802.11AX: NEXT GENERATION WIFI

1024 QAM & OFDMA

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WIFI 6 - 802.11AX

The 802.11ax amendment focuses on High Efficiency (HE):

- Increased number of bits in encoding
- Increased bandwidth efficiency
- Increased spatial efficiency

Generation	IEEE standard
Wi-Fi 6	802.11ax
Wi-Fi 5	802.11ac
Wi-Fi 4	802.11n

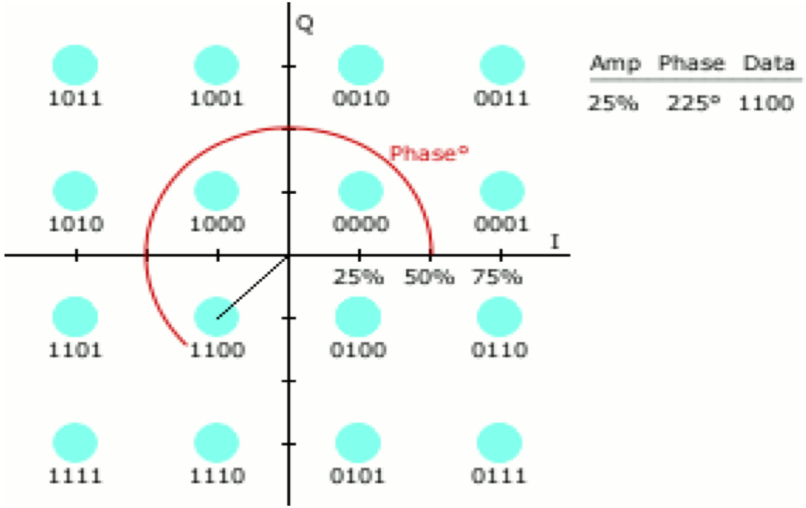
Examples of introduced features are:

- 1024 Quadrature Amplitude Modulation (QAM)
- Orthogonal Frequency Division Multiple Access (OFDMA)
- Multi-User Multiple-Input Multiple-Output (MU-MIMO)
- Basic Service Set (BSS) colouring

QUADRATURE AMPLITUDE MODULATION (QAM)

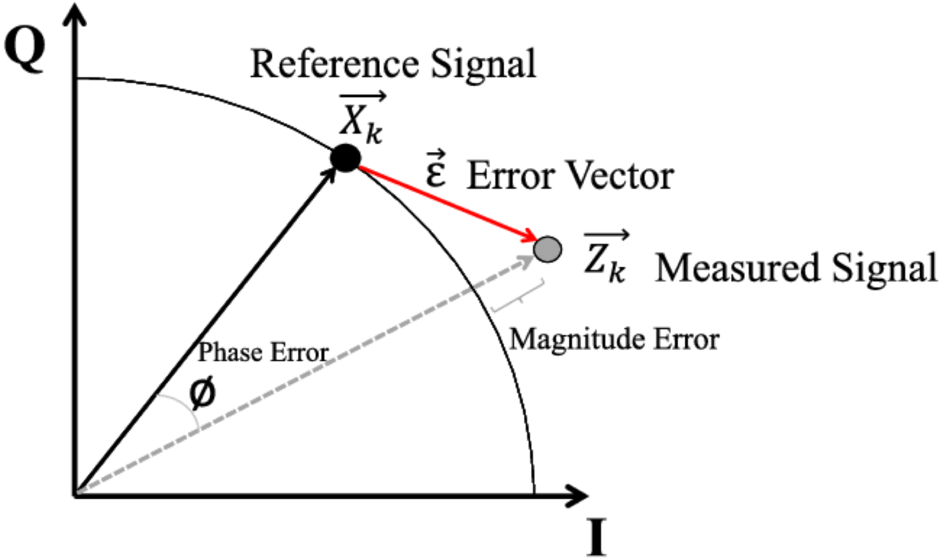
- Amplitude and Phase
- Number of points in constellation diagram = 2^{bits}
- 1024 QAM: expected +25% throughput
- Encoding 3/4 and 5/6
- Modulation & Coding Scheme (MCS)
    - MCS 8: 256 QAM, 3/4
    - MCS 9: 256 QAM, 5/6
    - MCS 10: 1024 QAM, 3/4
    - MCS 11: 1024 QAM, 5/6

16 QAM constellation diagram



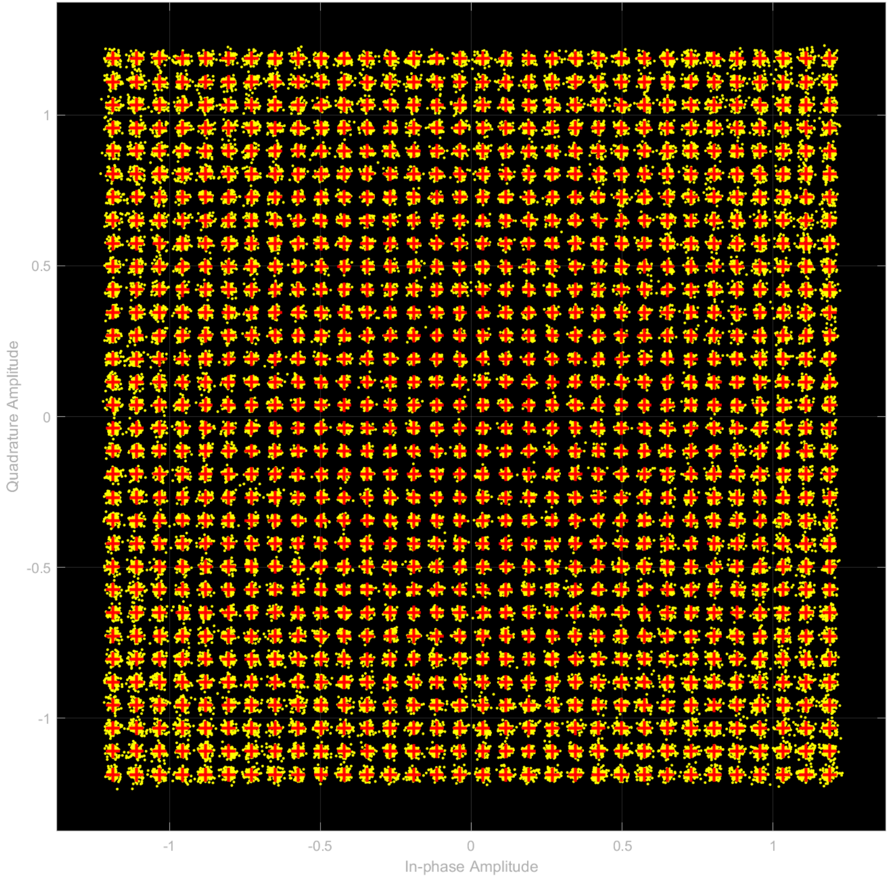
1024 QAM - EVM

- Constellation reference points
- Error Vector Magnitude (EVM)
- EVM threshold per level of QAM
- Thresholds:
  - 256 QAM: -32 dB
  - 1024 QAM: -35 dB



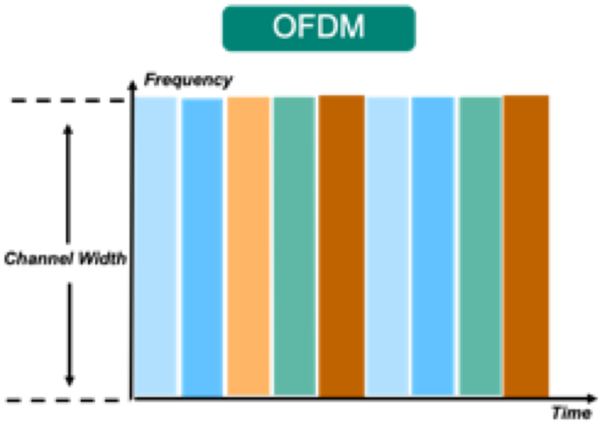
Source: https://www.researchgate.net/figure/Error-vector-magnitude-representation_fig3_311500178

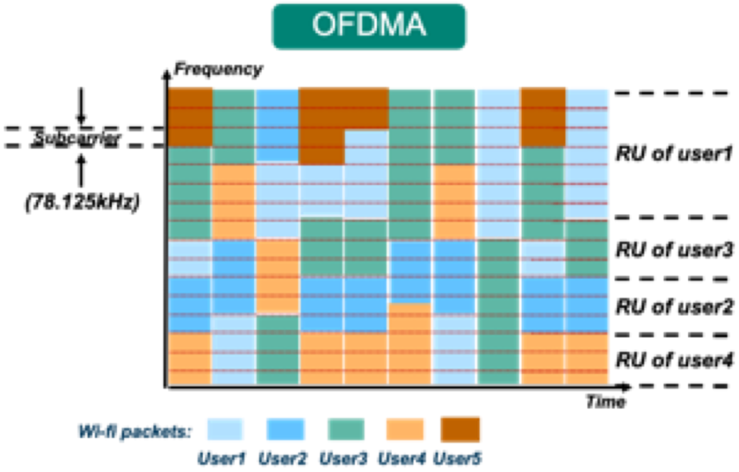
1024 QAM - CONSTELLATION DIAGRAM



ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS

- Multiplexing over bandwidth
- Resource Units (RU)
- Scheduler





Source: https://blogs.arubanetworks.com/solutions/whats-the-difference-between-ofdma-and-mu-mimo-in-11ax/

RU ALLOCATION INDEX

<table>
<tr><th>Allocation Index</th><th colspan="9">20 Mhz Subchannel Resource Unit Assignment</th></tr>
<tr><td>0</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td></tr>
<tr><td>1</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td><td colspan="2">52</td></tr>
<tr><td>2</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td><td colspan="2">52</td><td>26</td><td>26</td></tr>
<tr><td>3</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td><td colspan="2">52</td><td colspan="2">52</td></tr>
<tr><td>4</td><td>26</td><td>26</td><td colspan="2">52</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td></tr>
<tr><td>5</td><td>26</td><td>26</td><td colspan="2">52</td><td>26</td><td>26</td><td>26</td><td colspan="2">52</td></tr>
<tr><td>6</td><td>26</td><td>26</td><td colspan="2">52</td><td>26</td><td colspan="2">52</td><td>26</td><td>26</td></tr>
<tr><td>7</td><td>26</td><td>26</td><td colspan="2">52</td><td>26</td><td colspan="2">52</td><td colspan="2">52</td></tr>
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<tr><td>9</td><td colspan="2">52</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td><td colspan="2">52</td></tr>
<tr><td>10</td><td colspan="2">52</td><td>26</td><td>26</td><td>26</td><td colspan="2">52</td><td>26</td><td>26</td></tr>
<tr><td>11</td><td colspan="2">52</td><td>26</td><td>26</td><td>26</td><td colspan="2">52</td><td colspan="2">52</td></tr>
<tr><td>12</td><td colspan="2">52</td><td colspan="2">52</td><td>26</td><td>26</td><td>26</td><td>26</td><td>26</td></tr>
<tr><td>13</td><td colspan="2">52</td><td colspan="2">52</td><td>26</td><td>26</td><td>26</td><td colspan="2">52</td></tr>
<tr><td>14</td><td colspan="2">52</td><td colspan="2">52</td><td>26</td><td colspan="2">52</td><td>26</td><td>26</td></tr>
<tr><td>15</td><td colspan="2">52</td><td colspan="2">52</td><td>26</td><td colspan="2">52</td><td colspan="2">52</td></tr>
<tr><td>16-23(15+N)</td><td colspan="2">52</td><td colspan="2">52</td><td>0</td><td colspan="4">106 (N users)</td></tr>
<tr><td>24-31(23+N)</td><td colspan="4">106 (N users)</td><td>0</td><td colspan="2">52</td><td colspan="2">52</td></tr>
</table>

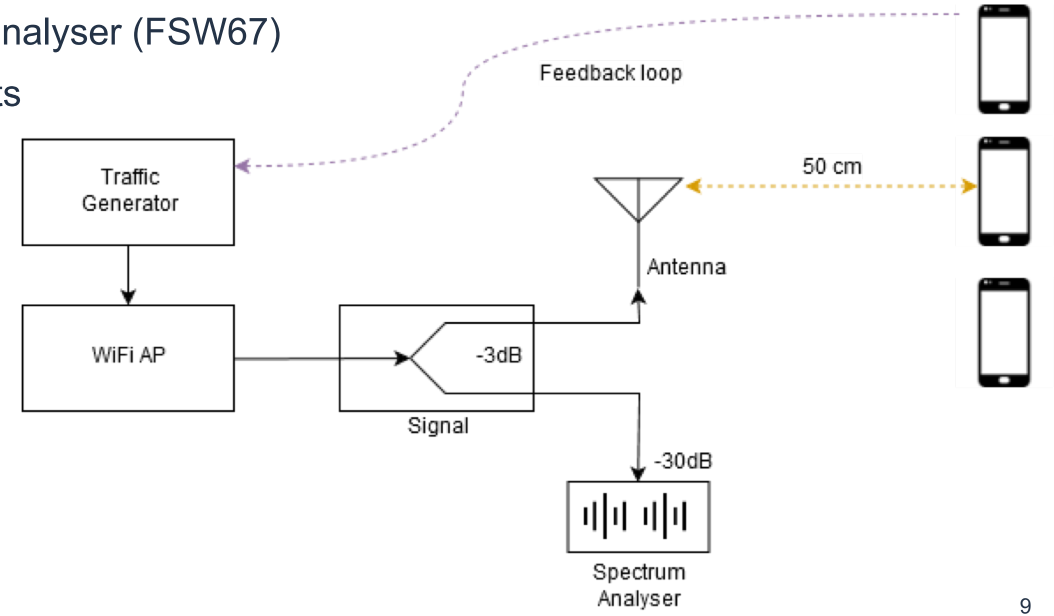
RESEARCH QUESTION

What is the performance of 1024-QAM and OFDMA of 802.11ax on state of the art implementations?

- What is the benefit of introducing 1024-QAM modulation compared to 256-QAM in terms of throughput?
- What is the benefit of the addition of OFDMA in terms of latency?

EXPERIMENT SETUP

- Reference boards of two vendors are compared
- Samsung S10 as 802.11ax capable clients
- Rohde & Schwarz signal & spectrum analyser (FSW67)
- Conducted transmission measurements
- Traffic generator using IxChariot
- Inside RF shielded room



ACCESS POINT SETUP

- AX mode
- Channel 140 on 5 GHz spectrum (5.7 GHz)
- 20 MHz bandwidth
- One spatial stream
- Guard interval of 0.8 μs
- Transmit power 24 dBm

1024 QAM

METHODS & RESULTS

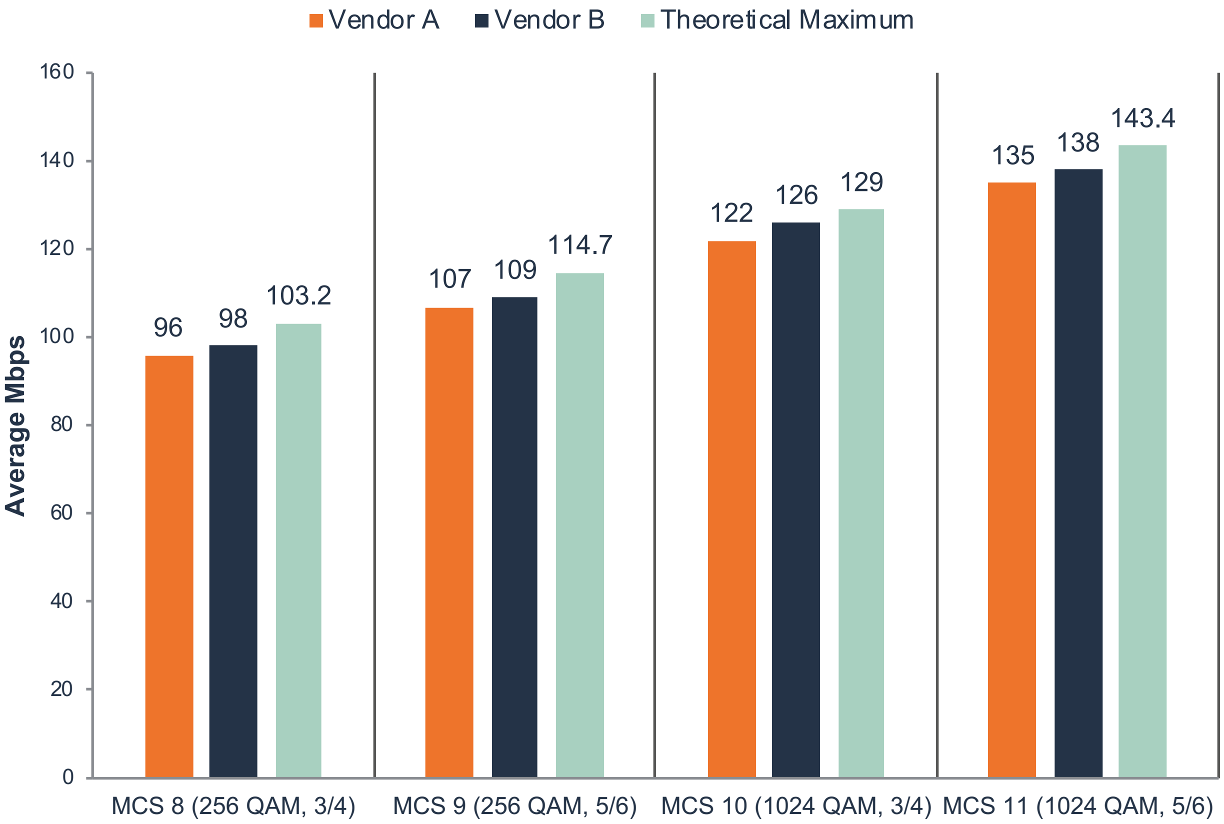
QAM METHODS

- Four measurements per vendor
  - MCS 8, 9, 10 and 11
- IxChariot UDP throughput test for 5 minutes
- One client
- Make a capture with Matlab every 30 seconds
  - 1 million samples over 25 ms
- Analyse results:
  - Calculate the average throughput
  - Calculate the EVM of the HE packets in the captures using MatLab
  - Estimate theoretical distance of 1024 QAM
- OFDMA is disabled

QAM RESULTS - THROUGHPUT

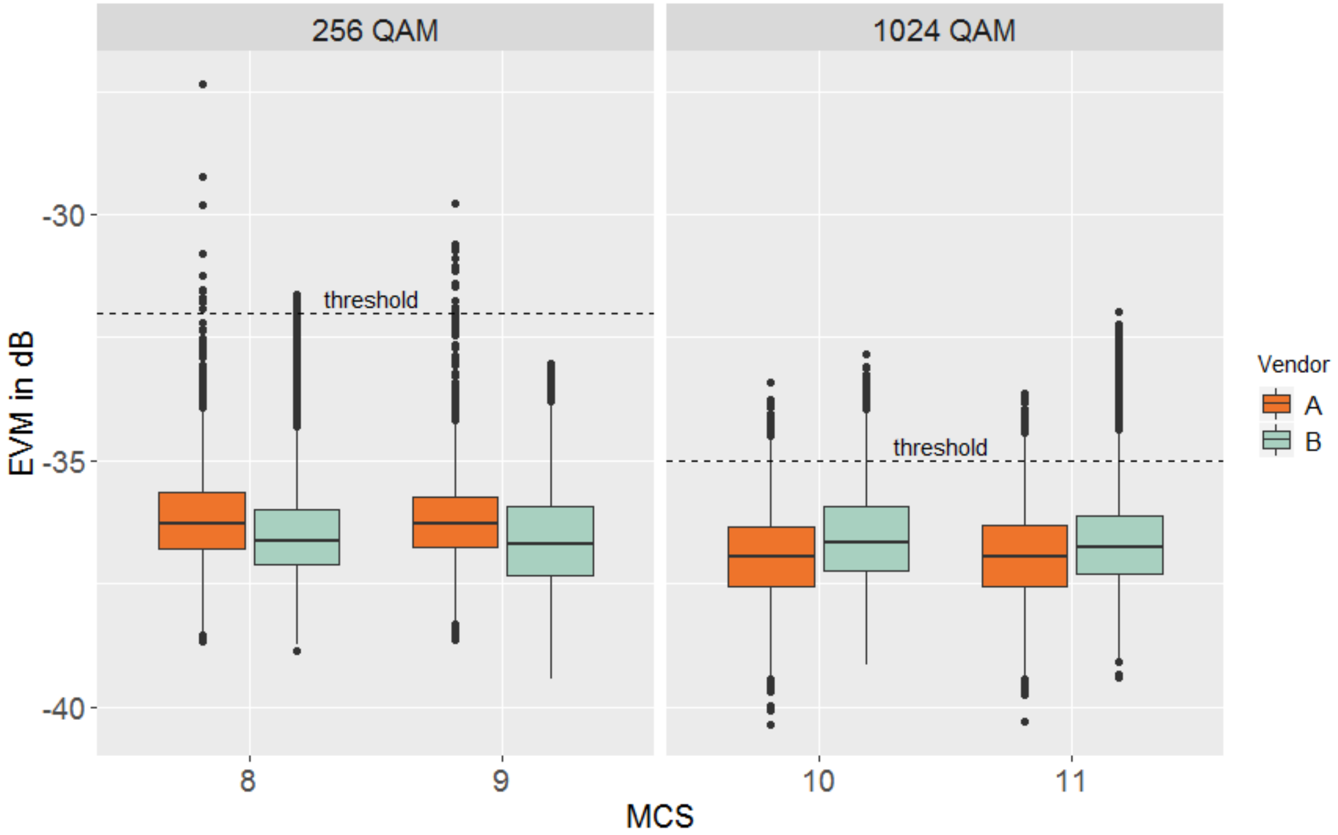
Average Mbps over 5 minutes

- Increase in throughput
- Vendor A:
  - MCS 8-10: 27%
  - MCS 9-11: 26%
- Vendor B:
  - MCS 8-10: 29%
  - MCS 9-11: 27%



QAM RESULTS - EVMS

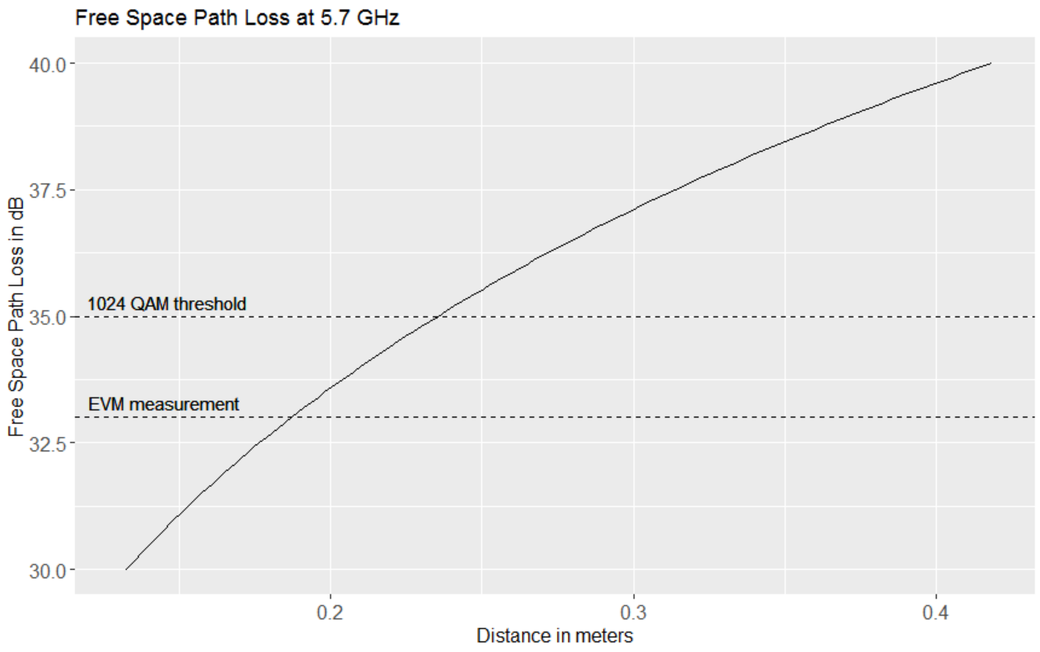
EVM measurements per MCS for each vendor with 33 dB attenuation



QAM RESULTS - DISTANCE

Estimate of theoretical distance

- At 33 dB attenuation EVM ≈ -36.76 dB
- Free Space Path Loss at 5.7 GHz
- FSPL.distance(33) ≈ 19 cm
- -35 + 36.76 = 1.76 dB
- FSPL.distance(33+1.76) ≈ 23 cm
- No antenna gain or cable loss!
- E.g: antenna gain = 6 dBi
- 23 * 6dB = 92 cm
- Wooden door: 6-7 dB at 5 GHz bands

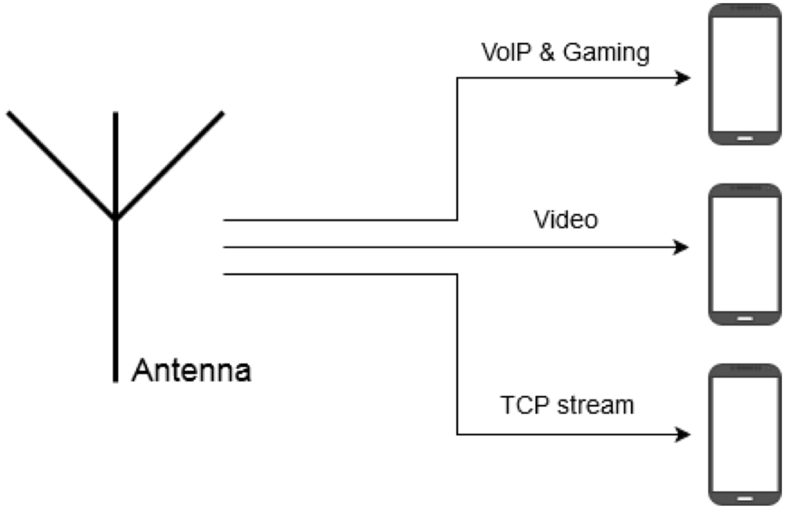


OFDMA

METHODS & RESULTS

OFDMA METHODS

- Two measurements per vendor
  - OFDMA enabled vs disabled
- IxChariot home environment traffic profile to 3 clients for 5 minutes
  - VoIP and Gaming to client 1
  - Video to client 2
  - TCP stream to client 3
- Make a capture every 30 seconds
  - 1 million samples over 25 ms
- Analyse results:
  - RU allocation using MatLab
  - Latency measurements
  - Air time saturation

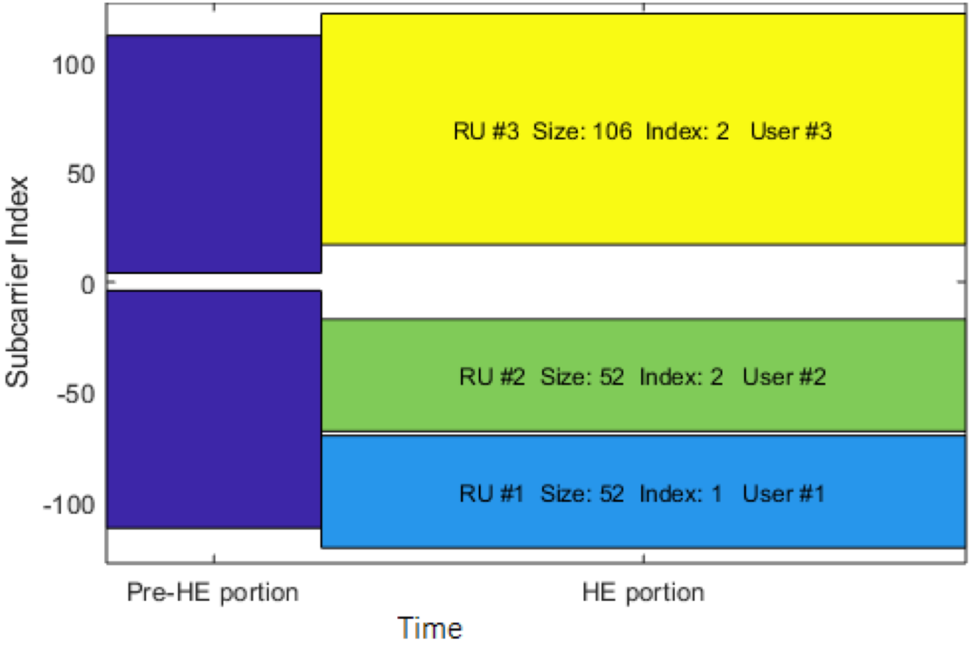


OFDMA RESULTS

- Results are vendor specific:
- Vendor A has OFDMA scheduler implemented
  - Number of OFDMA frames is dependent on:
    - Buffer sizes
    - Number of clients
    - Packet size
- Vendor B has no scheduler implemented
  - OFDMA frames configuration is binary
  - Either 100% or 0% OFDMA frames are sent
- Therefore results will be considered individually

OFDMA RESULTS - VENDOR A - RU ALLOCATION

- Dynamic RU allocation for three users
- Allocation index 16
- 1/9 of the bandwidth lost

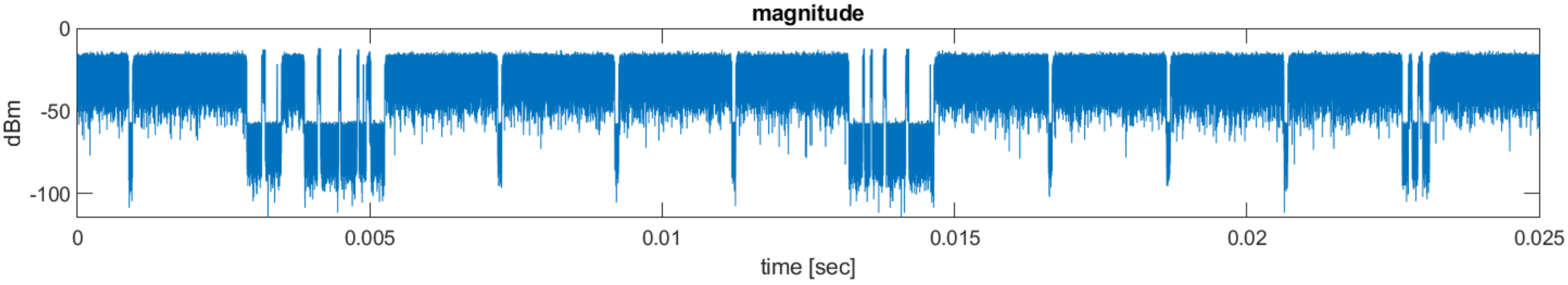


RU allocation index

15	52	52	26	52	52
16-23(15+N)	52	52	0	106 (N users)	

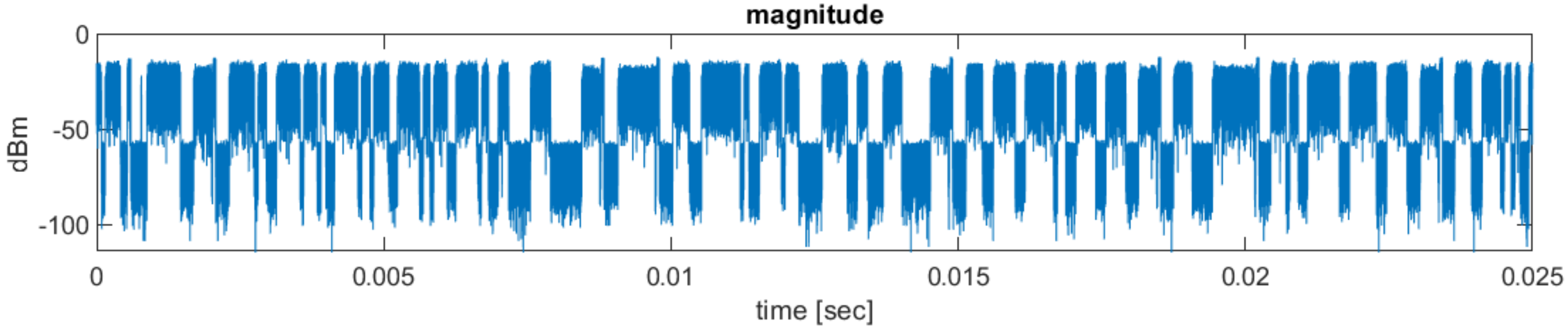
OFDMA RESULTS - VENDOR A - HOME ENVIRONMENT

- Link heavily used
- Yet only 1.15% of the traffic was OFDMA
- Low chance of having packets to multiple users at a single moment
- Packet size matters
- Nothing about the influence of OFDMA on the latency could be said



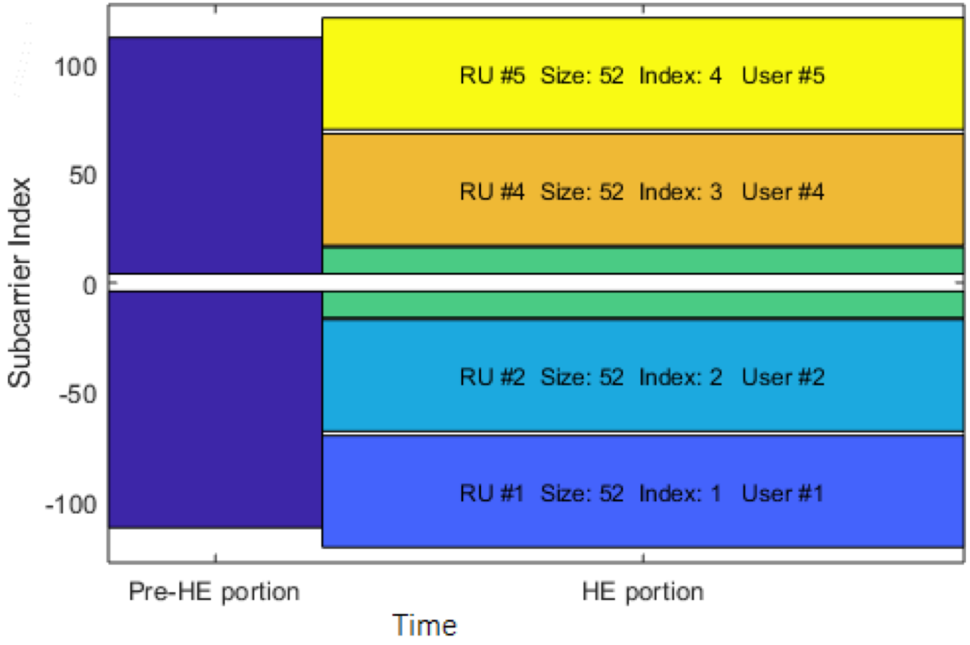
OFDMA RESULTS - VENDOR A - UNREALISTIC PROFILE

- Streaming 18 Mbps with packets of 448 bits to each client
- Only 36% of the traffic was OFDMA
- One-way delay average:
  - OFDMA: 7 ms
  - Without: 5 ms



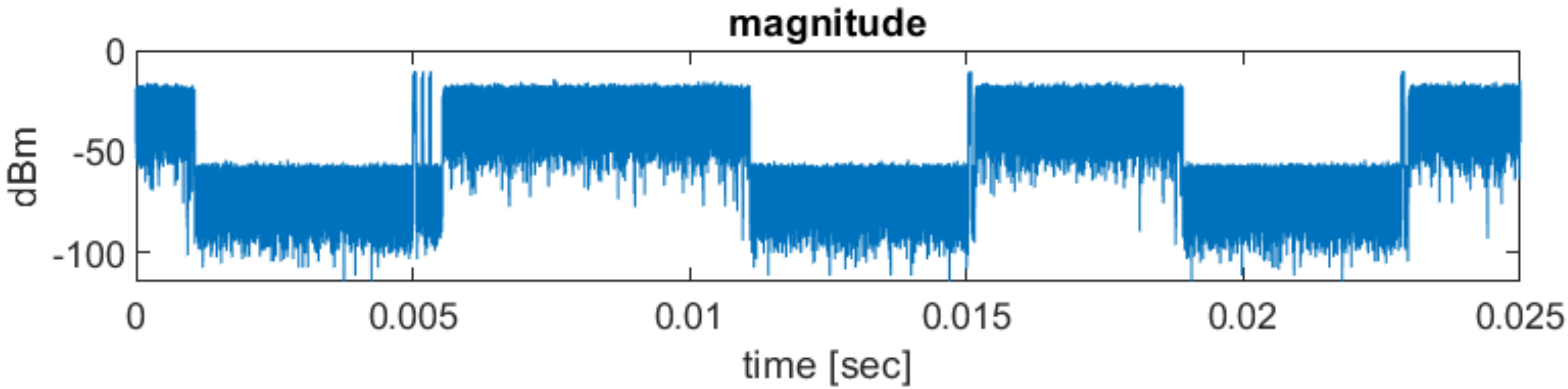
OFDMA RESULTS - VENDOR B - RU ALLOCATION

- Fixed resource allocation
- Only supports a few allocation indices
- Allocation index for 5 users used
- Only 3 RUs used
- Unused RUs are padded
- Results in unused bandwidth



OFDMA RESULTS - VENDOR B – HOME ENVIRONMENT

- 100% of traffic was OFDMA
- Low air time saturation
- Expected buffer timeouts
- Average latency decreased slightly to 4 ms compared to 7 ms



CONCLUSION

- 1024 QAM
  – Maximum throughput increased by 27% (between 8-10 and 9-11)
  – Close to theoretical max
  – Low distance of operation
  – EVM improvements also for lower MCS levels
- OFDMA
  – Latency not decreased within this test environment
  – Scheduler dependant:
    - Packet size, link saturation, number of clients
  – Can also increase latency
  – No benefit in home environment

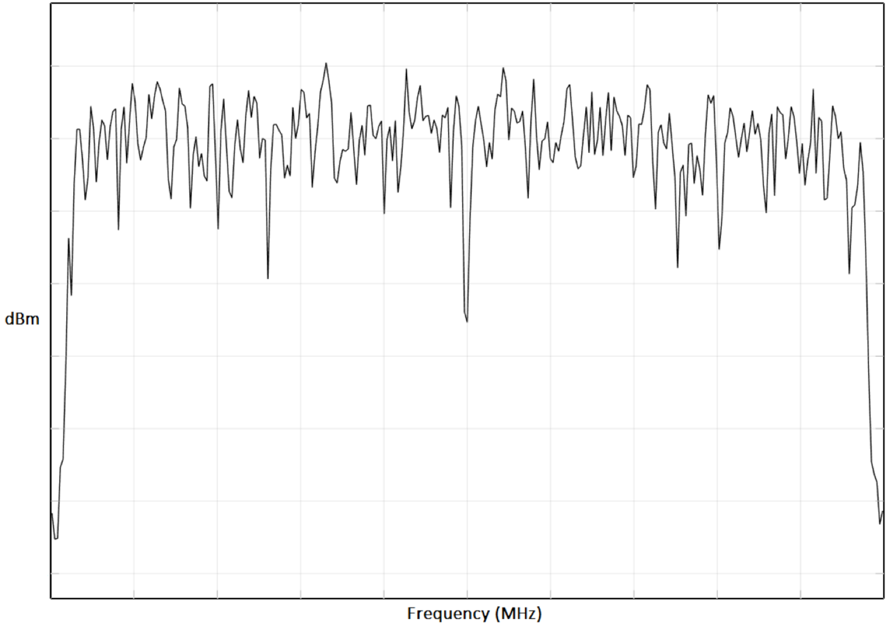
FUTURE WORK

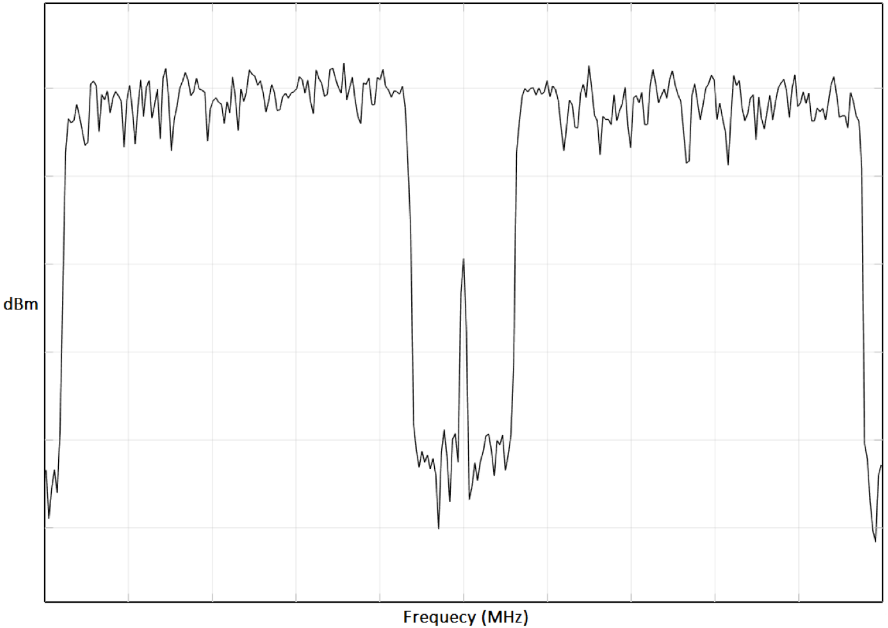
- 1024 QAM distance in practice
- OFDMA higher number of clients
- Stable release boards
- DL/UL MU-MIMO
- BSS Colouring
- 6 GHz band

QUESTIONS?

APPENDIX

OFDM VS OFDMA SPECTRUM





Allocation Index	20 MHz Subchannel Resource Unit (RU) Assignment								
0	26	26	26	26	26	26	26	26	26
1	26	26	26	26	26	26	26	52	
2	26	26	26	26	26	52		26	26
3	26	26	26	26	26	52		52	
4	26	26	52		26	26	26	26	26
5	26	26	52		26	26	26	52	
6	26	26	52		26	52		26	26
7	26	26	52		26	52		52	
8	52		26	26	26	26	26	26	26
9	52		26	26	26	26	26	52	
10	52		26	26	26	52		26	26
11	52		26	26	26	52		52	
12	52		52		26	26	26	26	26
13	52		52		26	26	26	52	
14	52		52		26	52		26	26
15	52		52		26	52		52	
16-23 (15 + N)	52		52		-	106 (N users)			
24-31 (23 + N)	106 (N users)				-	52		52	
32-39 (31 + N)	26	26	26	26	26	106 (N users)			
40-47 (39 + N)	26	26	52		26	106 (N users)			
48-55 (47 + N)	52		26	26	26	106 (N users)			
56-63 (55 + N)	52		52		26	106 (N users)			
64-71 (63 + N)	106 (N users)				26	26	26	26	26
72-79 (71 + N)	106 (N users)				26	26	26	52	
80-87 (79 + N)	106 (N users)				26	52		26	26
88-95 (87 + N)	106 (N users)				26	52		52	
96-99 (95 + M)	106				-	106 (M users)			
100-103 (99 + M)	106 (2 users)				-	106 (M users)			
104-107 (103 + M)	106 (3 users)				-	106 (M users)			
108-111 (107 + M)	106 (4 users)				-	106 (M users)			
112	52		52		-	52		52	
113	Empty 242-tone RU - No user assigned								
116-127	Reserved								
128-135 (127 + N)	106				26	106 (N users)			
136-143 (135 + N)	106 (2 users)				26	106 (N users)			
144-151 (143 + N)	106 (3 users)				26	106 (N users)			
152-159 (151 + N)	106 (4 users)				26	106 (N users)			
160-167 (159 + N)	106 (5 users)				26	106 (N users)			
168-175 (167 + N)	106 (6 users)				26	106 (N users)			
176-183 (175 + N)	106 (7 users)				26	106 (N users)			
184-191 (183 + N)	106 (8 users)				26	106 (N users)			
192-199 (191 + N)	242 (N users)								

26 tone RU assigned to 1 user as part of a 20 MHz subchannel assignment of 9 26-tone RUs

No users assigned to this RU; no data field transmitted on these subcarriers

The number of users (N) assigned to this 106-tone RU depends on the allocation index and must be 1-8.

The number of users (M) assigned to this 106-tone RU depends on the allocation index and must be 1-4.

The number of users assigned to the upper 106-tone RU depends on the allocation index, but 2 users are always assigned to the lower 106-tone RU

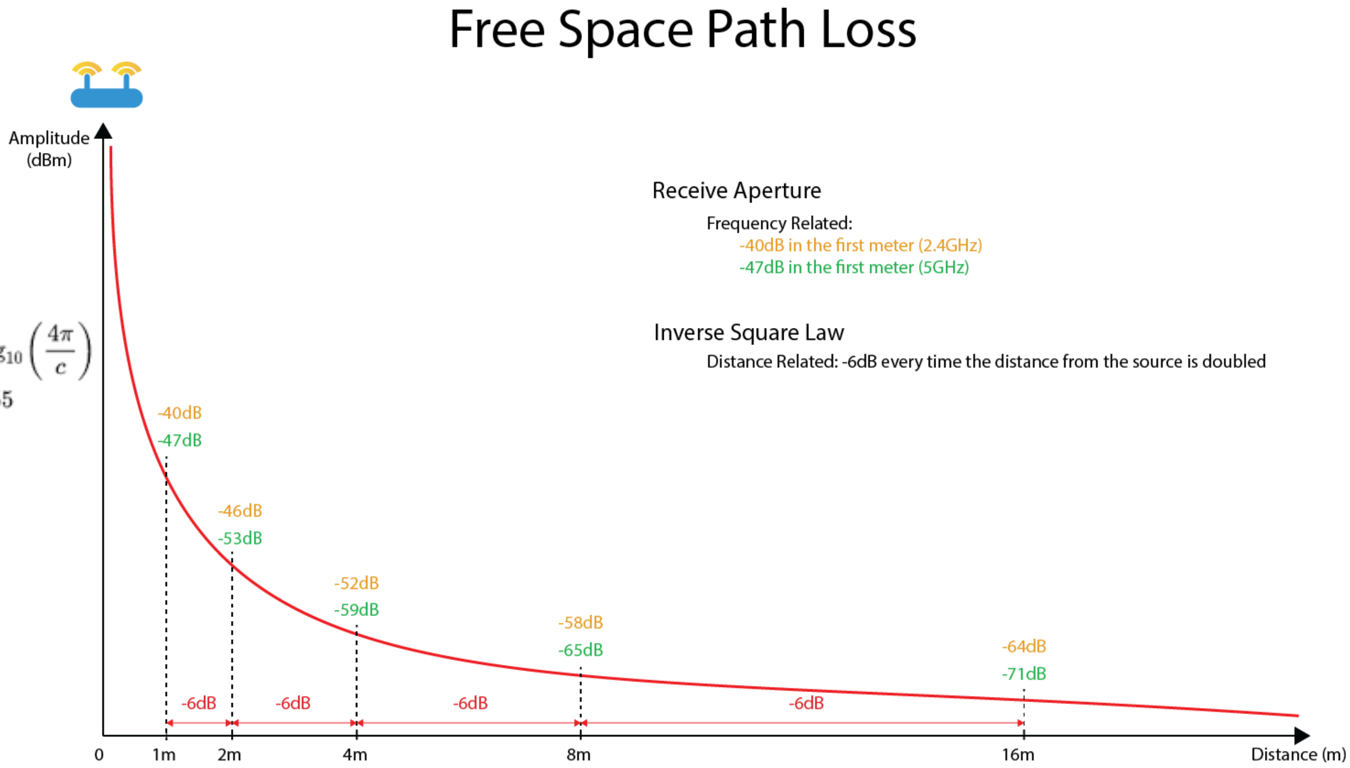
If selected, this 20 MHz subchannel is unused; the subchannel is punctured

- RU assigned to 1 user (green)
- RU assigned to 1-4/8 users, depending on the allocation index (blue)
- RU assigned to specified number of users, irrespective of the allocation index (orange)

Source: https://nl.mathworks.com/help/wlan/examples/802-11ax-parameterization-for-waveform-generation-and-simulation.html

FREE SPACE PATH LOSS

$$
\begin{aligned}
\mathrm{FSPL(dB)} &= 10\log_{10}\left(\left(\frac{4\pi df}{c}\right)^2\right) \\
&= 20\log_{10}\left(\frac{4\pi df}{c}\right) \\
&= 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) \\
&= 20\log_{10}(d) + 20\log_{10}(f) - 147.55
\end{aligned}
$$



Sources: https://en.wikipedia.org/wiki/Free-space_path_loss, https://www.semfionetworks.com/blog/free-space-path-loss-diagrams

THEORETICAL MAXIMUM CALCULATION

Number of Data Subcarriers — N_{SD}

Number of Coded Bits per Subcarrier per Stream — N_{BPSCS}

Coding — R

Number of Spatial Streams — N_{SS}

$$\text{Data Rate} = \frac{N_{SD} * N_{BPSCS} * R * N_{SS}}{T_{DFT} + T_{GI}}$$

OFDM Symbol Duration — T_{DFT}

Guard Interval Duration — T_{GI}

1024 QAM, MCS 11: 234 * 10 * (5/6) * 1 / (12.8 + 0.8) = 143.3824

Source: https://www.semfionetworks.com/blog/mcs-table-updated-with-80211ax-data-rates