Wi-Fi Technology Fundamentals

Module-5

Advanced Features and Standard Extensions

Session-5d

WiFi7 New Features – 320MHz, 4K QAM, MLO, Multi-RU, Preamble Puncturing

Last Session Recap.....

Module-5
Advanced Features and Standard Extensions
Session-5c
WiFi6e New Features

- ✓ 6GHz Channels
- ✓ Equipment/Device Classes
- ✓ Automatic Frequency Coordination
- ✓ WiFi 6E Main Use Cases
- ✓ Native WiFi6 Mode – Shortened Beacons
- ✓ In-Band Scanning Methods – FILS, PSC
- ✓ Out of Band Scanning – RNR
- ✓ Multi-BSSID

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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

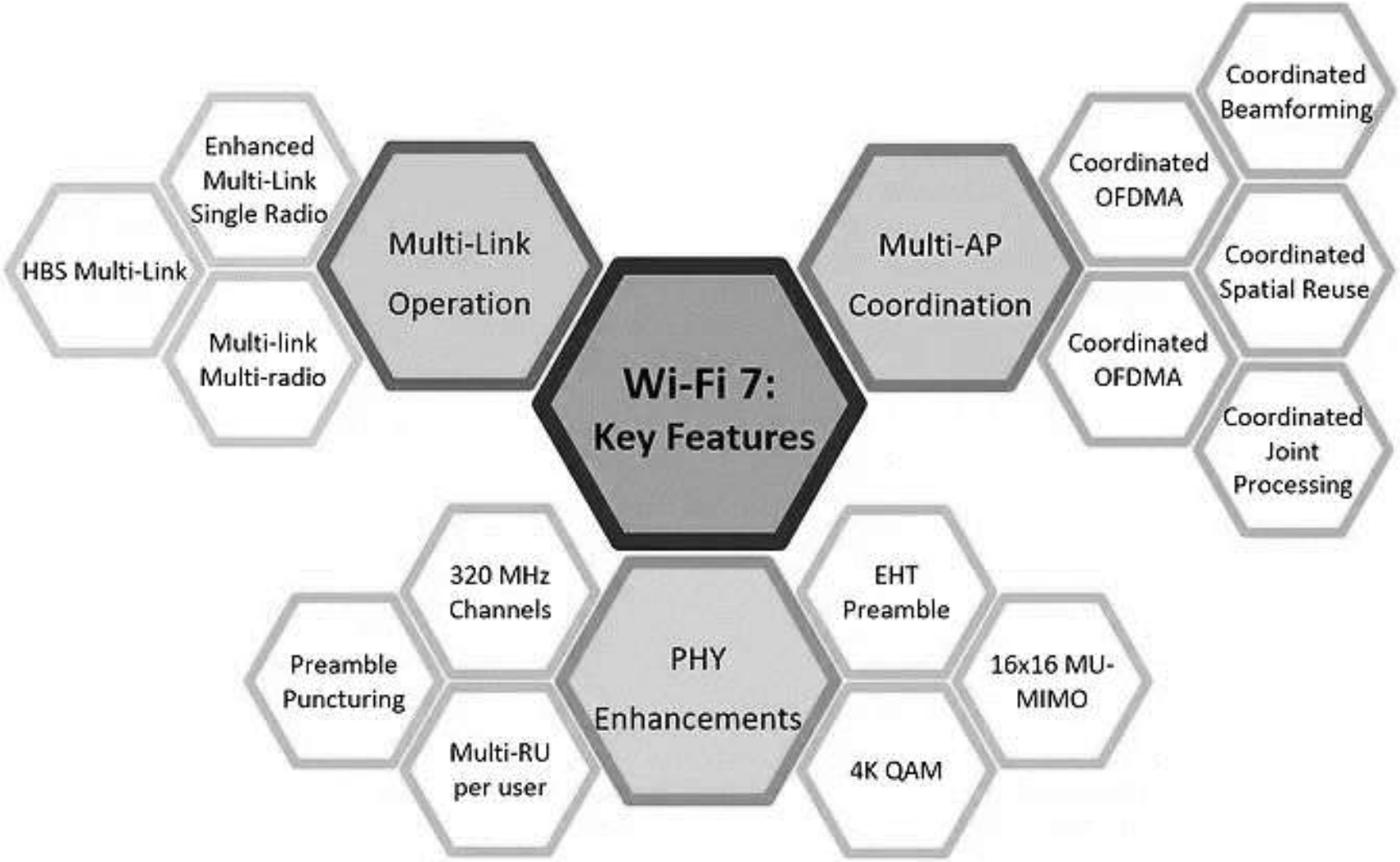
802.11be (Wi-Fi7) Key Features

Extremely High Throughput (EHT)

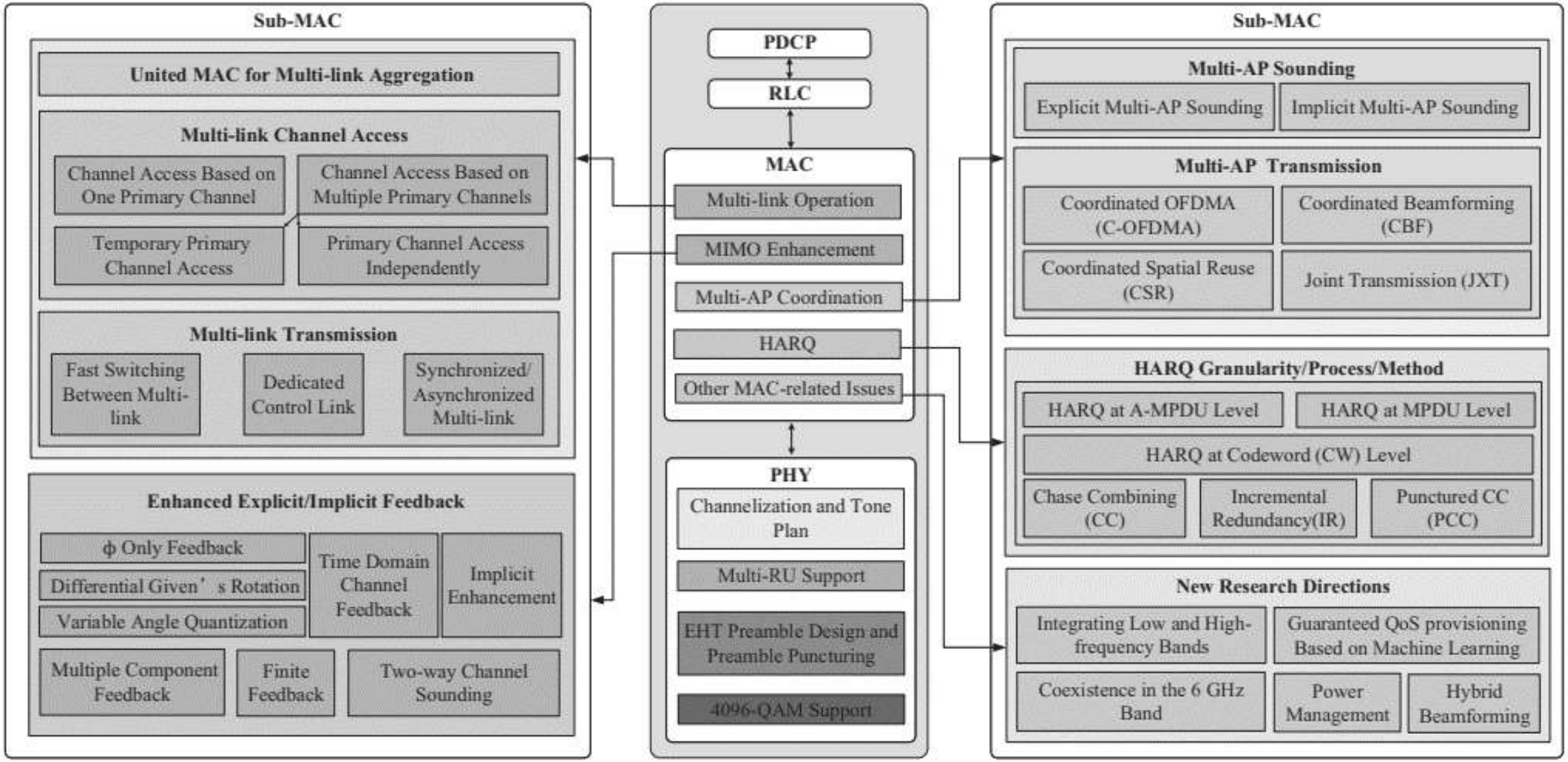
Lower Latency

Higher Reliability

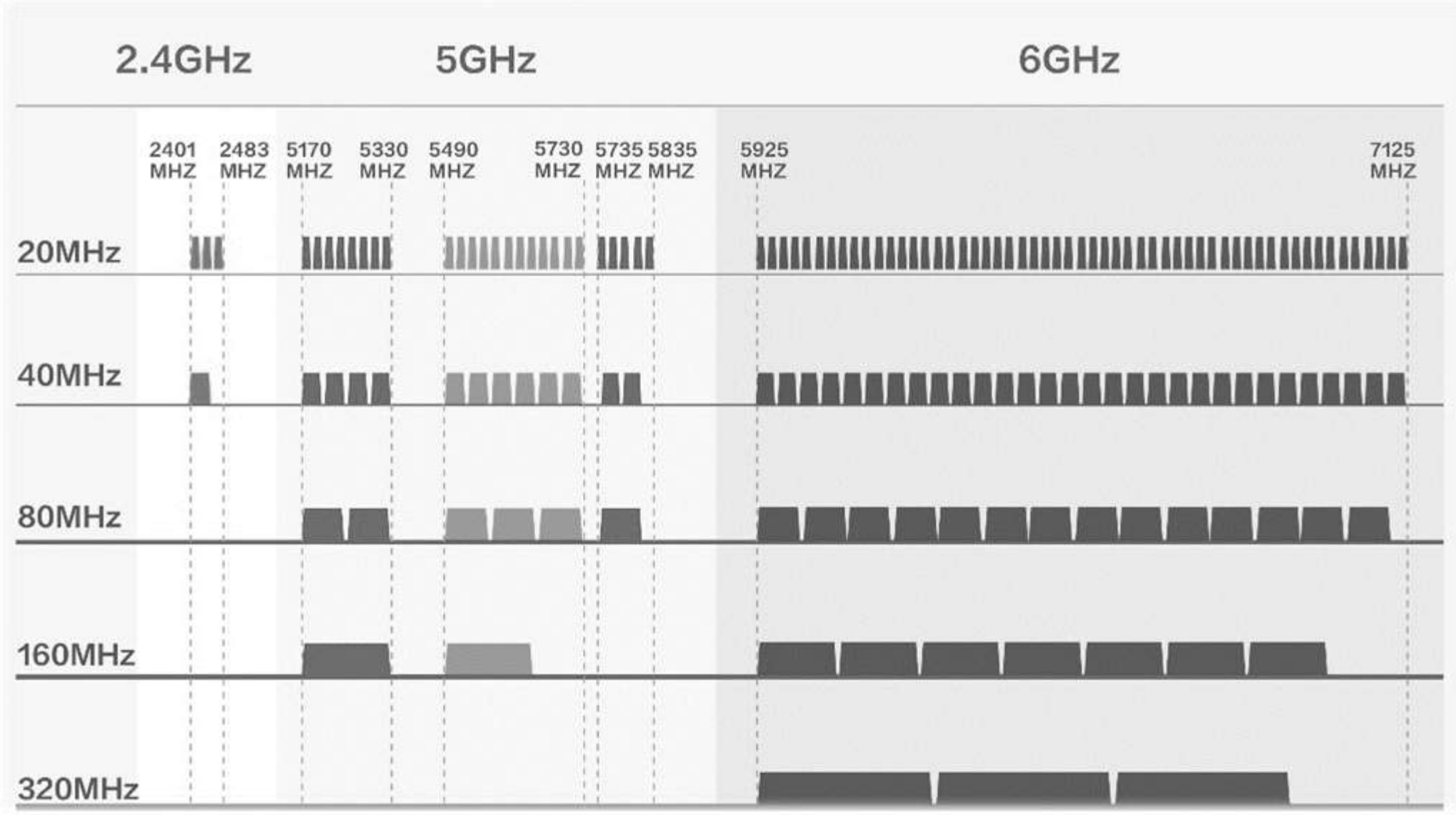
- 320 MHz Channel Bandwidth
- 4K QAM Modulation
- 16 Spatial Streams
- Multi Link Operation (MLO)
- Multi-RU OFDMA
- Preamble Puncturing
- Multi AP Coordination
- Hybrid ARQ



More Advanced View of what is new in 802.11be

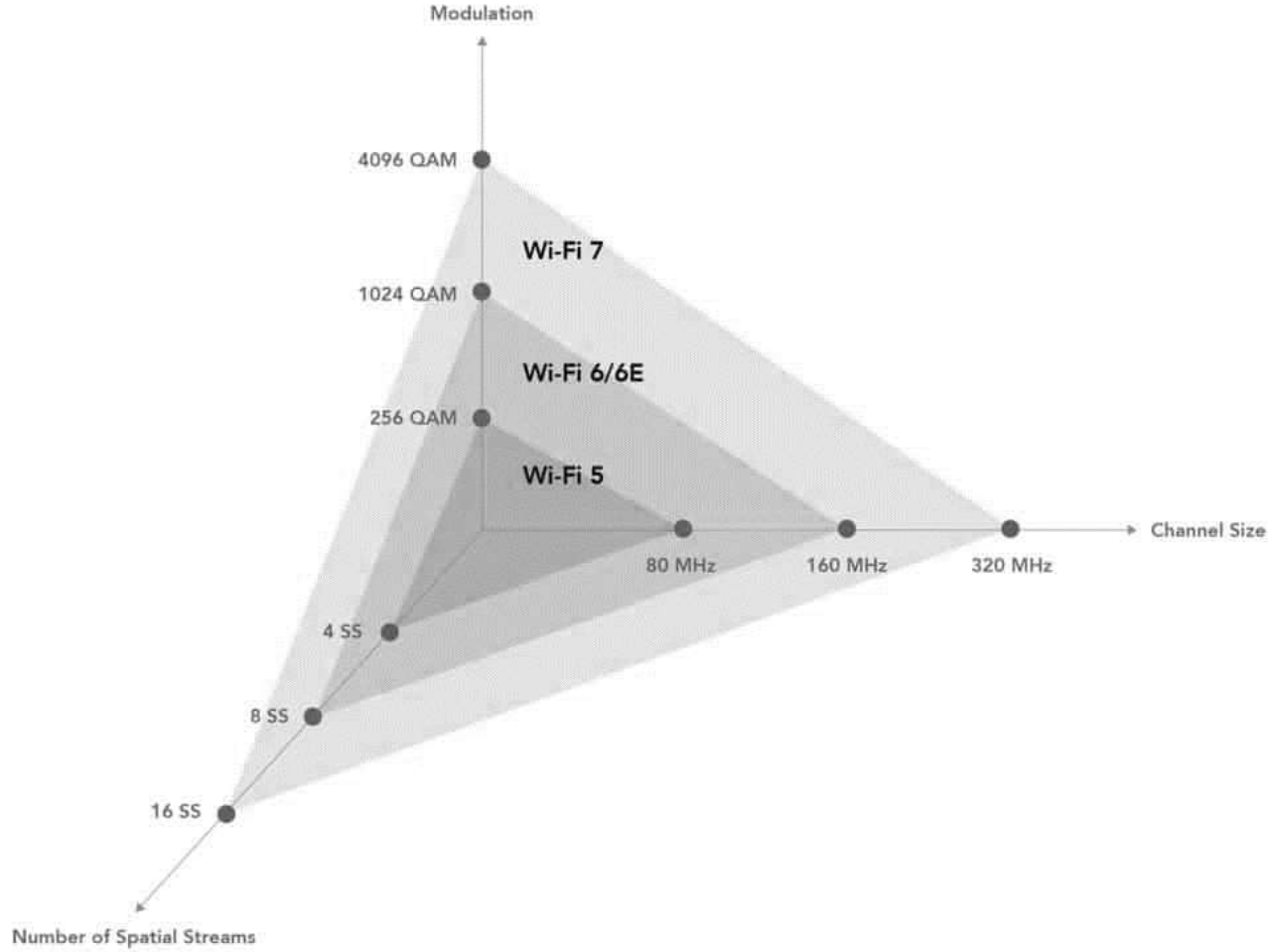


320MHz Channels



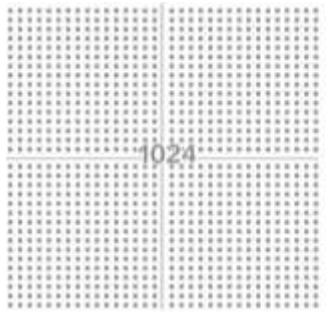
16 Spatial Streams

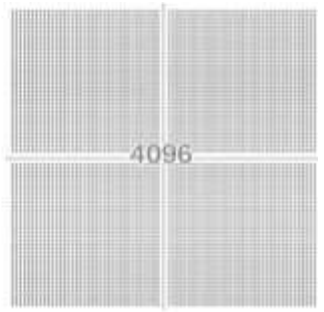
- WiFi7 standard allows for 16×16 MIMO, and thus doubling the maximum throughput compared to 802.11ax.
- While the theoretical maximum throughput can only be achieved between devices with the same antenna count, the number of MIMO streams for Client Stations is typically limited to 2 or 3.
- Larger spatial streams will only be practically used with Mu-MIMO.



4096QAM and MCS Table for Wi-Fi7

Parameter	Wi-Fi 6	Wi-Fi 7
Max channel bandwidth	160 MHz	320 MHz (3 channels in 6 GHz)
Highest modulation order	1024-QAM	4096-QAM
Max number of spatial streams	8	16
Max data rate*	~9.6 Gbps	~46.1 Gbps





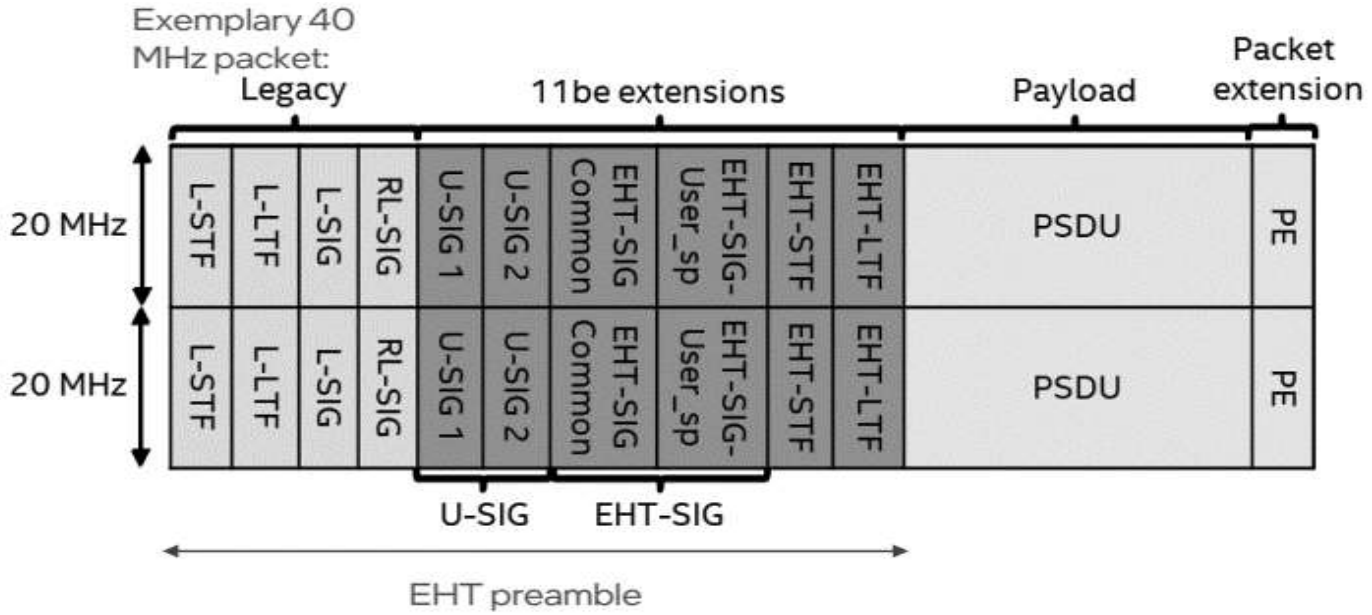
- 4 New MCS Indices Added
  - MCS12 - 4096QAM , ¾ Coding Rate
  - MCS13 – 4096QAM, 5/6 Coding Rate
  - MCS14 – BPSK-DCM-DUP , ½ Coding rate
  - MCS15 – BPSK-DCM, ½ Coding Rate

- DCM- Dual Carrier Modulation
  - Same coded bits are duplicated in 2 different tones for extra redundancy in edge cell scenarios and low data rate transmissions of IOT devices
- DCM- DUP
  - Dual Carrier Modulation again duplicated across multiple frequency channel for even more redundancy and reliability

MCS index[i]	Modulation type	Coding rate	Data rate (Mbit/s)[ii]														
			20 MHz channels			40 MHz channels			80 MHz channels			160 MHz channels			320 MHz channels		
			3200 ns GI[iii]	1600 ns GI	800 ns GI	3200 ns GI	1600 ns GI	800 ns GI	3200 ns GI	1600 ns GI	800 ns GI	3200 ns GI	1600 ns GI	800 ns GI	3200 ns GI	1600 ns GI	800 ns GI
0	BPSK	1/2	7	8	9	15	16	17	31	34	36	61	68	72	123	136	144
1	QPSK	1/2	15	16	17	29	33	34	61	68	72	122	136	144	245	272	288
2	QPSK	3/4	22	24	26	44	49	52	92	102	108	184	204	216	368	408	432
3	16-QAM	1/2	29	33	34	59	65	69	123	136	144	245	272	282	490	544	577
4	16-QAM	3/4	44	49	52	88	98	103	184	204	216	368	408	432	735	817	865
5	64-QAM	2/3	59	65	69	117	130	138	245	272	288	490	544	576	980	1089	1153
6	64-QAM	3/4	66	73	77	132	146	155	276	306	324	551	613	649	1103	1225	1297
7	64-QAM	5/6	73	81	86	146	163	172	306	340	360	613	681	721	1225	1361	1441
8	256-QAM	3/4	88	98	103	176	195	207	368	408	432	735	817	865	1470	1633	1729
9	256-QAM	5/6	98	108	115	195	217	229	408	453	480	817	907	961	1633	1815	1922
10	1024-QAM	3/4	110	122	129	219	244	258	459	510	540	919	1021	1081	1838	2042	2162
11	1024-QAM	5/6	122	135	143	244	271	287	510	567	600	1021	1134	1201	2042	2269	2402
12	4096-QAM	3/4	131	146	155	263	293	310	551	613	649	1103	1225	1297	2205	2450	2594
13	4096-QAM	5/6	146	163	172	293	325	344	613	681	721	1225	1361	1441	2450	2722	2882
14	BPSK-DCM-DUP	1/2							7	8	9	15	17	18	31	34	36
15	BPSK-DCM	1/2	4	4	4	7	8	9	15	17	18	31	34	36	61	68	72

PHY Headers Improvements (U-SIG/EHT-SIG)

- Every new standard extensions requires backward compatibility in the preamble for accurate signal detection.
- L-SIG fields are used for backward compatibility
- Wi-Fi7 introduces the concept of forward compatibility using the new Universal Signal (U-SIG) field.
- U-SIG consists of version independent fields such as BW, UL/DL TXOP Duration etc..
- U-SIG contains PHY version identifier starting for EHT which simplifies auto detection



U-SIG field of an EHT MU PPDU

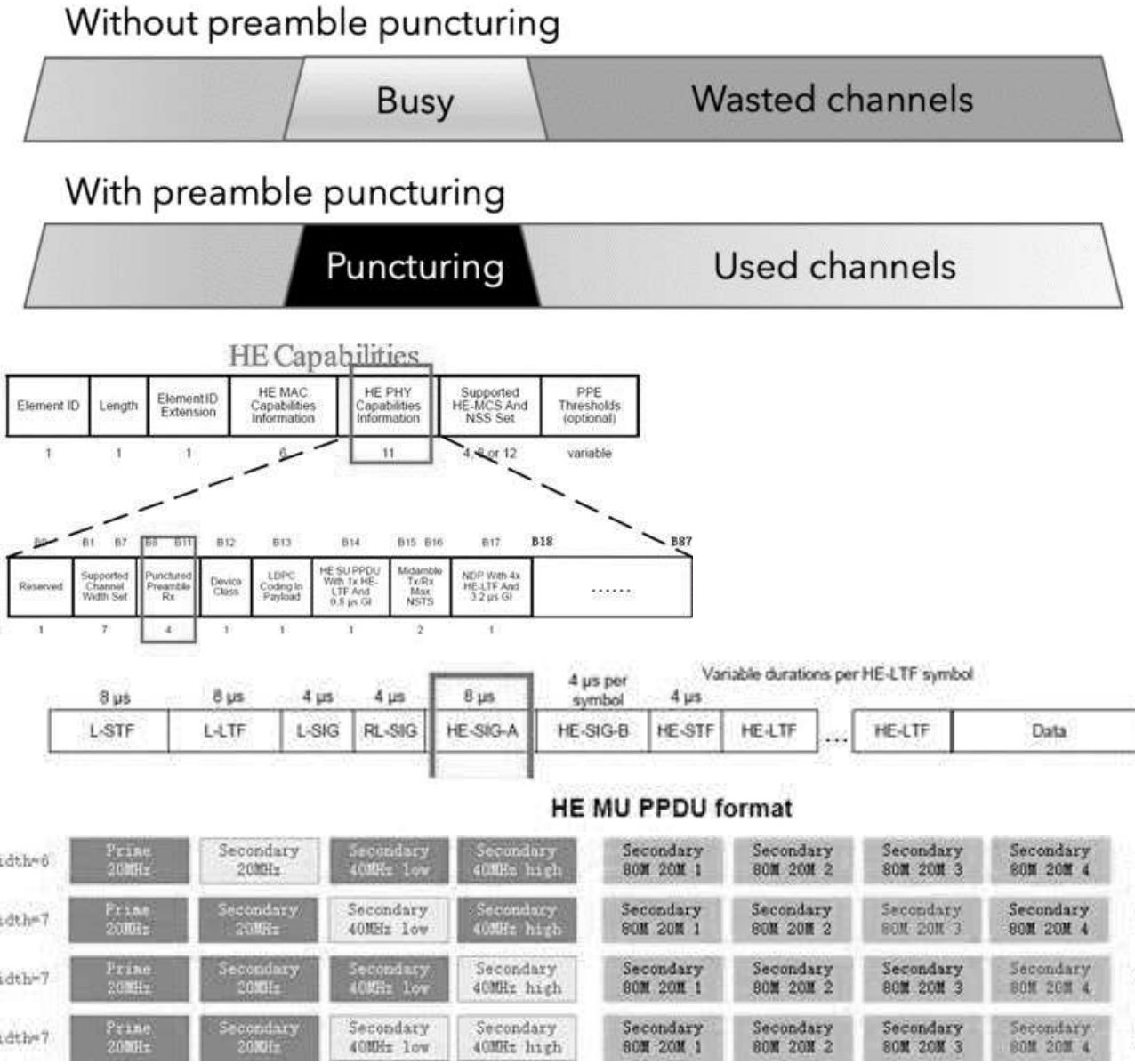
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Part 1	Version [1]			Bandwidth [1]			UL [1] DL	BSS color						TXOP							Disregard					V [1]
Part 2	Type		V [1]	Punctured channel info				V [1]	MCS			#EHT-SIG symbols				CRC					Tail					

[1] Values of these fields used for validation.

Preamble Puncturing

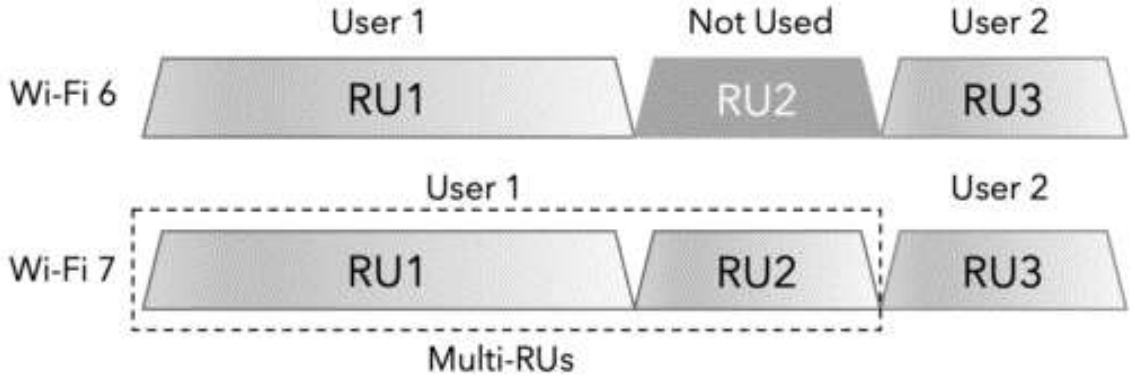
- In the past wider channels could not be used unless the entire channel was free.
- With wider channels enabled, data would only be sent on the primary 20MHz if any of the non-primary 20MHz channels making up a wider channel were busy.
- With preamble puncturing, the busy channels can be blocked or punctured from the wider channel allowing radios to leverage the clear channel blocks across a wider channel width.
- Preamble puncturing makes the use of wider channels more attractive with greater potential for realizing performance benefits from enabling wider channels.
- This technique can also used for DFS/AFC compliance

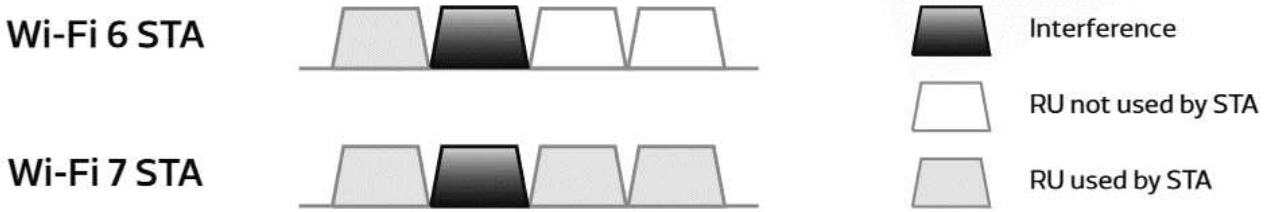
Two Parts of HE-SIG-A	Bit	Field	Number of bits	Description
HE-SIG-A1	B0	UL/DL	1	Indicates whether the PPDU is sent UL or DL: Set to 0 for DL, TDLS, mesh and IBSS Set to 1 for UL NOTE—The TDLS peer can identify the TDLS frame by To DS and From DS fields in the MAC header of the MPDU.
	B15-B17	Bandwidth	3	Set to 0 for 20 MHz. Set to 1 for 40 MHz. Set to 2 for 80 MHz non-preamble puncturing mode. Set to 3 for 160 MHz and 80+80 MHz non-preamble puncturing mode. If the SIGB Compression field is 0: Set to 4 for preamble puncturing in 80 MHz, where in the preamble only the secondary 20 MHz is punctured. Set to 5 for preamble puncturing in 80 MHz, where in the preamble only one of the two 20 MHz subchannels in secondary 40 MHz is punctured. Set to 6 for preamble puncturing in 160 MHz or 80+80 MHz, where in the primary 80 MHz of the preamble only the secondary 20 MHz is punctured. Set to 7 for preamble puncturing in 160 MHz or 80+80 MHz, where in the primary 80 MHz of the preamble the primary 40 MHz is present. If the SIGB Compression field is 1 then values 4–7 are reserved.

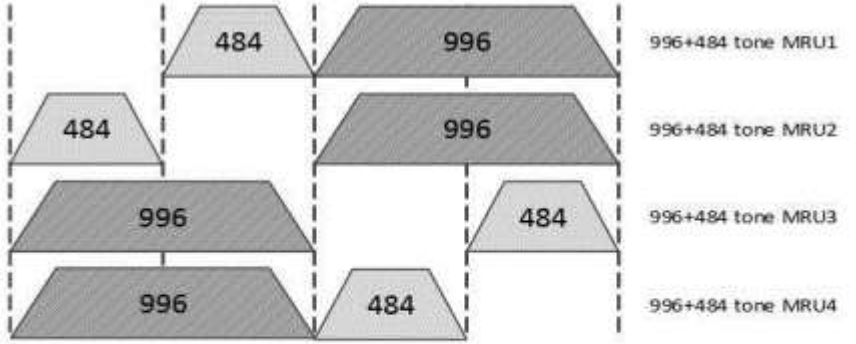


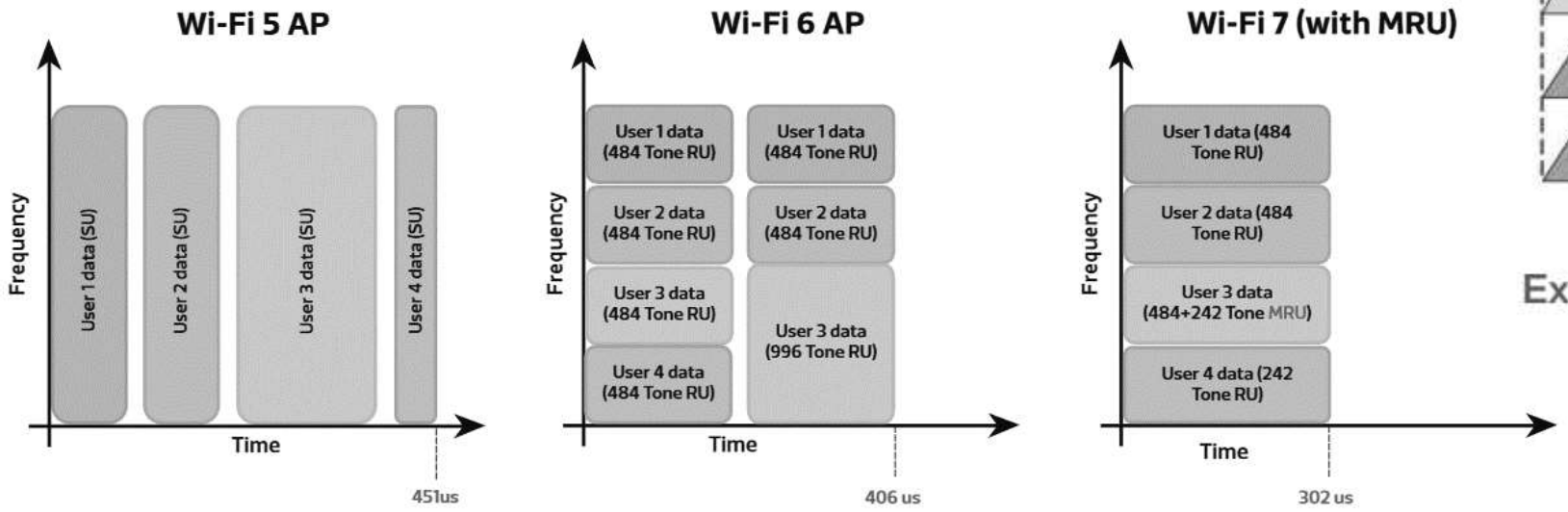
Multi-RU OFDMA

- Wi-Fi 6 introduced resource units (RU) where radios could send or receive on an assigned block of subcarriers or RUs.
- While this feature offered some efficiency improvements to Wi-Fi, clients could only be assigned one RU per TxOp sometimes leaving unused RUs which needed to be padded.
- Multi-RU allows radios to fill in those unused RUs with support for multiple RUs from the same user, further increasing transmission efficiency.









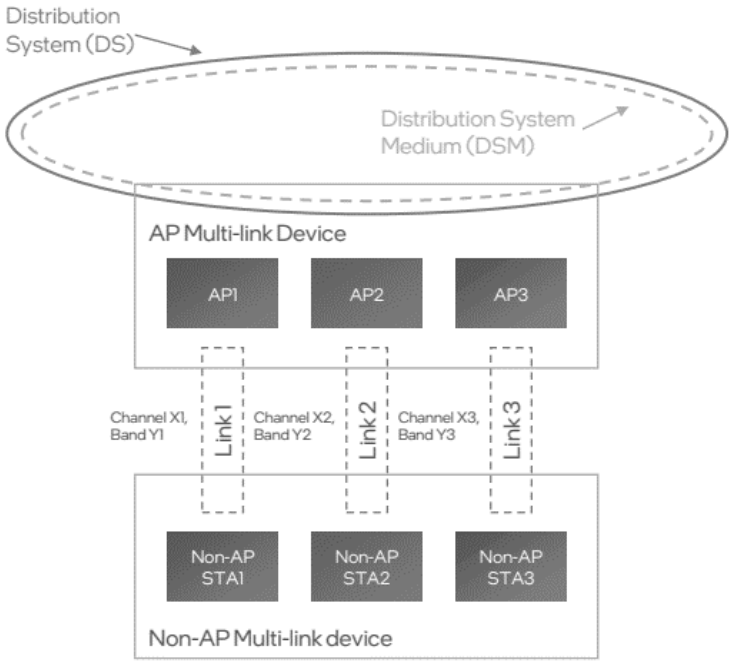
Example: Allowed 996+484-tone MRUs in non-OFDMA 160 MHz EHT PPDU

Multi Link Operation (MLO)

- Multi Link Operation is a new feature in Wi-Fi that allows APs and STAs to communicate over multiple channels/bands/radios simultaneously in order to improve throughput, latency and/or reliability
- With a common MAC layer and separate PHY layers, Wi-Fi 7 Access Points and Client Stations are capable of transmitting and receiving simultaneously on multiple links.
- By taking advantage of intelligent traffic scheduling and prioritization, MLO enables reduced latency and jitter by prioritizing data transmission on links with the best RF conditions or improve reliability by duplicating data on multiple links.

MLO Terminology and Framework

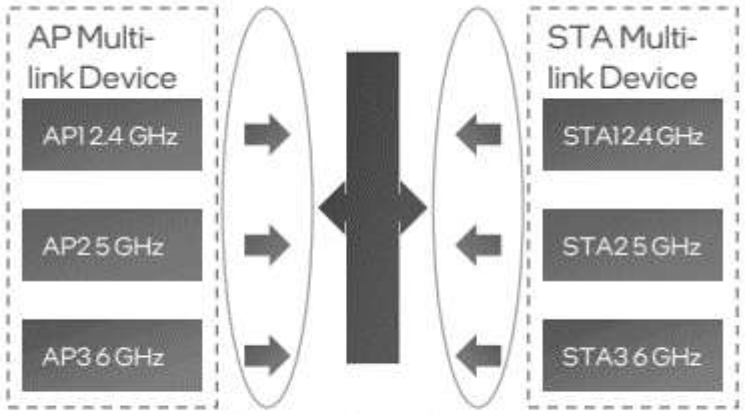
- A Device the supports MLO is referred to as a Multi Link Device (MLD)
- AP that supports MLO is referred to as AP MLD
- STA that supports MLO is referred to as non-AP MLD
- MLO can be supported both on single and multiple radio devices.



Types of MLO

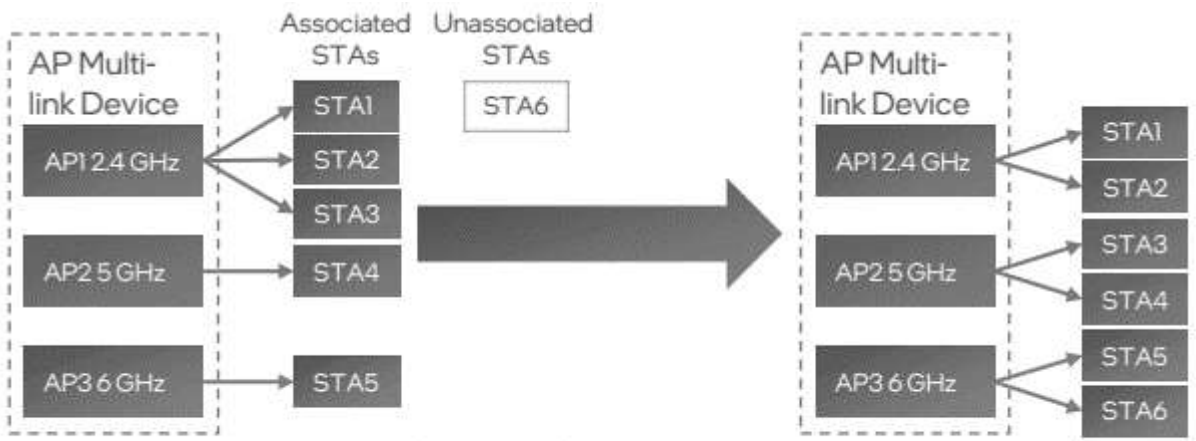
MLO Type	Number of Radios	Characteristics
Multi-link single radio (MLSR)	1	TX/RX over one link at a time.
Enhanced multi-link single radio (EMLSR)	1	MLSR with additional capability to listen to two links simultaneously.
Nonsimultaneous transmit and receive multi-link multi-radio (NSTR MLMR)	>=2	Simultaneous TX/TX, RX/RX over multiple links.
Simultaneous transmit and receive multi-link multi-radio (STR MLMR)	>=2	Simultaneous TX/TX, RX/RX, and TX/RX over multiple links.
Enhanced multi-link multi-radio (EMLMR)	>=2	MLMR with additional capability to dynamically reconfigure spatial multiplexing capability on each link.

Benefits of Multi Link Operation (MLO)



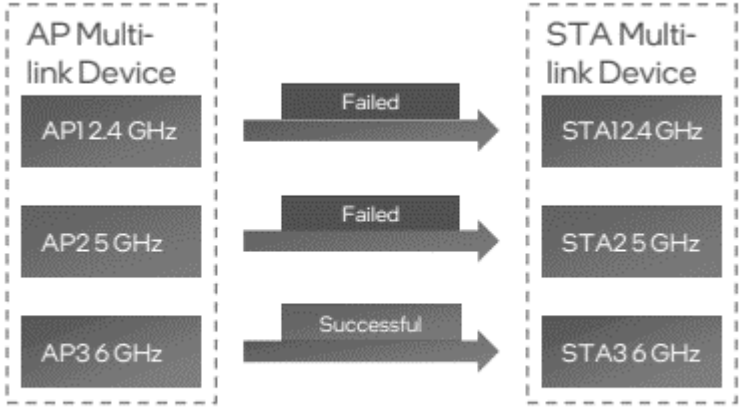
Throughput boost

Aggregating multiple links for data transmission



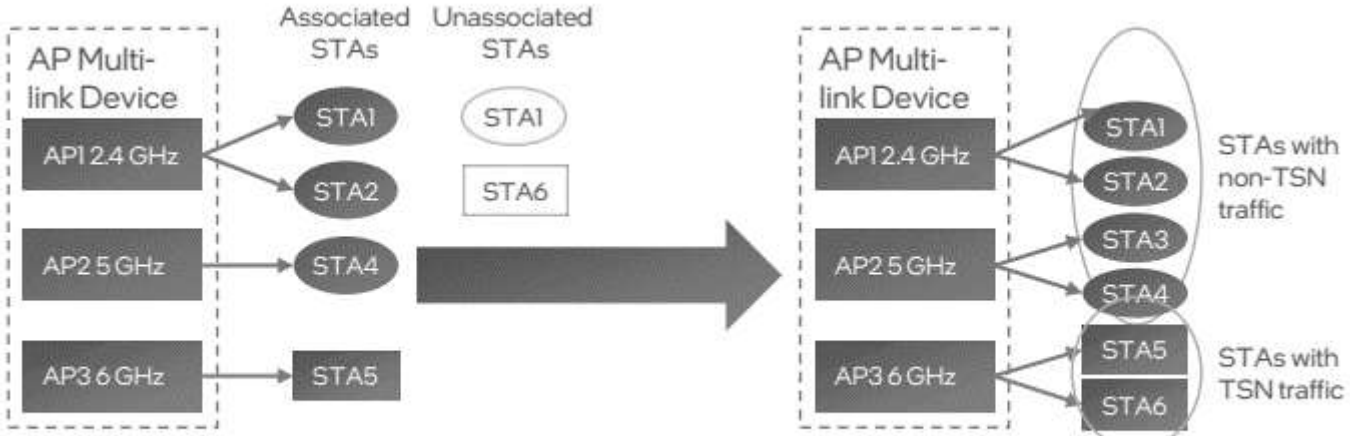
Latency improvement

Load balancing to mitigate congestion on one link



Increased reliability

Duplicating critical packets on multiple links

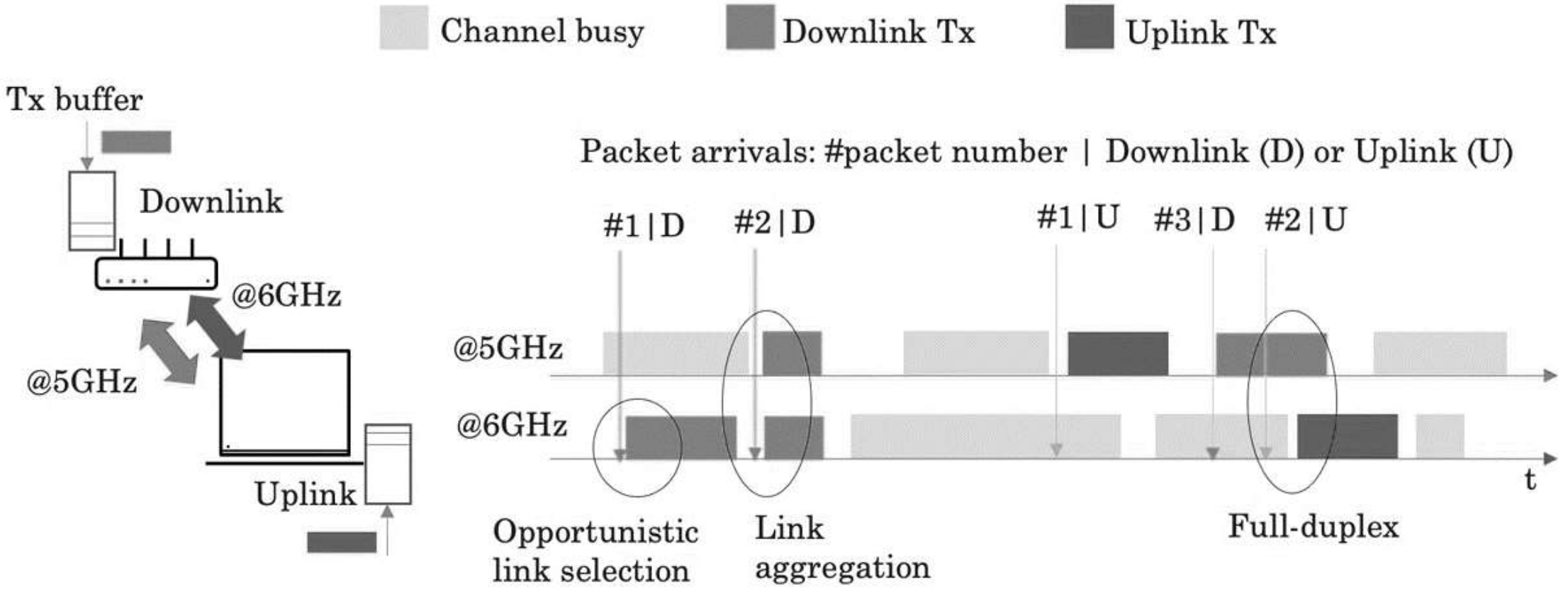


Traffic separation/differentiation

Separating different traffic flows to different links

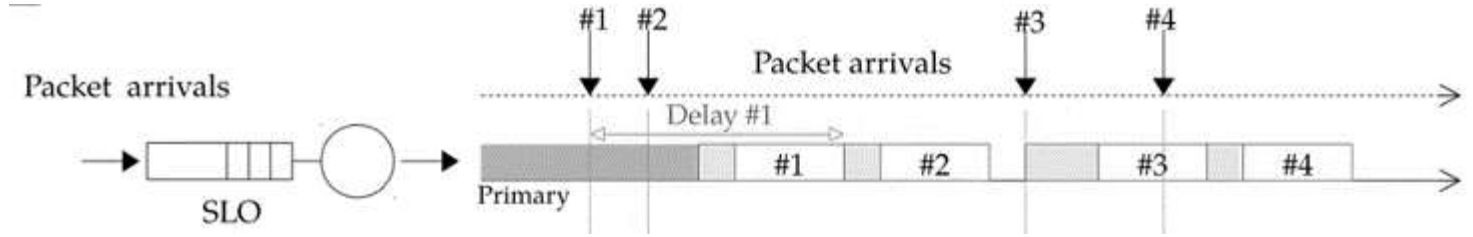
Multi Link Operation Example

#1 | D : Opportunistically select the best link available for DL transmission based on interference and channel availability.
#2 | D : Aggregate both 5GHz and 6GHz links achieve higher throughput in DL when both links are available.
#1 | U : Select the 5GHz link for UL transmission when only 5GHz link is available.
#3 | D : Full duplex transmissions with Downlink in 5GHz band and Uplink in the 6GHz band.
#2 | U : Full duplex transmissions with Downlink in 5GHz band and Uplink in the 6GHz band.

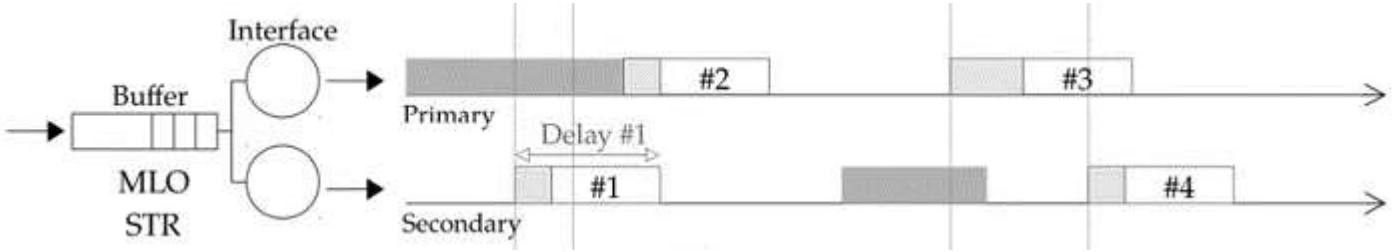


MLO Basic Modes

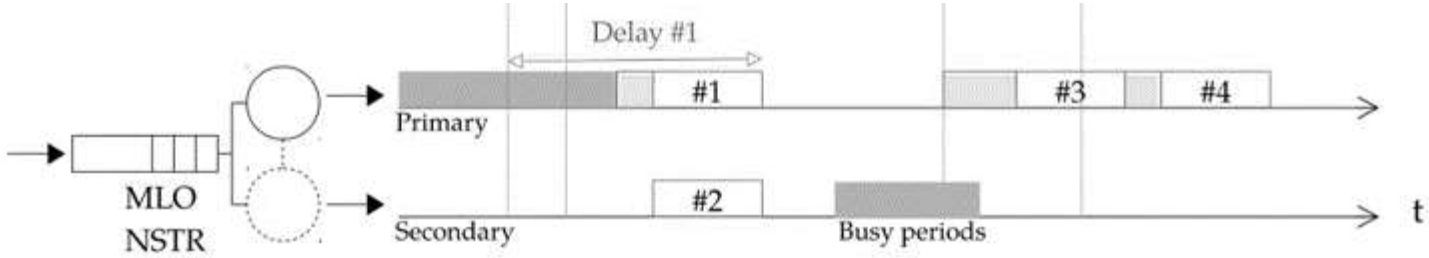
- SLO (Single Link Operation)
  - Only one radio interface /One Link



- MLO - STR (Simultaneous Tx and Rx)
  - Two independent radio interfaces
  - Each backoff and transmit independently
  - Packets are assigned to first available radio

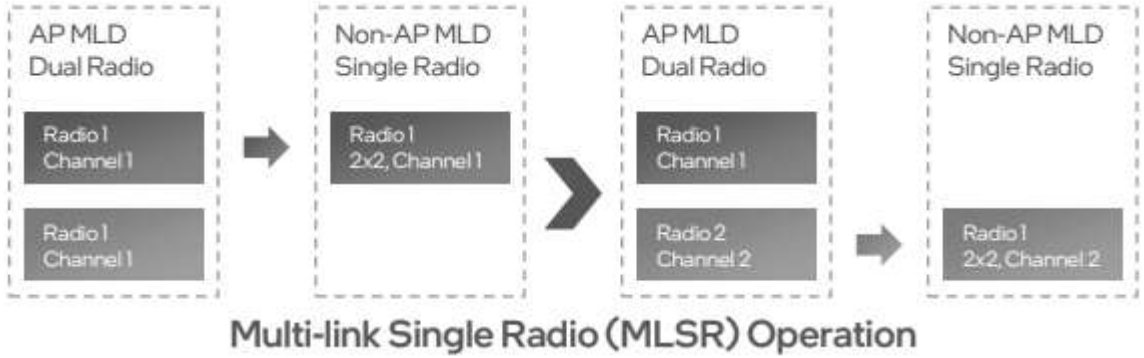


- MLO - NSTR (Non - Simultaneous Tx and Rx)
  - Interface #1 acts as the primary interface
  - There is a single backoff for medium access
  - Interface #2 can only be used when Interface #1 is available



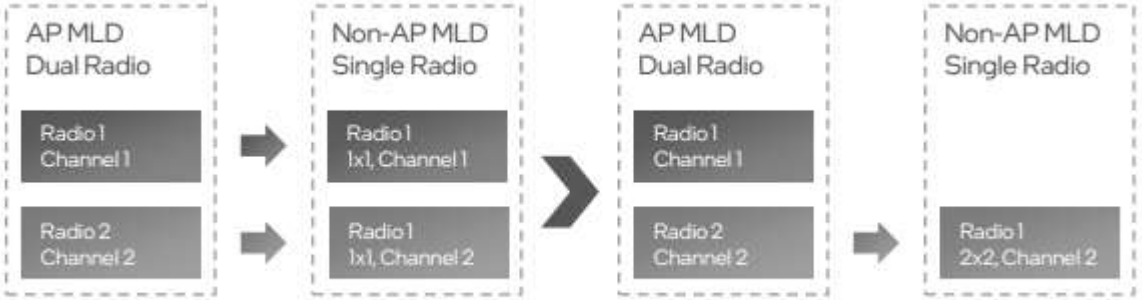
Single Radio MLO – MLSR and EMLSR

- **Multi-Link Single Radio (MLSR)**
  - STA can pick the best link to use for Tx and Rx and Transmit or Receive using the selected link/channel
  - Switching between channels/links can be done dynamically without need for new connection with new encryption keys



Multi-link Single Radio (MLSR) Operation

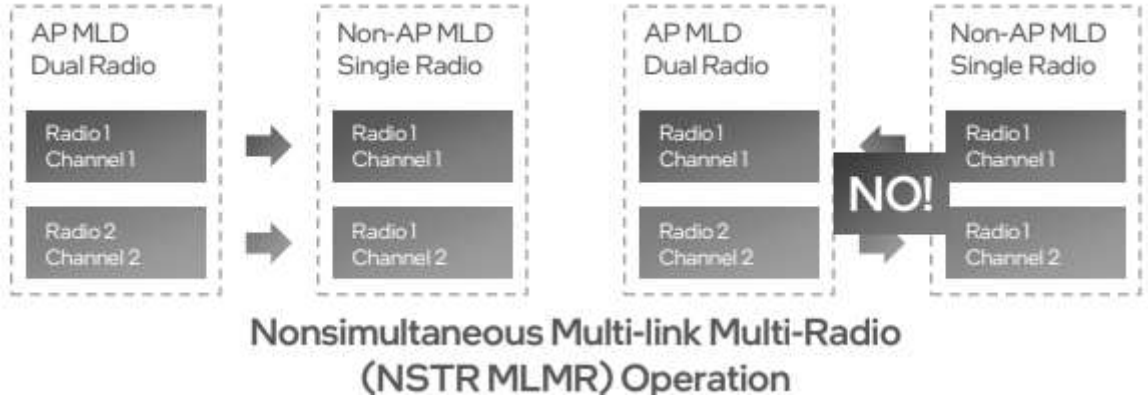
- **Enhanced Multi-Link Single Radio (EMLSR)**
  - A 2x2 MIMO single radio STA can listen to two radios links on an AP simultaneously in 1x1 mode.
  - Once the best channel/link is found, the transmission can happen on a single link in 2x2 MIMO.
  - Switching between links can happen seamlessly.



Enhanced Multi-link Single Radio (EMLSR) Operation

Multi Radio MLO – MLMR, STR-MLMR and NSTR-MLMR

- **Non Simultaneous Multi-Link Multi Radio (NSTR MLMR)**
  - STA can transmit or receive over multi links to multiple radios on the AP.
  - Simultaneous transmit on one radio and receive on the other radio on the STA is not allowed.
  - This is done to avoid interference issues on the closely placed radios on the STA.

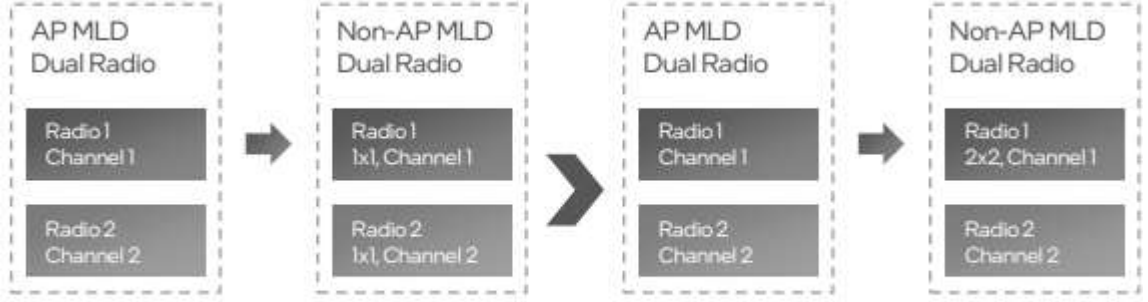


Nonsimultaneous Multi-link Multi-Radio (NSTR MLMR) Operation

- **Simultaneous Multi-Link Multi Radio (STR MLMR)**
  - STA can transmit or receive over multi links to multiple radios on the AP.
  - Simultaneous transmit on one radio and receive on the other radio on the STA is allowed.

Simultaneous Multi-link Multi-Radio (STR MLMR) Operation

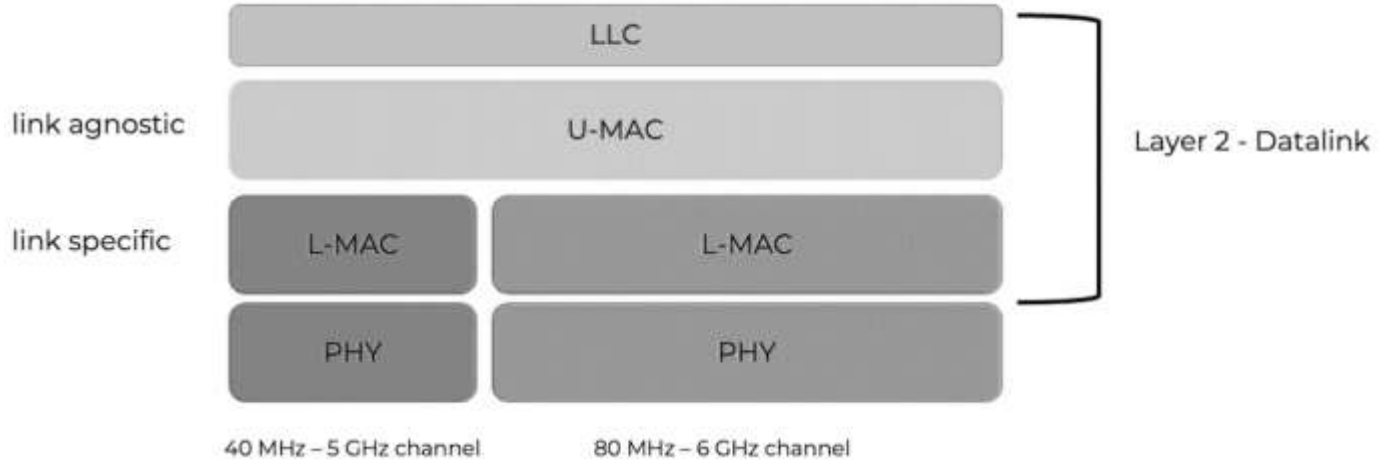
- **Enhanced Multi-Link Multi Radio (EMLMR)**
  - STA can listen to multiple radio links over multiple radio chains.
  - STA can transmit or receive over multi links to multiple radios on the AP.



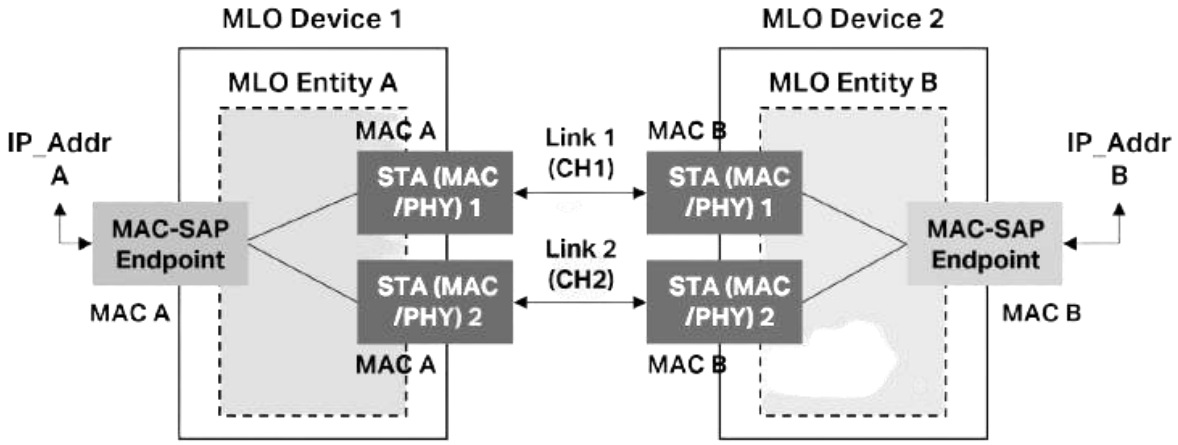
RX chain switching for Enhanced Multi-link Multi-Radio (EMLMR) Operation

MLO – 2 MAC Layers

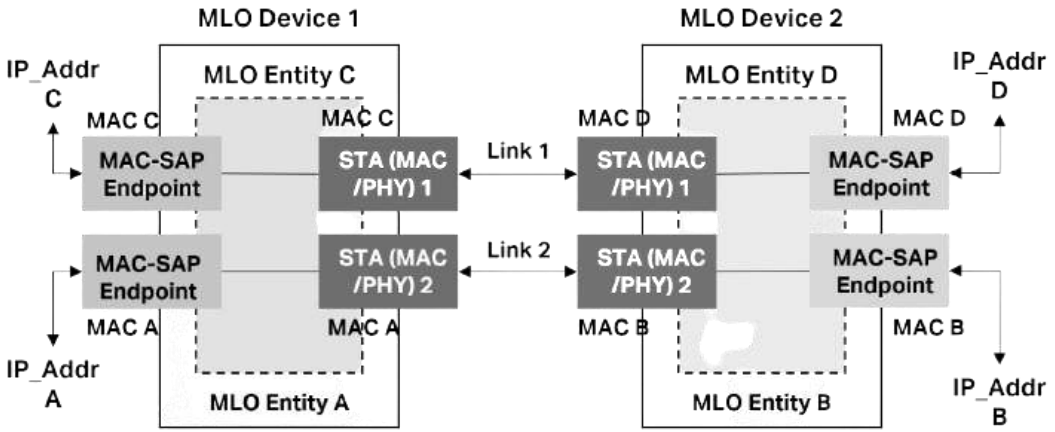
- Upper MAC is responsible for connectivity and security and interface with LLC
- Lower MAC responsible for medium access, data transmission, multi PHY management multi link operation.
- There will a single MAC address called the MLD MAC address which will be used for connectivity and security.
- Packet-Level Aggregation will aggregate transmission of packets from the same TID across multiple links to achieve better throughput and lower latency
- Flow-Level Aggregation can be used for mesh backhaul when two AP MLDs can aggregate multiple traffic flows for different devices across multiple links



Packet-Level Aggregation



Flow-Level Aggregation

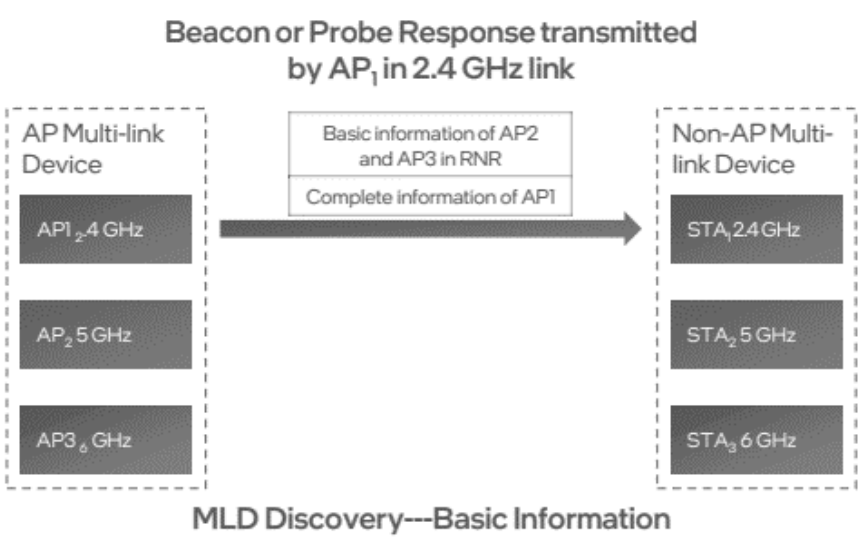


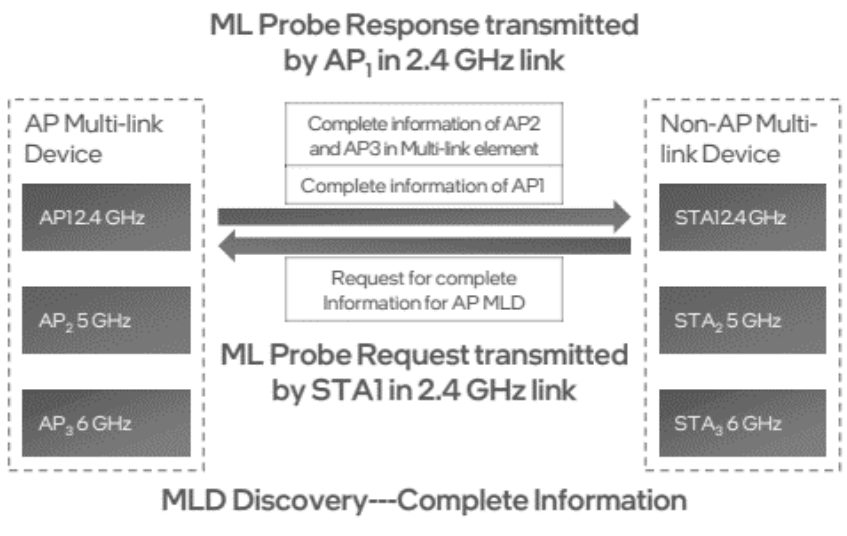
Multi Link Device Discovery

- On each link/channel, the AP MLD will usually transmit a link specific SSID and also an MLO SSID.
- Normal discovery process can use the standard active and/or passive scanning methods across all the links to obtain the MLO information
- More efficient methods of discovery would be to use RNR information elements that provide information about all the links/channels SSIDs on the same primary link probe response.
- MLD discovery methods can send Basic Information in the RNR or complete information in the Multi-Link Information Element.

wlan.fc.type_subtype==0x8

Source	Destination	Channel	Info
TPLink_47:b4:ec	Broadcast	1	Beacon frame, SN=225, FN=0, Flags=........C, BI=1000, SSID="TP-Link_B4EA_2G"
92:ed:00:47:b4:ec	Broadcast	1	Beacon frame, SN=912, FN=0, Flags=........C, BI=1000, SSID="TP-Link_B4EA_MLO"
62:ed:00:47:b4:ec	Broadcast	1	Beacon frame, SN=215, FN=0, Flags=........C, BI=1000, SSID=Wildcard (Broadcast)
TPLink_47:b4:ec	Broadcast	1	Beacon frame, SN=226, FN=0, Flags=........C, BI=1000, SSID="TP-Link_B4EA_2G"
92:ed:00:47:b4:ec	Broadcast	1	Beacon frame, SN=913, FN=0, Flags=........C, BI=1000, SSID="TP-Link_B4EA_MLO"
62:ed:00:47:b4:ec	Broadcast	1	Beacon frame, SN=216, FN=0, Flags=........C, BI=1000, SSID=Wildcard (Broadcast)
TPLink_47:b4:ec	Broadcast	1	Beacon frame, SN=227, FN=0, Flags=........C, BI=1000, SSID="TP-Link_B4EA_2G"
92:ed:00:47:b4:ec	Broadcast	1	Beacon frame, SN=914, FN=0, Flags=........C, BI=1000, SSID="TP-Link_B4EA_MLO"
62:ed:00:47:b4:ec	Broadcast	1	Beacon frame, SN=217, FN=0, Flags=........C, BI=1000, SSID=Wildcard (Broadcast)

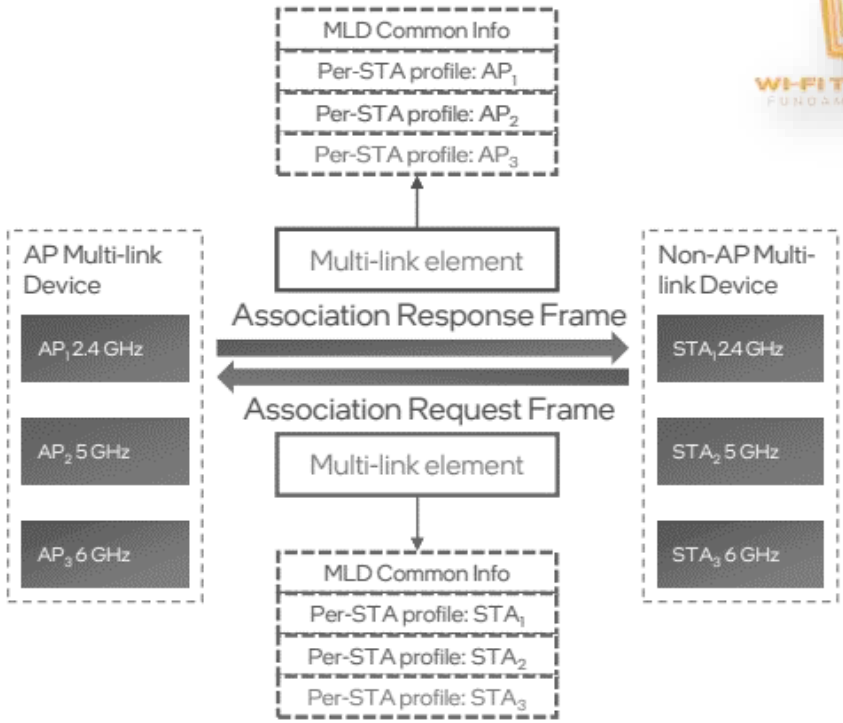


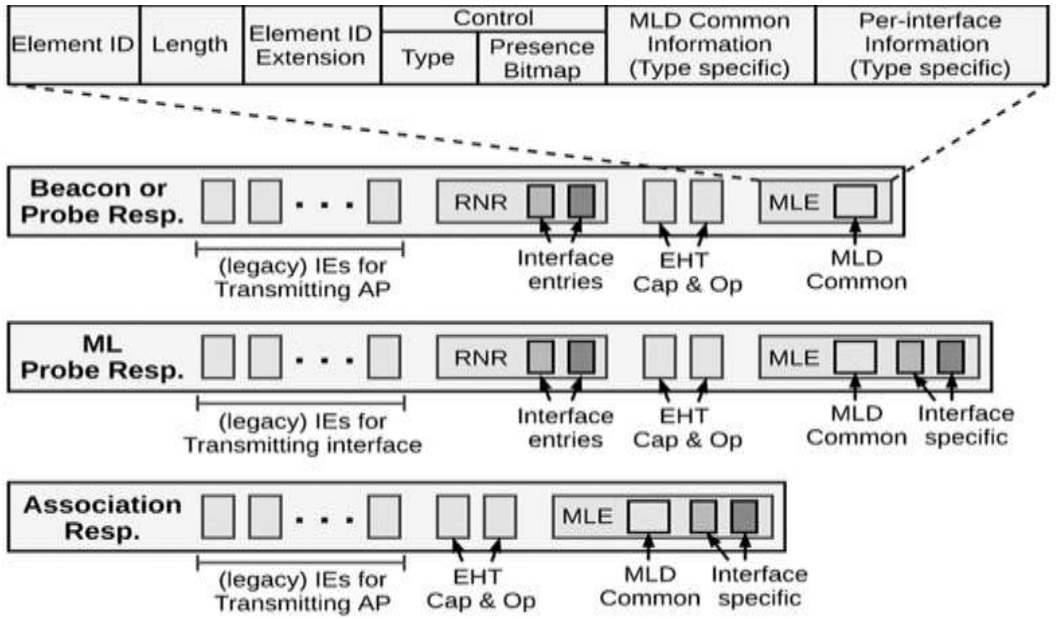


Multi Link Association and Security

- Normal process will require separate associations on all links but Multi Link association is only needed on a single link.
- Multi-Link Element in association response will contain all the MLD common information like MLD MAC address and also the per STA profile information.
- The single link association is also followed by a 4-way handshake process using the MLD MAC address and the keys generated will be used for encryption on all the links.
- No one key generation is needed when switching between links.

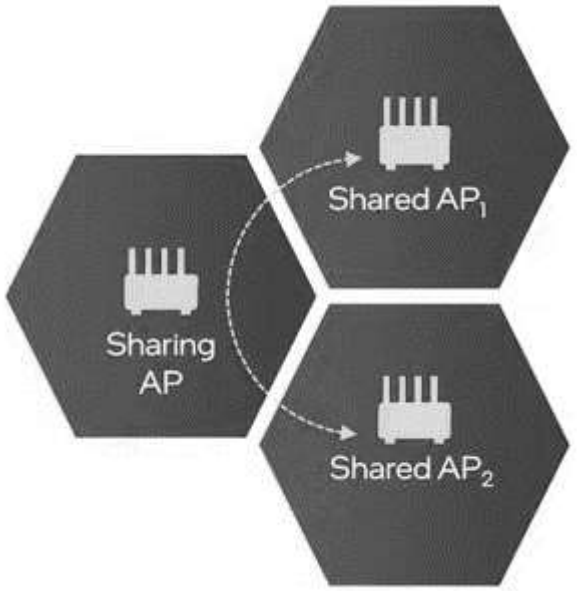
```
Frame 273: 479 bytes on wire (3832 bits), 479 bytes captured (3832 bits) on interface moni
Radiotap Header v0, Length 48
802.11 radio information
IEEE 802.11 Association Request, Flags: ........C
IEEE 802.11 Wireless Management
  Fixed parameters (4 bytes)
  Tagged parameters (399 bytes)
    Tag: SSID parameter set: "TP-Link_B4EA_MLO"
    Tag: Supported Rates 1, 2, 5.5, 11, 6, 9, 12, 18, [Mbit/sec]
    Tag: Extended Supported Rates 24, 36, 48, 54, [Mbit/sec]
    Tag: RSN Information
    Tag: HT Capabilities (802.11n D1.10)
    Tag: Extended Capabilities (10 octets)
    Ext Tag: HE Capabilities
    Ext Tag: HE 6 GHz Band Capabilities
    Ext Tag: Multi-Link (802.11be D3.0)
      Ext Tag length: 216 (Tag len: 217)
      Ext Tag Number: Multi-Link (802.11be D3.0) (107)
      Multi-Link Control: 0x0180 Basic
      Common Info
        Common Info Length: 11
        MLD MAC Address: Intel_79:80:07 (e4:60:17:79:80:07)
        EML Capabilities: 0x0033, EMLSR Support
        MLD Capabilities: 0x0000
      Subelement ID: Per-STA Profile (0x00)
      Subelement Length: 201
      Per-STA Profile 1
        Per-STA Profile, Link-ID = 2
      Basic STA Profile Count: 1
      STA Profiles LinkIds: 2
    Ext Tag: EHT Capabilities (802.11be D3.0)
    Tag: Supported Operating Classes
    Tag: RSN eXtension (1 octet)
    Tag: Vendor Specific: Microsoft Corp.: WMM/WME: Information Element
```

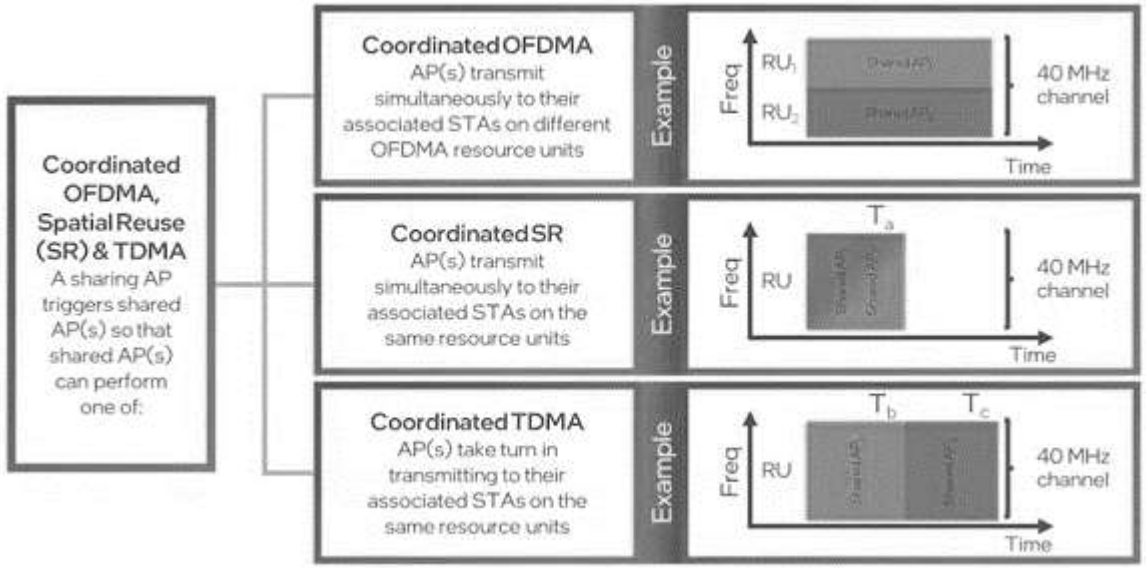


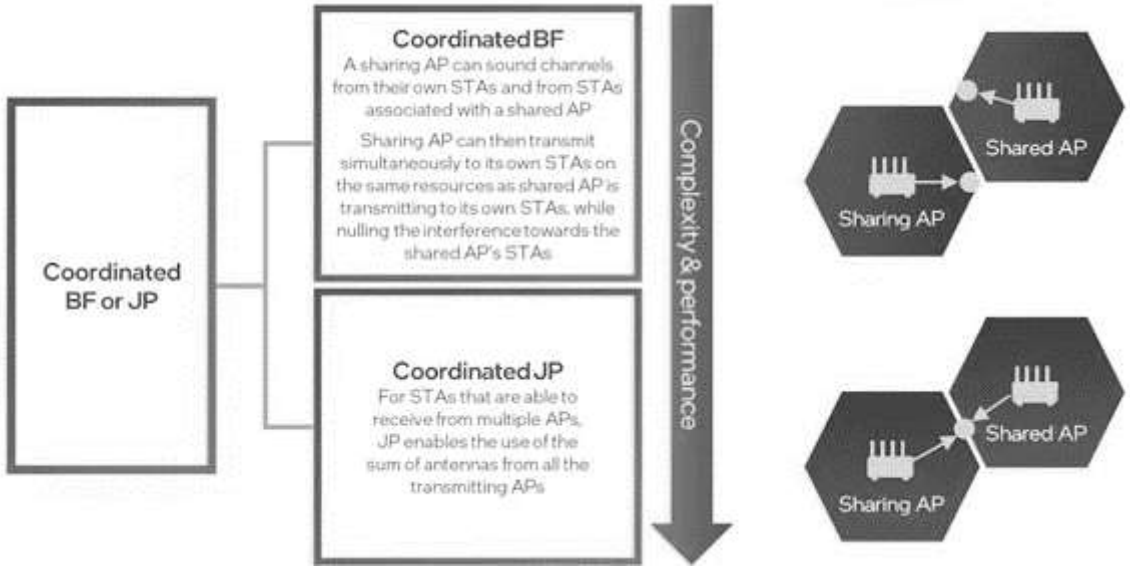


Multi-AP Coordination Concept

- Multiple APs coordinate their frequency and time transmissions attempting to avoid channel congestion and improve throughput and latency.
- Some Methods used are:
  - Low Complexity AP coordination
    - Coordinated OFDMA
    - Coordinated Spatial Reuse
    - Coordinated TDMA
  - More Complex AP coordination
    - Joint Transmissions (D-MIMO)
    - Coordinated Beamforming (CBF)



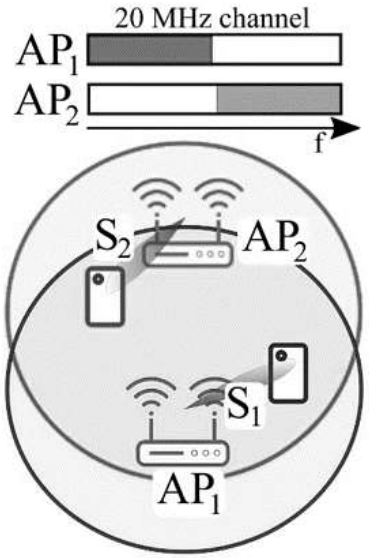


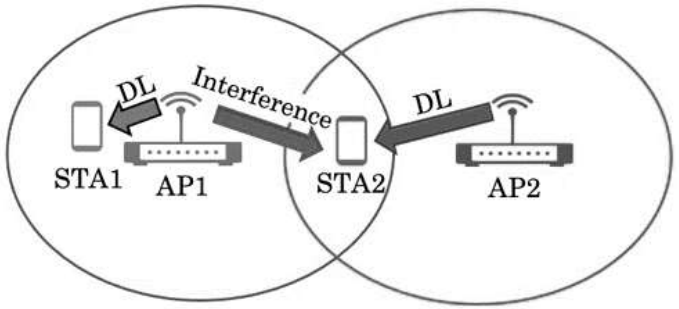


Multi-AP Coordination Methods

Coordinated OFDMA

- APs jointly allocate time and frequency resources
- Minimizes Inter BSS collision
- Reduces contention time

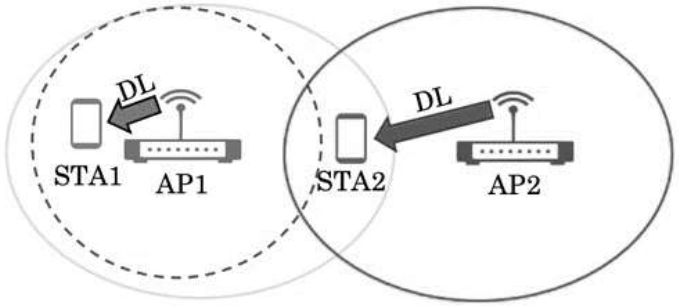




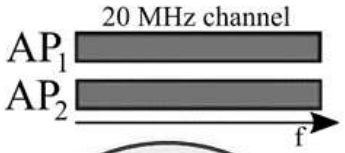
Non-coordinated TX generates a collision

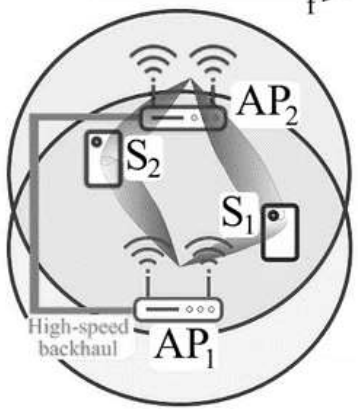
Coordinated Spatial Reuse

- This coordination works in the power domain.
- APs coordinate their TX power on a per transmission basis to avoid interference
- Both APs participate in joint scheduling



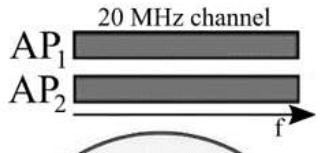
Coordinated TX: AP1 reduces its TX power to prevent collision

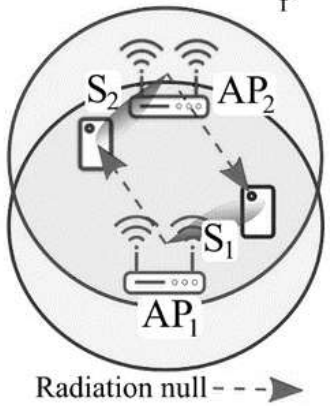




Joint Transmissions (D-MIMO)

- Joint spatial multiplexing across multiple APs to transmit from multiple APs to STA at the same time.
- Requires very complex synchronization and backhaul capability



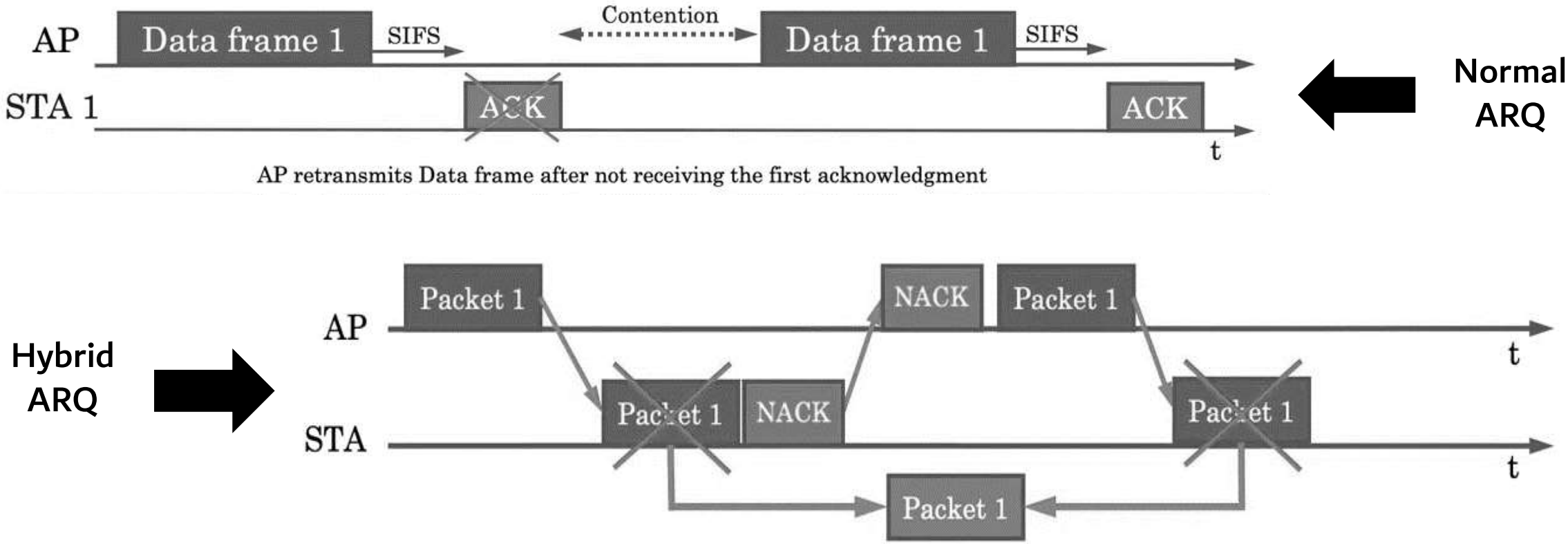


Coordinated Beamforming(CBF)

- Reuses time/freq resources via radiation nulls using coordinated Beamforming.
- AP1 and transmit to S1 but create a null for S2 and AP2 can transmit to S2 but create a null to S1, thus improving beamforming efficiency across BSSs

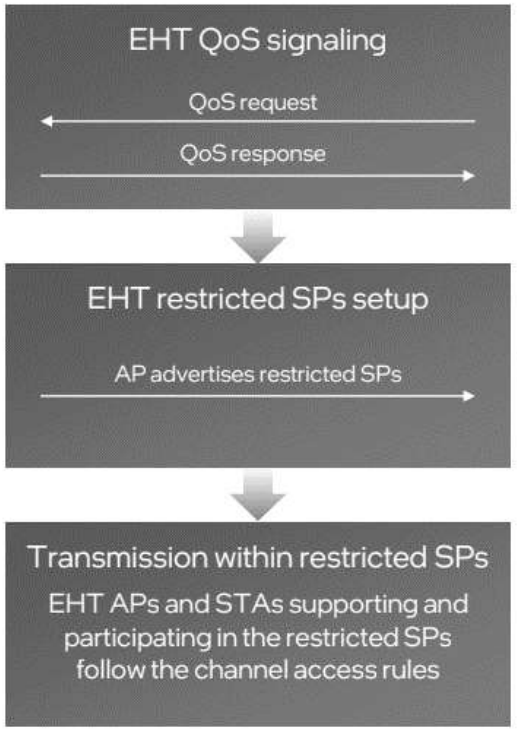
Hybrid Automatic Repeat Request (ARQ)

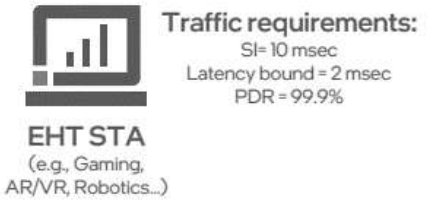
- In Normal ARQ, failed ACKs will trigger retransmissions using exponential backoff and reduced PHY rates, which results in poor medium utilization.
- In Hybrid ARQ approach, the receiver will keep the corrupted frames and combine them with the retransmitted frames to get an SNR gain of 4-6dB.
- This allows for the transmitter to use higher modulation rates even for the retransmissions and hence using the medium mode effectively.

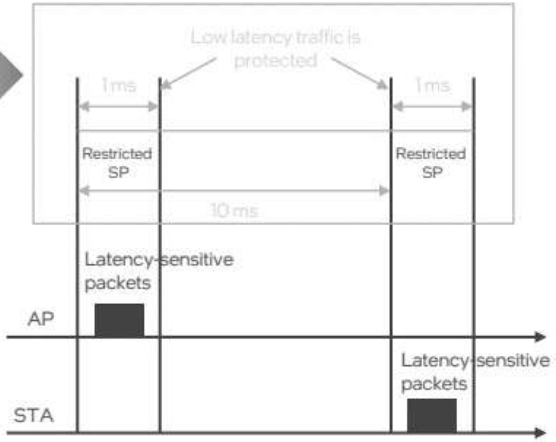


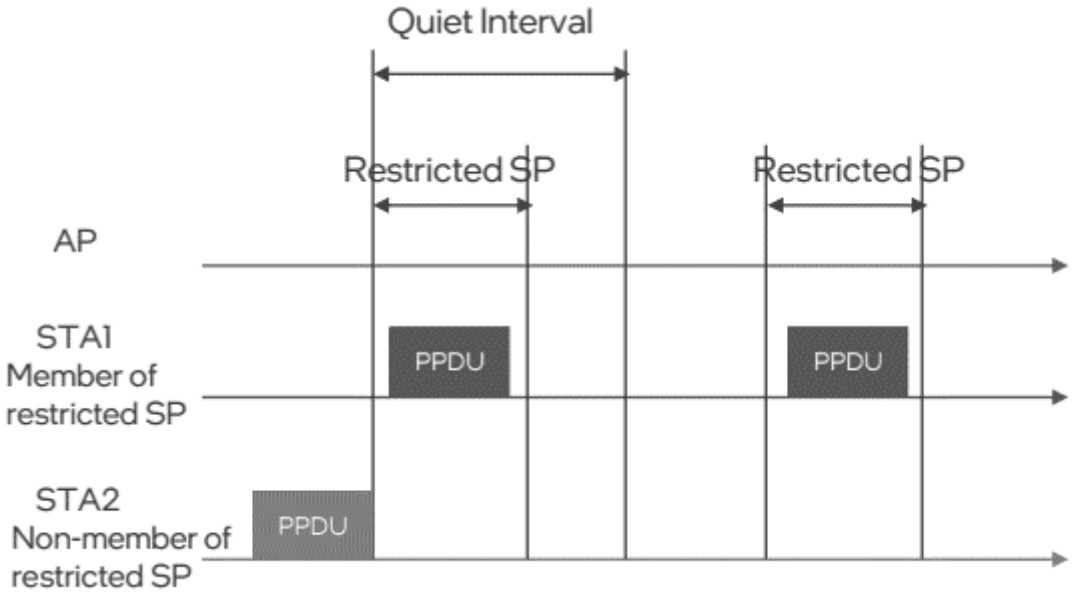
Enhanced QoS – Restricted Service Periods

- Designed to provide deterministic low latency to applications and devices like Industrial IOT, AR/VR.
- First step is for the AP to understand the traffic patterns of the delay sensitive applications.
- Based on this the AP will announce quiet intervals during will all STAs will refrain from accessing the medium.
- If there is any EHT- STA that has active transmissions, it will end its TXOP before the restricted service period.



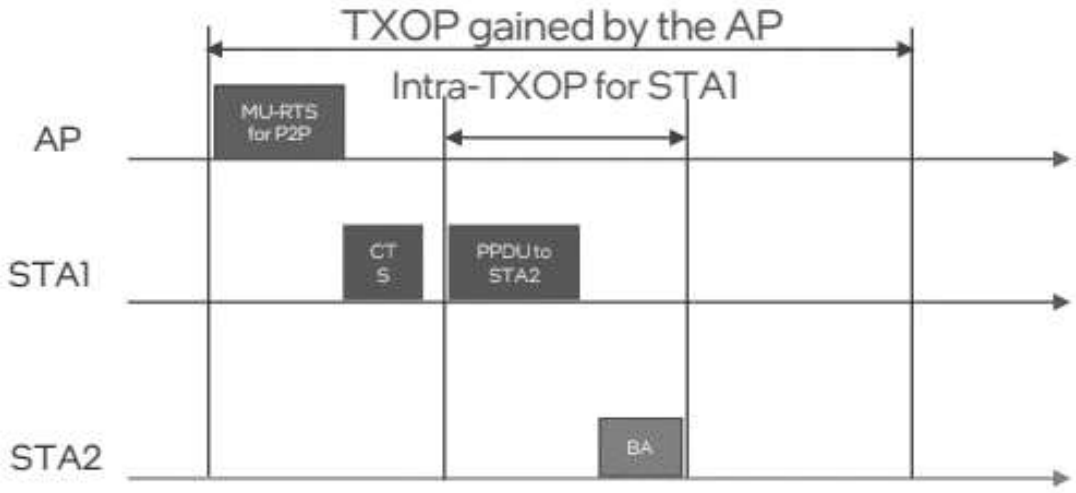






Triggered Peer-to-Peer Transmissions

- This feature allows for direct links between two STAs
- Example use cases are video casting applications, VR applications and other wireless file transfer applications.
- AP can broadcast an MU-RTS frame to trigger P2P transmission periods.
- P2P transmissions can happen during this period.



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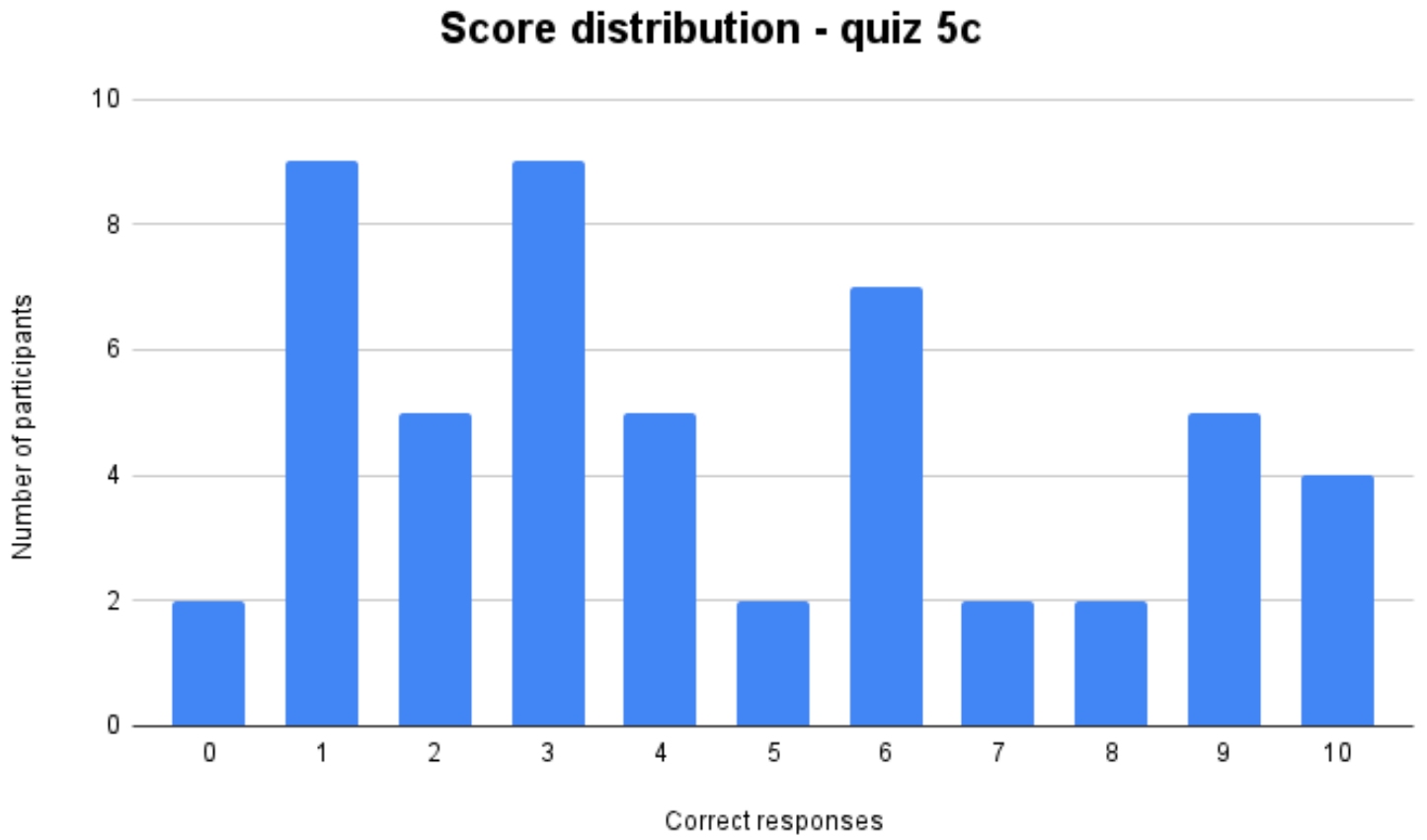
Q&A

Quiz 5c Results

Nikhitha Thashamshetty

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QUIZ!
TIME