth, more MIMO streams, high-density modulation

ax 2019

802.11 standards: others

- 802.11e: QoS enhancements
- 802.11i: security
- 802.11k: radio resource management
- 802.11p: vehicular environments (WAVE)
- 802.11s: mesh networking
- 802.11u: interworking with cellular systems
- ... many others

Wireless Channel

Wireless Channel

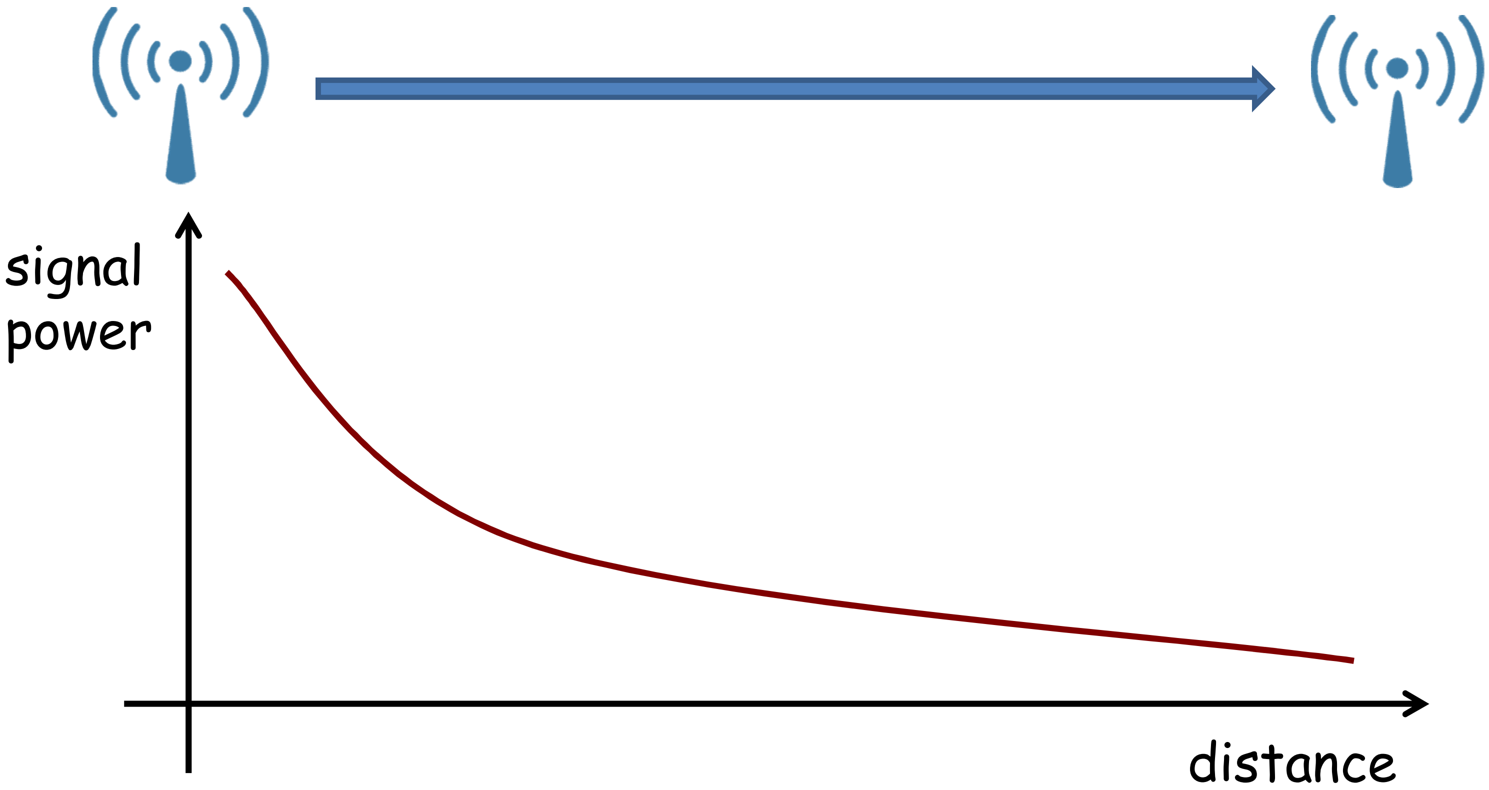
- Signal transmitted onto the wireless channel from a transmit (TX) antenna 안테나로 쏴서 안테나로 받음

- Signal travels through the air and is received at the receive (RX) antenna

Signal Attenuation

- As the signal travels through the air, its power is attenuated

무선은 공간으로 퍼지는 거기 때문에 거리가 멀수록 크게 줄어듦



Pathloss

- The receiver (P_r) is basically a function of transmit power (P_t) and the distance between transmitter and receiver (R)

pathloss exponent: depends on the environment

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2$$

R - 송수신자 거리

Friis propagation model: used in free space

- Signal attenuation based on distance is called pathloss

* G_t = transmit antenna gain, G_r = receive antenna gain, λ = wavelength

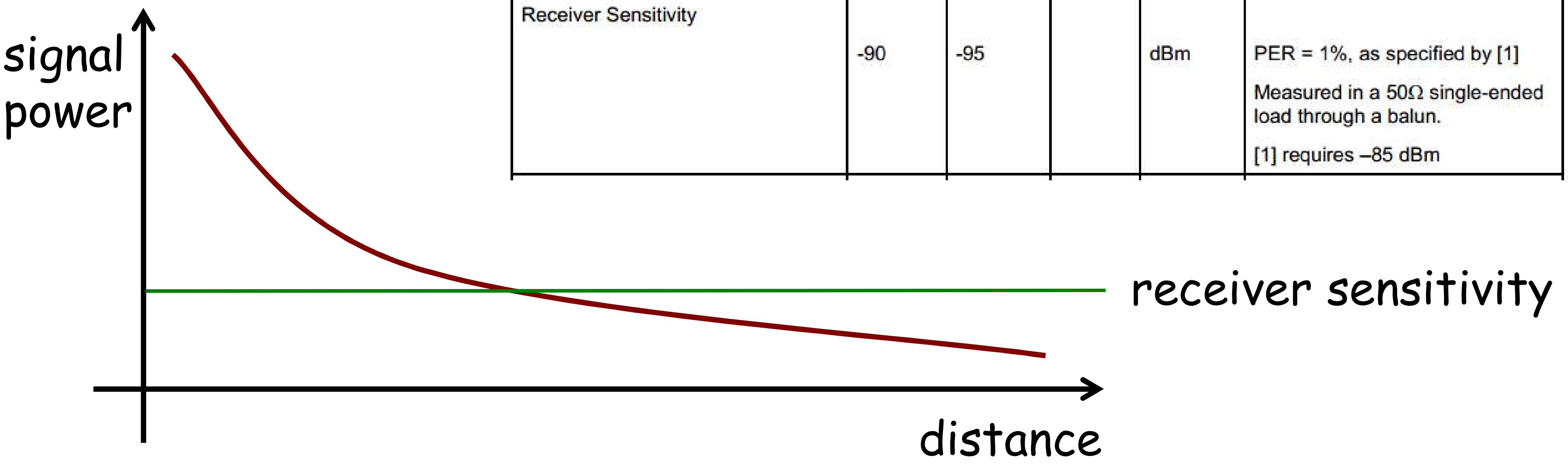
Receiver Sensitivity

- Receive antenna can receive the signal only when the signal power is stronger than the receiver sensitivity
  - Receiver sensitivity depends on the hardware

Chipcon Products from Texas Instruments **CC2420**

6.3 Receive Section typ 대체로 -95db까지 감지할 수 있다

Parameter	Min.	Typ.	Max.	Unit	Condition / Note
Receiver Sensitivity	-90	-95		dBm	PER = 1%, as specified by [1] Measured in a 50Ω single-ended load through a balun. [1] requires –85 dBm



SNR

- Even if signal is received stronger than RX sensitivity, whether the receiver can decode the signal depends on the SNR (Signal-to-Noise Ratio)

$$\mathrm{SNR} = \frac{P_{\mathbf{signal}}}{P_{\mathbf{noise}}},$$

- Sometimes, the term SINR (Signal-to-Interference-plus-Noise Ratio) is used

$$\mathrm{SINR}(x) = \frac{P}{I + N}$$

SNR and Signal Decoding

- The minimum SNR required for decoding depends on modulation and coding

- Higher modulation and coding level requires higher SNR

Fading

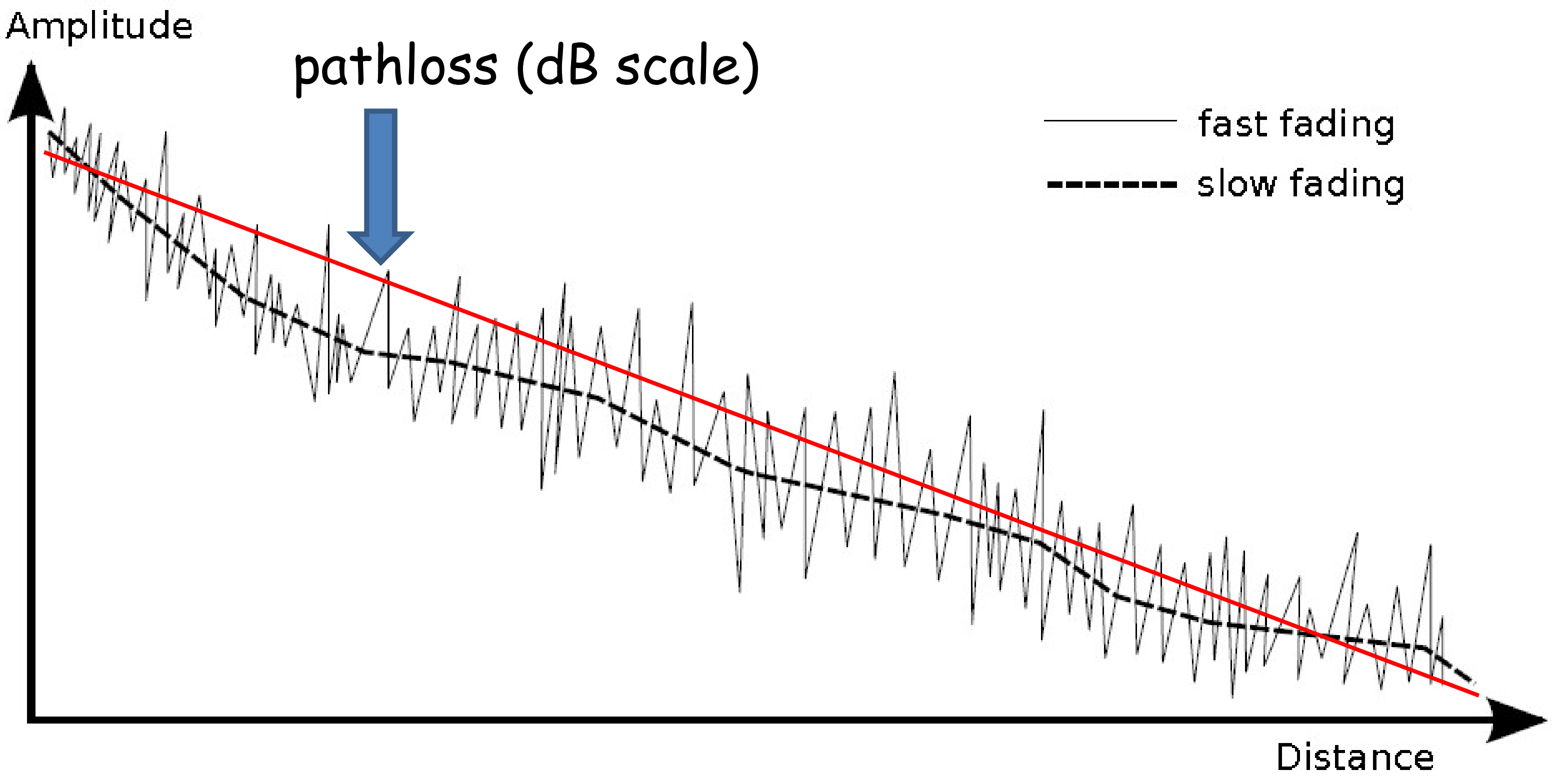
- Factors affecting received signal power
  - Pathloss
  - Fading
- Fading
  - Deviation of attenuation affecting a signal
- Types of fading
  - Slow fading (large-scale fading, shadowing)
  - Fast fading (small-scale fading)

Slow vs. Fast Fading

- Slow (large-scale) fading 장애물 때문에 신호감소
  - Large obstruction such as hill or large building obscures the main signal path between the transmitter and the receiver
  - Modeled using log-normal distribution

- Fast (small-scale) fading 위상이 겹치거나 상쇄되면서 파장이 증가, 감소가 빠르게 되면서 예측하기가 어려움
  - Caused by multipath propagation 여러 경로로 들어와서 어떻게 합쳐지느냐에 따라 왔다갔다함
  - Amplitude and phase change imposed by the channel varies considerably over the period of use

Pathloss and Fading



Wi-Fi: Physical Layer Aspects

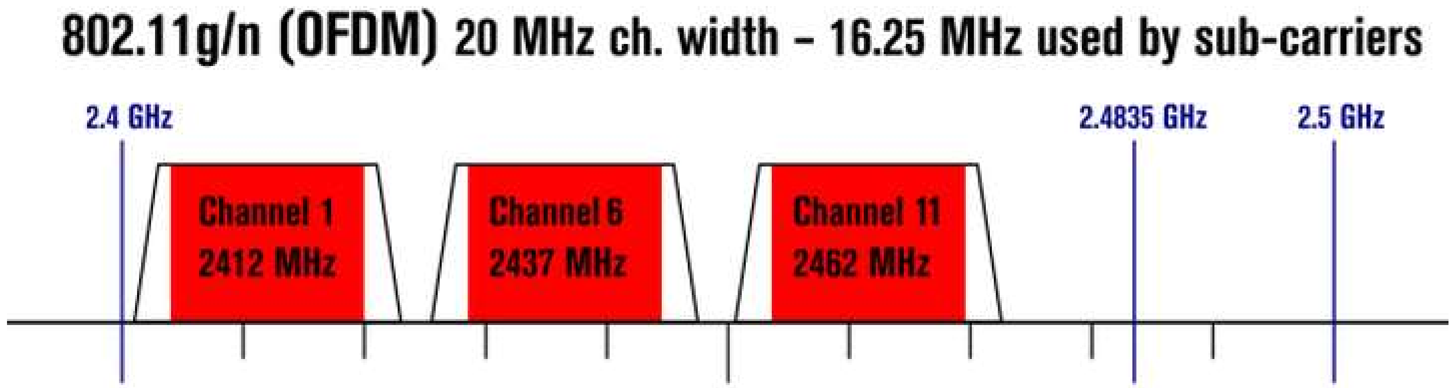
Physical Layer

- Signal generation from bits
- Recovery of bits from the received signal
- Tightly coupled with physical medium
- Modulation and coding scheme (MCS)

Modulation

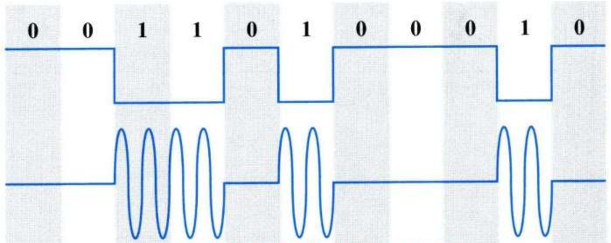
- Process of varying one or more properties of carrier signal with a modulating signal which contains information

- Carrier signal: a high frequency signal for carrying data
  - E.g. WLAN channels



Modulation

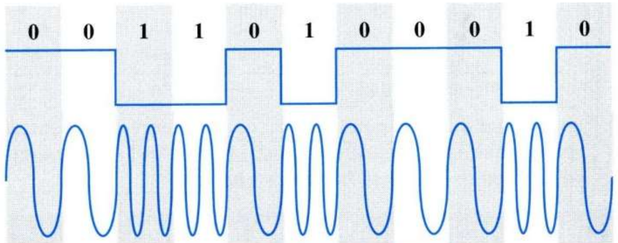
- ASK



Amplitude Shift Keying (ASK)
Two Amplitude Levels to represent 0 & 1

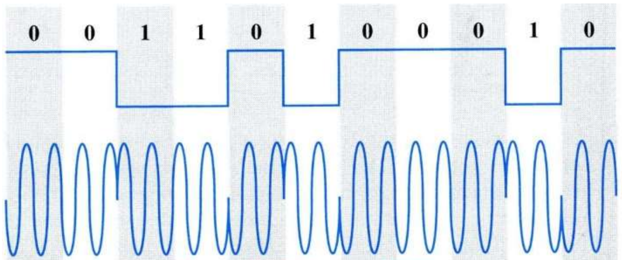
symbol

- FSK



Frequency Shift Keying (FSK)
Two frequencies to represent 0 & 1

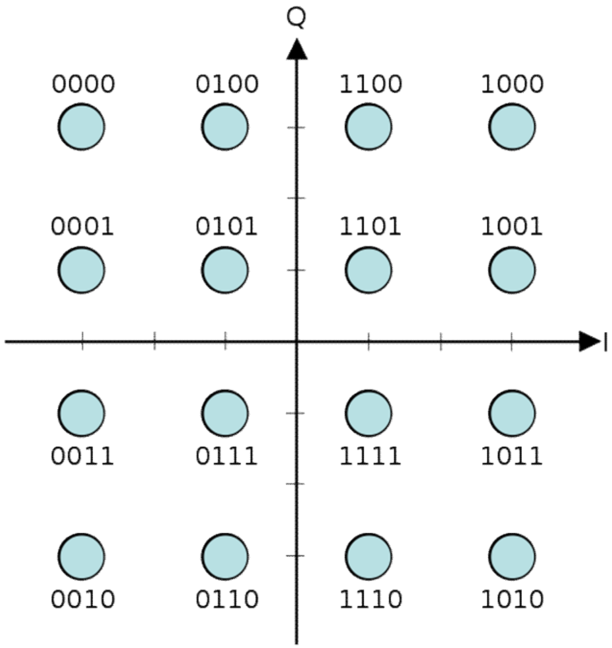
- PSK



Phase Shift Keying (PSK)
Or called BPSK, uses two phases to represent 0 & 1

Modulation

- QAM (Quadrature Amplitude Modulation)
  - PSK + ASK



constellation diagram for 16-QAM

Modulation used in Wi-Fi

- BPSK (Binary PSK): encode 1 bit on a symbol
  - 2 different signals
- QPSK (Quadrature PSK): encode 2 bits on a symbol
  - 4 different signals
- 16-QAM: encode 4 bits on a symbol
  - 16 different signals
- 64-QAM: encode 6 bits on a symbol
  - 64 different signals

Coding (Channel Coding)

- Insert error-correcting codes (ECC) in order to make the message tolerable to errors

- E.g. Hamming (7,4) code
  - Corrects 1-bit error in a 7-bit message

- Coding rate
  - Ratio of data bits in the message
  - E.g. 3/4 coding rate: 75% data, 25% ECC

MCS (Modulation and Coding Scheme)

- Defines modulation scheme and coding rate
  - The transmitter should tell the receiver which MCS level it is using

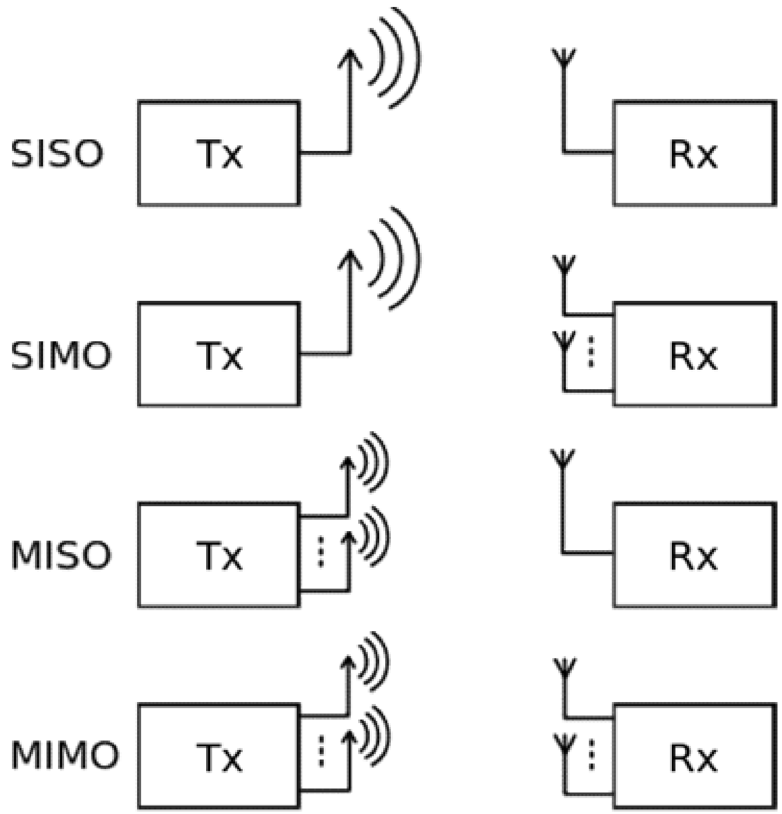
MCS Index	Type	Coding Rate	Spatial Streams	Data Rate (Mbps) with 20 MHz CH		Data Rate (Mbps) with 40 MHz CH	
				800 ns	400 ns (SGI)	800 ns	400 ns (SGI)
0	BPSK	1 / 2	1	6.50	7.20	13.50	15.00
1	QPSK	1 / 2	1	13.00	14.40	27.00	30.00
2	QPSK	3 / 4	1	19.50	21.70	40.50	45.00
3	16-QAM	1 / 2	1	26.00	28.90	54.00	60.00
4	16-QAM	3 / 4	1	39.00	43.30	81.00	90.00
5	64-QAM	2 / 3	1	52.00	57.80	108.00	120.00
6	64-QAM	3 / 4	1	58.50	65.00	121.50	135.00
7	64-QAM	5 / 6	1	65.00	72.20	135.00	150.00
8	BPSK	1 / 2	2	13.00	14.40	27.00	30.00
9	QPSK	1 / 2	2	26.00	28.90	54.00	60.00
10	QPSK	3 / 4	2	39.00	43.30	81.00	90.00
11	16-QAM	1 / 2	2	52.00	57.80	108.00	120.00
12	16-QAM	3 / 4	2	78.00	86.70	162.00	180.00
13	64-QAM	2 / 3	2	104.00	115.60	216.00	240.00
14	64-QAM	3 / 4	2	117.00	130.00	243.00	270.00
15	64-QAM	5 / 6	2	130.00	144.40	270.00	300.00
16	BPSK	1 / 2	3	19.50	21.70	40.50	45.00
...	...	...	...	...	...	...	...
31	64-QAM	5 / 6	4	260.00	288.90	540.00	600.00

MCS (Modulation and Coding Scheme)

- Selection of MCS level depends on the link quality
- Higher MCS level requires higher SNR
- Since the SNR can change dynamically over time, MCS level is changed adaptively

MIMO (Multiple Input Multiple Output)

- Use of multiple antennas at both the transmitter and the receiver to improve communication performance



MIMO: advantages

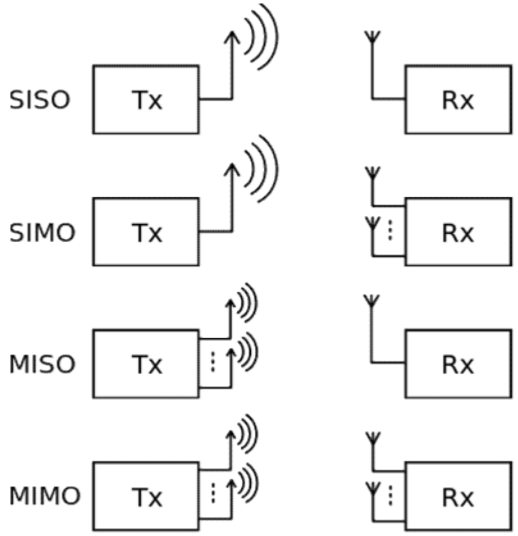
송신자가 2개의 안테나로 서로 다른 정보를 보냄
수신자는 2개의 안테나로 송신자가 각 안테나에 보내는 걸 받음
spacial stream 2개

- Array gain: improves spectral efficiency
  - Transmit different data on multiple antennas

송신자 4개, 수신자 2개면
spacial stream은 2임. 둘 중 작은 것으로 결정

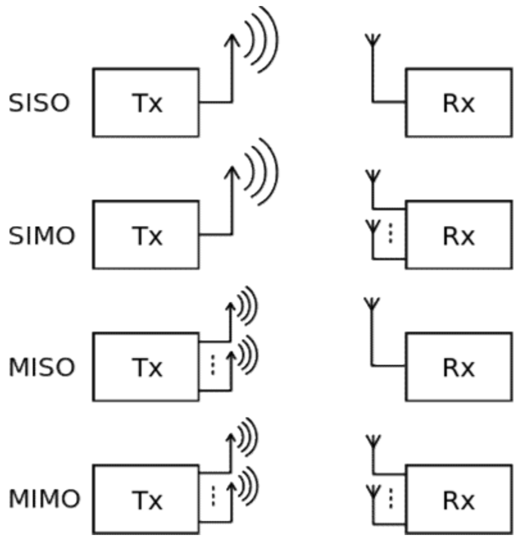
안테나가 여러개 -> 각 안테나에서 보내는 신호의 pass loss가 다름 -> 좋은 신호를 선택

- Diversity gain: improves link reliability
  - Transmit the same data on multiple antennas using space-time coding



MIMO: array gain

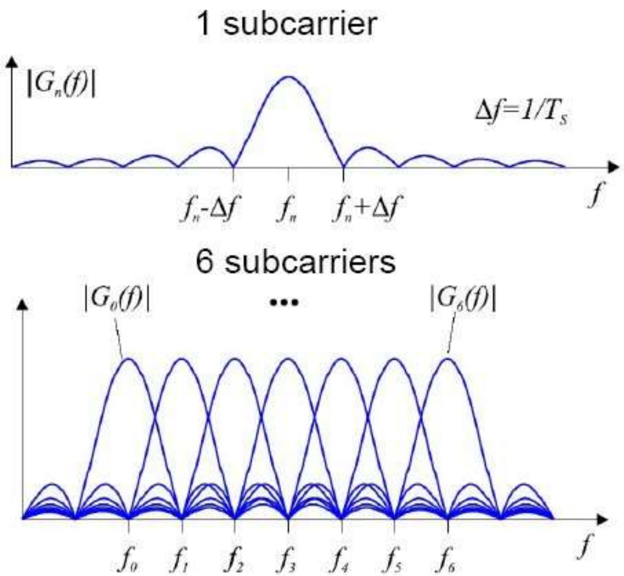
- M transmit antenna, N receive antennas
- Array gain: min (M, N)
- E.g.) 2 TX antennas and 4 RX antennas
  → 2x transmit rate compared to SISO

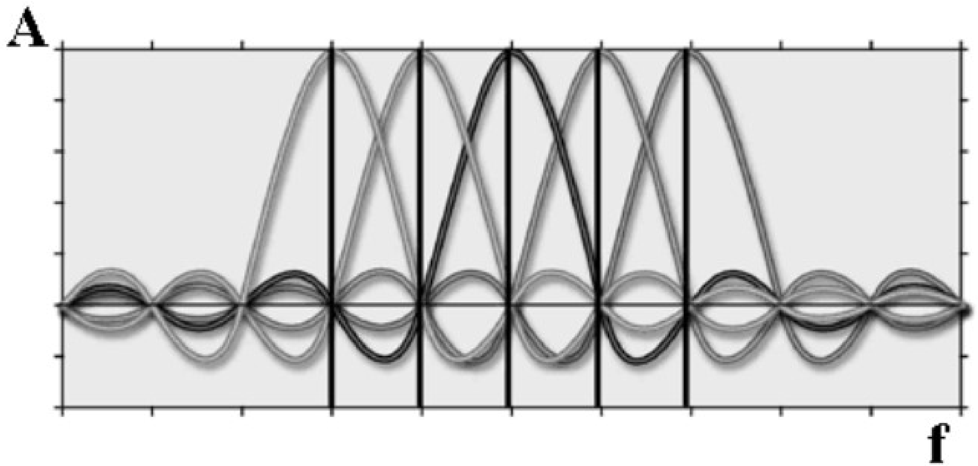


Physical layer: OFDM

- A specialized FDM (frequency division multiplexing)

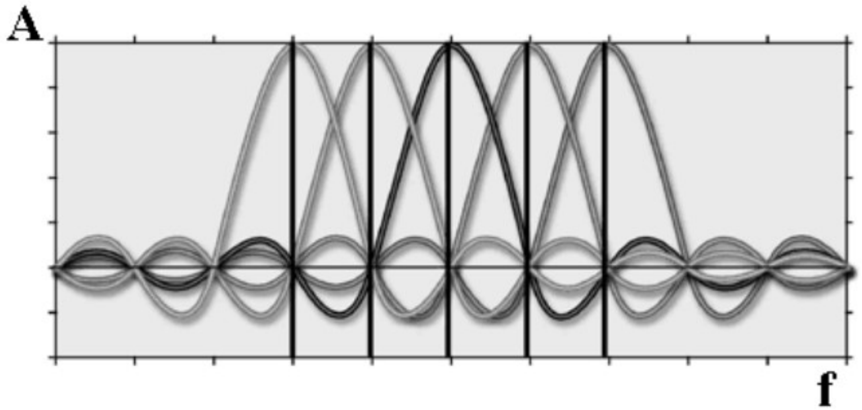
- Sub-carriers are chosen so that they are orthogonal to each other – they do not interfere with each other





Why OFDM?

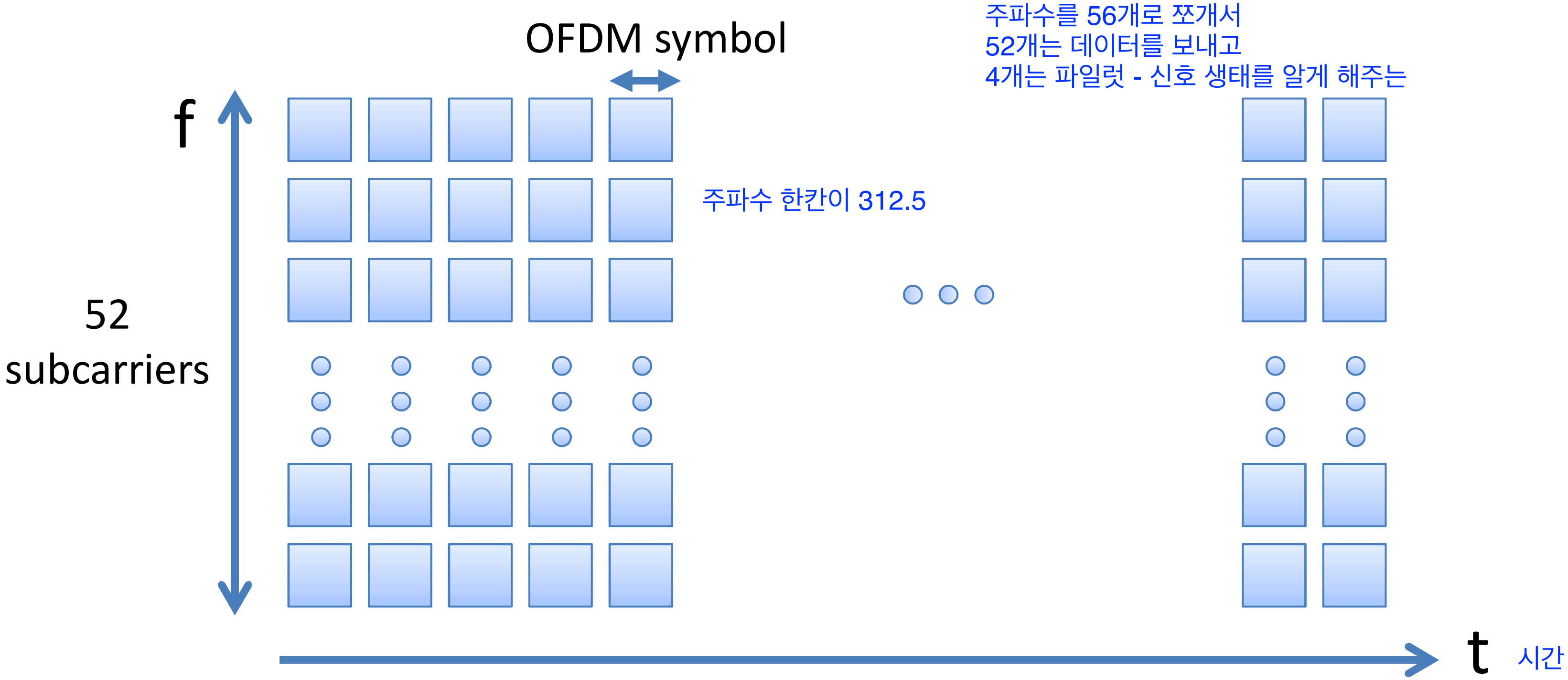
- Can easily adapt to channel conditions
- Robust against narrow-band co-channel interference
- Robust against inter-symbol interference (ISI) and fading caused by multipath propagation
- High spectrum efficiency compared to spread spectrum techniques



802.11n OFDM – 20MHz channel

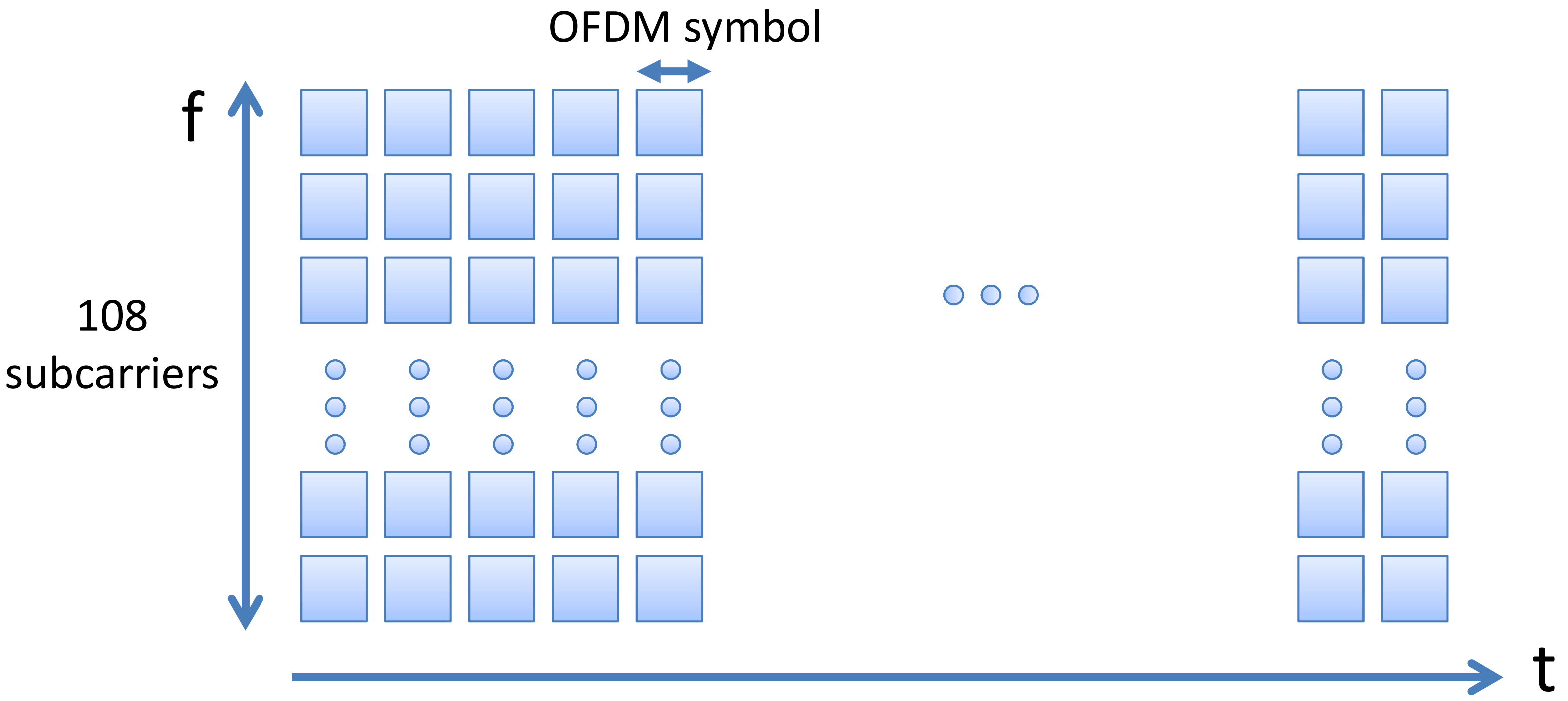
- 20MHz channel, divided into 56 subcarriers
  - 52 subcarriers used for data, 4 subcarriers for pilot
  - Each subcarrier: 312.5kHz, signal bandwidth: 17.5MHz
  - Symbol duration: 3.6us (guard interval: 0.4us)

실제로는 3.2 (0.4가 포함)



802.11n OFDM – 40MHz channel

- 40MHz channel, divided into 114 subcarriers
  - 108 subcarriers used for data, 6 subcarriers for pilot
  - Each subcarrier: 312.5kHz, signal bandwidth: 35.625MHz
  - Symbol duration: 3.2us + guard interval



802.11n OFDM – Modulation & Coding

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16	BPSK	1 / 2	3	19.50	21.70	40.50	45.00
...	...	...	...	...	...	...	...
31	64-QAM	5 / 6	4	260.00	288.90	540.00	600.00

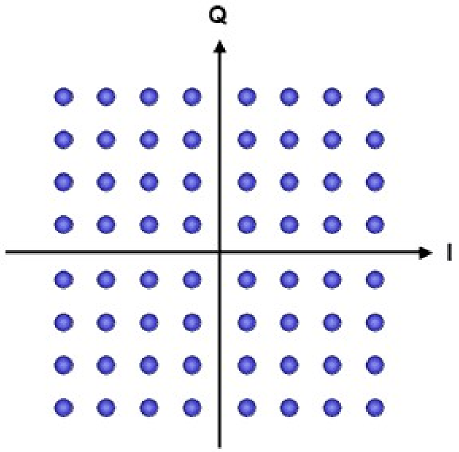
short guard interval

= 150 * 4(spacial stream)

Achieving 600Mbps

- Modulation: 64QAM
  - 6 bits are coded per subcarrier
- Coding: 5/6

  실제 데이터는 5비트
  같이 가는 1비트는 redunancy
  - 16.6% redundant bits for error correction



64 QAM

- Data bits per OFDM symbol (40MHz)
  - 6 x (5/6) x 108 subcarriers = 540 bits

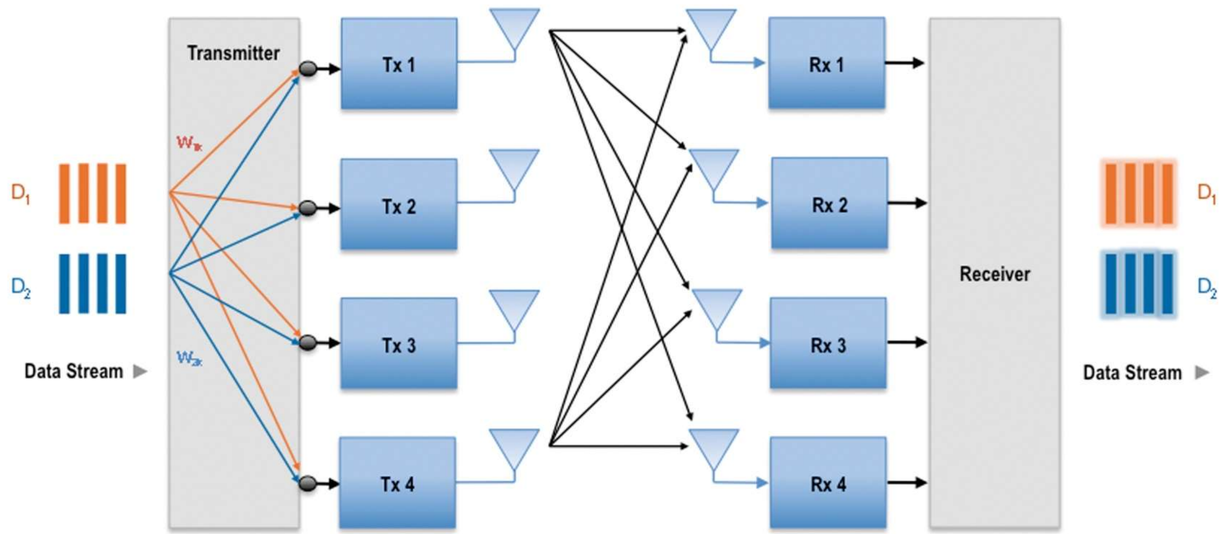
  40mhz는 108개 subcarrier
  20mhz는 56개 subcarrier

  277 777 (x축으로 1초 동안 오는 subcarrier) * 108 (y축 subcarrier) * 6(64 qam bit) * 5/6(bit rate)
- Number of OFDM symbols per second = 277,777

  1s / 3.6us = 277 777
- Data rate: 540 x 277,777 = 150Mbps

Achieving 600Mbps

- MIMO (Multiple Input Multiple Output)
  - Linear capacity growth with minimum number of antennas
    - 4x4 MIMO → 4 times capacity compared to SISO
  - Use 4x4 MIMO: 150Mbps → 600Mbps!



End of Class