Wi-Fi Technology Fundamentals

WI-FI TECHNOLOGY
FUNDAMENTALS COURSE

Module-5

Advanced Features and Standard Extensions

Session-5b

WiFi6 New Features- OFDMA, Mu-MIMO, BSS Coloring, TWT

Last Session Recap……

Module-5

Advanced Features and Standard Extensions

Session-5a

Advanced MAC Features

- ✓ Dynamic Frequency Selection
- ✓ 802.11k – Radio Resource Management
- ✓ Auto Channel Selection
- ✓ 802.11v – Wireless Network Management
- ✓ 802.11r – Fast BSS Transition

How to Stay Connected?

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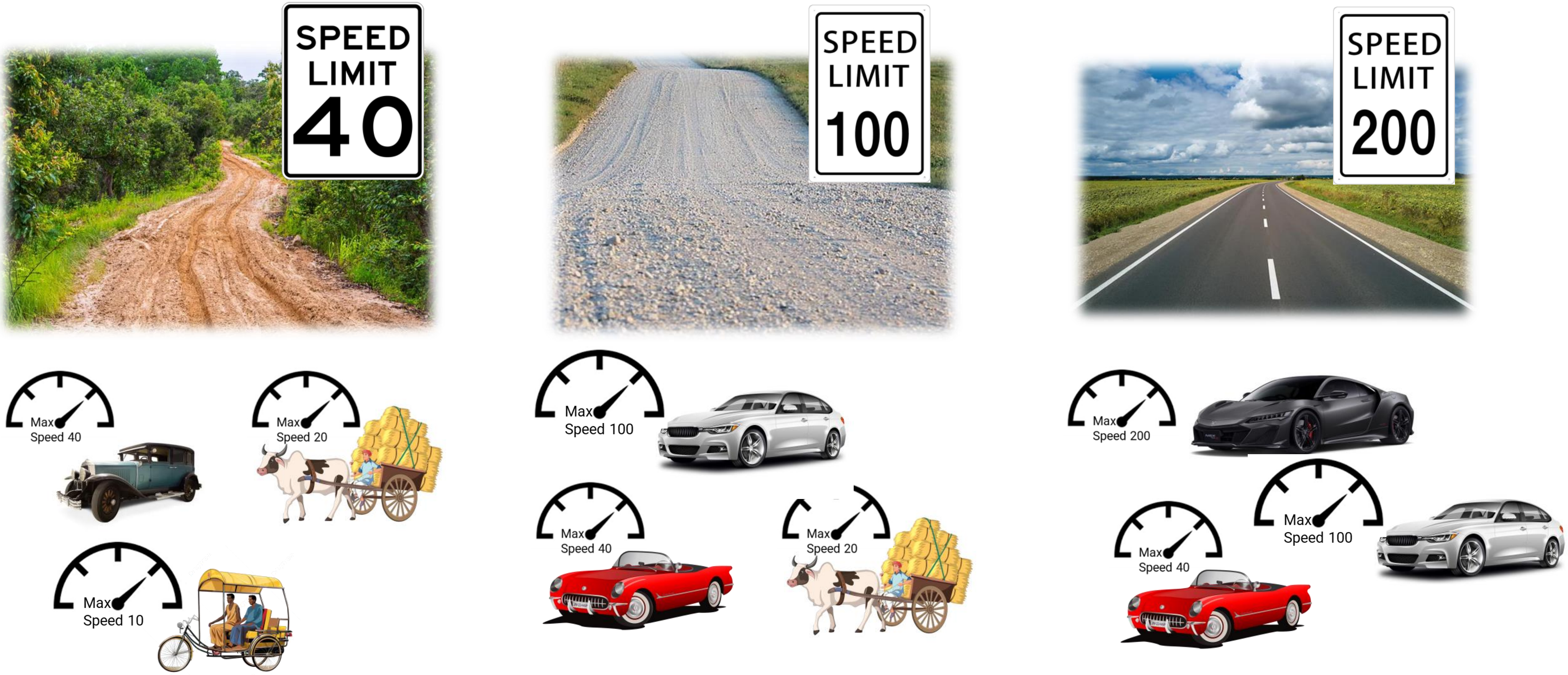
WiFi Technology Generations

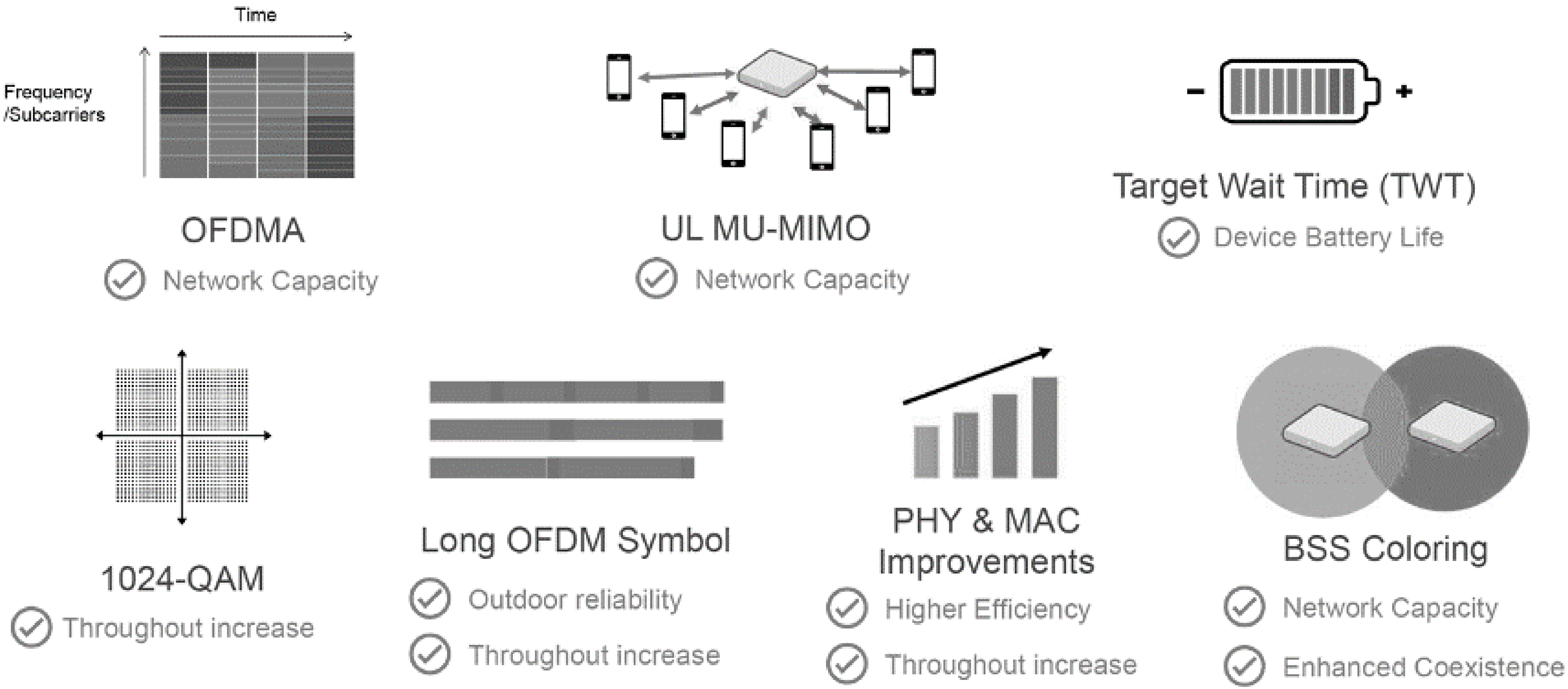
	Wi-Fi 4 (IEEE 802.11n)	Wi-Fi 5 (IEEE 802.11ac)	Wi-Fi 6 (IEEE 802.11ax)	Wi-Fi 6E (IEEE 802.11ax)	Wi-Fi 7 (IEEE 802.11be)
Frequency bands operations	2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990)	5GHz (5.030 - 5.990)	2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990)	2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990) 6GHz (5.925 7.125)	2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990) 6GHz (5.925 7.125)
Maximum bandwidth per channel	2.4GHz: 40MHz 5GHz: 40MHz	2.4GHz: 40MHz 5GHz: 80MHz	2.4GHz: 40MHz 5GHz: 160MHz	2.4GHz: 40MHz 5GHz: 160MHz 6GHz: 160MHz	2.4GHz: 40MHz 5GHz: 160MHz 6GHz: 320MHz
Maximum number of non-overlapping channels	2.4GHz: 3 Channel:1,6,11	5GHz: Channels:36,52 (80MHz)	2.4GHz: 2 (40MHz) Channel:1,11 5GHz: Channel 36: 5.180 GHz to 5.340 GHz (160 MHz width) or Channel:36,52,100,116,132(80 MHz)	2.4GHz: 2 (40MHz) Channel:1,5,9,13 5GHz: Channel 36: 5.180 GHz to 5.340 GHz (160 MHz width) Channel 36,52,100,116,132 (80MHz) 6GHz: 7 (160MHz)	2.4GHz: Channel 1,5,9,13 (40MHz) 5GHz: 2 (160MHz) or Channel 36,149 (80MHz) 6GHz: Channel 31, 63, 95, 127, 159, 191 (320MHz)
Maximum MIMO configuration	4x4	4x4	8x8	8x8	16x16
Highest modulation	64 QAM	256 QAM	1024 QAM (1K QAM)	1024 QAM (1K QAM)	4096 QAM (4K QAM)
Maximum PHY datarate	600 Mbps	1.73 Gbps	9.6 Gbps	9.6 Gbps	46.1 Gbps
Multi user MIMO (MU-MIMO)	N/A	Downlink (Wave 2 only)	Downlink Uplink	Downlink Uplink	Downlink Uplink
Multi user OFDMA (bandwidth sharing)	N/A	N/A	Yes	Yes	Yes
Target Wake Time (TWT)	N/A	N/A	Yes	Yes	Yes (improved)
Multi Link Operation / Multi Resource Unit	N/A	N/A	N/A	N/A	Yes

The Backward Compatibility Problem

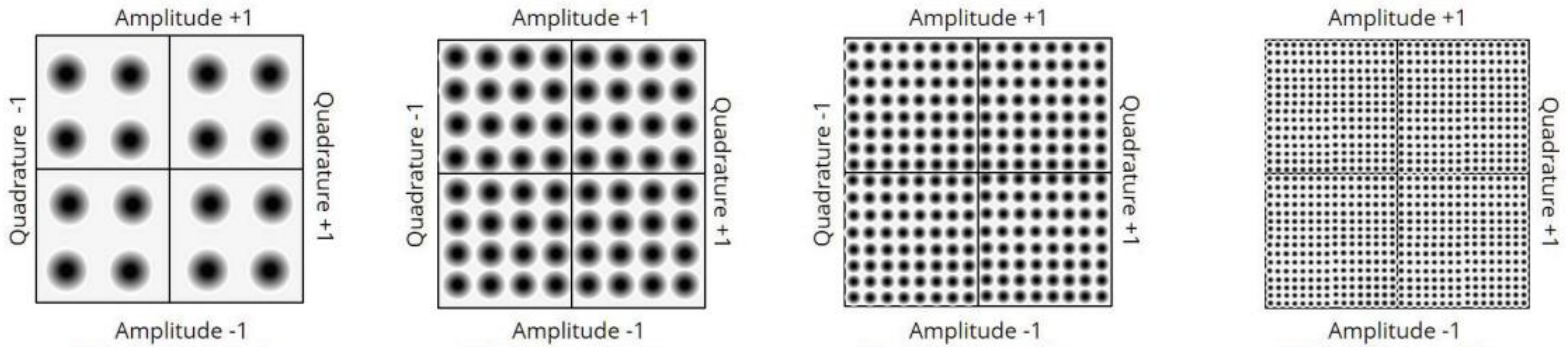


What is new with 802.11ax (WiFi6)

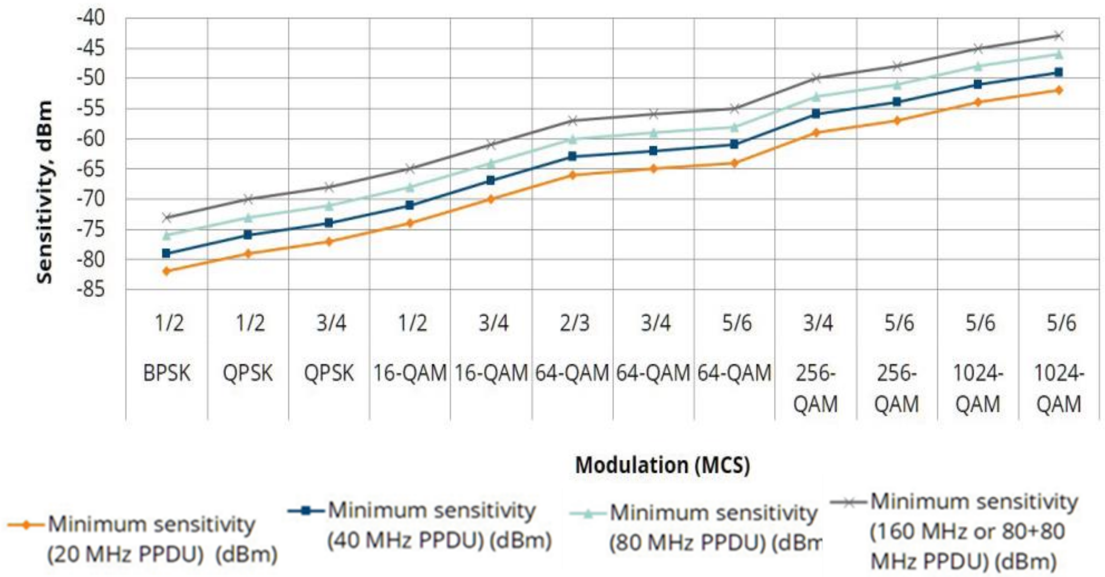
- High Efficiency (HE) Wi-Fi



1024 QAM

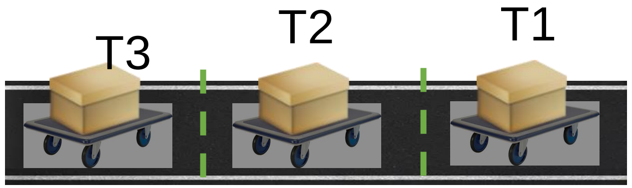


16-QAM constellation
64-QAM constellation
256-QAM constellation
1024-QAM constellation

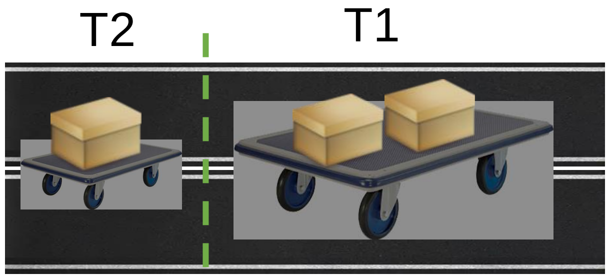


MCS	Modulation & Rate	20 MHz 1x SS	20 MHz 2x SS	20 MHz 4x SS	20 MHz 8x SS	40 MHz 1x SS	40 MHz 2x SS	40 MHz 4x SS	40 MHz 8x SS	80 MHz 1x SS	80 MHz 2x SS	80 MHz 4x SS	80 MHz 8x SS
0	BPSK 1/2	8.6	17.2	34.4	68.8	17.2	34.4	68.8	137.6	36.0	72.1	144.1	288.2
1	QPSK 1/2	17.2	34.4	68.8	137.6	34.4	68.8	137.6	275.3	72.1	144.1	288.2	576.5
2	QPSK 3/4	25.8	51.6	103.2	206.5	51.6	103.2	206.5	412.9	108.1	216.2	432.4	864.7
3	16-QAM 1/2	34.4	68.8	137.6	275.3	68.8	137.6	275.3	550.6	144.1	288.2	576.5	1,152.9
4	16-QAM 3/4	51.6	103.2	206.5	412.9	103.2	206.5	412.9	825.9	216.2	432.4	864.7	1,729.4
5	64-QAM 1/2	68.8	137.6	275.3	550.6	137.6	275.3	550.6	1,101.2	288.2	576.5	1,152.9	2,305.9
6	64-QAM 3/4	77.4	154.9	309.7	619.4	154.9	309.7	619.4	1,238.8	324.3	648.5	1,297.1	2,594.1
7	64 QAM 5/6	86.0	172.1	344.1	688.2	172.1	344.1	688.2	1,376.5	360.3	720.6	1,441.2	2,882.4
8	256-QAM 3/4	103.2	206.5	412.9	825.9	206.5	412.9	825.9	1,651.8	432.4	864.7	1,729.4	3,458.8
9	256-QAM 5/6	114.7	229.4	458.8	917.6	229.4	458.8	917.6	1,835.3	480.4	960.8	1,921.6	3,843.1
10	1024-QAM 3/4	129.0	258.1	516.2	1,032.4	258.1	516.2	1,032.4	2,064.7	540.4	1,080.9	2,161.8	4,323.5
11	1024-QAM 5/6	143.4	286.8	573.5	1,147.1	286.8	573.5	1,147.1	2,294.1	600.5	1,201.0	2,402.0	4,803.9

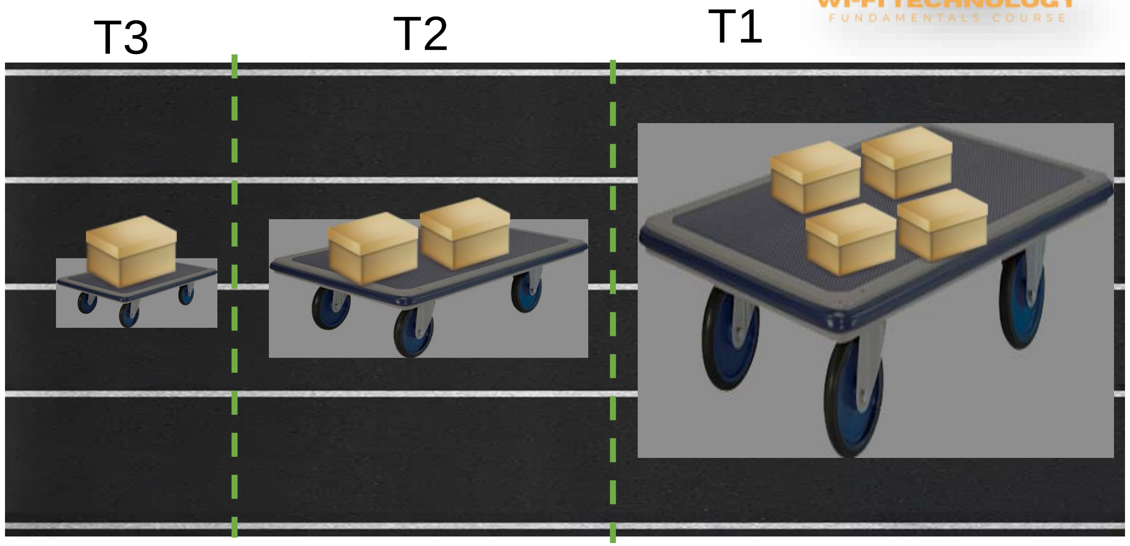
Concept of OFDMA



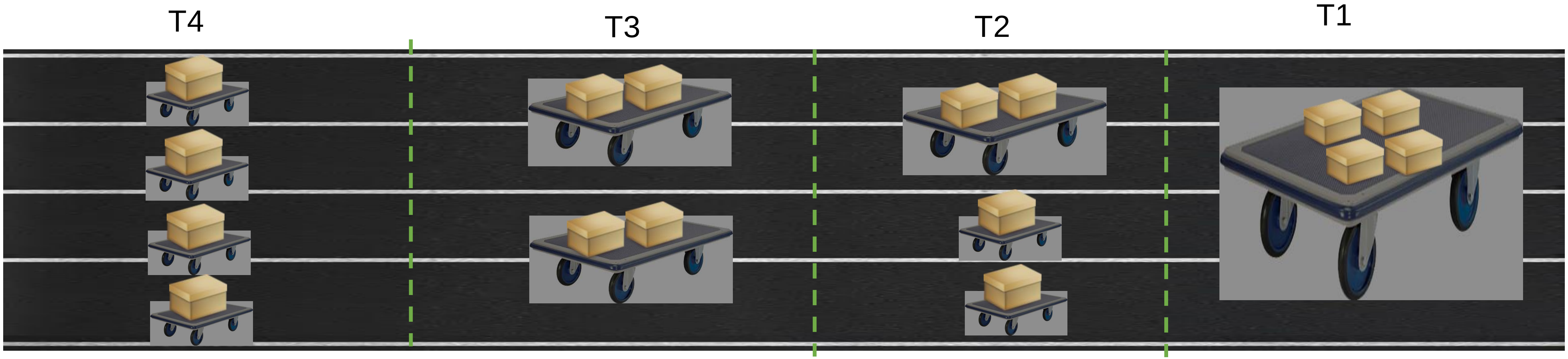
40MHz Channels - OFDM



80MHz Channels - OFDM

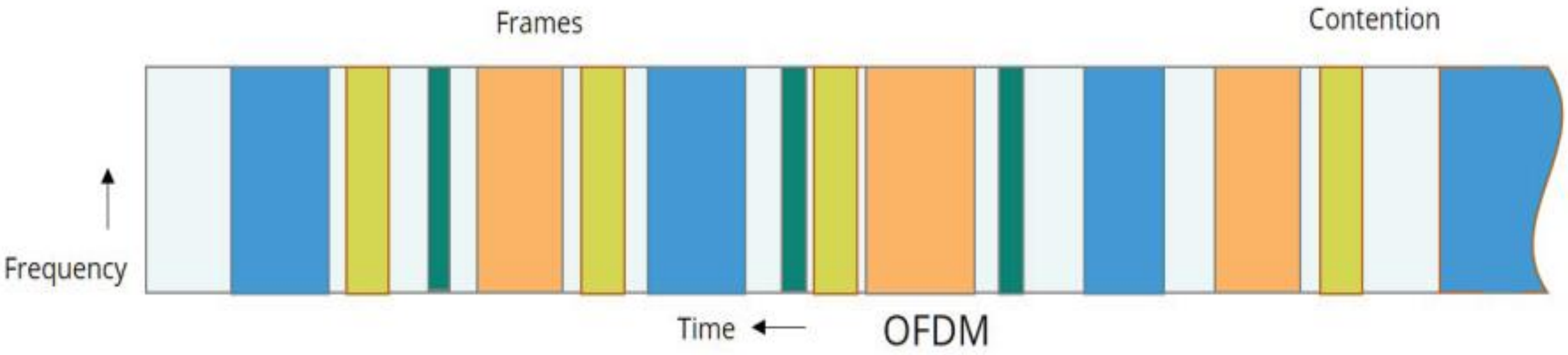


160MHz Channels - OFDM

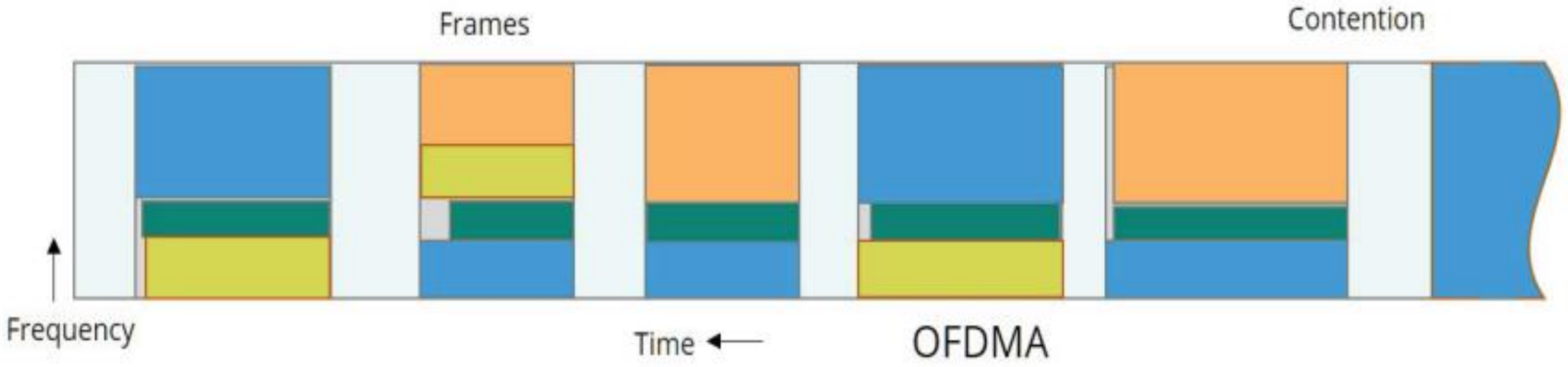


160MHz Channels - OFDMA

How does OFDMA increase spectral efficiency?



- Each frame is transmitted across the whole channel width.
- Each transmit opportunity requires contention, losing spectral efficiency.
- Low-rate transmissions can block the channel for others, increasing latency and jitter.

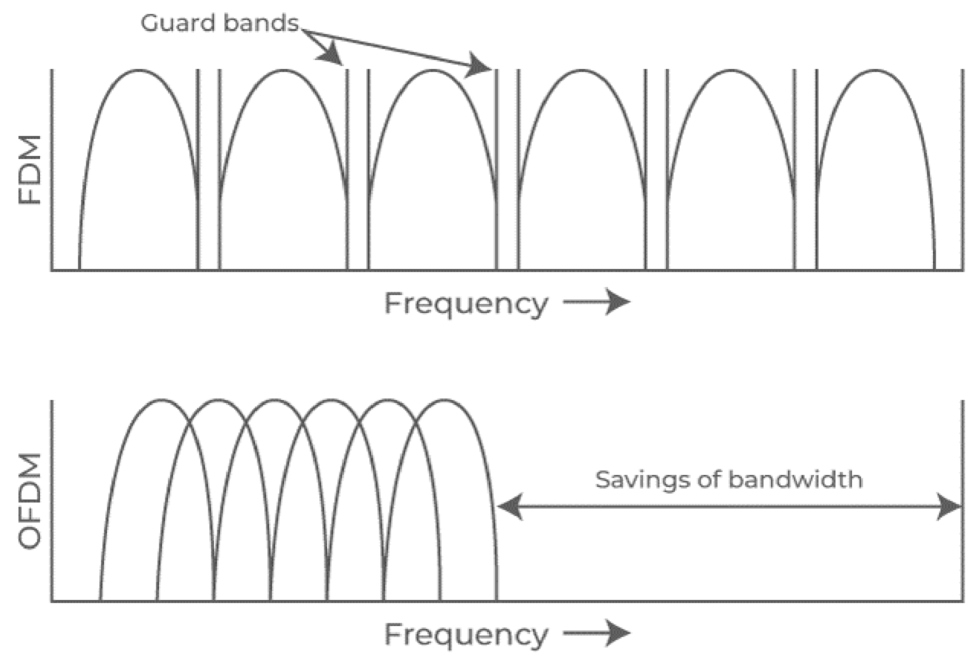


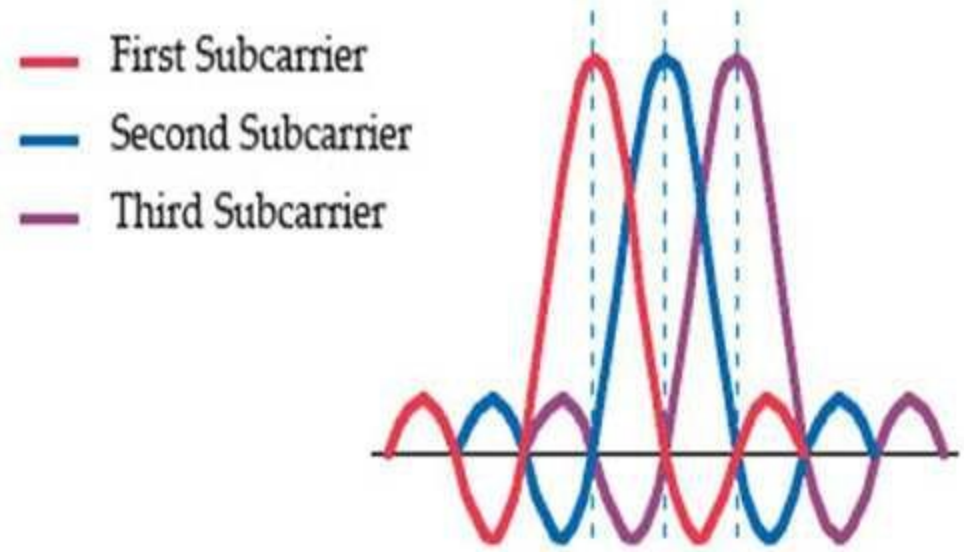
- As each transmit opportunity can be shared across a number of frames, there is less contention overhead.
- Low data-rate traffic can reduce its contention and header overhead.
- Traffic requiring lower latency or jitter can be allocated more frequent transmit opportunities.

Orthogonal Frequency Division Multiplexing (OFDM)

In OFDM, several bits can be sent in parallel, or at the same time, in separate sub stream channels. This enables each sub stream's data rate to be lower than would be required by a single stream of similar bandwidth. This makes the system less susceptible to interference and enables more efficient data bandwidth.

Standard	Modulation Technique
802.11	FSSS, DSSS
802.11b	DSSS, CCK
802.11a	OFDM
802.11g	OFDM
802.11n (WiFi4)	OFDM
802.11ac (WiFi5)	OFDM
802.11ax (WiFi6)	OFDMA



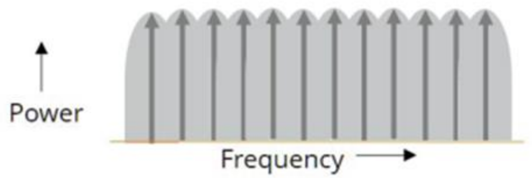


802.11ax OFDM PHY Changes

- Subcarrier spacing reduced by 4x from 312.5KHz to 78.125KHz which now allows for 256 subcarriers in single 20MHz channel.
- 234 of the 256 will be data subcarriers. In comparison 11ac only has 52 data subcarriers per 20MHz channel.
- The subcarriers are called tones in 802.11ax which means we have 256 tones in each 20Mhz channel.

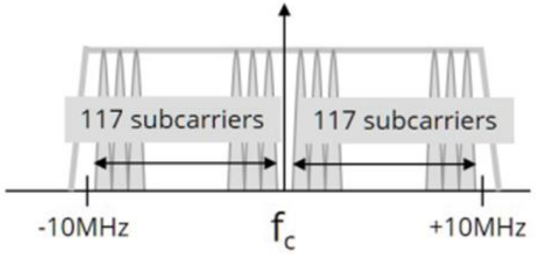
	802.11ac	802.11ax
Bands	5 GHz only	2.4 GHz and 5 GHz
Channels	20, 40, 80, 80+80, 160 MHz	20, 40, 80, 80+80, 160 MHz
FFT Sizes	64, 128, 256, 512	256, 512, 1024, 2048
Subcarrier spacing	312.5 kHz	78.125 kHz
OFDM symbols	3.2 usec	12.8 usec
OFDM symbol cyclic prefix	0.8 or 0.4 usec	0.8 or 1.6 or 3.2 usec
Highest modulation	256 QAM	1024 QAM
Spatial streams	1-8 (not implemented beyond 4)	1-8 (may be implemented)

802.11ax



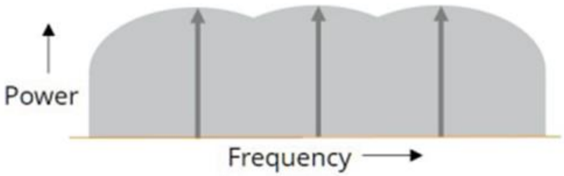
Subcarrier spacing 78.125 kHz
256* subcarriers in a 20 MHz channel

Symbol duration 12.8 usec
With 0.8, 1.6 or 3.2 usec cyclic prefix



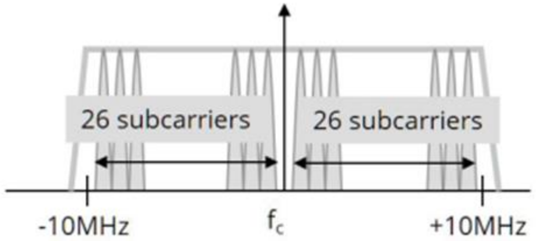
20 MHz channel showing 234 data subcarriers

802.11ac



Subcarrier spacing 312.5 kHz
64* subcarriers in a 20 MHz channel
* Not all usable

Symbol duration 3.2 usec
With 0.4 or 0.8 usec cyclic prefix



20 MHz channel showing 52 data subcarriers

Longer Guard Interval for better Range

- The standard also introduces new guard interval options
- Longer guard intervals are designed to provide improved performance in environments with multi-path and delay spread.
- These longer guard intervals help to prevent inter-symbol interference in outdoor environments and therefore improve coverage and performance.

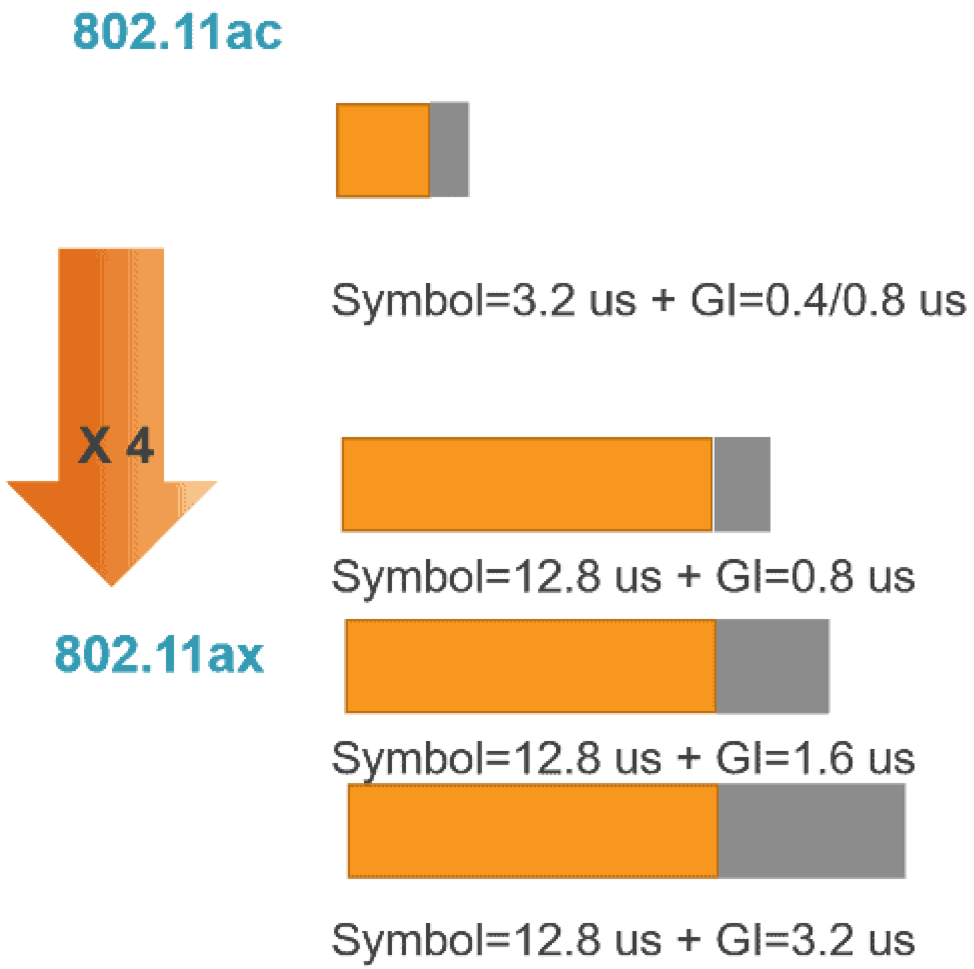
802.11ac had two Guard Interval (GI) options

- long GI (0.8µs)
- short GI (0.4µs)

802.11ax has three types of GI

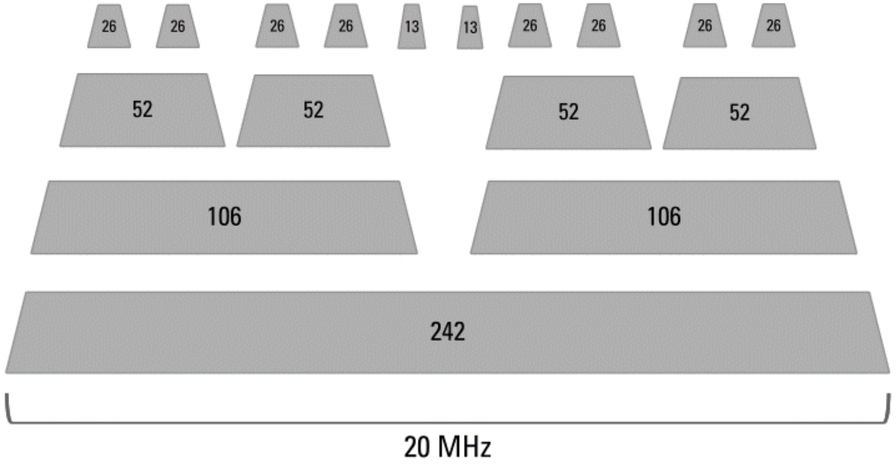
- normal GI (0.8 µs)
- double (1.6 µs) GI
- quadruple (3.2 µs) GI.

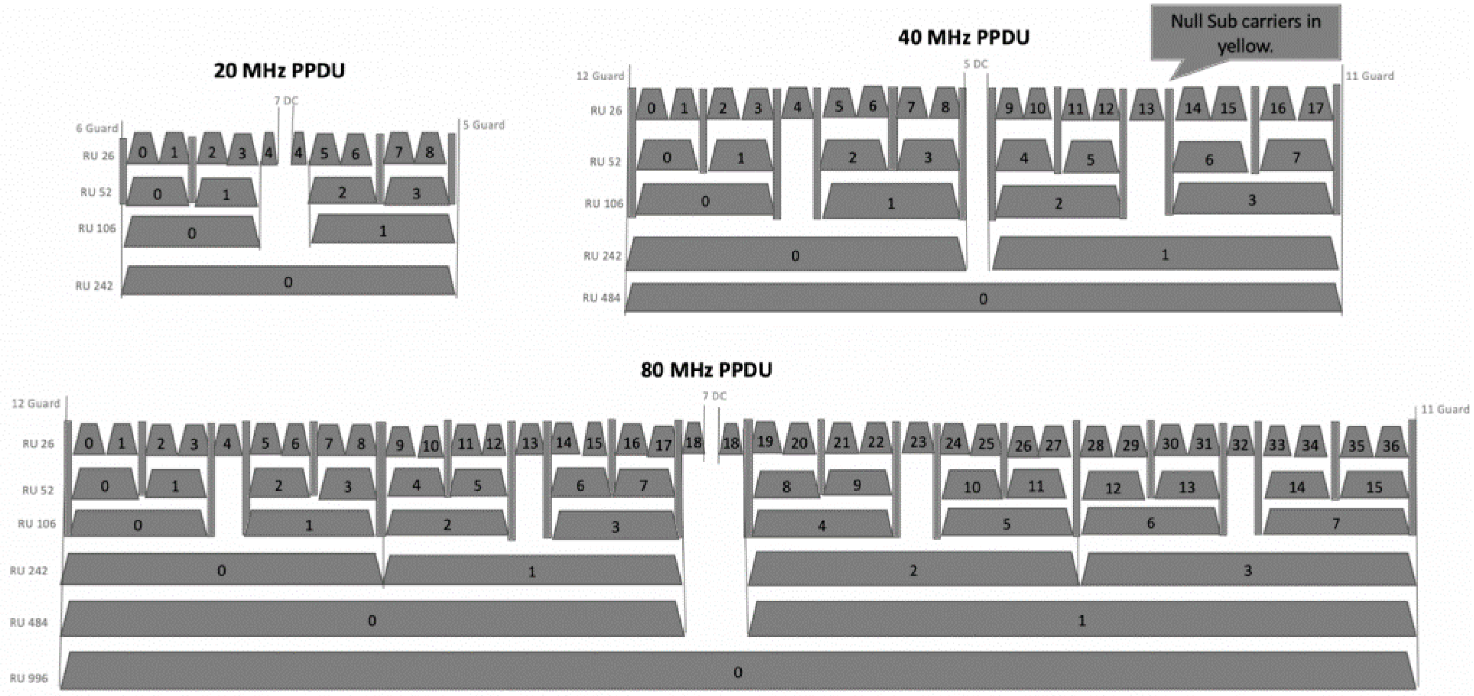
Overall efficiency is preserved since in 802.11ax the symbol duration is four times longer than in 802.11ac, therefore the overhead generated by even the longest guard interval is the same percentage of the symbol time as in the previous generation, but with the added benefits of longer guard interval.

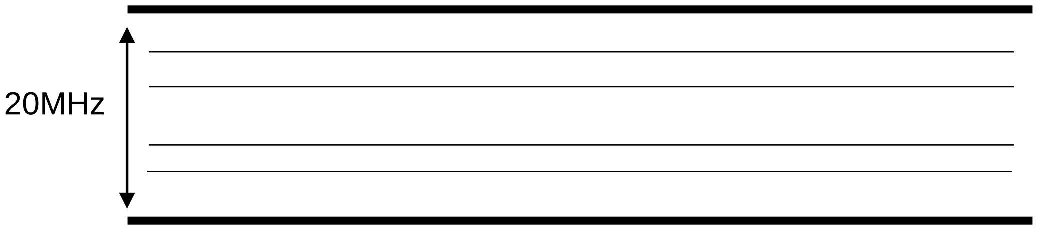


Resource Units

- A Resource Unit (RU) is a group of sub carriers (tones) that can be assigned to a single User.
- Each RU or group of RUs can be allocated to different users to achieve OFDM – Multiple Access, also referred to as OFDMA
- The 20MHz channel can be sub divided into as small as 2MHz channels. Each 2MHz corresponds to 26 tones.



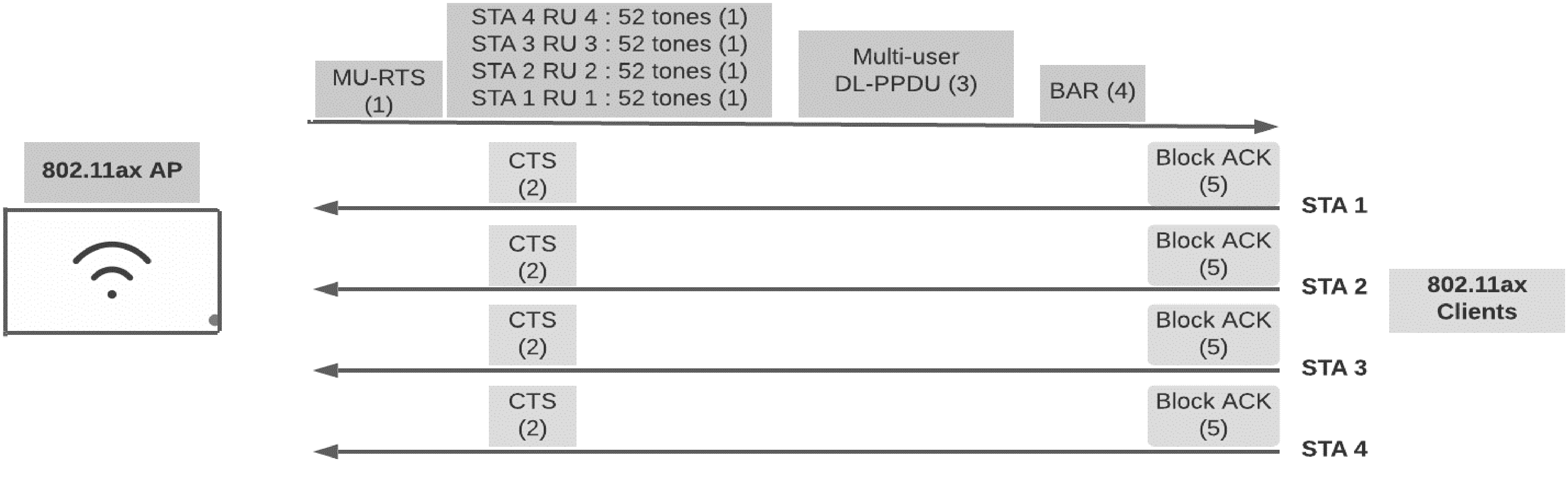




RU type	20 MHz BW	40 MHz BW	80 MHz BW	80+80/160 MHz BW
26-tone RU	9	18	37	74
52-tone RU	4	8	16	32
106-tone RU	2	4	8	16
242-tone RU	1	2	4	8
484-tone RU	N/A	1	2	4
996-tone RU	N/A	N/A	1	2
2x996-tone RU	N/A	N/A	N/A	1

Downlink OFDMA Frame Exchange Process

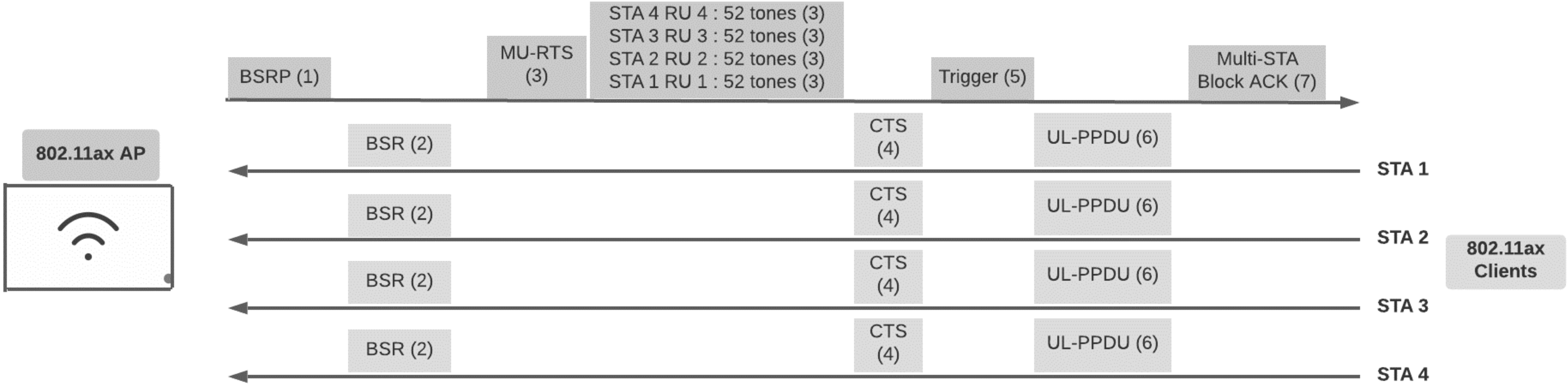
1. The AP sends a multiuser request-to-send (MU-RTS) frame to associated client STAs.
    1. The MU-RTS frame contains a list of RU assignments for each 802.11ax client and helps coordinate the multiuser frame exchange
    2. The MU-RTS frame also contains a timer (network allocation vector (NAV)) to notify clients how long the exchange will take
    3. This frame is transmitted using OFDM across the entire channel so legacy clients know to remain silent through the OFDMA frame exchange
2. The 802.11ax clients send clear-to-send (CTS) responses in parallel using their assigned RUs.
3. The AP transmits each client's data in parallel using the assigned RUs.
4. The AP sends a block acknowledgement request (BAR) to confirm if each client received the transmission successfully.
5. If the data frames were received successfully, the clients respond with a block acknowledgement (ACK) in parallel.



Source: https://documentation.meraki.com/MR/Wi-Fi_Basics_and_Best_Practices/Wi-Fi_6_%28802.11ax%29_Technical_Guide

Uplink OFDMA Frame Exchange Process

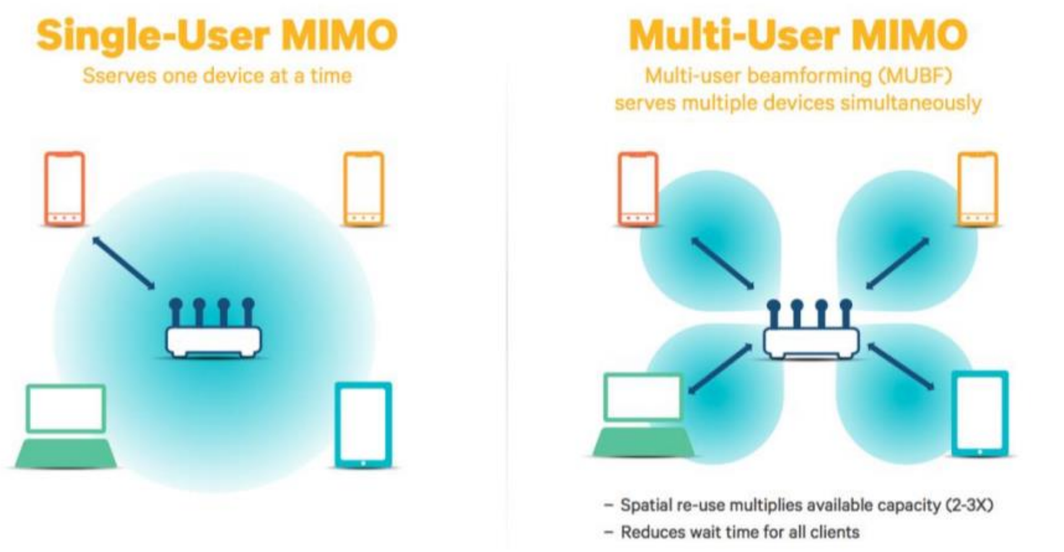
1. The 802.11ax AP sends a buffer status report poll (BSRP) to check how much buffered data the clients are ready to send.
2. Clients respond with a buffer status report (BSR). This helps the AP plan RU size and quantity.
3. The AP sends a multiuser request-to-send (MU-RTS) frame to all clients.
    1. The MU-RTS frame contains a list of RU assignments for each 802.11ax client and helps coordinate the multiuser frame exchange
    2. The MU-RTS frame also contains a timer to notify clients how long the exchange will take
    3. This frame is transmitted using OFDM across the entire channel so legacy clients know to remain silent through the OFDMA frame exchange
4. The 802.11ax clients send clear-to-send (CTS) responses in parallel using their assigned RUs.
5. The AP sends one last trigger frame to coordinate each client's transmission.
6. The clients transmit their data frames to the AP in parallel.
7. If the data frames were received successfully, the AP responds with a block acknowledgement (ACK).

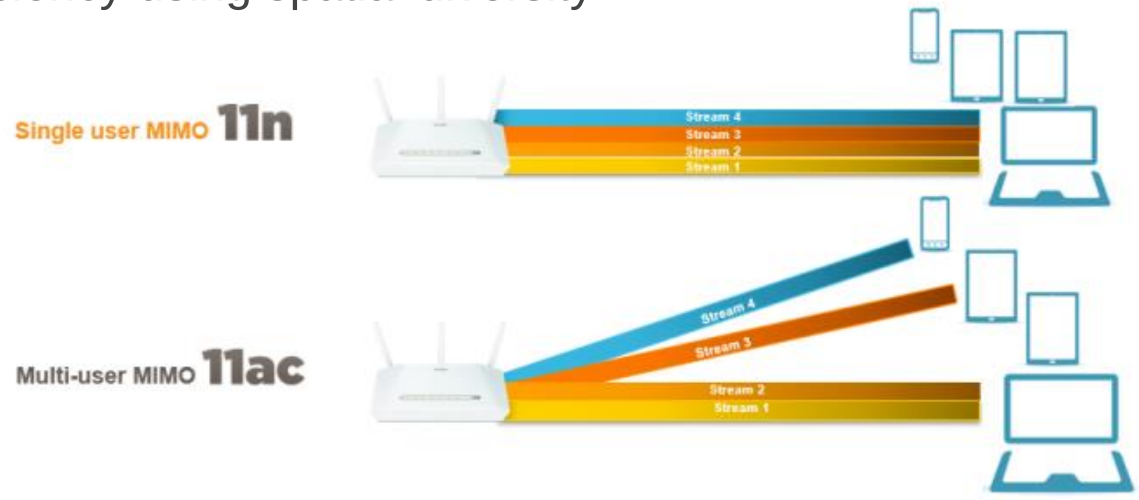


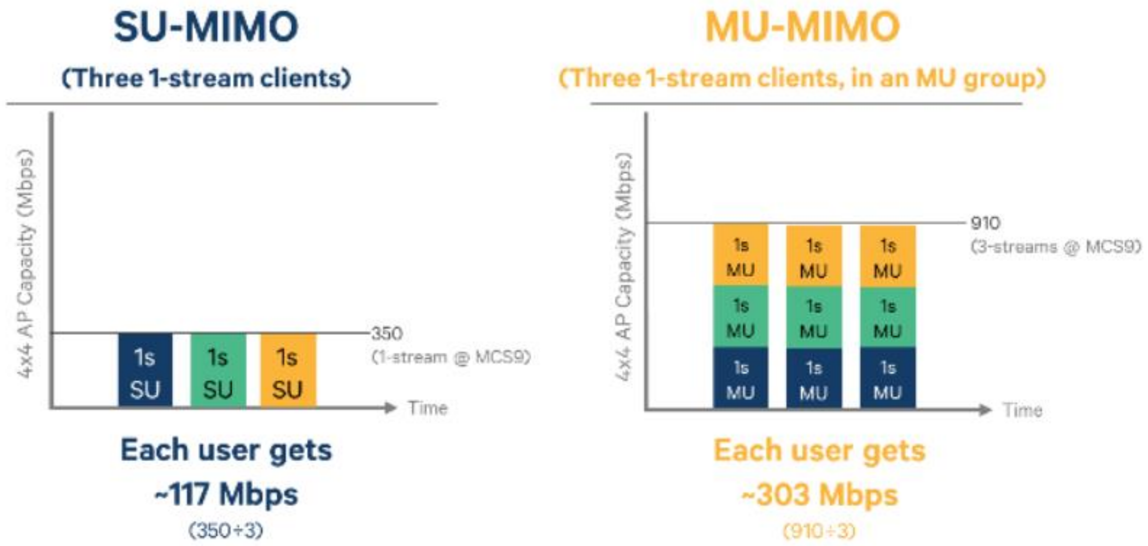
Source: https://documentation.meraki.com/MR/Wi-Fi_Basics_and_Best_Practices/Wi-Fi_6_%28802.11ax%29_Technical_Guide

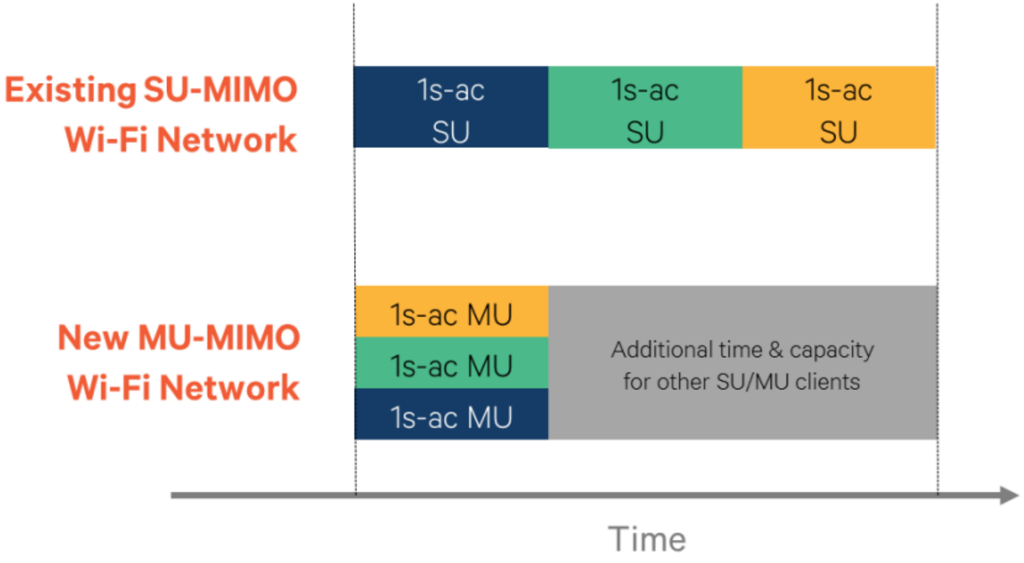
Multi User – MIMO Basics

- Basic concept of Mu-MIMO is to improve spectral efficiency using spatial diversity



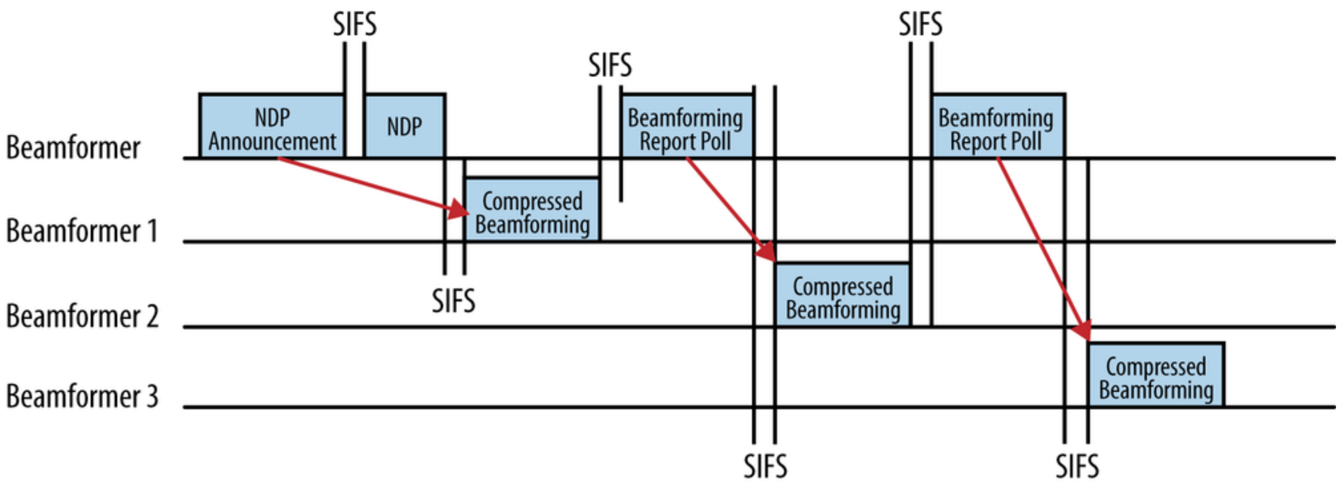


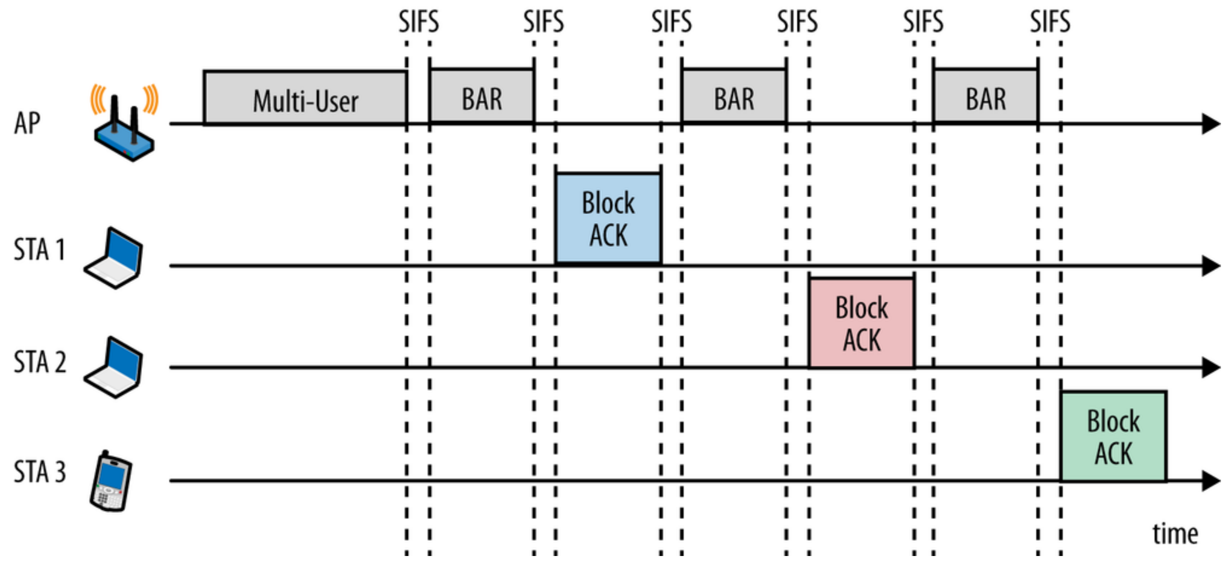


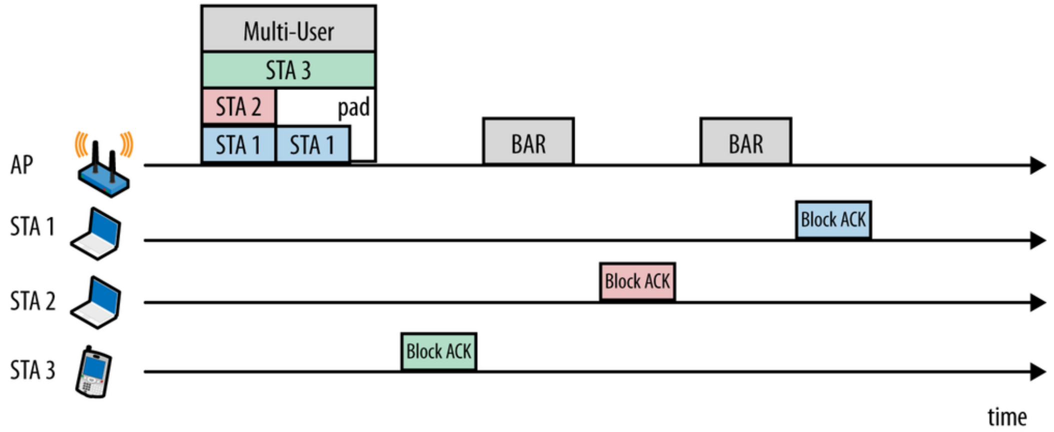


Downlink Mu-MIMO in 802.11ac

- AP will send a Null Data Packet (NDP) Announcement which signals the STAs to collect channel state information.
- AP then Polls each station to receive the beamforming report.
- Based on this data the AP can then decide how to do the beamforming to multiple stations.
- After MU transmission then the AP will poll each STA for receive the individual block ACKs from each STA
- The Channel information data cannot be easily collected within a SIFS time as the computations can be complex.
- The entire explicit sounding procedure and ACK procedure are serial and polling based which cause lot of inefficient use of medium
- There is no Uplink Mu-MIMO which means that for TCP the ACKs should still be transmitted serially in the Uplink.

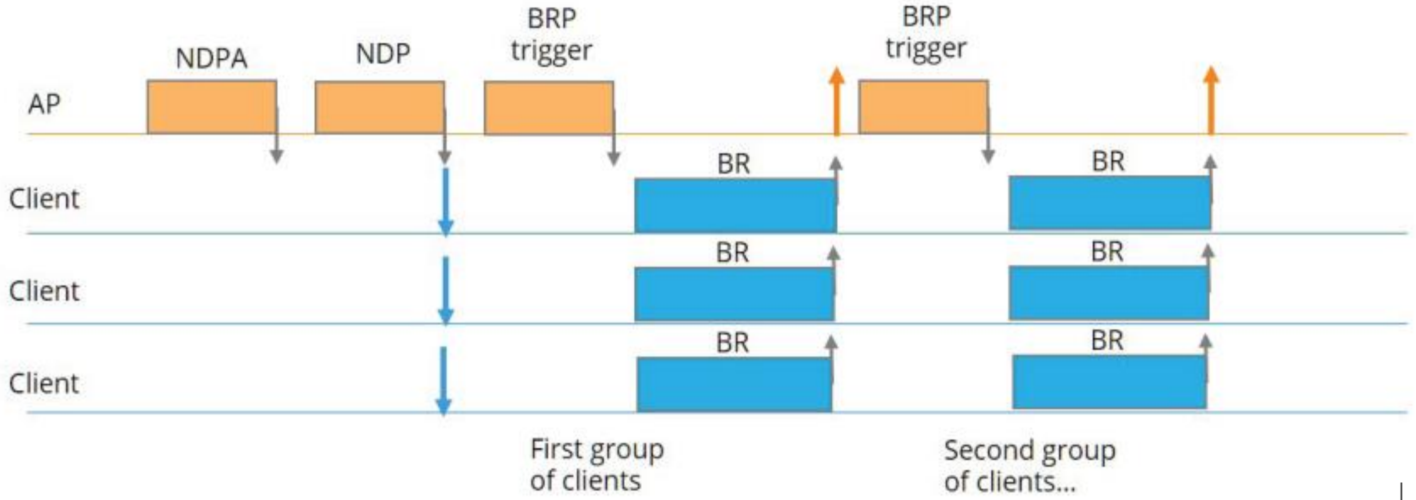




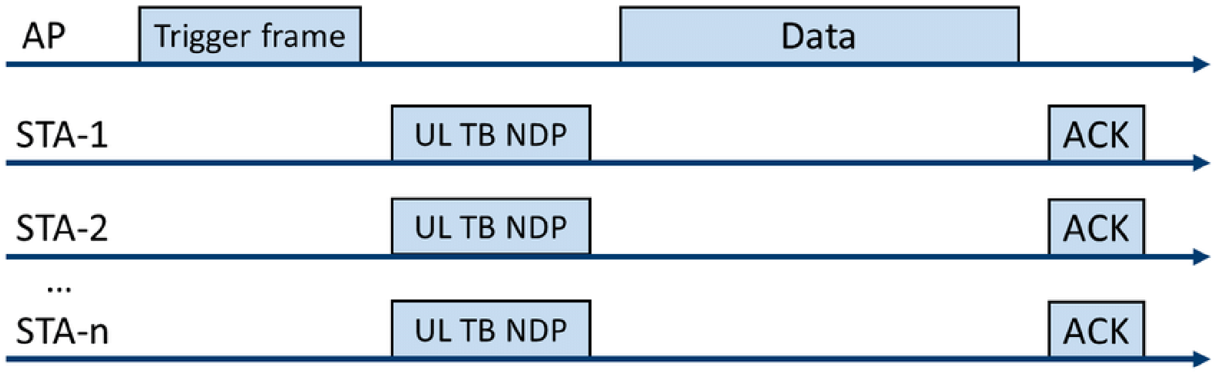


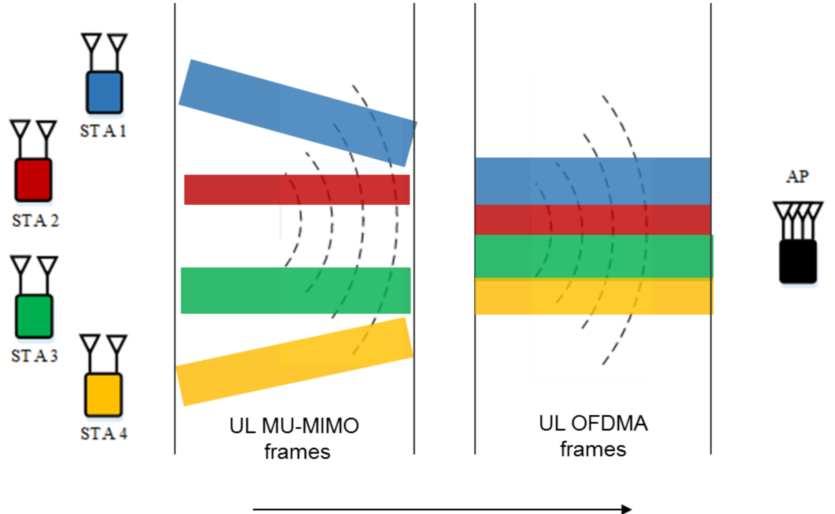
Downlink/Uplink Mu-MIMO in 802.11ax

- In 802.11ax Mu-MIMO is supported both in Uplink and Downlink.
- When AP sends a beamforming report poll, all the STAs can send a Beamforming report at the same time using UL-OFDMA or UL-MIMO
- After sending the data simultaneously to all the users, the blocks ACKs can also be received simultaneously in the uplink and this reduces the inefficiencies from DL-Only Mu-MIMO
- All Uplink and Downlink transmissions are controlled and scheduled by the AP using Trigger frames.
- APs can use a combination of MU-OFDMA and MU-MIMO to achieve the most optimal use of the spectrum.



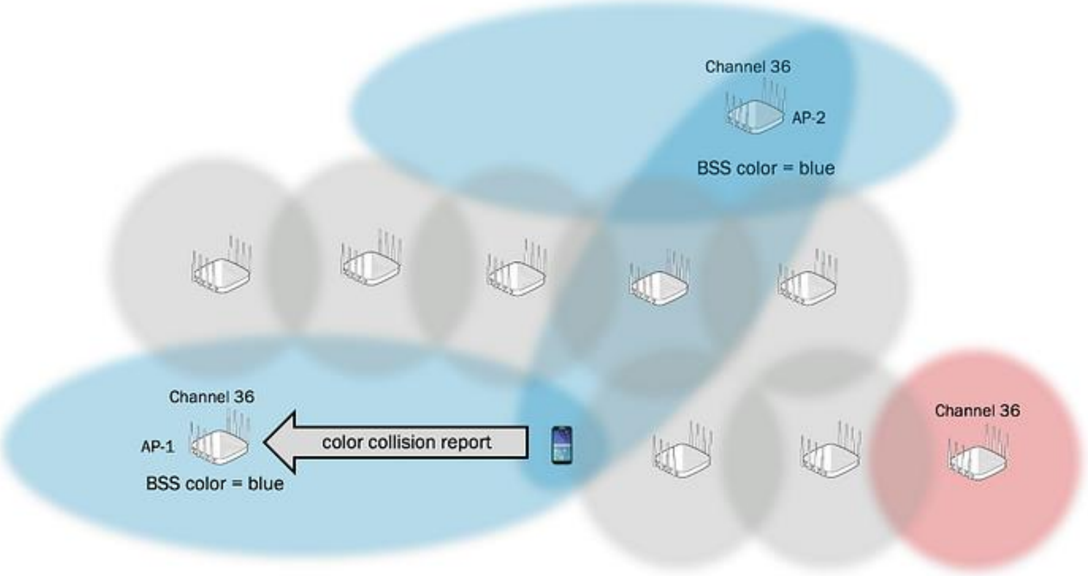
NDP	Null-data packet
NDPA	Null-data packet announcement
BRP	Beamforming report poll
BR	Beamforming report

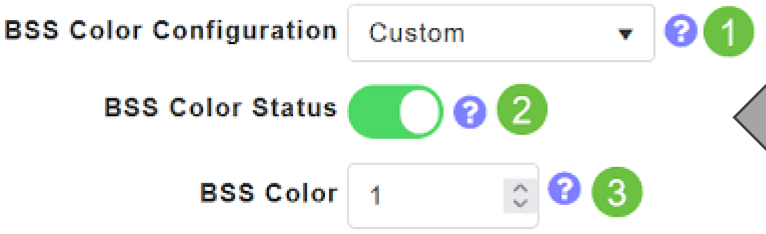




BSS Coloring

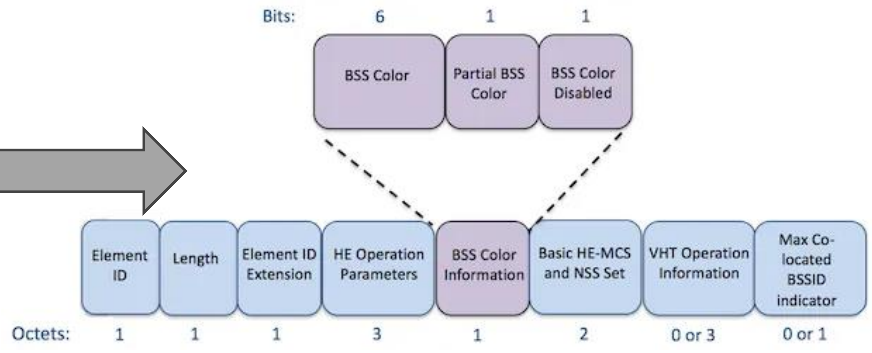
- Overlapping BSS (OBSS) occurs when many APs and clients hear each other on the same channel. It is also more commonly known as co-channel interference.
- BSS coloring aims at increasing the number of concurrent transmissions in a specific area based on a newly defined Overlapping BSS/Preamble-Detection threshold.
- When a Wi-Fi 6 radio is listening to the medium and hears the PHY header of an 802.11ax frame sent by another Wi-Fi 6 radio, the listening radio will check the BSS color of the transmitting radio. Channel access is dependent on the color detected:
  - If the color is the same, then the frame is considered an intra-BSS transmission and the listening radio will defer. In other words, the transmitting radio belongs to the same BSS as the receiver; therefore, the listening radio will defer.
  - If the color is different, then the frame is considered an inter-BSS transmission from an OBSS, and deferral may not be necessary for the listening radio.

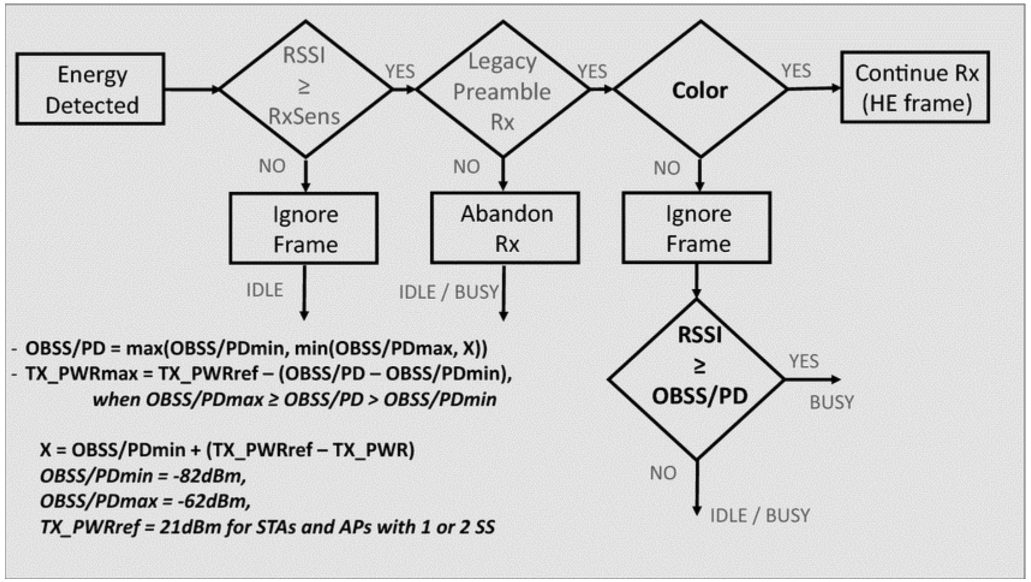




BSS Color setting on AP

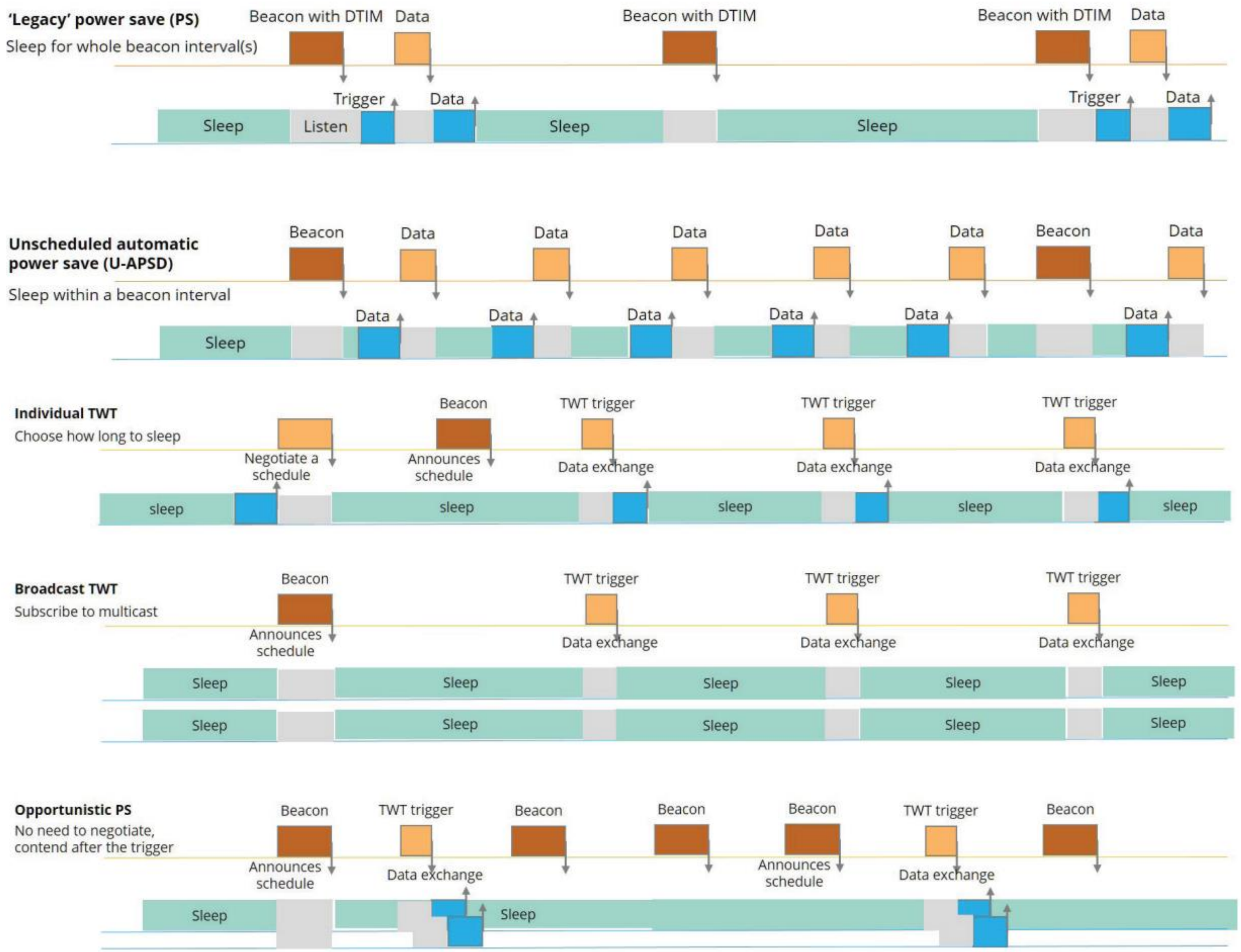
HE Operations Element





Target Wake Time (TWT)

- Target Wake Time (TWT) is a new feature that allows an Access Point (AP) and stations to “wake up” at negotiated times.
- The stations and AP reach a TWT agreement that defines when a station is awake to receive and send data.
- Without TWT, the AP will broadcast a beacon frame to alert some stations to possible data transmissions.
- When multiple client have data to receive they all have to stay awake even though only one client can receive at a time.
- TWT allows each station to negotiate their periods with the AP to transmit and receive data packets before the beacon period.
- Stations only wake up at TWT sessions and remain in sleep mode for the rest of the time.



References

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https://www.youtube.com/watch?v=pHN2VEdWXgI

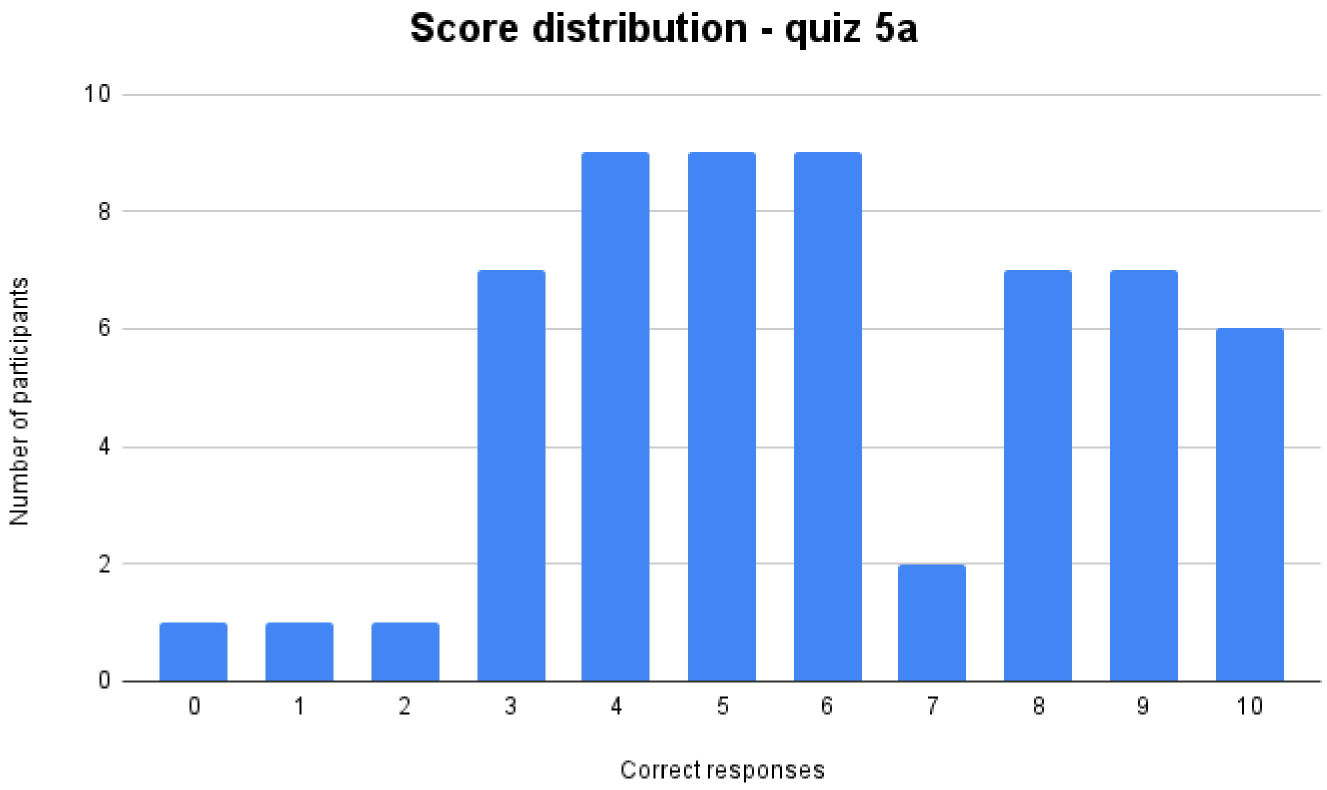

Q&A

Quiz 5a Results

Winner

Meena Kumari

Number of participants - 59



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