# Wi-Fi for Hams

*A Practical Explanation*

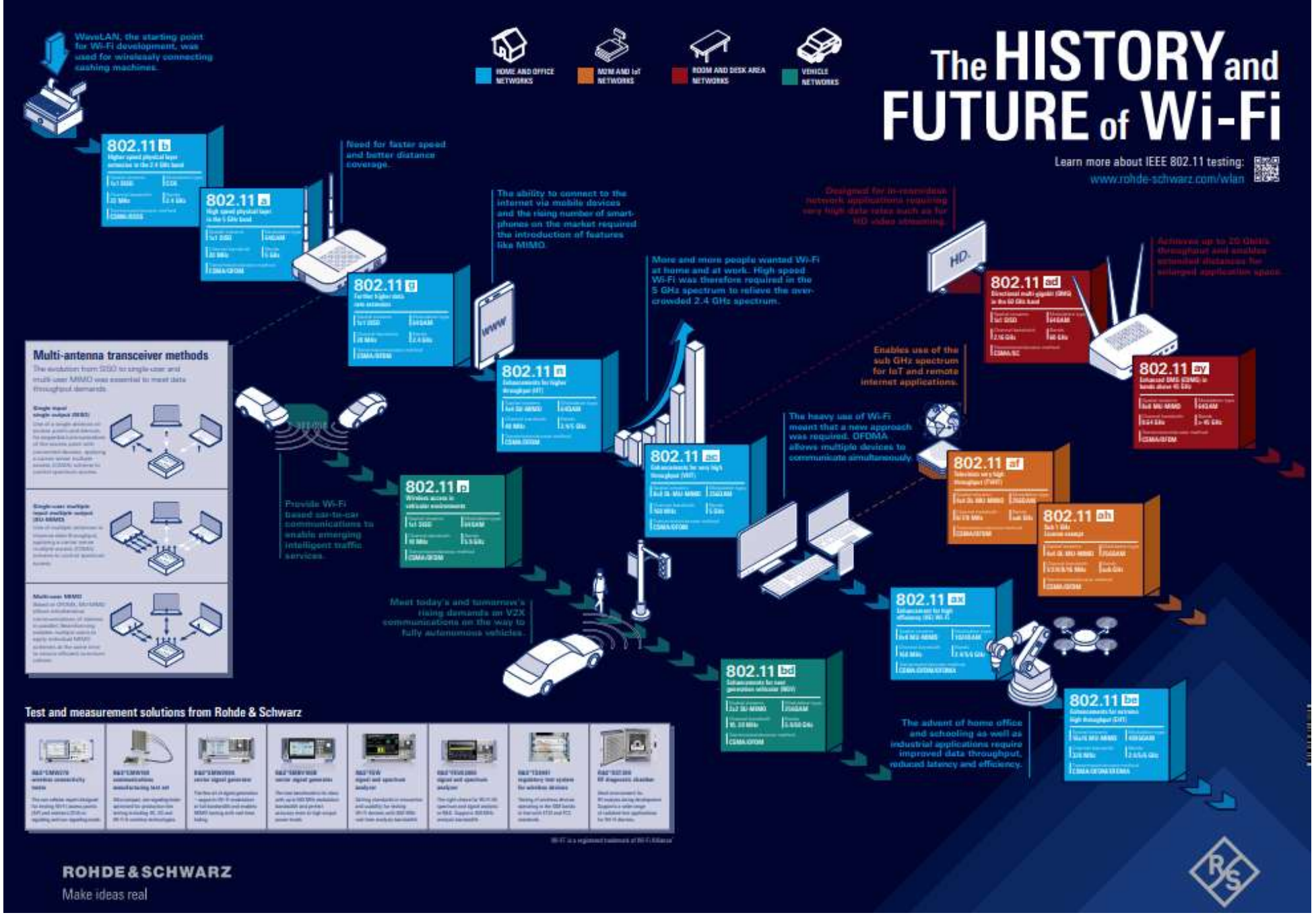
Kevin Scott

K4GTR

kevindscott@bellsouth.net

# History of Wi-Fi

- Wi-Fi was a pun on “Hi-Fi” and not short for “Wireless Fidelity”
- WaveLAN, created by NCR and AT&T to link cash registers was the precursor for Wi-Fi.
- Wi-Fi was formalized as 802.11 by the IEEE (Institute of Electrical and Electronics Engineers)
  - To fulfill the need for high-speed data communications as an extension of the Ethernet (10/100/1000+ Mbps) protocol through wireless technologies instead
  - For portable, mobile and fixed remote applications
- All Wi-Fi IEEE specifications fall into the 802.11 standards family
  - Compare to FCC Part 97 rules for the Radio Amateur Service
- Wi-Fi certification of products is performed by The Wi-Fi Alliance (www.wi-fi.org )
  - It is a worldwide network of companies that provide Wi-Fi and related equipment
  - Look for this logo on officially certified Wi-Fi devices and equipment


The HISTORY and FUTURE of Wi-Fi
Learn more about IEEE 802.11 testing:
www.rohde-schwarz.com/wlan
HOME AND OFFICE NETWORKS
M2M AND IoT NETWORKS
ROOM AND DESK AREA NETWORKS
VEHICLE NETWORKS
WaveLAN, the starting point for Wi-Fi development, was used for wirelessly connecting cashing machines.
802.11 b
802.11 a
802.11 g
802.11 n
802.11 ac
802.11 ad
802.11 ay
802.11 af
802.11 ah
802.11 ax
802.11 bd
802.11 be
Need for faster speed and better distance coverage.
The ability to connect to the internet via mobile devices and the rising number of smartphones on the market required the introduction of features like MIMO.
More and more people wanted Wi-Fi at home and at work. High speed Wi-Fi was therefore required in the 5 GHz spectrum to relieve the overcrowded 2.4 GHz spectrum.
Designed for in-room/desk network applications requiring very high data rates such as for HD video streaming.
Achieves up to 25 Gbit/s throughput and enables extended distances for enlarged application space.
Enables use of the sub GHz spectrum for IoT and remote internet applications.
The heavy use of Wi-Fi meant that a new approach was required. OFDMA allows multiple devices to communicate simultaneously.
Provide Wi-Fi based car-to-car communications to enable emerging intelligent traffic services.
Meet today's and tomorrow's rising demands on V2X communications on the way to fully autonomous vehicles.
The advent of home office and schooling as well as industrial applications require improved data throughput, reduced latency and efficiency.
Multi-antenna transceiver methods
The evolution from SISO to single-user and multi-user MIMO was essential to meet data throughput demands.
Test and measurement solutions from Rohde & Schwarz
ROHDE&SCHWARZ
Make ideas real

# Acronyms and Definitions

- Spatial Streams
  - A method to use various polarizations and antenna diversity to achieve higher throughput than if using a single frequency/single stream. Common number of streams in current products are 2, 3 & 4 streams and 8, 8+8 and 16 streams for new and future products
- MCS – Modulation and Coding Scheme
  - Defines spatial streams and data rate
- RSSI – Receive Signal Strength Indicator
- Modulation Types:
  - CCK – Complementary Code Keying
  - DSSS – Direct Sequence Spread Spectrum
  - BPSK – Binary Phase Shift Keying
  - QAM – Quadrature Amplitude Modulation
  - OFDM – Orthogonal Frequency-Division Multiplexing
  - OFDMA – Orthogonal Frequency-Division Multiple Access
    - Allows multiple users due to sub-carriers

# Acronyms and Definitions continued

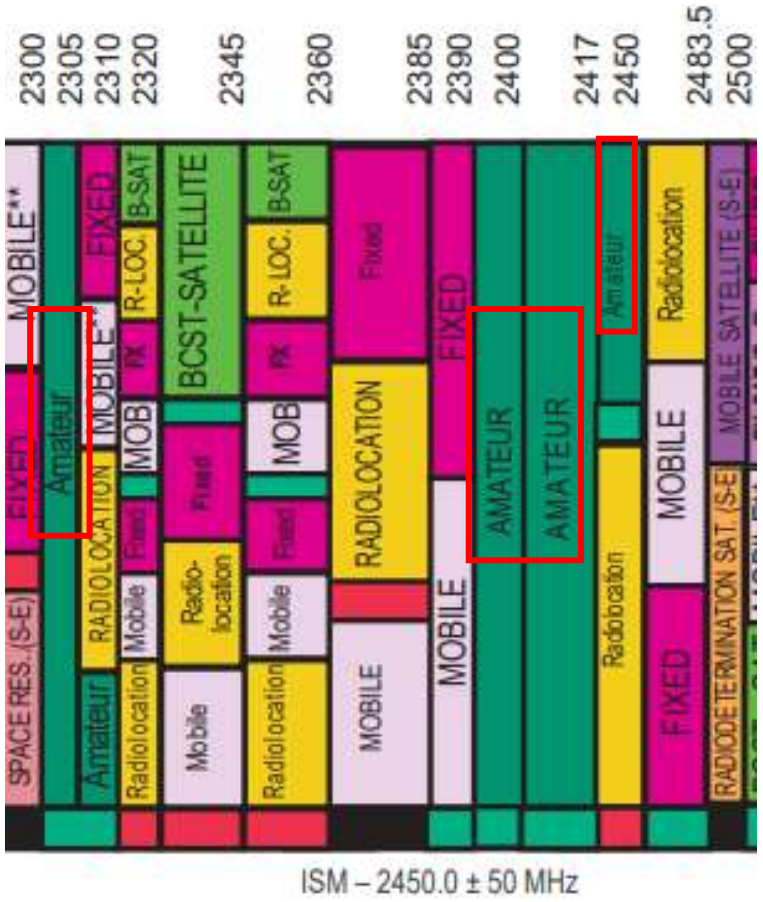
- AP – Access Point (this is your home's Wi-Fi router)
- SISO – Single Input/Single Output (single transmission stream)
- SU-MIMO – Single User Multiple Input/Multiple Output
- DL-MU-MIMO – Download Multiple User MIMO
- RU – Resource Units (smaller frequency allocations for each user on a full Wi-Fi channel)
- U-NII – Unlicensed National Information Infrastructure radio band
- ISM – Industrial, Scientific and Medical; refers to unlicensed bands
- DFS – Dynamic Frequency Selection (listen for RADAR before use)
  - Used on U-NII-2 and 2e sub-bands
- CSMA – Carrier Sense Multiple Access/Collision Avoidance
- BER – Bit Error Rate

# Wi-Fi Throughput Speeds

- Important Note:  The maximum network speeds are controlled by:
  - Incoming data rate from your Internet Service Provider (ISP) – The “Outside” World
  - The Wi-Fi generation of your wireless router
  - The capability of your device’s Wi-Fi network card or IC
    - 2.4/5 GHz
    - 20/40/80/160 MHz channels
    - The number of spatial streams
  - Distance from your Wi-Fi router
    - MCS level
      - MCS0 is slowest
      - MCS7, 8, 9 or 11 is the fastest

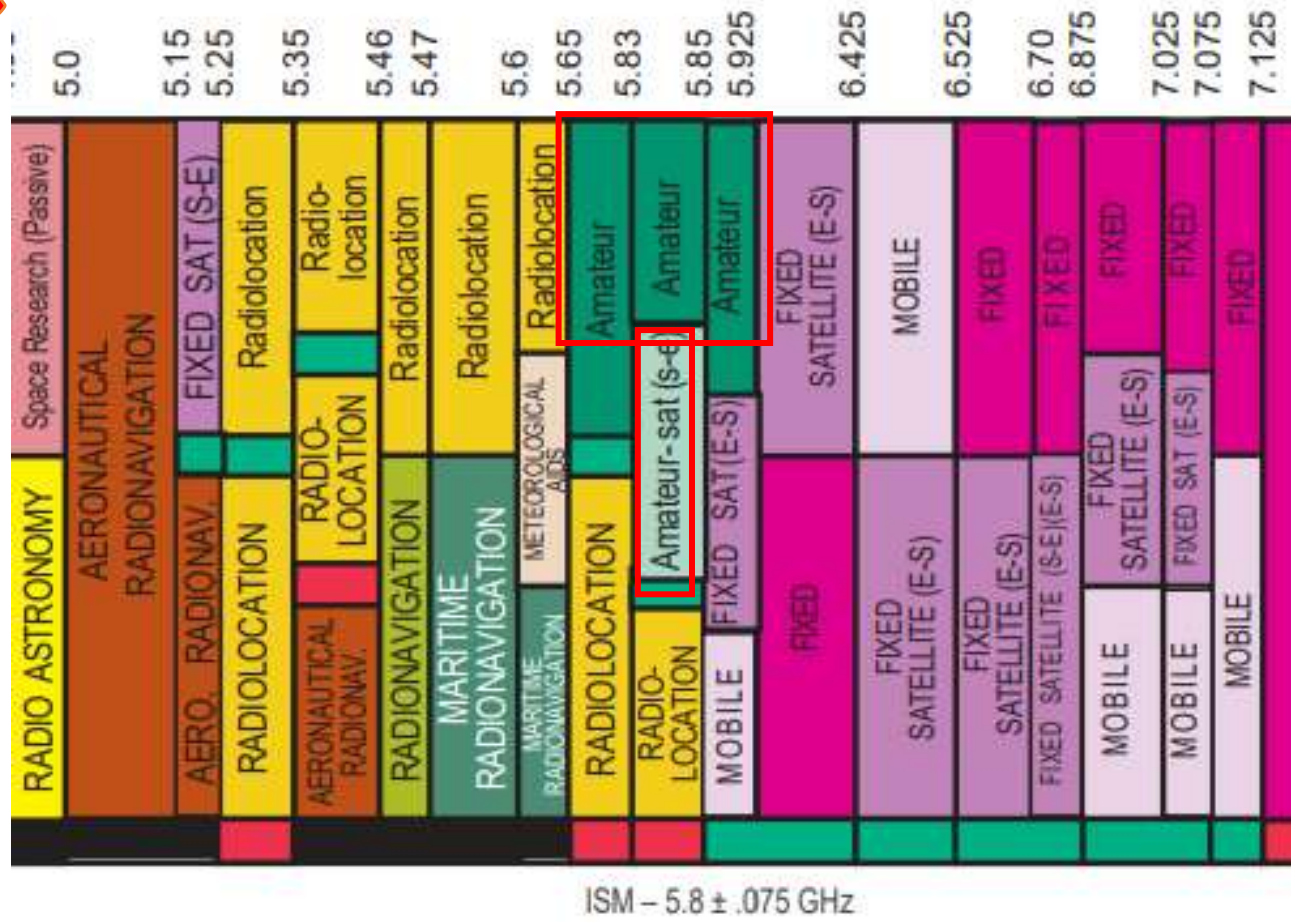
# FCC Allocations

**2.4 GHz (60 MHz BW)**

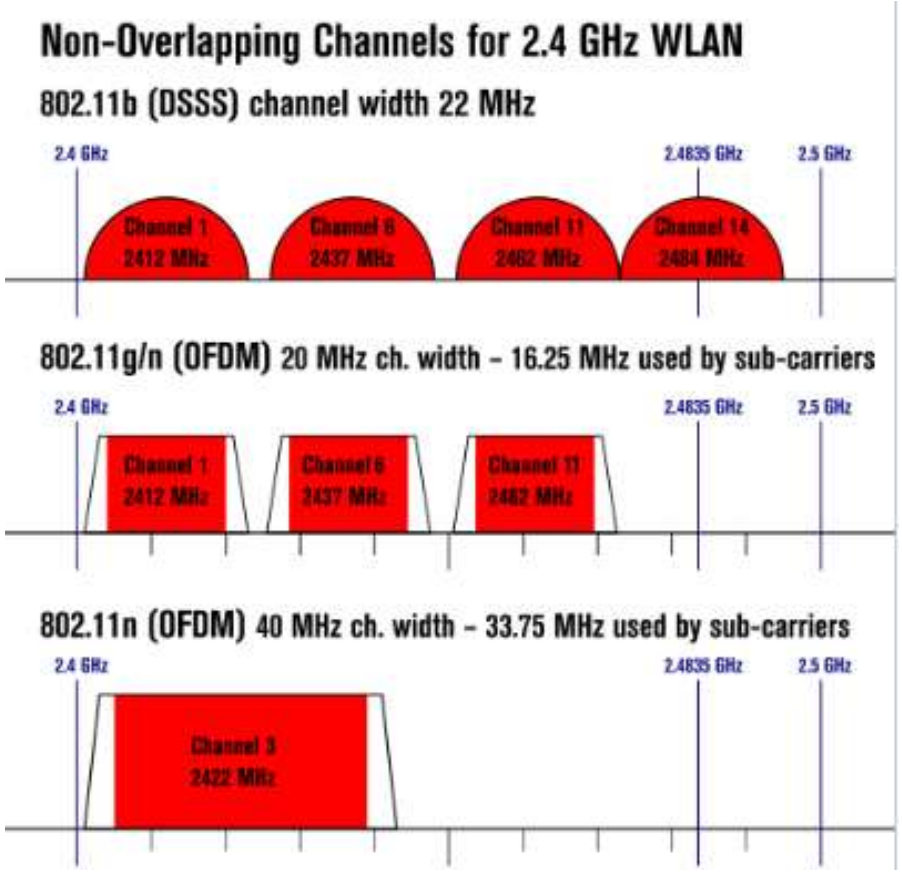



Microwave Ovens

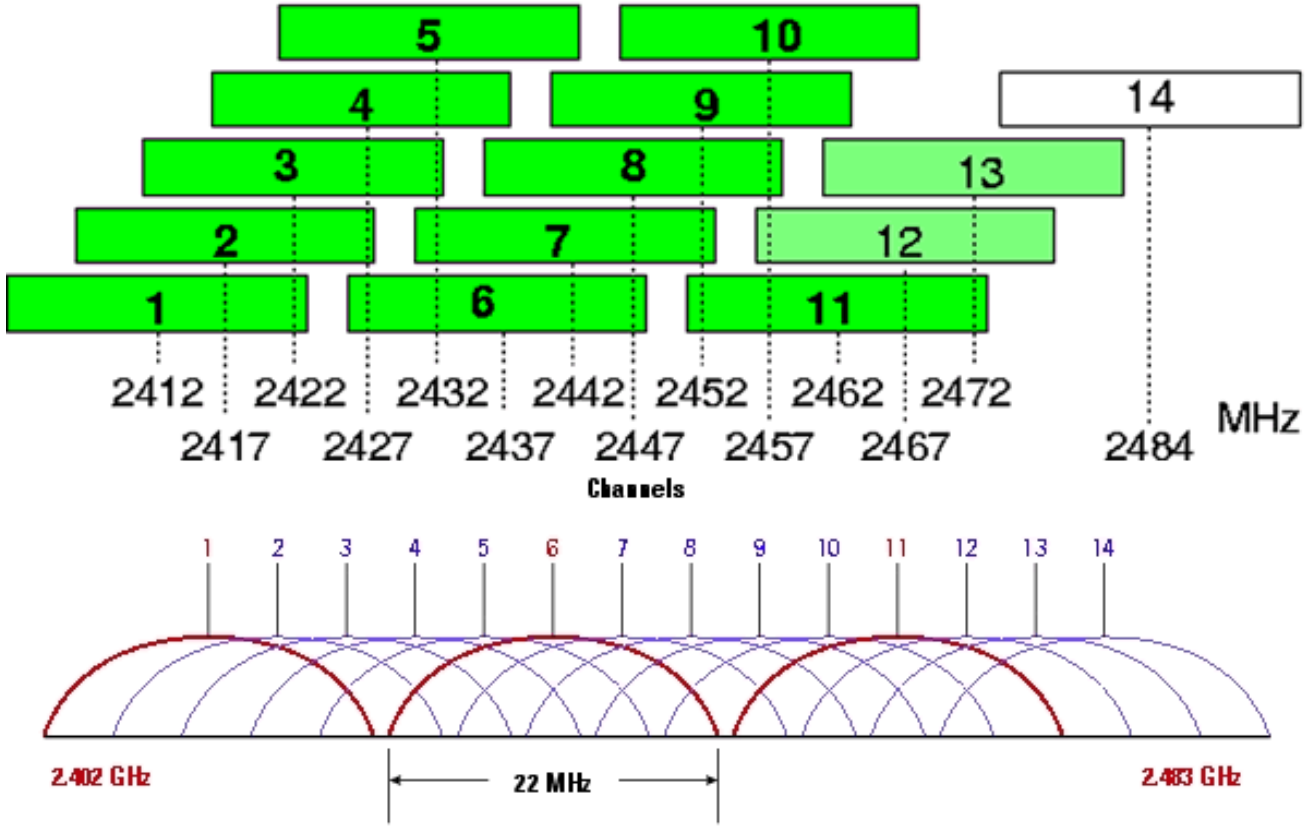
**5 GHz (685 MHz BW) & 6/7 GHz (1190 MHz BW)**



# 2.4 GHz Channels

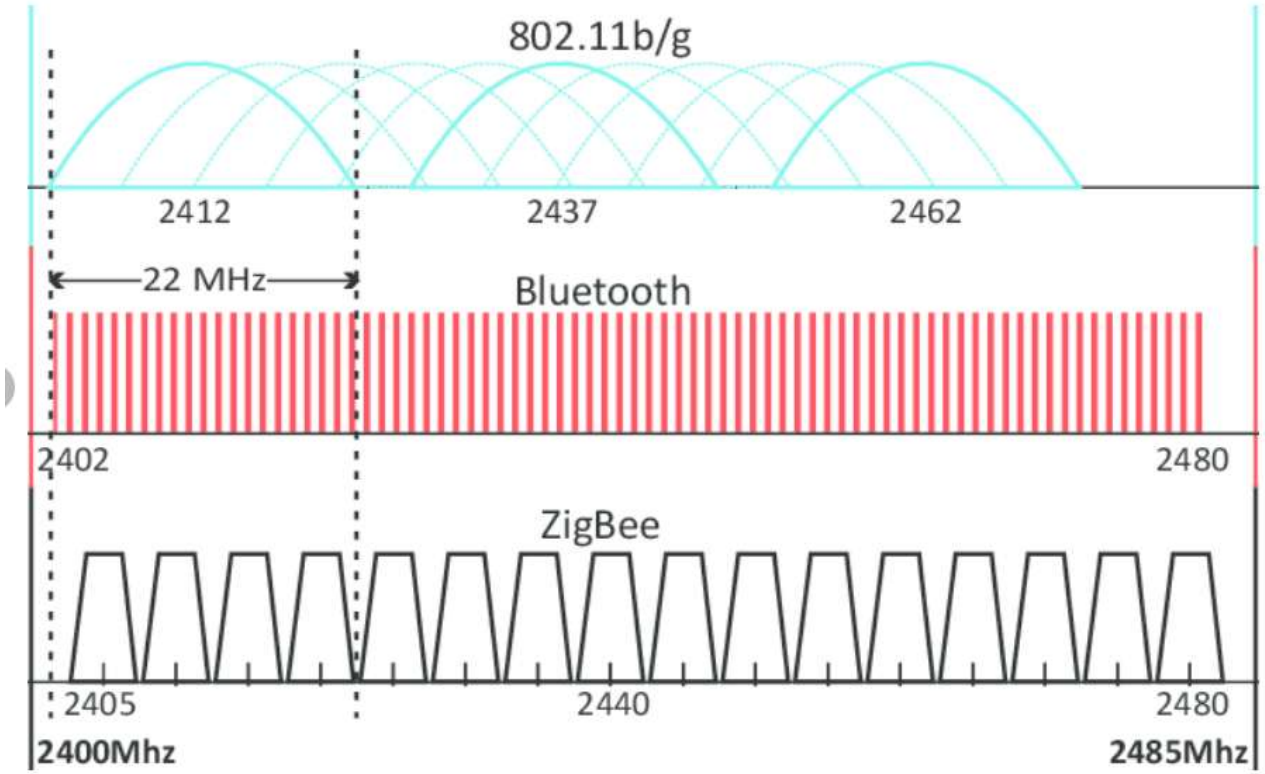



- Note that you can only have THREE non-overlapping channels
  - Most commonly used channels are 1, 6 and 11



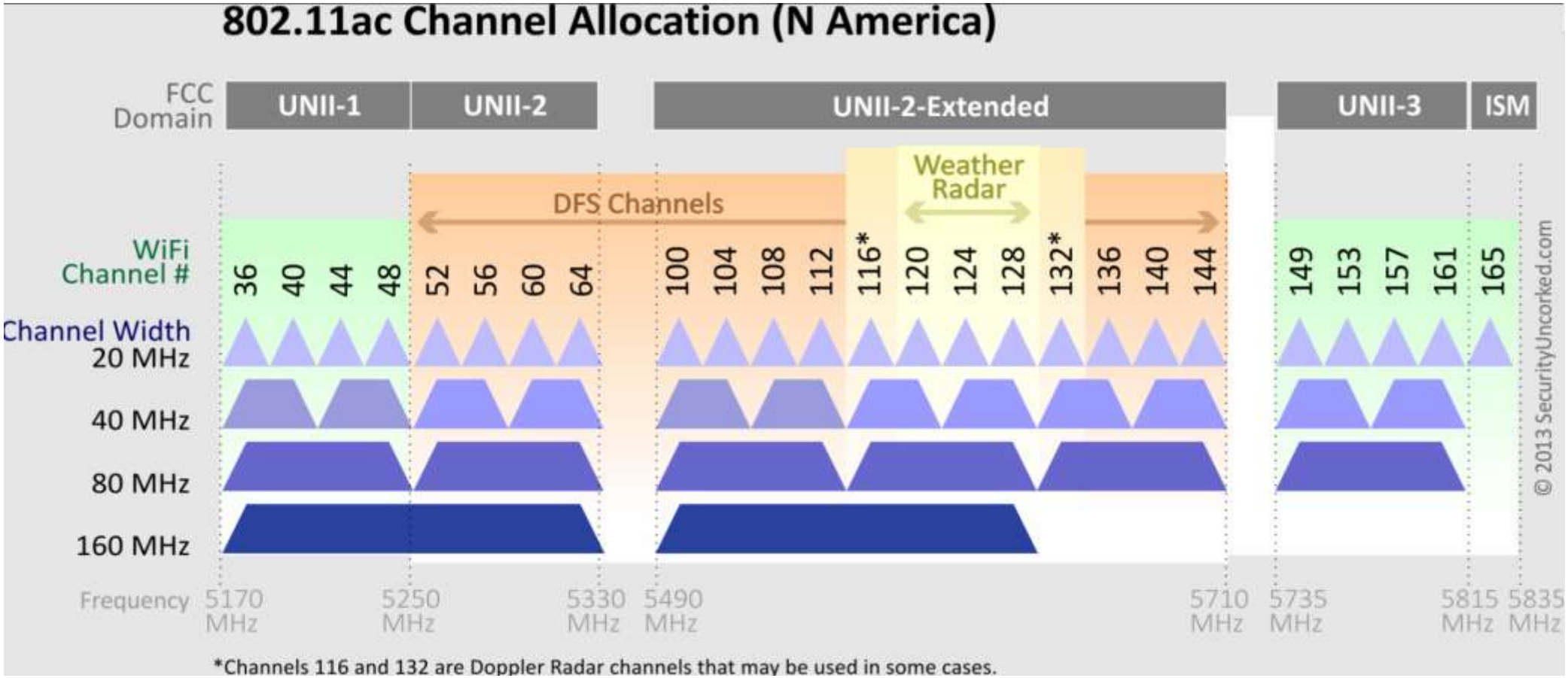
# 2.4 GHz is CROWDED

- Wi-Fi channels
- IoT (Internet of Things) devices
- Bluetooth
  - “Classic” (Seventy-nine 1 MHz channels)
  - “BLE” Bluetooth Low Energy (Forty 2 MHz channels)
- Microwave ovens ~2.5 GHz

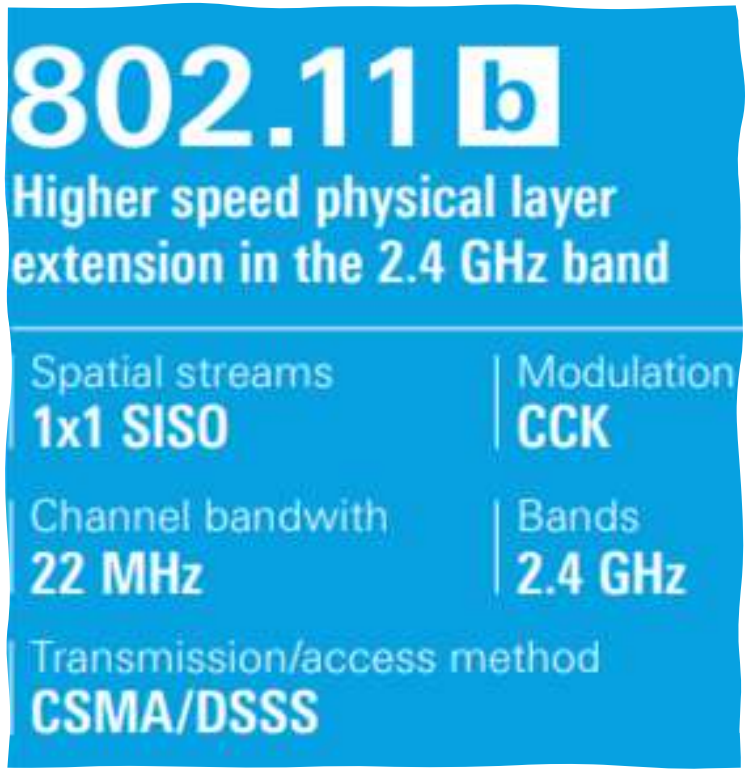


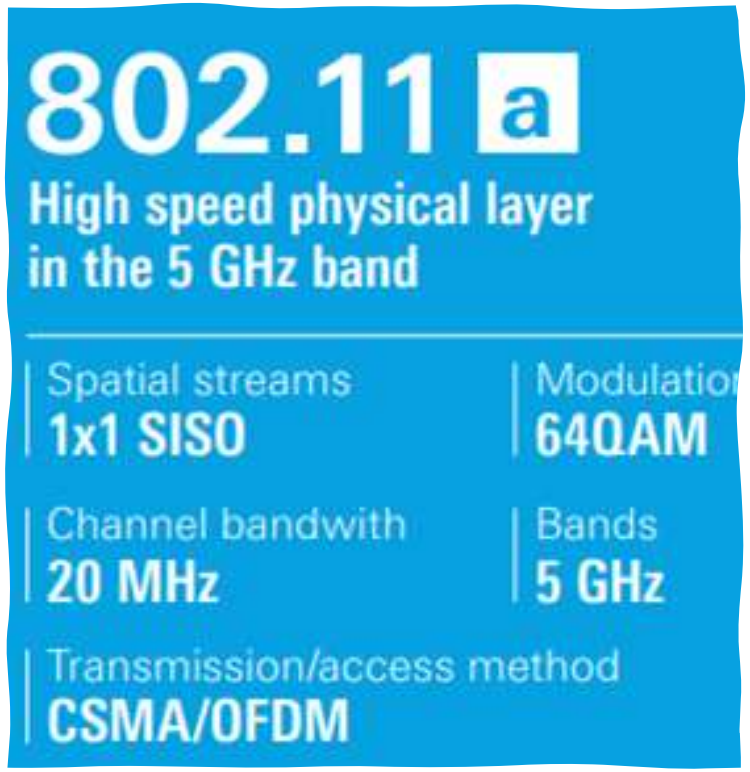

802.11, Bluetooth and ZigBee Channels in the 2.4 GHz ISM Band

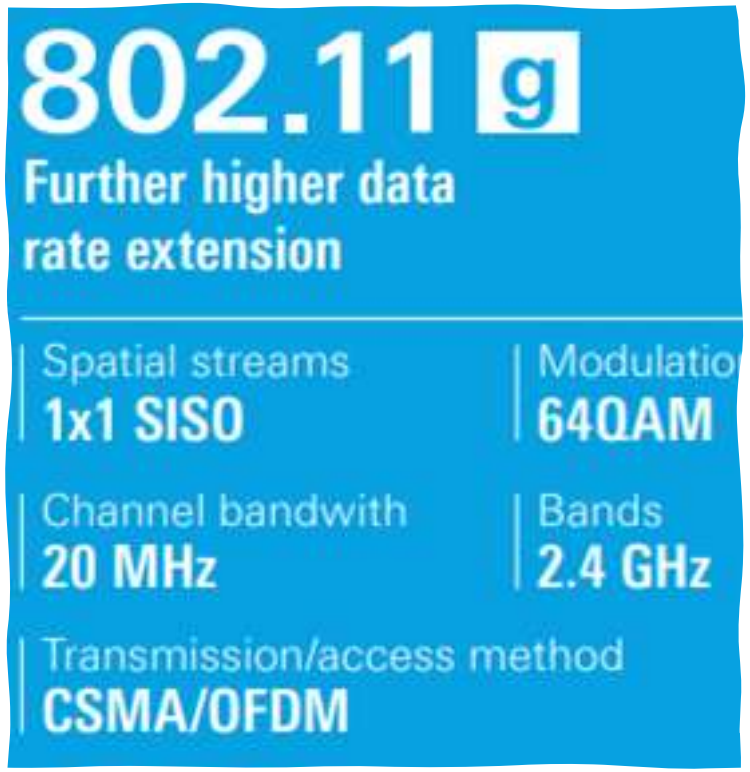
# Current 5 GHz Channels



# 802.11b/a/b Definitions

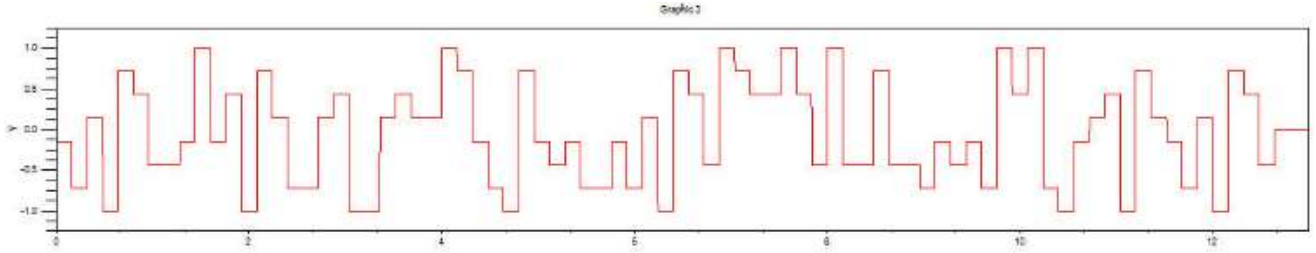


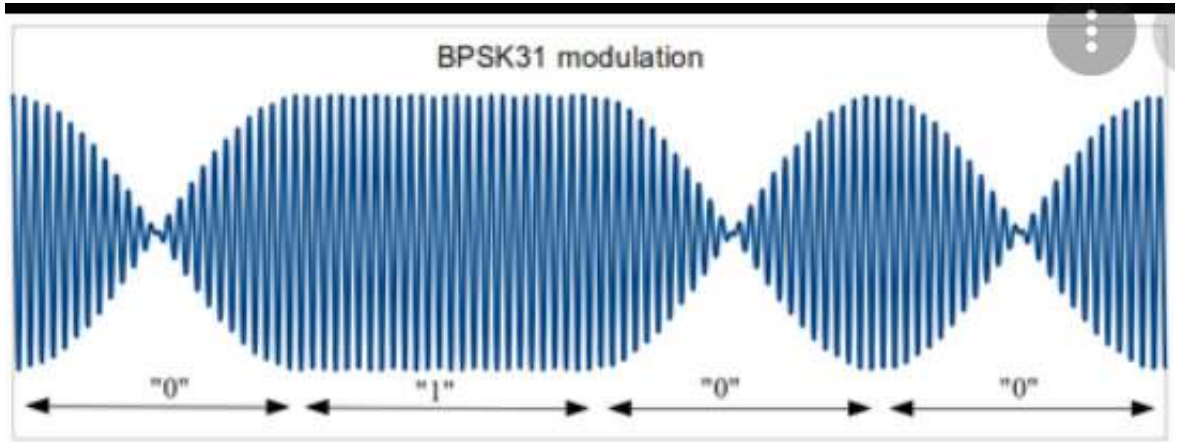



# FT8 and PSK31 Modulation (as a comparison)

- FT8 (8-GFSK, Eight-State Gaussian Frequency Shift Keying)

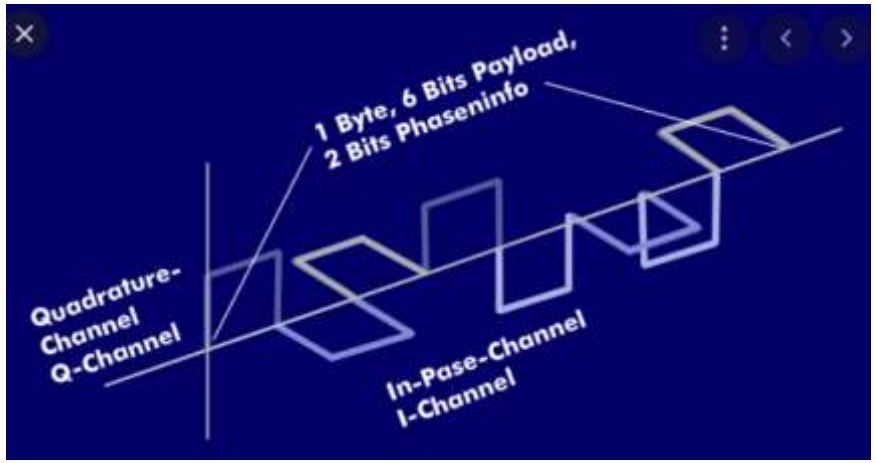


- PSK31 (Phase-Shift Keying)

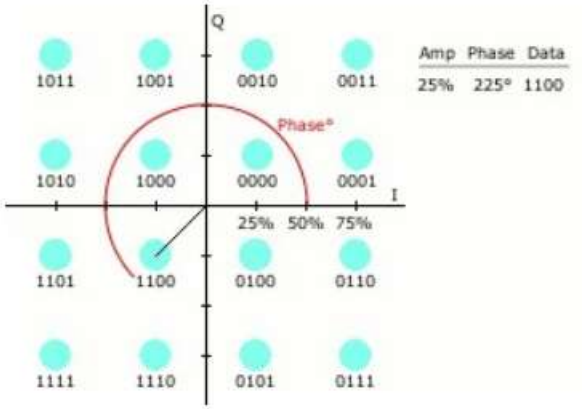


# Earlier Wi-Fi Modulation Types (b/a/g/n)

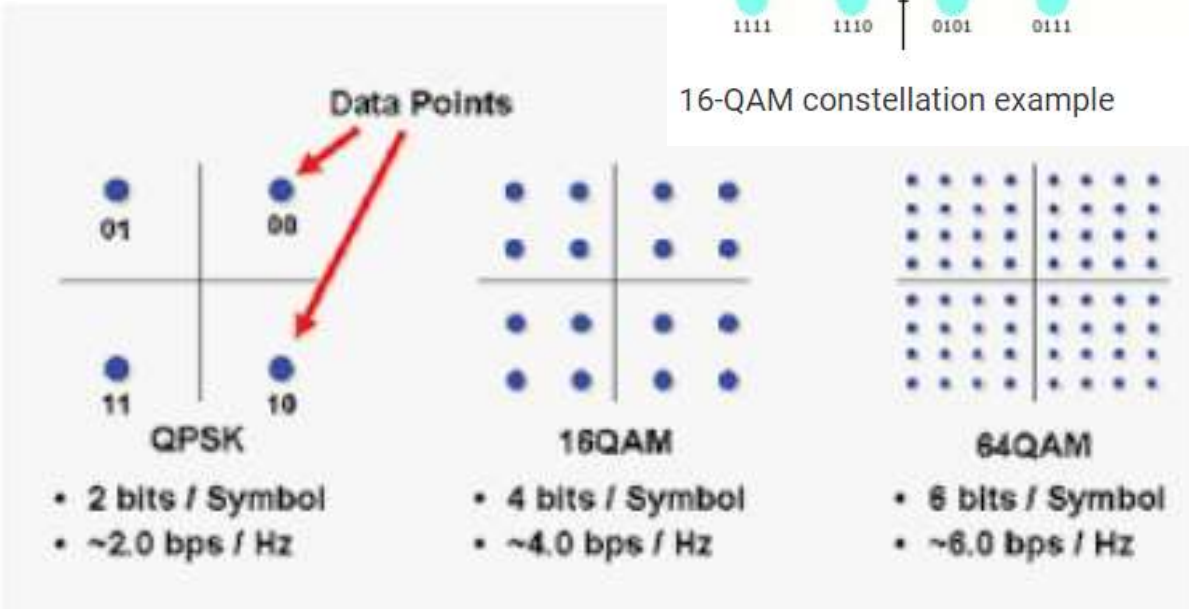
- CCK




- 4 – 64 QAM

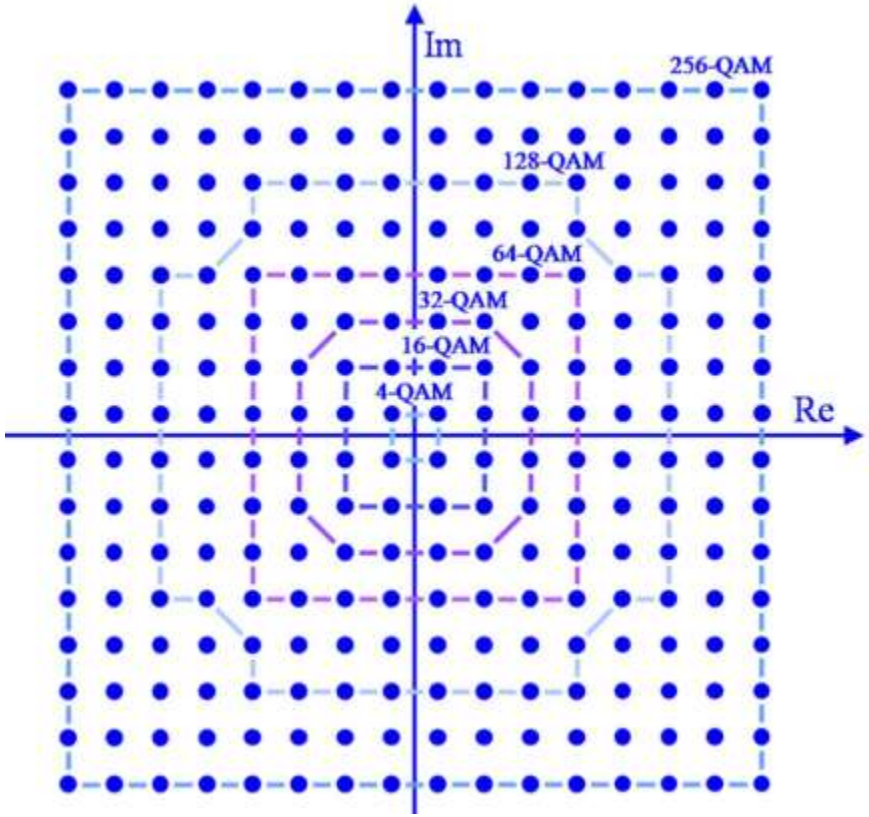


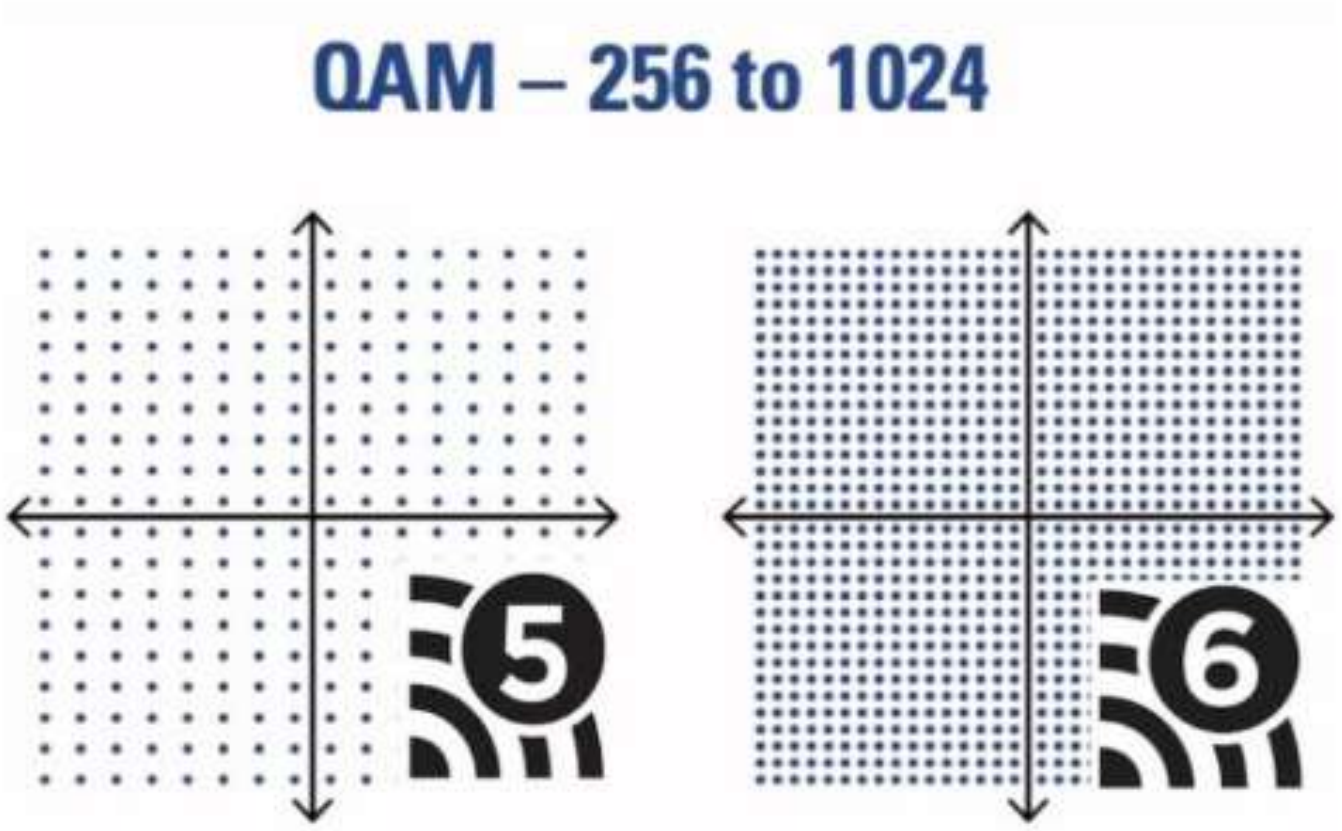

16-QAM constellation example



# QAM Constellations

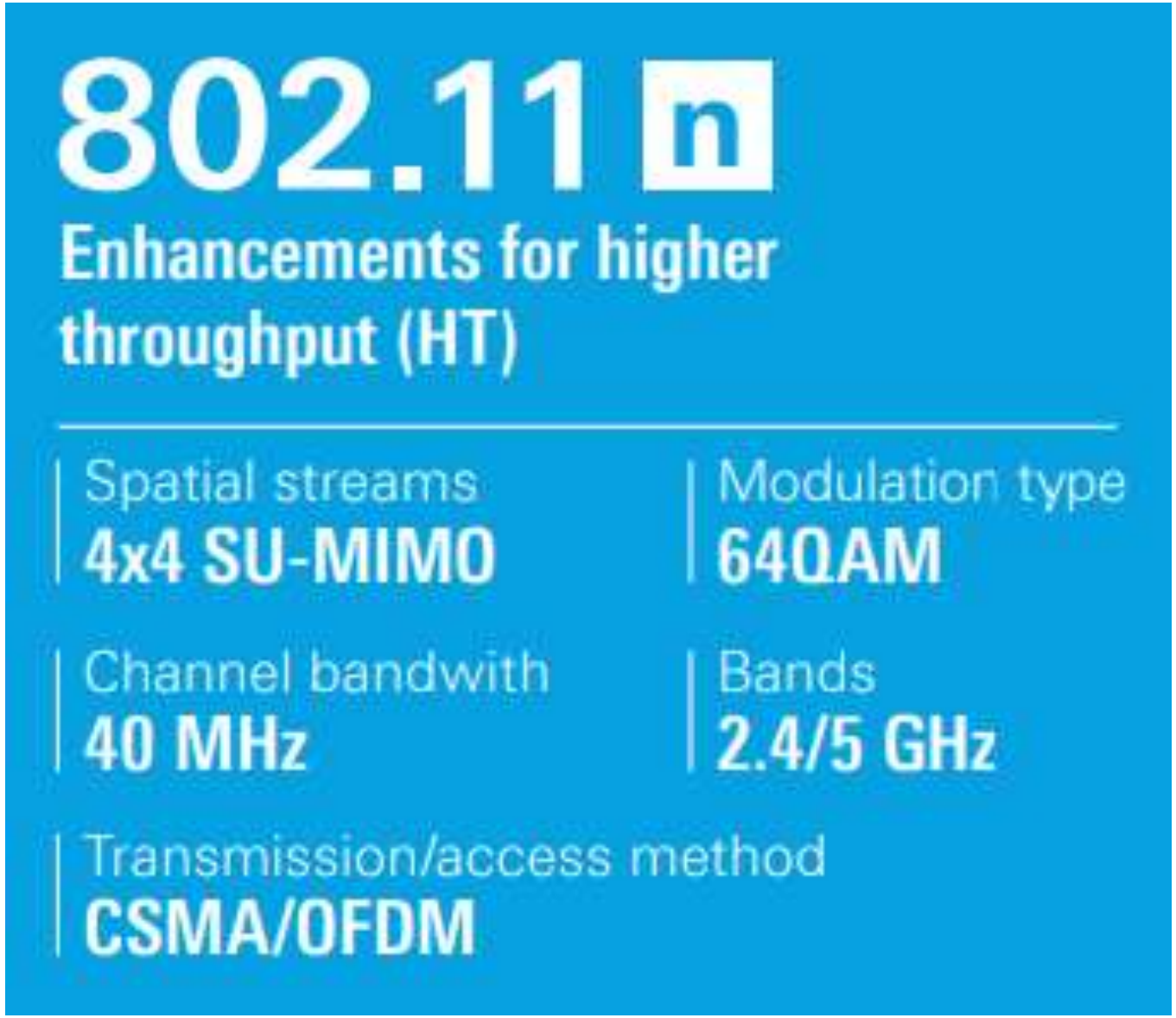
- 4 to 256 QAM



# 802.11n = Wi-Fi 4

- Key Improvements
  - Multiple special streams
  - Wider bandwidth
    - 2.4 GHz – 40 MHz
    - 5 GHz – 40 MHz



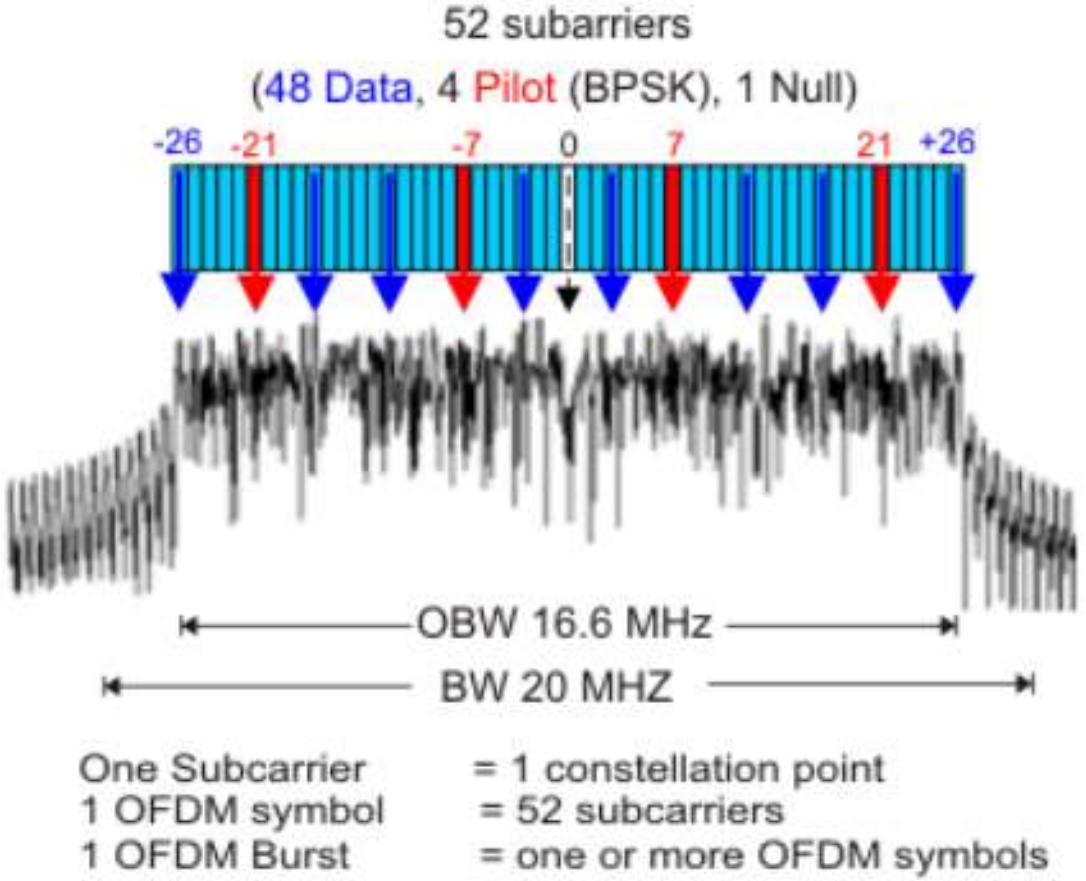
# 802.11n/ac/ax – Wi-Fi 4 to Wi-Fi 6

**Improvements shown by arrows**

| | Wi-Fi 4 (802.11n) *High Throughput (HT)* | Wi-Fi 5 (802.11ac) *Very High Throughput (VHT)* | Wi-Fi 6 (802.11ax) *High Efficiency (HE)* |
|---|---|---|---|
| **Supported bands** | 2 GHz, 5 GHz | 5 GHz | 2 GHz, 5 GHz |
| **Channel bandwidth (MHz)** | 20, 40 → | 20, 40, 80, 80+80, 160 | 20, 40, 80, 80+80, 160 |
| **Transmission scheme** | OFDM | OFDM → | OFDM, **OFDMA** |
| **Subcarrier spacing** | 312.5 kHz | 312.5 kHz → | **78.125 kHz** |
| **Guard interval** | 0.4 µs, 0.8 µs | 0.4 µs, 0.8 µs | 0.8 µs, **1.6 µs, 3.2 µs** |
| **Spatial streams** | 4x4 (SU-MIMO only) → | 8x8 (incl. DL-MU-MIMO) → | 8x8 (incl. MU-MIMO) |
| **Modulation (highest)** | 64QAM → | 256QAM → | **1024QAM** |
| **Max. data rate*** | *540 Mbps* → | *6 934 Mbps* → | *9 765 Mbps* |

# OFDM Modulation (a/g/n/ac – Wi-Fi 4/5)

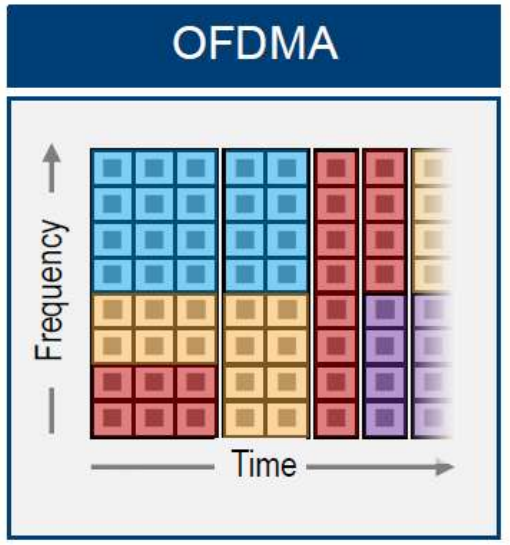
| 802.11a OFDM PHY Parameters | |
|---|---|
| BW | 20 MHZ |
| OBW | 16.6 MHZ |
| Subcarrer Spacing | 312.5 Khz (20MHz/64 Pt FFT) |
| Information Rate | **6**/9/**12**/18/**24**/36/48/54 Mbits/s |
| Modulation | BPSK, QPSK, 16QAM, 64QAM |
| Coding Rate | 1/2, 2/3, 3/4 |
| Total Subcarriers | 52 (Freq Index -26 to +26) |
| Data Subcarriers | 48 |
| Pilot Subcarriers* | 4 (-21, -7, +7, +21)<br>*Always BPSK |
| DC Subcarrier | Null (0 subcarrier) |

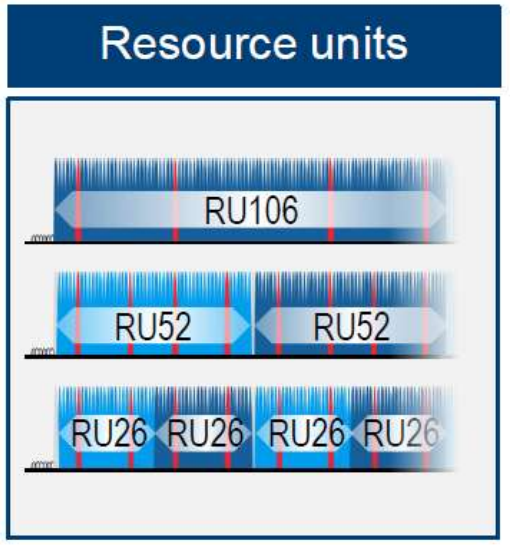


# OFDMA Modulation (ax - Wi-Fi 6)

- OFDMA uses QAM subcarriers
- Can split up subcarriers in multiple sizes for "packing" more users

***More Speed***

# MCS Tables

- Lists the potential maximum data rate based on:
  - Number of Spatial Streams
    - Horizontal polarization
    - Vertical polarization
    - Orthogonal polarization
    - Spatial diversity
      - This is more pronounced as the wavelength gets shorter/frequency higher
  - MCS Level
    - This changes based on bit error rate
    - Affected by distance from AP

# 802.11ax MCS Table

| MCS Index | Spatial Stream | Modulation | Coding | MU-OFDMA (802.11ax) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 26-tone RU | | | 52-tone RU | | | 106-tone RU | | | 242-tone RU | | | 484-tone RU | | | 996-tone RU | | |
| | | | | 0.8µs GI | 1.6µs GI | 3.2µs GI | 0.8µs GI | 1.6µs GI | 3.2µs GI | 0.8µs GI | 1.6µs GI | 3.2µs GI | 0.8µs GI | 1.6µs GI | 3.2µs GI | 0.8µs GI | 1.6µs GI | 3.2µs GI | 0.8µs GI | 1.6µs GI | 3.2µs GI |
| 0 | 1 | BPSQ | 1/2 | 0.9 | 0.8 | 0.8 | 1.8 | 1.7 | 1.5 | 3.8 | 3.5 | 3.2 | 8.6 | 8.1 | 7.3 | 17.2 | 16.3 | 14.6 | 36.0 | 34.0 | 30.6 |
| 1 | 1 | QPSK | 1/2 | 1.8 | 1.7 | 1.5 | 3.5 | 3.3 | 3.0 | 7.5 | 7.1 | 6.4 | 17.2 | 16.3 | 14.6 | 34.4 | 32.5 | 29.3 | 72.1 | 68.1 | 61.3 |
| 2 | 1 | QPSK | 3/4 | 2.6 | 2.5 | 2.3 | 5.3 | 5.0 | 4.5 | 11.3 | 10.6 | 9.6 | 25.8 | 24.4 | 21.9 | 51.6 | 48.8 | 43.9 | 108.1 | 102.1 | 91.9 |
| 3 | 1 | 16-QAM | 1/2 | 3.5 | 3.3 | 3.0 | 7.1 | 6.7 | 6.0 | 15.0 | 14.2 | 12.8 | 34.4 | 32.5 | 29.3 | 68.8 | 65.0 | 58.5 | 144.1 | 136.1 | 122.5 |
| 4 | 1 | 16-QAM | 3/4 | 5.3 | 5.0 | 4.5 | 10.6 | 10.0 | 9.0 | 22.5 | 21.3 | 19.1 | 51.6 | 48.8 | 43.9 | 103.2 | 97.5 | 87.8 | 216.2 | 204.2 | 183.8 |
| 5 | 1 | 64-QAM | 2/3 | 7.1 | 6.7 | 6.0 | 14.1 | 13.3 | 12.0 | 30.0 | 28.3 | 25.5 | 68.8 | 65.0 | 58.5 | 137.6 | 130.0 | 117.0 | 288.2 | 272.2 | 245.0 |
| 6 | 1 | 64-QAM | 3/4 | 7.9 | 7.5 | 6.8 | 15.9 | 15.0 | 13.5 | 33.8 | 31.9 | 28.7 | 77.4 | 73.1 | 65.8 | 154.9 | 146.3 | 131.6 | 324.3 | 306.3 | 275.6 |
| 7 | 1 | 64-QAM | 5/6 | 8.8 | 8.3 | 7.5 | 17.6 | 16.7 | 15.0 | 37.5 | 35.4 | 31.9 | 86.0 | 81.3 | 73.1 | 172.1 | 162.5 | 146.3 | 360.3 | 340.3 | 306.3 |
| 8 | 1 | 256-QAM | 3/4 | 10.6 | 10.0 | 9.0 | 21.2 | 20.0 | 18.0 | 45.0 | 42.5 | 38.3 | 103.2 | 97.5 | 87.8 | 206.5 | 195.0 | 175.5 | 432.4 | 408.3 | 367.5 |
| 9 | 1 | 256-QAM | 5/6 | 11.8 | 11.1 | 10.0 | 23.5 | 22.2 | 20.0 | 50.0 | 47.2 | 42.5 | 114.7 | 108.3 | 97.5 | 229.4 | 216.7 | 195.0 | 480.4 | 453.7 | 408.3 |
| 10 | 1 | 1024-QAM | 3/4 | 13.2 | 12.5 | 11.3 | 26.5 | 25.0 | 22.5 | 56.3 | 53.1 | 47.8 | 129.0 | 121.9 | 109.7 | 258.1 | 243.8 | 219.4 | 540.4 | 510.4 | 459.4 |
| 11 | 1 | 1024-QAM | 5/6 | 14.7 | 13.9 | 12.5 | 29.4 | 27.8 | 25.0 | 62.5 | 59.0 | 53.1 | 143.4 | 135.4 | 121.9 | 286.8 | 270.8 | 243.8 | 600.5 | 567.1 | 510.4 |
| 0 | 2 | BPSQ | 1/2 | 1.8 | 1.7 | 1.5 | 3.5 | 3.3 | 3.0 | 7.5 | 7.1 | 6.4 | 17.2 | 16.3 | 14.6 | 34.4 | 32.5 | 29.3 | 72.1 | 68.1 | 61.3 |
| 1 | 2 | QPSK | 1/2 | 3.5 | 3.3 | 3.0 | 7.1 | 6.7 | 6.0 | 15.0 | 14.2 | 12.8 | 34.4 | 32.5 | 29.3 | 68.8 | 65.0 | 58.5 | 144.1 | 136.1 | 122.5 |
| 2 | 2 | QPSK | 3/4 | 5.3 | 5.0 | 4.5 | 10.6 | 10.0 | 9.0 | 22.5 | 21.3 | 19.1 | 51.6 | 48.8 | 43.9 | 103.2 | 97.5 | 87.8 | 216.2 | 204.2 | 183.8 |
| 3 | 2 | 16-QAM | 1/2 | 7.1 | 6.7 | 6.0 | 14.1 | 13.3 | 12.0 | 30.0 | 28.3 | 25.5 | 68.8 | 65.0 | 58.5 | 137.6 | 130.0 | 117.0 | 288.2 | 272.2 | 245.0 |
| 4 | 2 | 16-QAM | 3/4 | 10.6 | 10.0 | 9.0 | 21.2 | 20.0 | 18.0 | 45.0 | 42.5 | 38.3 | 103.2 | 97.5 | 87.8 | 206.5 | 195.0 | 175.5 | 432.4 | 408.3 | 367.5 |
| 5 | 2 | 64-QAM | 2/3 | 14.1 | 13.3 | 12.0 | 28.2 | 26.7 | 24.0 | 60.0 | 56.7 | 51.0 | 137.6 | 130.0 | 117.0 | 275.3 | 260.0 | 234.0 | 576.5 | 544.4 | 490.0 |
| 6 | 2 | 64-QAM | 3/4 | 15.9 | 15.0 | 13.5 | 31.8 | 30.0 | 27.0 | 67.5 | 63.8 | 57.4 | 154.9 | 146.3 | 131.6 | 309.7 | 292.5 | 263.3 | 648.5 | 612.5 | 551.3 |
| 7 | 2 | 64-QAM | 5/6 | 17.6 | 16.7 | 15.0 | 35.3 | 33.3 | 30.0 | 75.0 | 70.8 | 63.8 | 172.1 | 162.5 | 146.3 | 344.1 | 325.0 | 292.5 | 720.6 | 680.6 | 612.5 |
| 8 | 2 | 256-QAM | 3/4 | 21.2 | 20.0 | 18.0 | 42.4 | 40.0 | 36.0 | 90.0 | 85.0 | 76.5 | 206.5 | 195.0 | 175.5 | 412.9 | 390.0 | 351.0 | 864.7 | 816.7 | 735.0 |
| 9 | 2 | 256-QAM | 5/6 | 23.5 | 22.2 | 20.0 | 47.1 | 44.4 | 40.0 | 100.0 | 94.4 | 85.0 | 229.4 | 216.7 | 195.0 | 458.8 | 433.3 | 390.0 | 960.8 | 907.4 | 816.7 |
| 10 | 2 | 1024-QAM | 3/4 | 26.5 | 25.0 | 22.5 | 52.9 | 50.0 | 45.0 | 112.5 | 106.3 | 95.6 | 258.1 | 243.8 | 219.4 | 516.2 | 487.5 | 438.8 | 1080.9 | 1020.8 | 918.8 |
| 11 | 2 | 1024-QAM | 5/6 | 29.4 | 27.8 | 25.0 | 58.8 | 55.6 | 50.0 | 125.0 | 118.1 | 106.3 | 286.8 | 270.8 | 243.8 | 573.5 | 541.7 | 487.5 | 1201.0 | 1134.3 | 1020.8 |
| 0 | 3 | BPSQ | 1/2 | 2.6 | 2.5 | 2.3 | 5.3 | 5.0 | 4.5 | 11.3 | 10.6 | 9.6 | 25.8 | 24.4 | 21.9 | 51.6 | 48.8 | 43.9 | 108.1 | 102.1 | 91.9 |
| 1 | 3 | QPSK | 1/2 | 5.3 | 5.0 | 4.5 | 10.6 | 10.0 | 9.0 | 22.5 | 21.3 | 19.1 | 51.6 | 48.8 | 43.9 | 103.2 | 97.5 | 87.8 | 216.2 | 204.2 | 183.8 |
| 2 | 3 | QPSK | 3/4 | 7.9 | 7.5 | 6.8 | 15.9 | 15.0 | 13.5 | 33.8 | 31.9 | 28.7 | 77.4 | 73.1 | 65.8 | 154.9 | 146.3 | 131.6 | 324.3 | 306.3 | 275.6 |
| 3 | 3 | 16-QAM | 1/2 | 10.6 | 10.0 | 9.0 | 21.2 | 20.0 | 18.0 | 45.0 | 42.5 | 38.3 | 103.2 | 97.5 | 87.8 | 206.5 | 195.0 | 175.5 | 432.4 | 408.3 | 367.5 |
| 4 | 3 | 16-QAM | 3/4 | 15.9 | 15.0 | 13.5 | 31.8 | 30.0 | 27.0 | 67.5 | 63.8 | 57.4 | 154.9 | 146.3 | 131.6 | 309.7 | 292.5 | 263.3 | 648.5 | 612.5 | 551.3 |
| 5 | 3 | 64-QAM | 2/3 | 21.2 | 20.0 | 18.0 | 42.4 | 40.0 | 36.0 | 90.0 | 85.0 | 76.5 | 206.5 | 195.0 | 175.5 | 412.9 | 390.0 | 351.0 | 864.7 | 816.7 | 735.0 |
| 6 | 3 | 64-QAM | 3/4 | 23.8 | 22.5 | 20.3 | 47.6 | 45.0 | 40.5 | 101.3 | 95.6 | 86.1 | 232.3 | 219.4 | 197.4 | 464.6 | 438.8 | 394.9 | 972.8 | 918.8 | 826.9 |
| 7 | 3 | 64-QAM | 5/6 | 26.5 | 25.0 | 22.5 | 52.9 | 50.0 | 45.0 | 112.5 | 106.3 | 95.6 | 258.1 | 243.8 | 219.4 | 516.2 | 487.5 | 438.8 | 1080.9 | 1020.8 | 918.8 |
| 8 | 3 | 256-QAM | 3/4 | 31.8 | 30.0 | 27.0 | 63.5 | 60.0 | 54.0 | 135.0 | 127.5 | 114.8 | 309.7 | 292.5 | 263.3 | 619.4 | 585.0 | 526.5 | 1297.1 | 1225.0 | 1102.5 |
| 9 | 3 | 256-QAM | 5/6 | 35.3 | 33.3 | 30.0 | 70.6 | 66.7 | 60.0 | 150.0 | 141.7 | 127.5 | 344.1 | 325.0 | 292.5 | 688.2 | 650.0 | 585.0 | 1441.2 | 1361.1 | 1225.0 |
| 10 | 3 | 1024-QAM | 3/4 | 39.7 | 37.5 | 33.8 | 79.4 | 75.0 | 67.5 | 168.8 | 159.4 | 143.4 | 387.1 | 365.6 | 329.1 | 774.3 | 731.3 | 658.1 | 1621.3 | 1531.3 | 1378.1 |
| 11 | 3 | 1024-QAM | 5/6 | 44.1 | 41.7 | 37.5 | 88.2 | 83.3 | 75.0 | 187.5 | 177.1 | 159.4 | 430.1 | 406.3 | 365.6 | 860.3 | 812.5 | 731.3 | 1801.5 | 1701.4 | 1531.3 |

# Zoomed MCS Table 11ax Three Streams

| MCS Index | Spatial Stream | Modulation | Coding | 80MHz | | | 160MHz | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.8µs GI | 1.6µs GI | 3.2µs GI | 0.8µs GI | 1.6µs GI | 3.2µs GI |
| 0 | 3 | BPSQ | 1/2 | 108.1 | 102.1 | 91.9 | 216.2 | 204.2 | 183.8 |
| 1 | 3 | QPSK | 1/2 | 216.2 | 204.2 | 183.8 | 432.4 | 408.3 | 367.5 |
| 2 | 3 | QPSK | 3/4 | 324.3 | 306.3 | 275.6 | 648.5 | 612.5 | 551.3 |
| 3 | 3 | 16-QAM | 1/2 | 432.4 | 408.3 | 367.5 | 864.7 | 816.7 | 735.0 |
| 4 | 3 | 16-QAM | 3/4 | 648.5 | 612.5 | 551.3 | 1297.1 | 1225.0 | 1102.5 |
| 5 | 3 | 64-QAM | 2/3 | 864.7 | 816.7 | 735.0 | 1729.4 | 1633.3 | 1470.0 |
| 6 | 3 | 64-QAM | 3/4 | 972.8 | 918.8 | 826.9 | 1945.6 | 1837.5 | 1653.8 |
| 7 | 3 | 64-QAM | 5/6 | 1080.9 | 1020.8 | 918.8 | 2161.8 | 2041.7 | 1837.5 |
| 8 | 3 | 256-QAM | 3/4 | 1297.1 | 1225.0 | 1102.5 | 2594.1 | 2450.0 | 2205.0 |
| 9 | 3 | 256-QAM | 5/6 | 1441.2 | 1361.1 | 1225.0 | 2882.4 | 2722.2 | 2450.0 |
| 10 | 3 | 1024-QAM | 3/4 | 1621.3 | 1531.3 | 1378.1 | 3242.6 | 3062.5 | 2756.3 |
| 11 | 3 | 1024-QAM | 5/6 | 1801.5 | 1701.4 | 1531.3 | 3602.9 | 3402.8 | 3062.5 |

Mbps

# Zoomed MCS Table 11ax
# Eight Streams/160 MHz Channel

| MCS Index | | | Spatial Stream | Modulation | Coding | 160MHz | | |
|---|---|---|---|---|---|---|---|---|
| HT | VHT | HE | | | | 0.8µs GI | 1.6µs GI | 3.2µs GI |
| | 0 | 0 | 8 | BPSK | 1/2 | 576.5 | 544.4 | 490 |
| | 1 | 1 | 8 | QPSK | 1/2 | 1152.9 | 1088.9 | 980 |
| | 2 | 2 | 8 | QPSK | 3/4 | 1729.4 | 1633.3 | 1470 |
| | 3 | 3 | 8 | 16-QAM | 1/2 | 2305.9 | 2177.8 | 1960 |
| | 4 | 4 | 8 | 16-QAM | 3/4 | 3458.8 | 3266.7 | 2940 |
| | 5 | 5 | 8 | 64-QAM | 2/3 | 4611.8 | 4355.6 | 3920 |
| | 6 | 6 | 8 | 64-QAM | 3/4 | 5188.2 | 4900 | 4410 |
| | 7 | 7 | 8 | 64-QAM | 5/6 | 5764.7 | 5444.4 | 4900 |
| | 8 | 8 | 8 | 256-QAM | 3/4 | 6917.6 | 6533.3 | 5880 |
| | 9 | 9 | 8 | 256-QAM | 5/6 | 7686.3 | 7259.3 | 6533.3 |
| | | 10 | 8 | 1024-QAM | 3/4 | 8647.1 | 8166.7 | 7350 |
| | | 11 | 8 | 1024-QAM | 5/6 | 9607.8 | 9074.1 | 8166.7 |

Mbps

# Propagation of 2.4/5/6 GHz

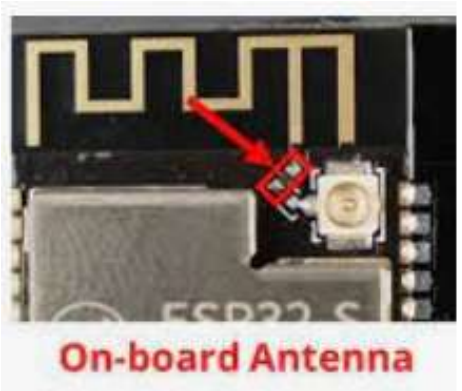
- Just like on VHF and UHF, the lower the frequency, the better the range in free space
- At microwave frequencies, building materials, water vapor and content, etc. all affect propagation to a larger effect especially as you go higher in frequency
- Sources of RF noise at lower frequencies do not affect microwave frequencies to the same degree
  - Lightning
  - Harmonic content of appliances, lights, power supplies, etc.
- Distance from the transceiver still applies

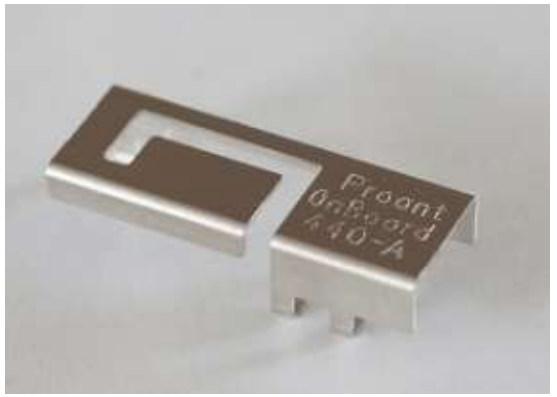
# Power Tables 2.4 and 5 GHz

- Wi-Fi devices are rated mostly in terms of “dBm”
- 2.4 GHz
  - Max EIRP 36 dBm (4 watts)
    - If the antenna gain is increased for more directional range, the transmitter power must be reduced accordingly
- 5 GHz
  - Max EIRP 30 dBm (1 watt)
  - U-NII sub-bands have lower power specifications and are based on a special formula.
- Refer to these tables for more details: https://www.air802.com/fcc-rules-and-regulations.html

# Antenna Types

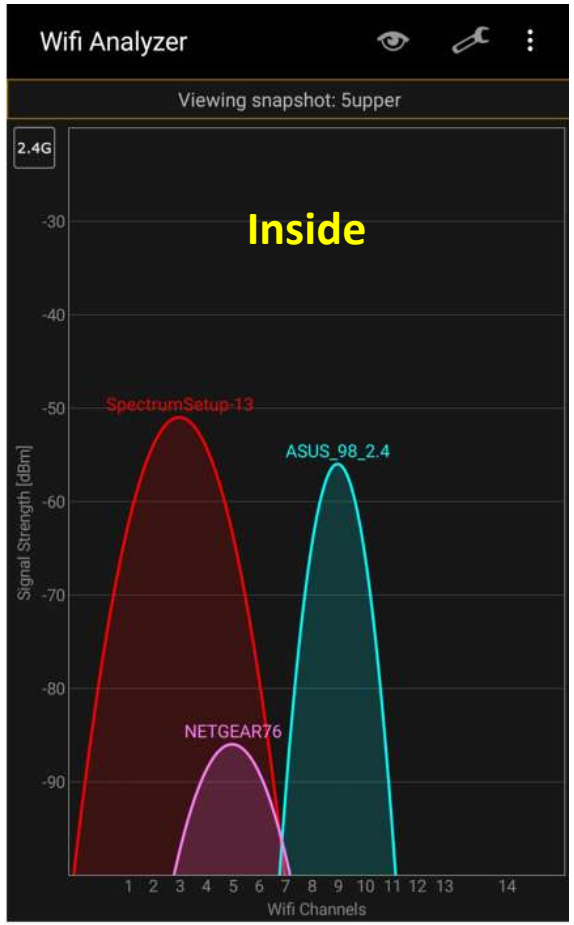
- On-board antennas with 0 dBi gain or less (for more of an omni pattern)
- Quarter-wave monopole with a ground plane reference (0  to 2.19dBi gain)
- Coaxial dipole (2.19 dBi)
- Colinear (5 to 8 dBi)
- Panel (10 - 20 dBi)
  - Indoor
  - Outdoor for Enterprise APs
- Most products use designs that cannot be replaced by the end user

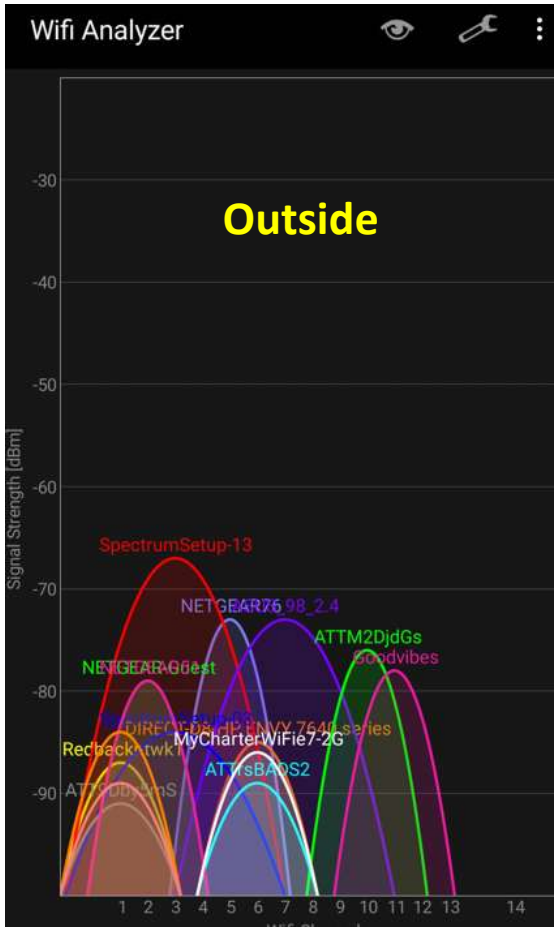


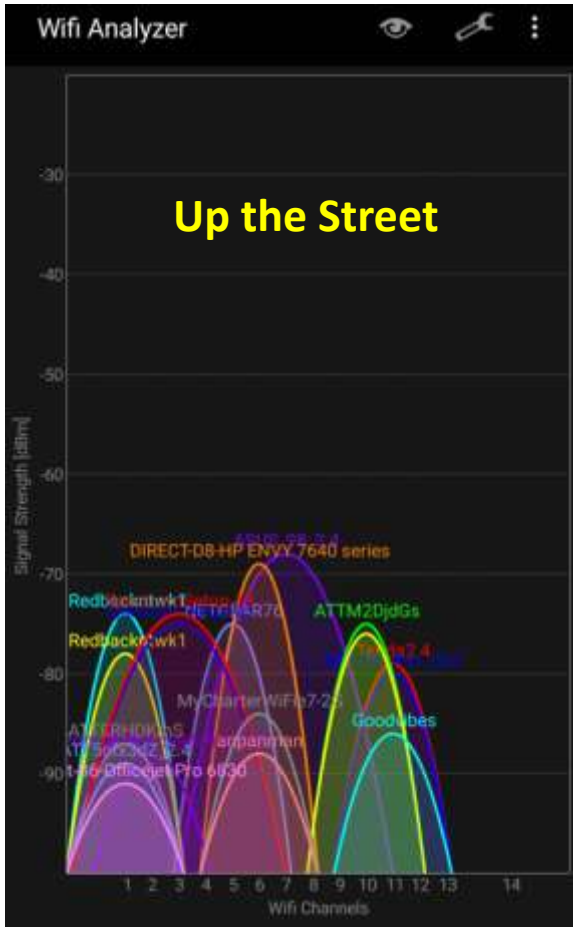




# Cool Tools – Wi-Fi Analyzer App (Android)

## 2.4 GHz

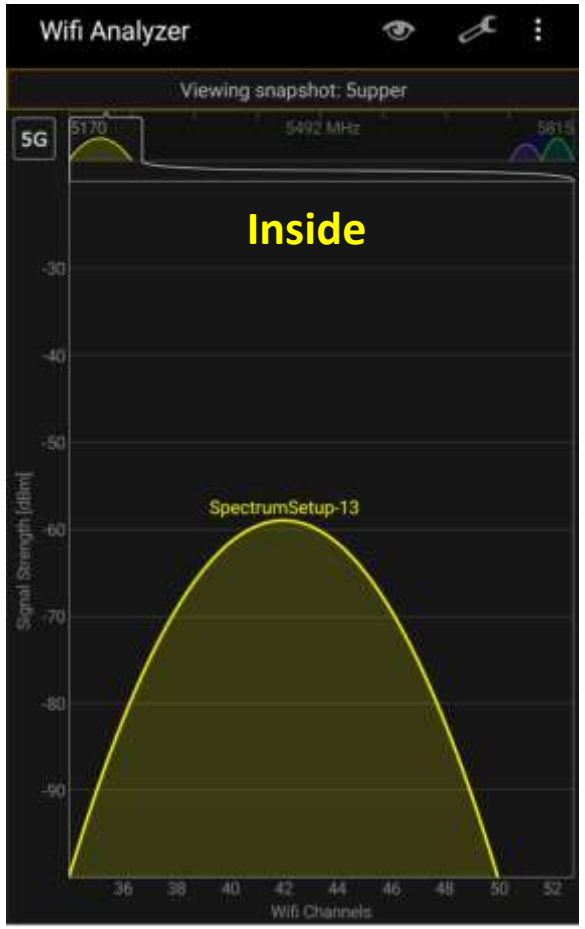


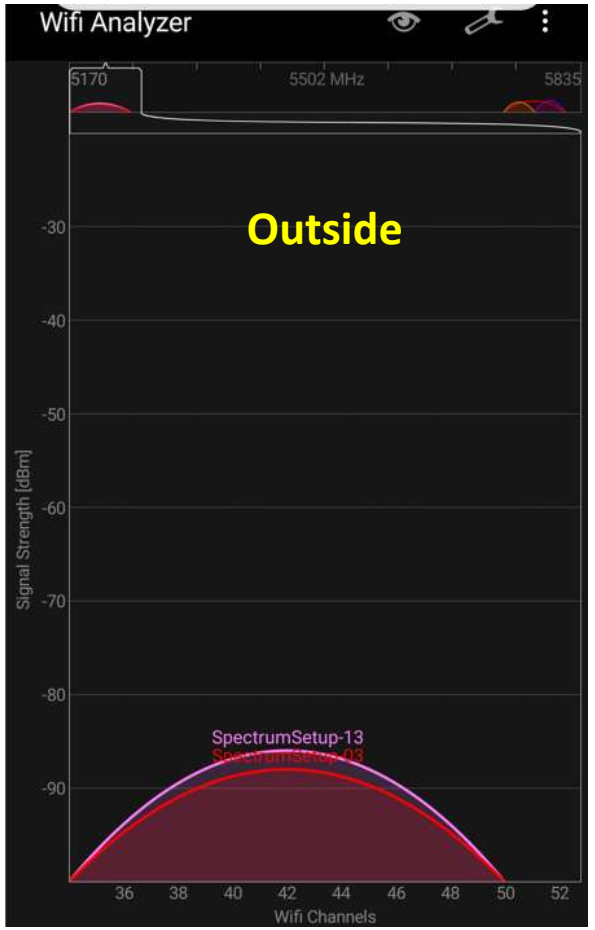



# Cool Tools – Wi-Fi Analyzer App (Android)

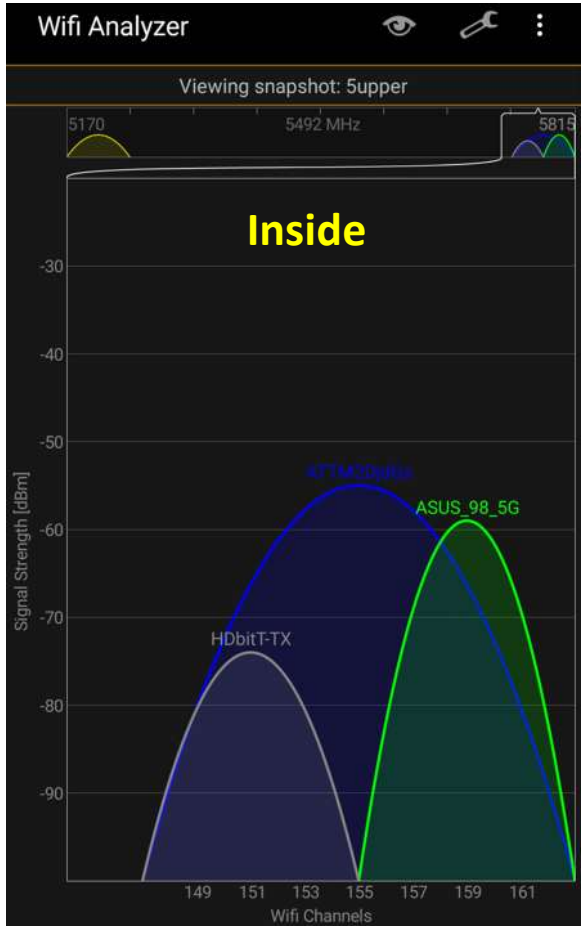
## 5 GHz (lower band)

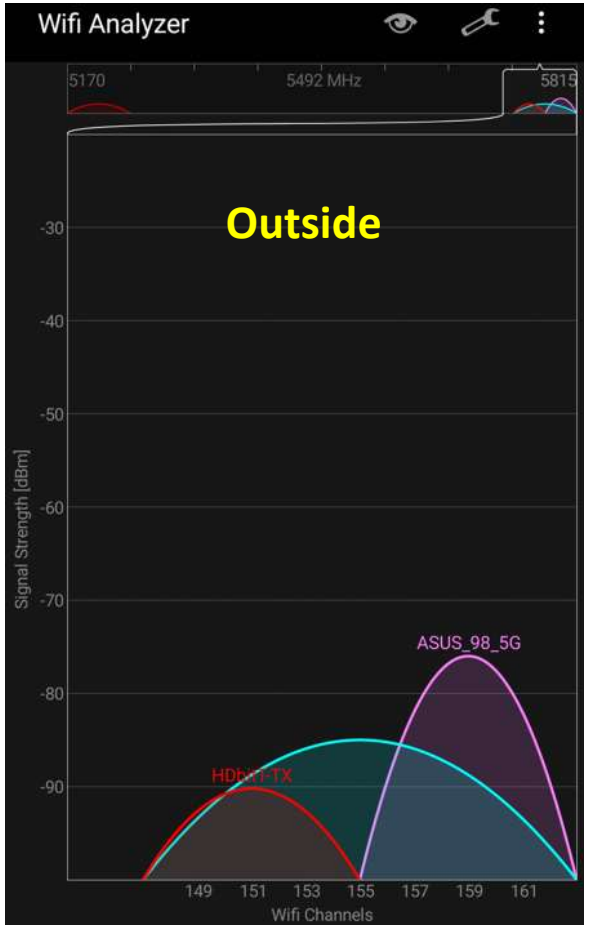


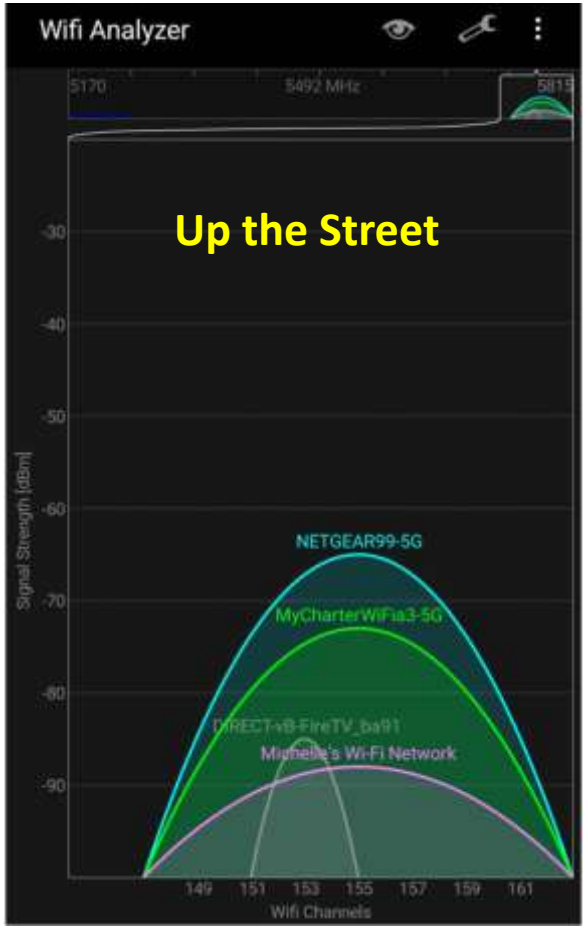




# Cool Tools – Wi-Fi Analyzer App (Android)

## 5 GHz (upper band)



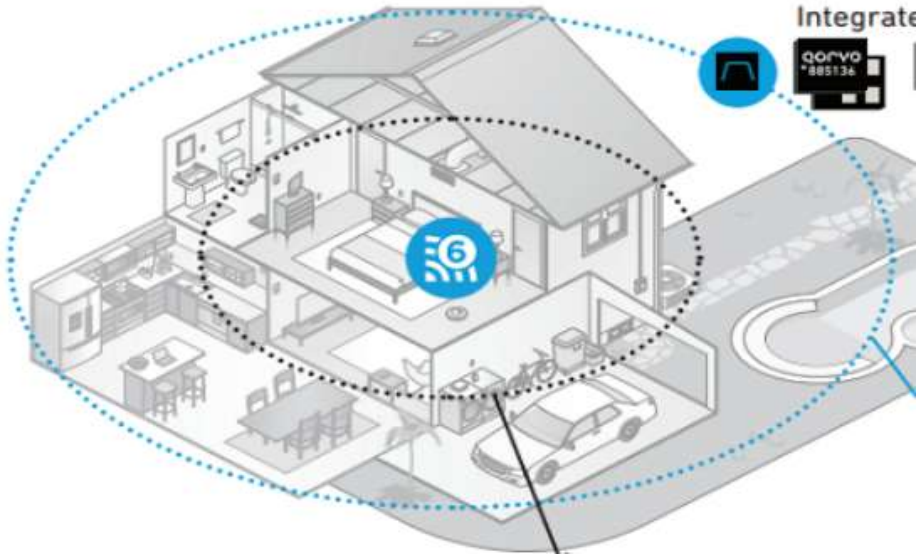



# Mesh Networks and Wi-Fi Extenders

- These are designed to solve one problem:  bad signal strength
- Mesh networks typically slow down your throughput speed as they “store and forward” data from one AP to the next
- Some Wi-Fi Extenders can also slow down throughput by
  - Use of 20 MHz channels vs 40/80 MHz
  - Operate only on 2.4 GHz, a crowded band
  - Operate as “half duplex” devices
- For best throughput, use a Wi-Fi Extender that uses an un-used and dedicated 5 GHz channel to continuously stream DUPLEX data (such as a DFS channel in the U-NII2 band)
- See this article for really good information on this topic: https://www.pcmag.com/how-to/wi-fi-range-extender-vs-mesh-network-whats-the-difference

# Optimizing Wi-Fi Throughput in your House

- Place in a central location in your house
  - Not a corner of your house
    - Better to run a longer Ethernet cable to your router to get to a better location
  - Avoid nearby metal objects
    - Mirrors
    - Steel wall studs
    - Refrigerator, etc.
    - Not behind your big screen TV
  - Off of the floor
  - Not in your attic
    - The devices are typically rated for operation below 40 degree C.  Extended exposure to the high heat in an attic will reduce the operation life of your Wi-Fi AP
- For better coverage, use two AP's connected via an Ethernet cable and programmed to non-interfering channels



# What's next?

# Wi-Fi 6e

In the US, there will be nearly 1200 MHz of new spectrum

- Canada & Mexico are following this same bandwidth plan

Includes SEVEN consecutive 160 MHz channels for high-speed capability. These are not overlapped channels

# 5 & 6 GHz Channels up to 7.125 GHz

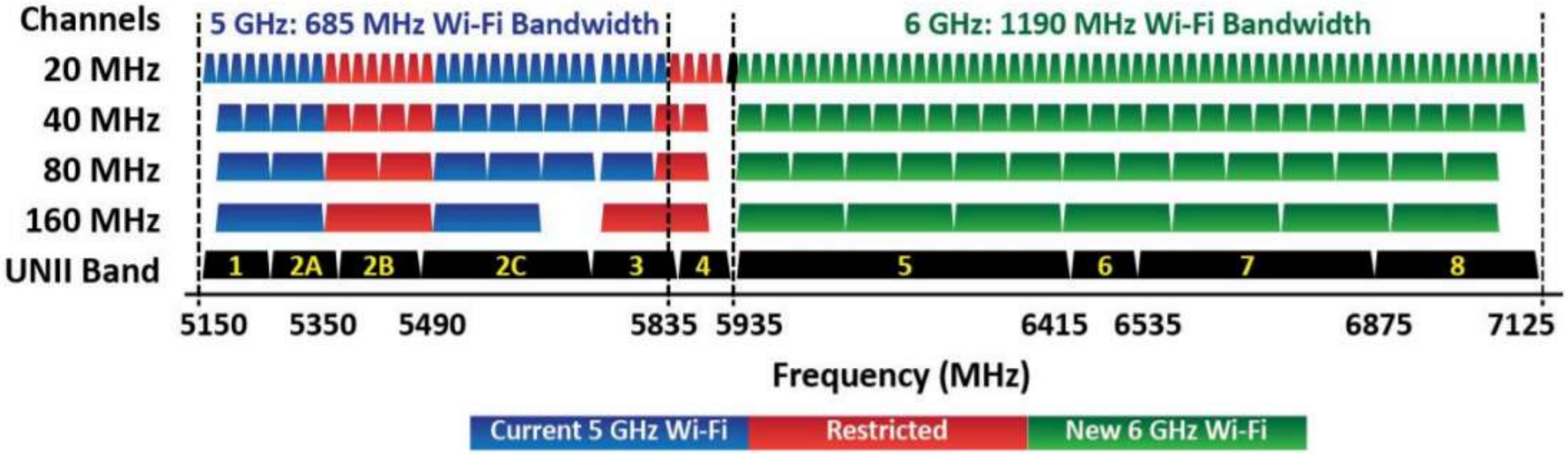
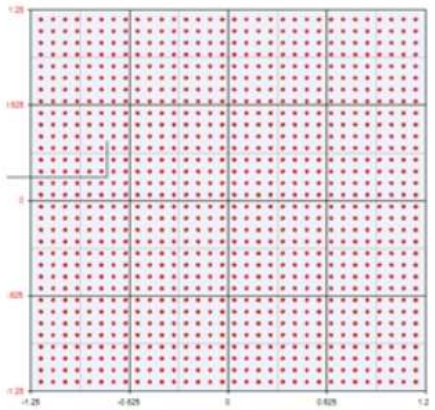


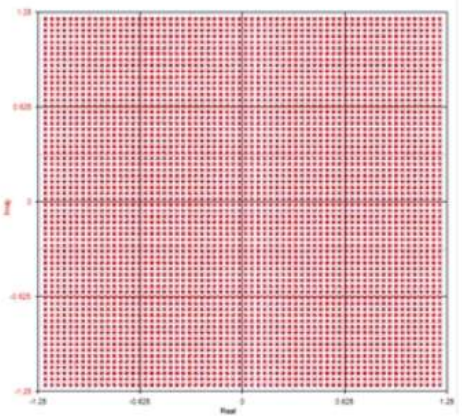

**Figure 1. The U.S. FCC's proposed division of the 6 GHz band into four sub-bands**

# 802.11be – Wi-Fi 7

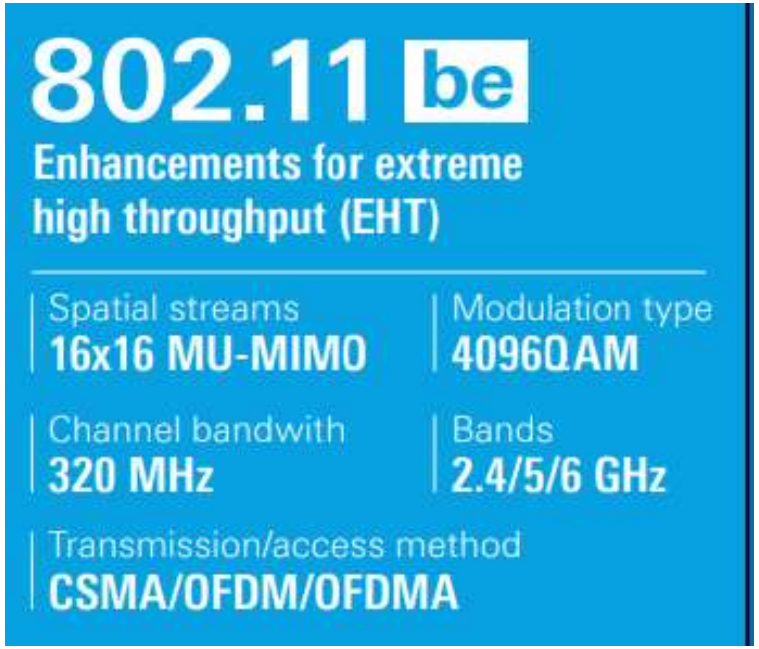
- 320 MHz Channels
- Faster Modulation 4096 QAM
  - Compare constellations as shown



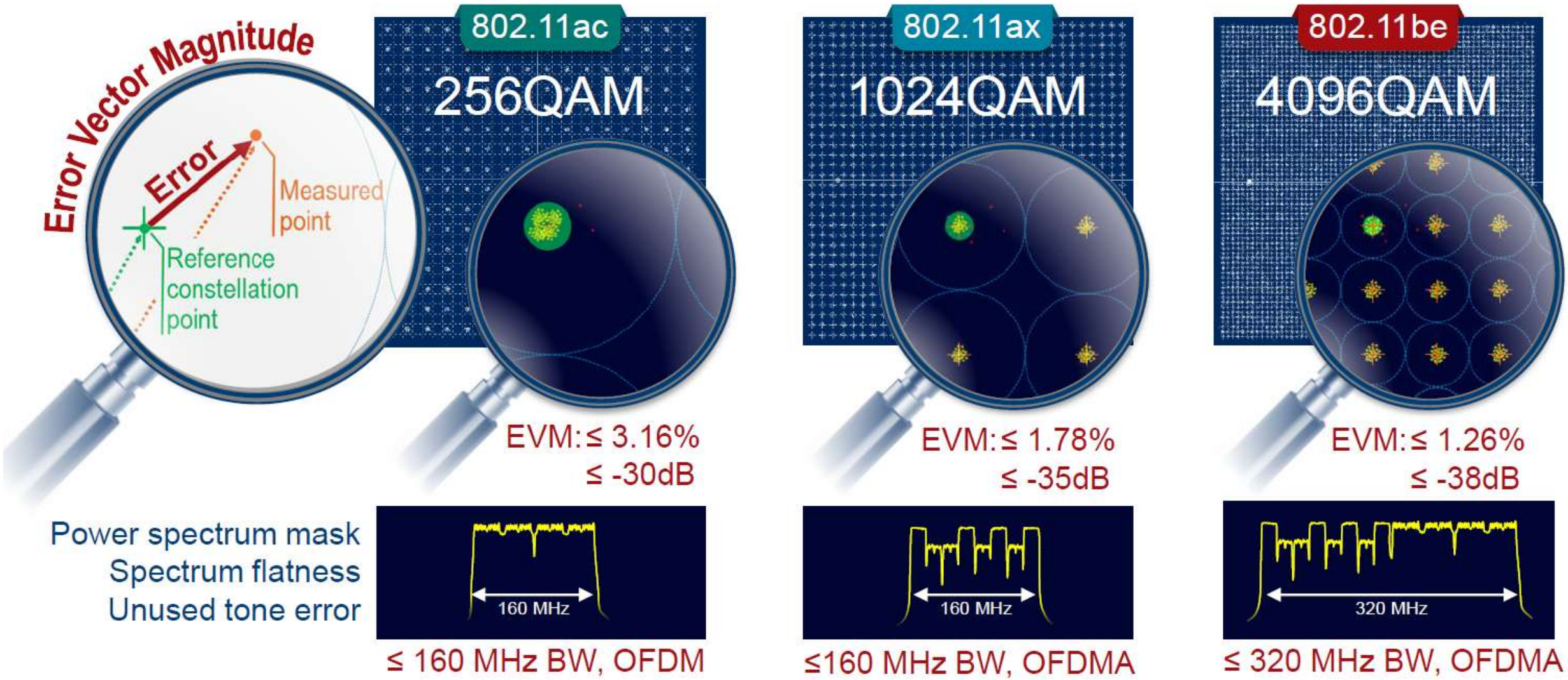
QAM-1024



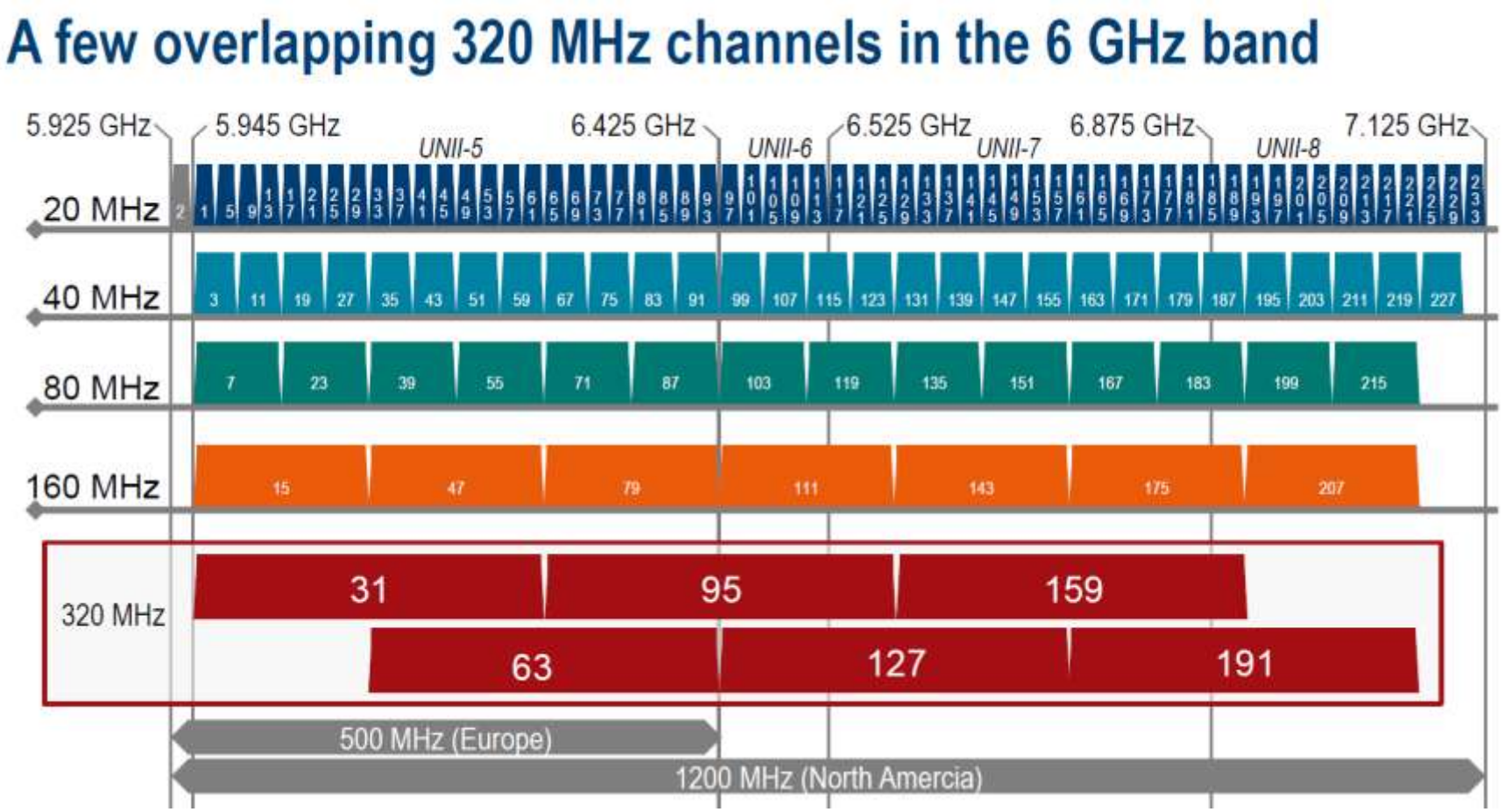
QAM-4096



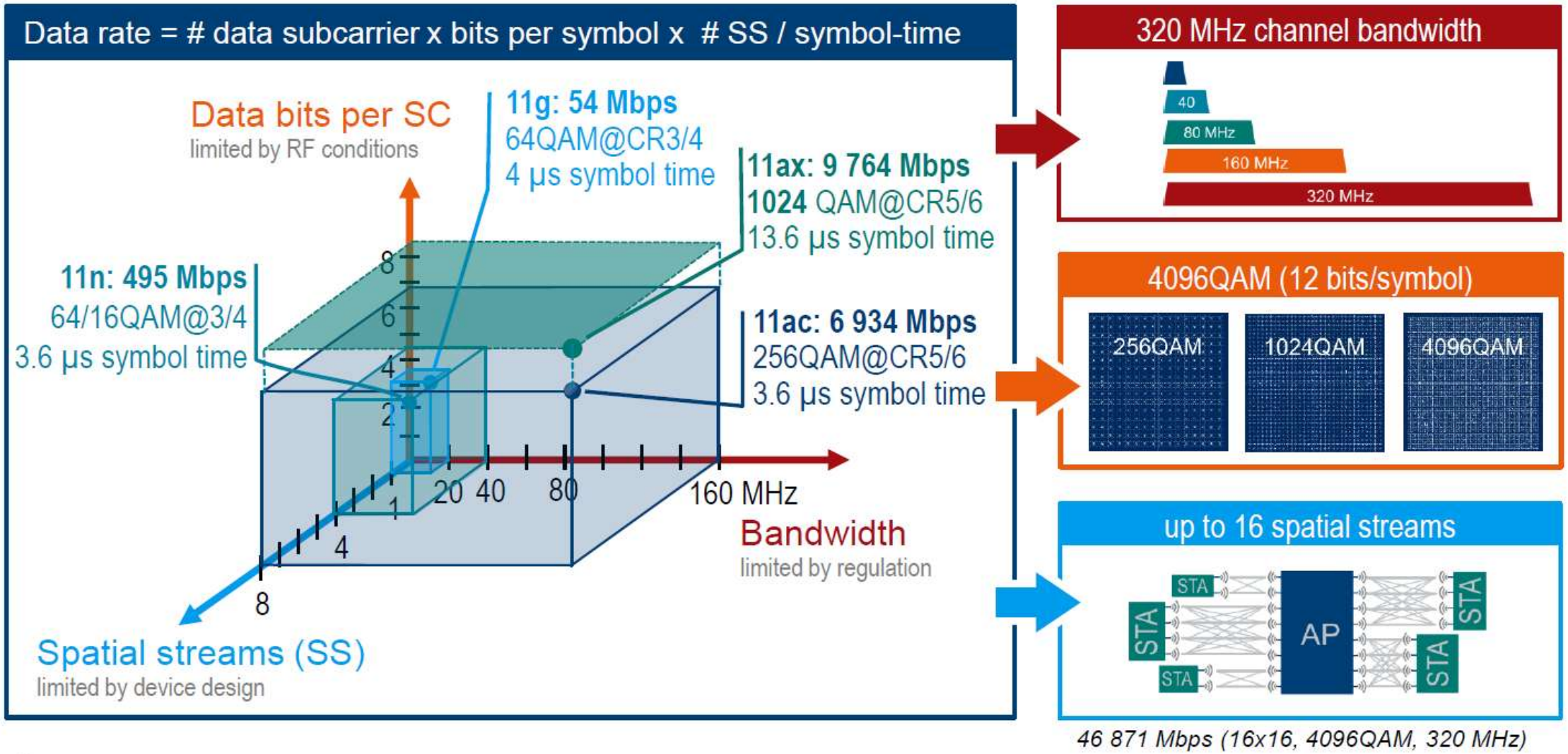
# Wi-Fi 7 pushes RF performance requirements to the next level



# 320 MHz Channels



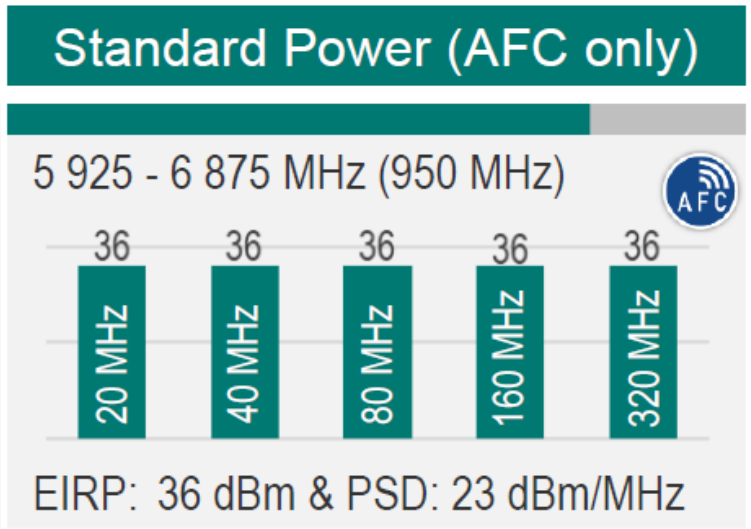
# The everlasting demand for higher data rates and its limitations

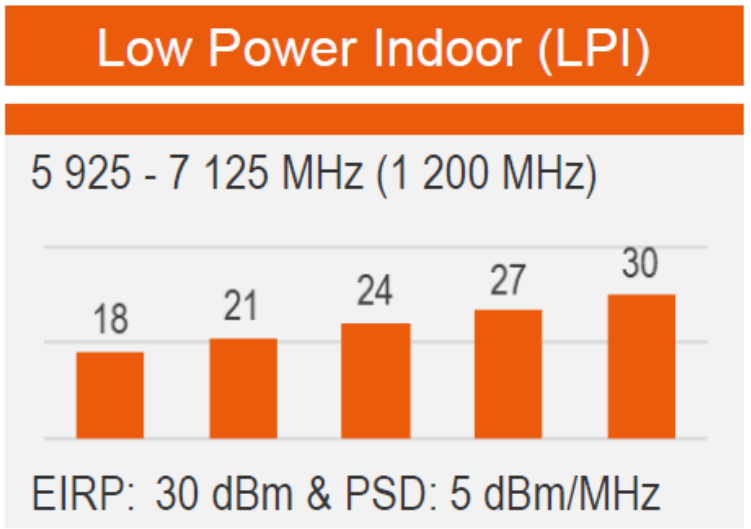


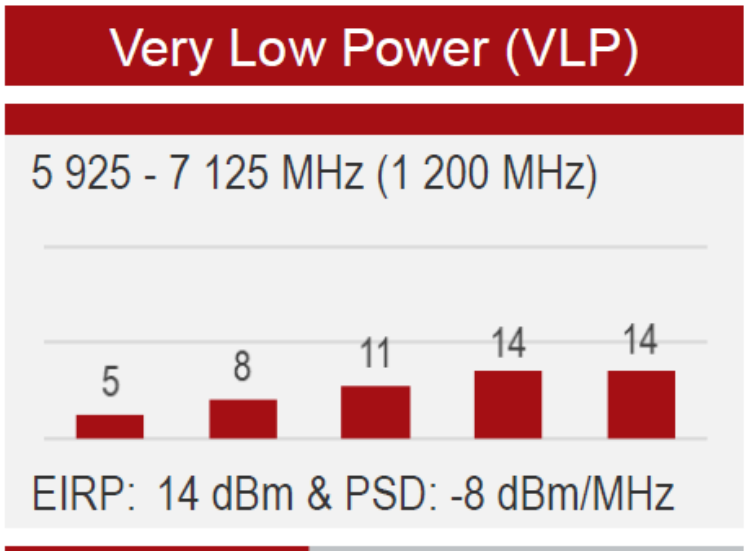

*46 871 Mbps (16x16, 4096QAM, 320 MHz)*

# 6 GHz Power Tables

- For Outdoor AP's must use frequency coordination called AFC
- Other AP types use PSD (Power Spectral Density) formulas to determine EIRP power limits



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