

IEEE802 포럼 [최신 무선랜 표준기술 워크숍]



IEEE 802.11be MAC

IEEE 802.11be (Wi-Fi 7) 표준화 동향

July 23, 2020

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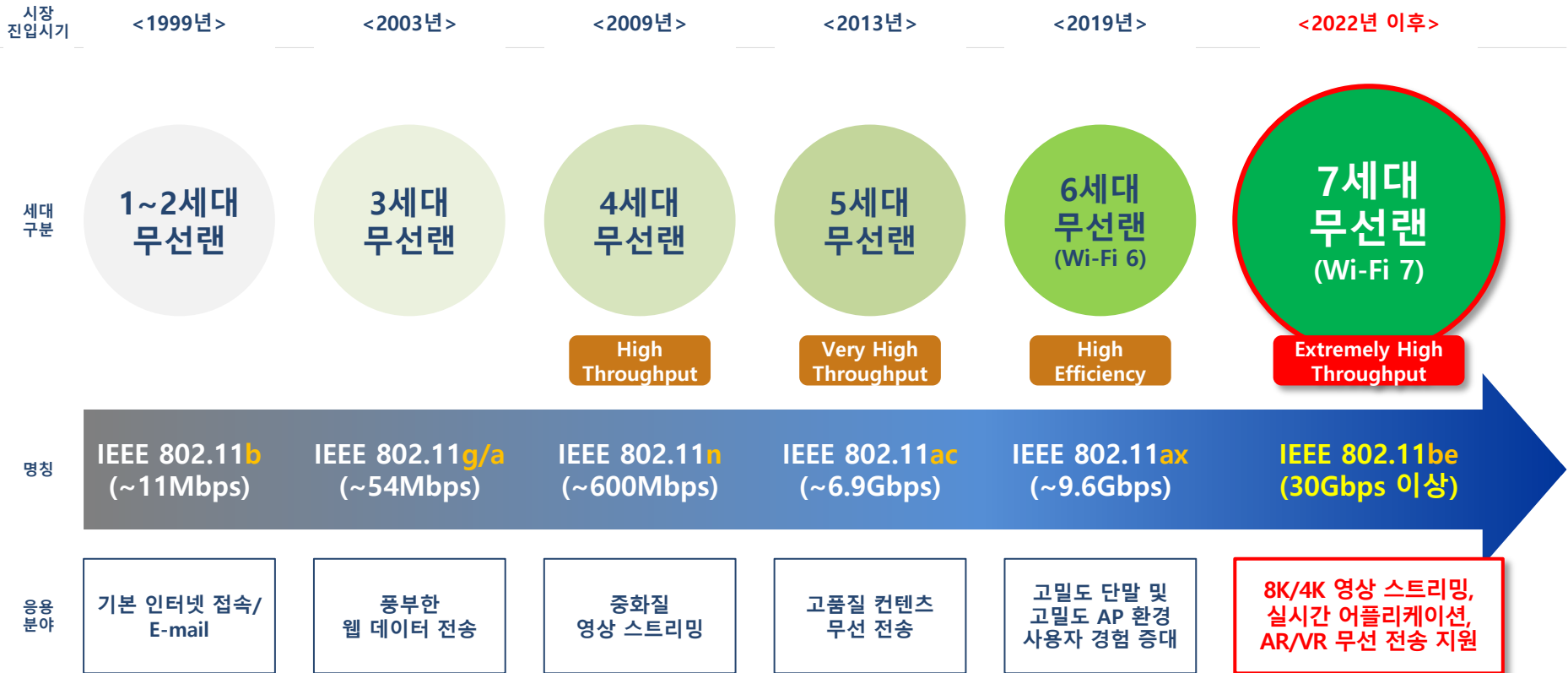
IEEE 802.11be (Wi-Fi 7)

EHT (Extremely High Throughput)

Introduction

○ 무선랜 기술의 세대 구분

무선랜 기술은 사용자 편의 및 시장의 요구에 대응하여 지속적인 발전이 이루어졌으며, MIMO, OFDM(A) 등 새로운 통신 기술의 도입을 통해 기존의 성능을 훨씬 뛰어넘는 진화를 추진함



○ EHT candidate features and timeline

- Main candidate features

- EHT PAR (Project Authorization Request)

- 8.1 Additional Explanatory Notes** : Item 5.2b:

- The focus of this amendment is on WLAN indoor and outdoor operation with stationary and pedestrian speeds in the 2.4, 5 and 6 GHz frequency bands.

- The main candidate features that have been discussed are:

- 320 MHz bandwidth and more efficient utilization of non-contiguous spectrum,
 - Multi-band/multi-channel aggregation and operation,
 - 16 spatial streams and Multiple Input Multiple Output (MIMO) protocols enhancements,
 - Multi-Access Point (AP) Coordination (e.g. coordinated and joint transmission),
 - Enhanced link adaptation and retransmission protocol (e.g. Hybrid Automatic Repeat Request (HARQ)),
 - If needed, adaptation to regulatory rules specific to 6 GHz spectrum.

- Timeline

MILESTONE	PROJECTED
PAR approved	Mar 2019
First TG meeting	May 2019
D0.1	Sep 2020
D1.0 Letter Ballot	May 2021
D2.0 LB recirculation	Mar 2022
D3.0 LB recirculation	Nov 2022
Initial Sponsor Ballot (D4.0)	May 2023
Final 802.11 WG approval	Mar 2024
802 EC approval	Mar 2024
RevCom and SASB approval	May 2024

← Now

IEEE 802.11be (Wi-Fi 7) MAC

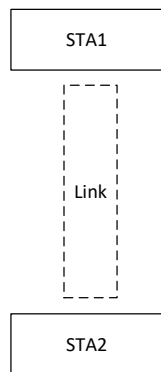
Based on 11be SFD and related contributions

Multi-link device

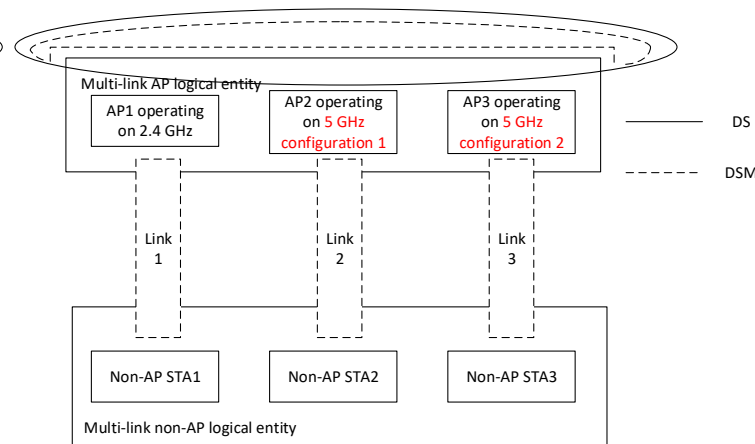
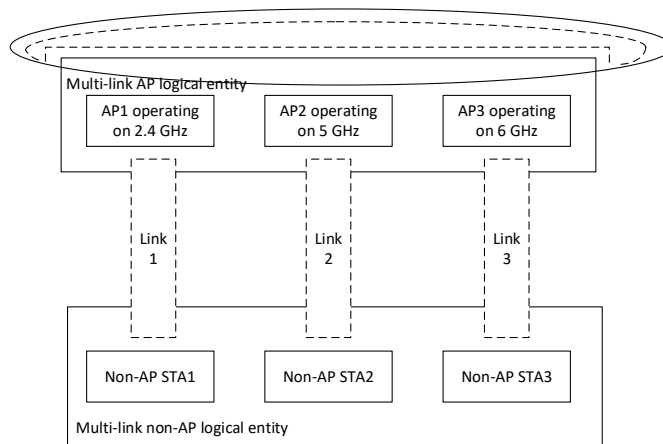
- **Multi-link device (MLD)**

- A device that has more than one affiliated STA and has one MAC SAP to LLC, which includes one MAC data service.
- AP MLD: An MLD, where each STA affiliated with the MLD is an AP.
- Non-AP MLD: An MLD, where each STA affiliated with the MLD is a non-AP STA.
- Application examples: Steering, load balancing, multi-link aggregation, etc.

- **Single link**



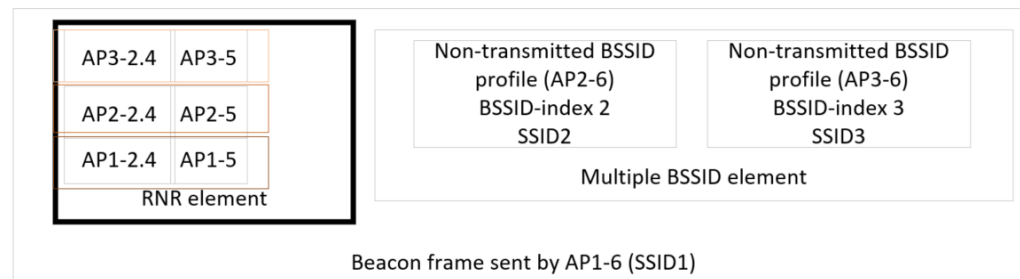
- **Multi-link examples**



○ Multi-link discovery (1/6)

- **MLD discovery**

- A non-AP MLD needs to discover an AP MLD before multi-link setup.
- All APs that are part of the same MLD as a reporting AP and that are collocated with the reporting AP shall be reported in the RNR (Reduced Neighbor Report) element that is included in the beacons and the broadcast probe responses when the reporting AP is either not part of a multiple BSSID set or corresponds to a transmitted BSSID in a multiple BSSID set.
 - RNR provides basic information (e.g., operating class, channel, BSSID, short SSID).



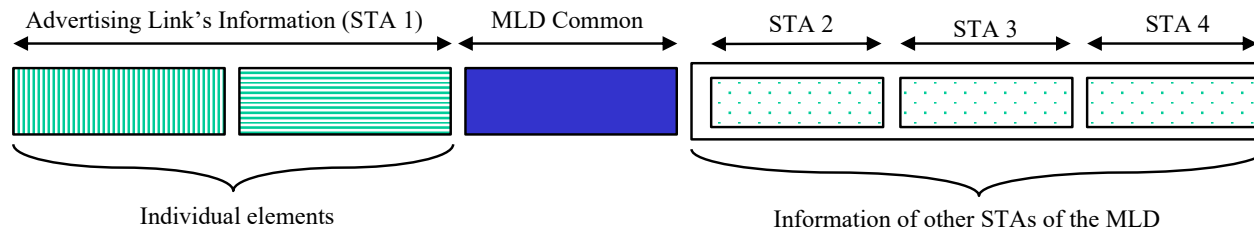
○ Multi-link discovery (2/6)

- **MLD discovery**

- A TBTT Information field of the RNR element, corresponding to a reported AP that is part of the same MLD as the reporting AP, includes an indication that the reported AP is part of the same MLD as the reporting AP.
- A STA of a non-AP MLD can send a probe request frame to an AP belonging to an AP MLD, which enables to request a probe response from the AP that includes the complete set of capabilities, parameters and operation elements of other APs affiliated to the same MLD as the AP.
 - A non-AP MLD may want to have the complete information on an AP MLD before multi-link setup.

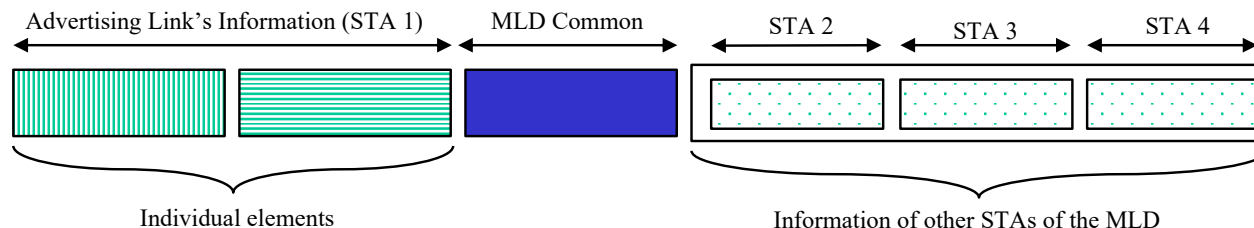
○ Multi-link discovery (3/6)

- **Multi-link operation (MLO) information**
 - A STA of an MLD provides MLO information in its management frames during discovery and ML setup.
 - **MLD (common) information**
 - Information common to all the STAs of the MLD
 - **Per-link information**
 - Capabilities and Operational parameter of other STAs of the MLD other than the advertising STA



○ Multi-link discovery (4/6)

- **Multi-link operation (MLO) information**
 - **An AP of an AP MLD advertises complete or partial information of other links.**
 - Partial information to prevent frame bloating
 - Example advertising complete or partial information
 - Frames exchanged during ML setup are expected to carry complete information.
 - Beacon frame is expected to carry partial information.
 - **The MLO framework should follow an inheritance model when advertising complete information of other link(s).**
 - Parameter (element) not advertised in a link's profile has the same value as the advertising link.

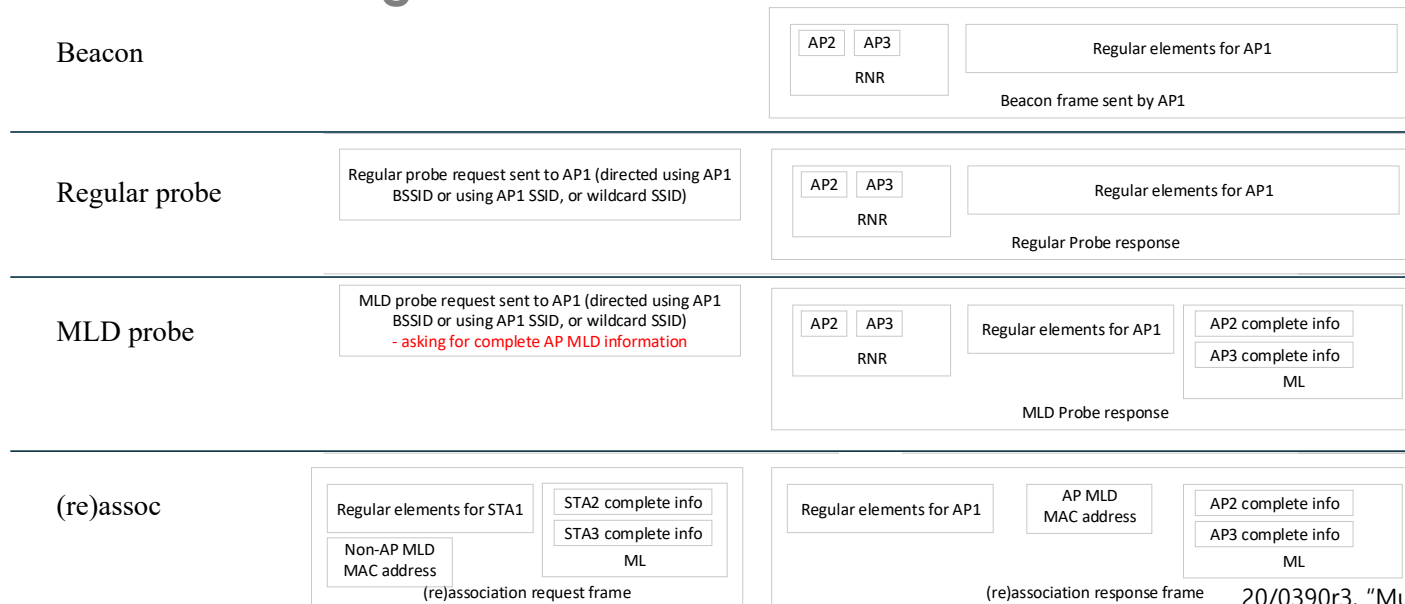


○ Multi-link discovery (5/6)

- Multi-link element

- 802.11be agrees to define a new Multi-Link element (MLE) to report/describe multiple STAs of an MLD with at least the following characteristics:

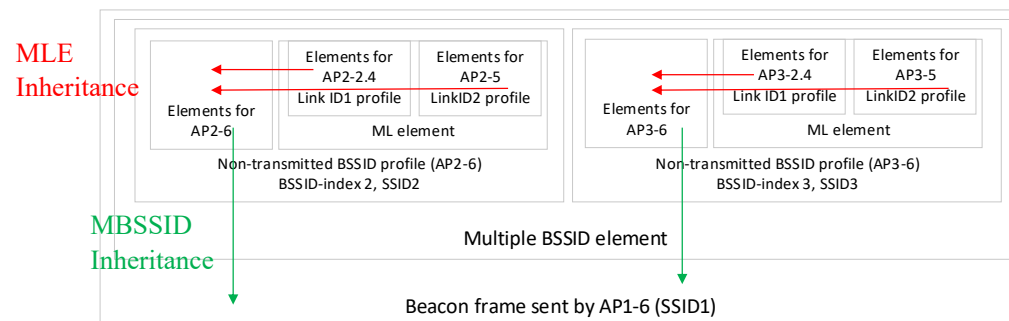
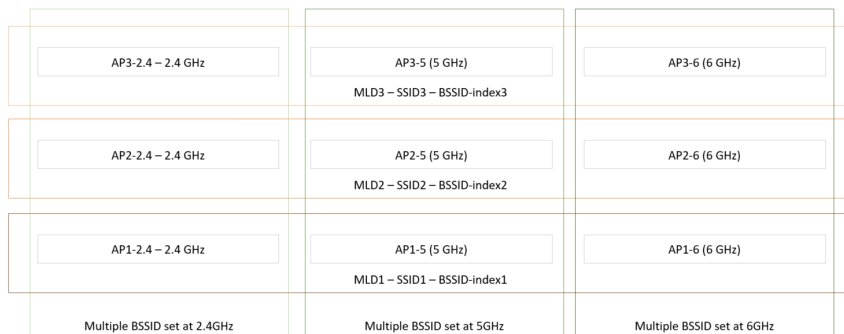
- MLD-level information may be included.
- A STA profile subelement is included for each reported STA (if any) and is made of a variable number of elements describing this STA.



○ Multi-link discovery (6/6)

- **Multi-link element**

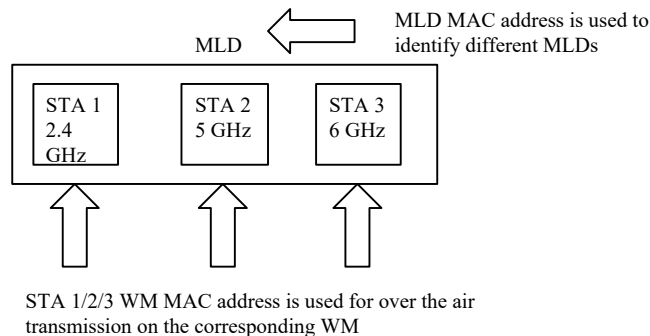
- **ML element can be included in a nontransmitted BSSID profile of a multiple BSSID set.**
- **Inheritance mechanism**
 - The value of an element of a reported STA that is not present in a STA profile of a ML element, if any, included in a nontransmitted BSSID profile of a nontransmitted BSSID in a multiple BSSID element is the same as the element of the nontransmitted BSSID, present elsewhere in the frame or as the element of the reporting STA, present elsewhere in the frame.



○ Multi-link setup (1/6)

- **MLD MAC address**

- **An MLD has a MAC address that singly identifies the MLD management entity.**



20/0054r3, "MLD MAC address and WM address"

- **An EHT MLD shall indicate its MLD MAC address during ML setup.**

20/0119r2, "Follow up discussion on multi-link operations"

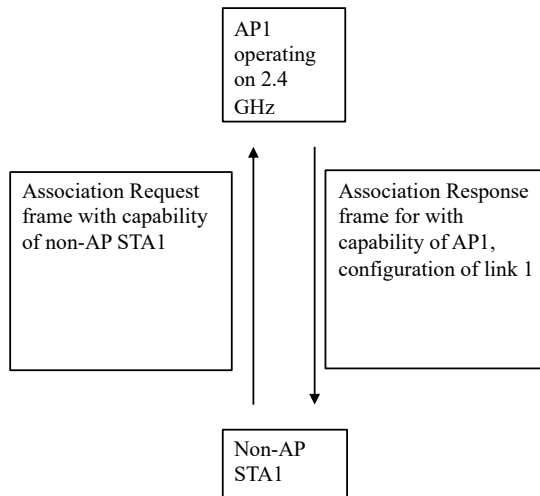
- **The value of the RA/TA fields sent over-the-air in the MAC header of a frame is the MAC address of the STA affiliated with the MLD corresponding to that link.**

19/1899r7, "MLA MAC addresses considerations"

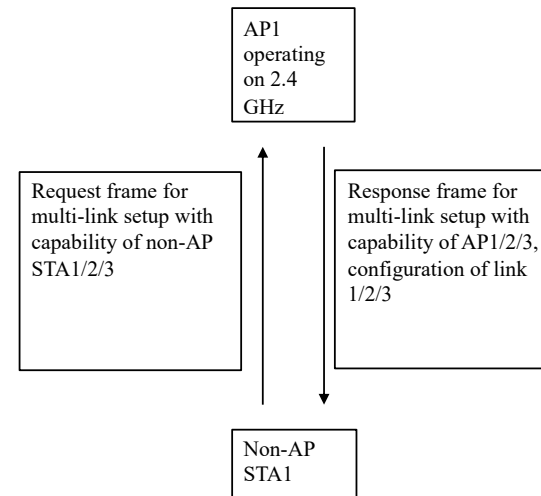
○ Multi-link setup (2/6)

- **Multi-link setup signaling exchange**
 - 802.11be defines a multi-link setup signaling exchange executed over one link initiated by a non-AP MLD with an AP MLD.
 - Capabilities and operating parameters for multiple links can be negotiated during a single setup signaling exchange.

- **Single link**

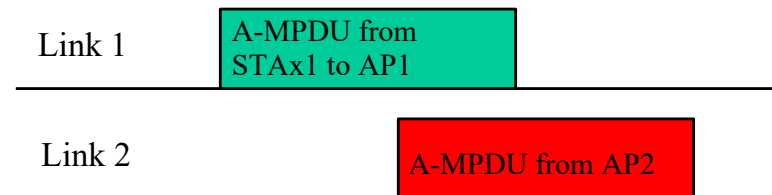
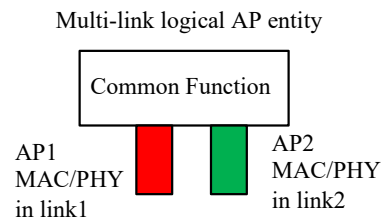


- **Multi-link**



○ Multi-link setup (3/6)

- Capabilities of simultaneous frame exchanges on multiple links
 - An MLD can indicate capability to support exchanging frames simultaneously on a set of affiliated STAs to another MLD.
 - An MLD that supports multiple links can announce whether it can support transmission on one link concurrent with reception on the other link for each pair of links.
 - A non-AP MLD may update its ability to perform simultaneous transmission and reception on a pair of setup links after multi-link setup.



○ Multi-link setup (4/6)

- **Frames for multi-link setup**

- Existing frames are reused for discovering APs that are affiliated with AP MLD.
- Association Request and Association Response frames are reused for multi-link setup.

20/0028r5, "Indication of multi-link Information"

- **Operational parameters**

- Each STA of an MLD may independently select and manage its operational parameters unless specified otherwise in the 802.11be standard.
 - Selection and management of operational parameters for a link may depend on local conditions of the link.
 - Operational parameters example: BSS color, (MU) EDCA, UORA, SRP, etc.

20/0314r1, "MLO: BSS color"

○ Multi-link setup (5/6)

- **Multi-link teardown**

- **802.11be defines a mechanism to teardown an existing multi-link setup agreement.**

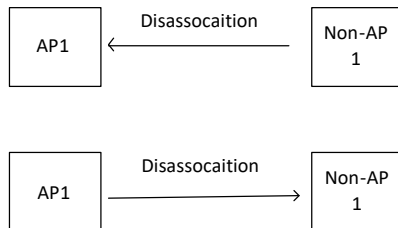
- For the association between an AP and a non-AP STA, there is disassociation to teardown the setup.

- **Disassociation frame is reused for multi-link teardown.**

- Authentication frame is reused for multi-link SAE exchange and multi-link Open System authentication.

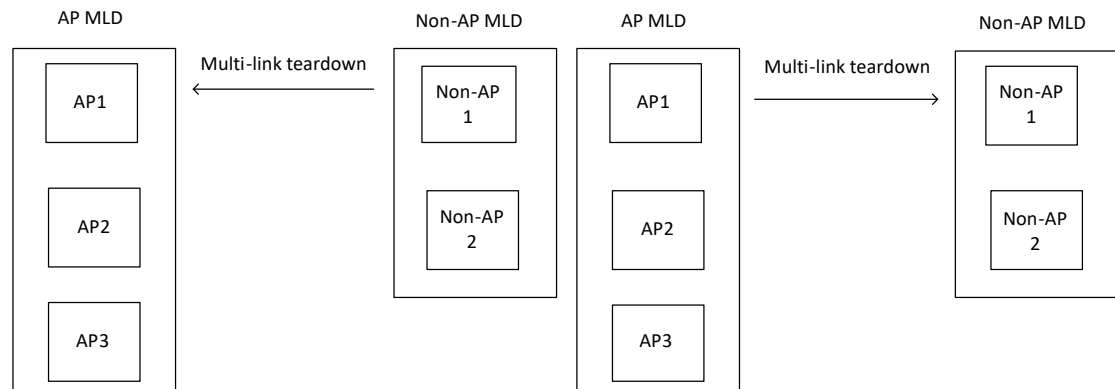
- **Single link**

Disassociation



- **Multi-link**

Multi-link teardown



○ Multi-link setup (6/6)

- **Multi-link resetup**

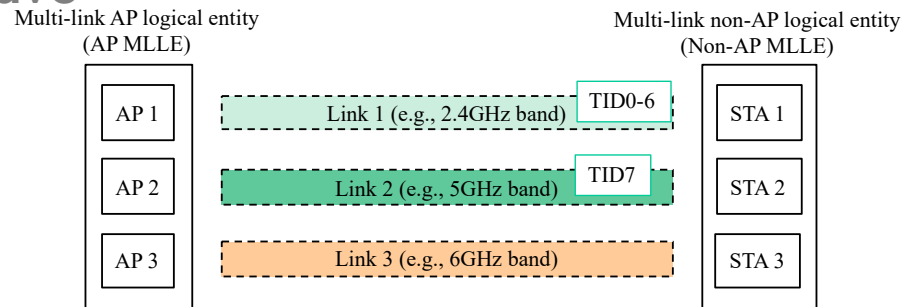
- **A multi-link resetup mechanism enables to resetup with another AP MLD or to change configuration of existing multi-link setup.**
- **Reassociation Request/Response frame is used for a multi-link resetup.**
 - When a non-AP MLD that has multi-link setup with current AP MLD sends a Reassociation Request frame to a new AP MLD, AP MLD MAC address of the current AP MLD is used in Current AP Address field of the frame.
 - When a STA of a non-AP MLD that has multi-link setup with current AP MLD sends a Reassociation Request frame to a new AP that is not affiliated with an AP MLD, AP MLD MAC address of the current AP MLD is used in Current AP Address field of the frame.

○ TID-to-link mapping (1/4)

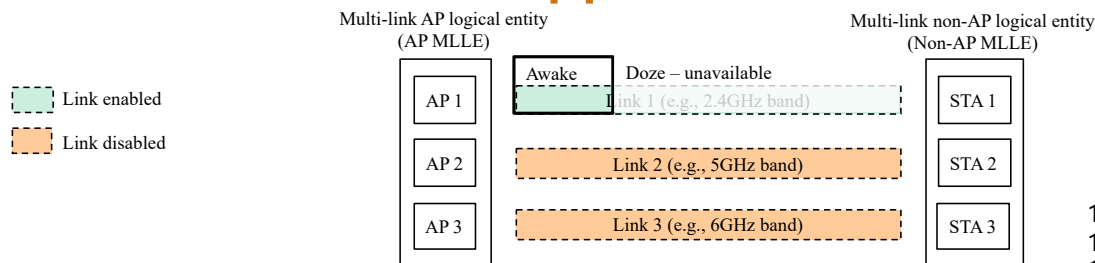
- TID-to-link mapping

- 802.11be defines a directional-based TID-to-link mapping mechanism among the setup links of an MLD.

- TID-to-link mapping for managing QoS, load balancing and power save



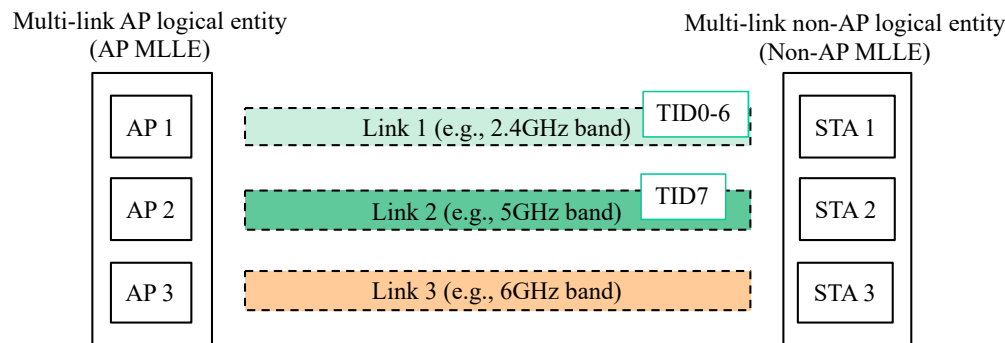
- A link, that is setup as part of a multi-link setup, is defined as Enabled if that link can be used for frame exchange and at least one TID is mapped to that link.



○ TID-to-link mapping (2/4)

- TID-to-link mapping

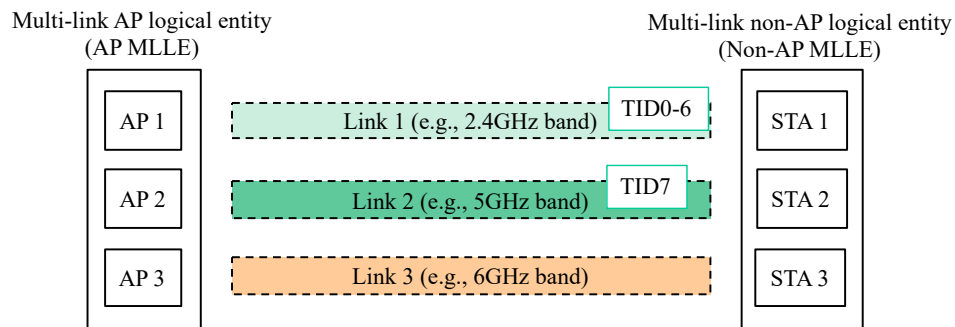
- By default, after the multi-link setup, all TIDs are mapped to all setup links.
- The multi-link setup may include the TID-to-link mapping negotiation.
 - TID-to-link mapping can have the same or different link-set for each TID unless a non-AP MLD indicates that it requires to use the same link-set for all TIDs during the multi-link setup phase.
- The TID-to-link mapping can be updated after multi-link setup through a negotiation, which can be initiated by any MLD.
 - When the responding MLD cannot accept the update, it can reject the TID-to-link mapping update.



○ TID-to-link mapping (3/4)

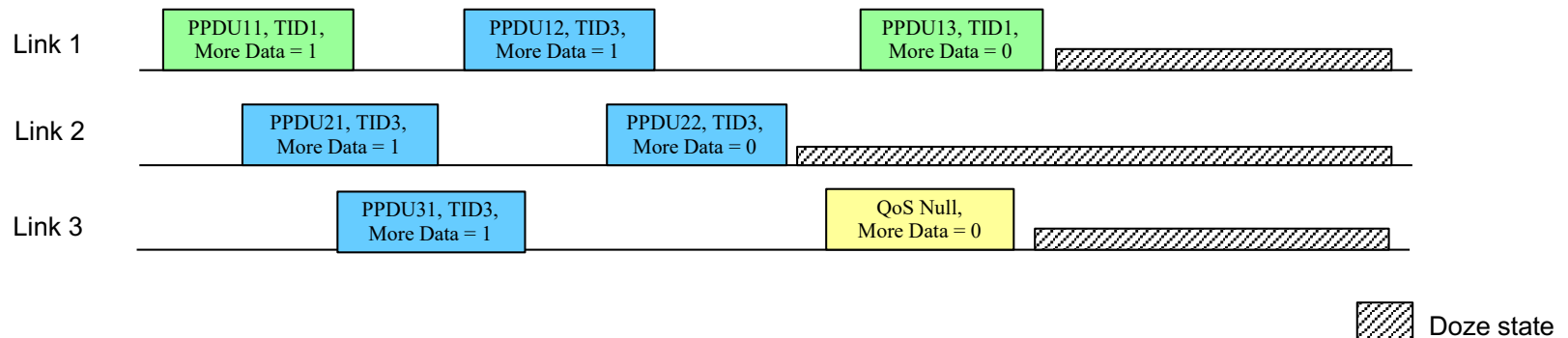
- TID-to-link mapping

- At any point in time, a TID shall always be mapped to at least one link that is set up, unless admission control is used.
- Management frames are allowed on all enabled links.
- If a TID is mapped in DL to a set of enabled links for a non-AP MLD, the non-AP MLD can retrieve buffered BUs corresponding to that TID on any links within this set of enabled links.



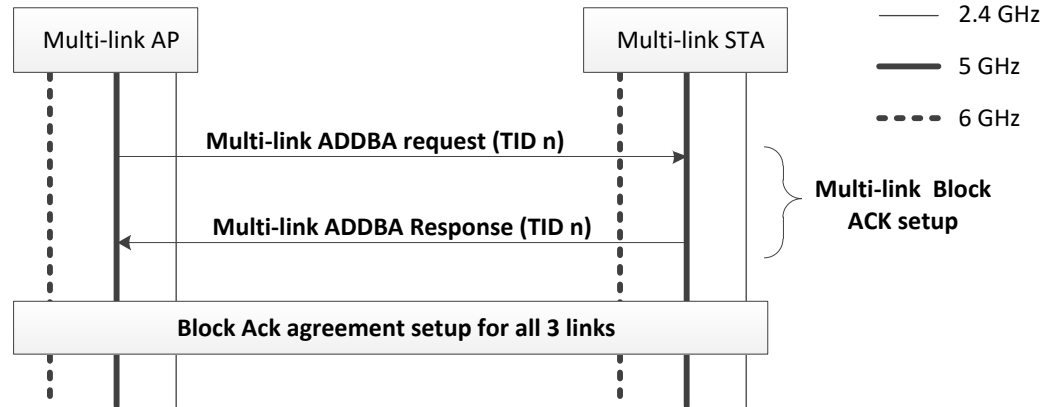
○ TID-to-link mapping (4/4)

- **More Data subfield setting**
 - When AP MLD transmit a BU in one link to a non-AP MLD, if there is at least one additional buffered BU of any TID or management frames that is mapped to this link by TID-to-link mapping or default mapping for the same non-AP MLD, the More Data subfield is set to 1, otherwise the More Data subfield is set to 0.
 - A STA uses the More Data subfield to indicate to a STA in PS mode that more BUs are buffered for that STA at the AP.



○ Multi-link block ack (1/5)

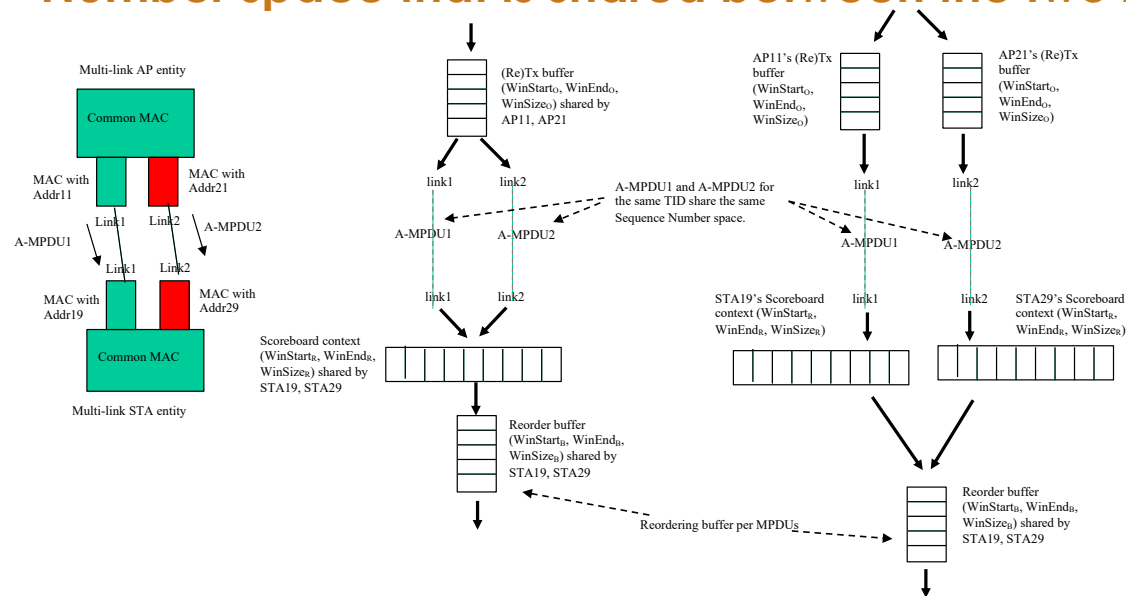
- Block ack agreement



- A single block ack agreement is negotiated between two MLDs for a TID that may be transmitted over one or more links.
- A block ack agreement for multi-link operation is setup by using ADDBA request and ADDBA response frames.
- The established block ack agreement allows the QoS Data frames of the TID, aggregated within the A-MPDUs, to be exchanged between the two MLDs on any available link.

Multi-link block ack (2/5)

- **Receive reordering buffer control**
 - For each block ack agreement, there exists one receive reordering buffer based on MPDUs in the MLD which is the recipient of the QoS Data frames for that block ack agreement.
 - After the BA agreement of a TID between two MLDs, the common reordering buffer of the TID are applied on all setup links (No need to reestablish BA agreement after TID-to-link mapping update).
 - The receive reordering buffer operation is based on the Sequence Number space that is shared between the two MLDs.



○ Multi-link block ack (3/5)

- **Block ack bitmap**
 - **802.11be adds 512 and 1024 bitmap sizes.**
 - To increase MAC efficiency considering higher peak throughput of 802.11be that supports 320 MHz bandwidth, 16 spatial streams, 4K QAM, and multi-link operation
 - 802.11be uses B3 equal to 1, B2 B1 equal to 0 and B0 equal to 0 in Fragment Number field to indicate 512 BA bitmap length and to use B3 equal to 1, B2 B1 equal to 0 and B0 equal to 1 in Fragment Number field to indicate 1024 BA bitmap length in compressed BA and multi-STA BA.
- **Fragment Number subfield encoding for the Multi-STA BlockAck variant**

Fragment Number subfield			Fragmentation Level 3 (ON/OFF)	Block Ack Bitmap subfield length (octets)	Maximum number of MSDUs/A-MSDUs that can be acknowledged
B3	B2 B1	B0			
0	0	0	OFF	8	64
0	1	0		16	128
0	2	0		32	256
0	3	0		4	32
0	0	1	ON	8	16
0	1	1		16	32
0	2	1		32	64
0	3	1		4	8
1	Any	Any		Reserved	Reserved

NOTE—A Multi-STA BlockAck frame with B0 of the Fragment Number subfield set to 1 cannot be sent to an HE STA unless the HE Capabilities element received from the HE STA has the Dynamic Fragmentation Support subfield equal to 3 (see 26.3 (Fragmentation and defragmentation)).

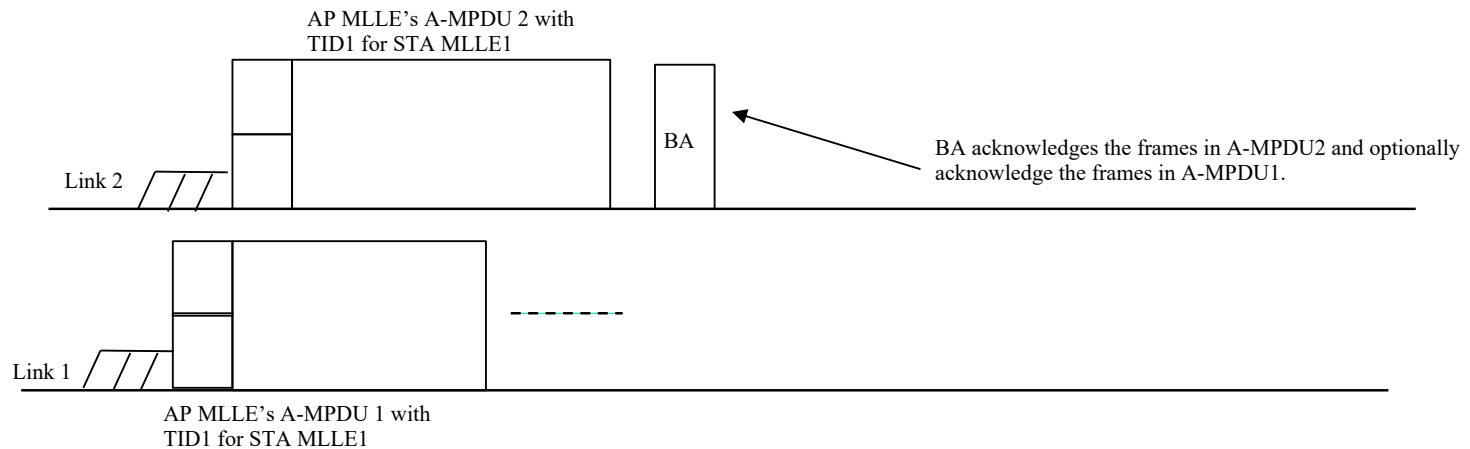
20/0053r4, "Multi-link BA"

20/0441r3, "MLA: BA format"

20/0397r4, "Sequence number and BA operation with large BA buffer size"

○ Multi-link block ack (4/5)

- Receive status on multiple links



- The receive status of QoS Data frames of a TID received on a link shall be signaled on the same link and may be signaled on other available link(s).

○ Multi-link block ack (5/5)

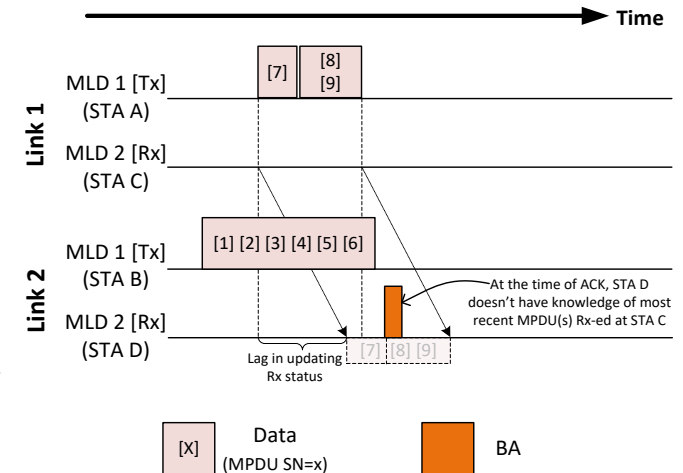
- **Receive status on multiple links**

- **STAs of an MLD may not exchange information instantaneously.**

- A STA of an MLD may not have knowledge of the most recently received (or transmitted) MPDUs by another STA of that MLD.

- **An originator MLD of a BA agreement:**

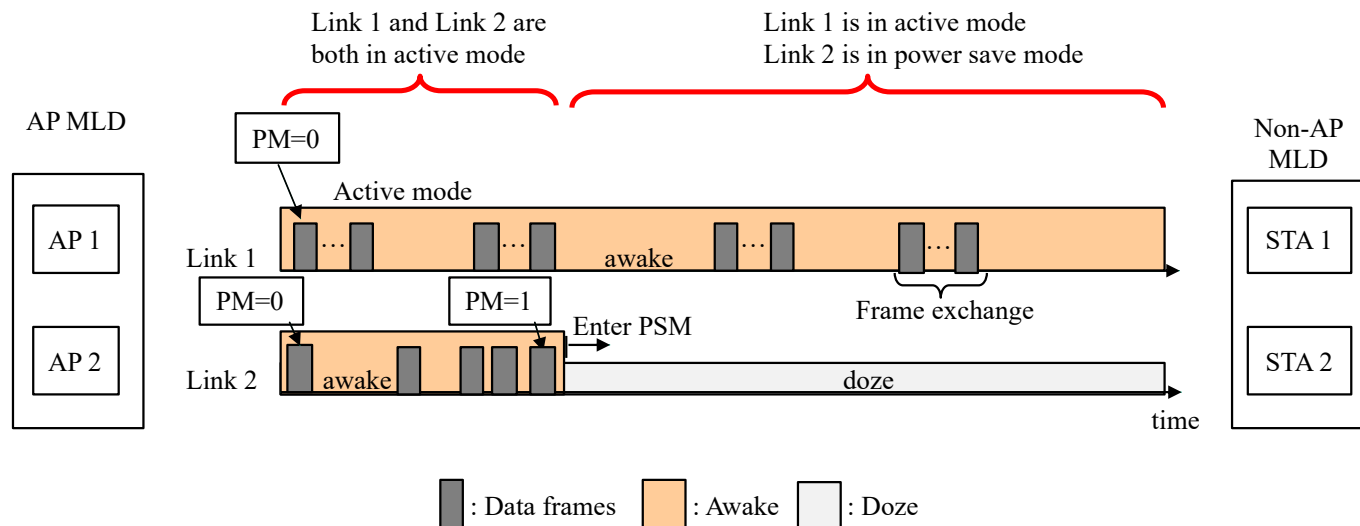
- shall update the receive status for an MPDU corresponding to the BA agreement if the received status indicates successful reception.
- shall not update the receive status for an MPDU corresponding to the BA agreement that has been already positively acknowledged.
 - A value 0 in the BA Bitmap provides no information.



Multi-link power save (1/4)

- Multi-link power save

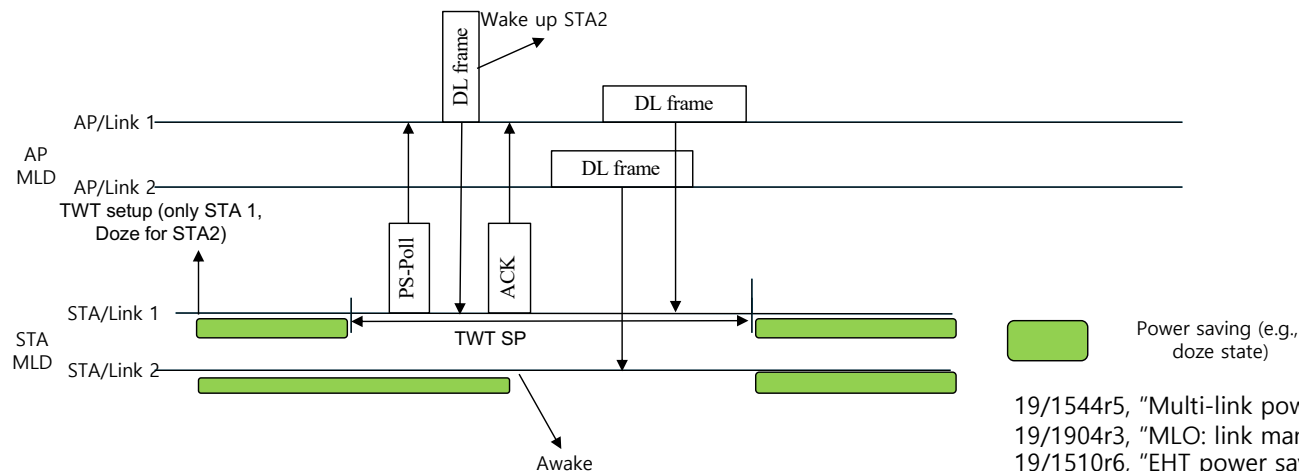
- For each of the enabled links, frame exchanges are possible when the corresponding non-AP STA of the enabled link is in the awake state.
- Each non-AP STA affiliated with a non-AP MLD that is operating on an enabled link maintains its own power state/mode.



○ Multi-link power save (2/4)

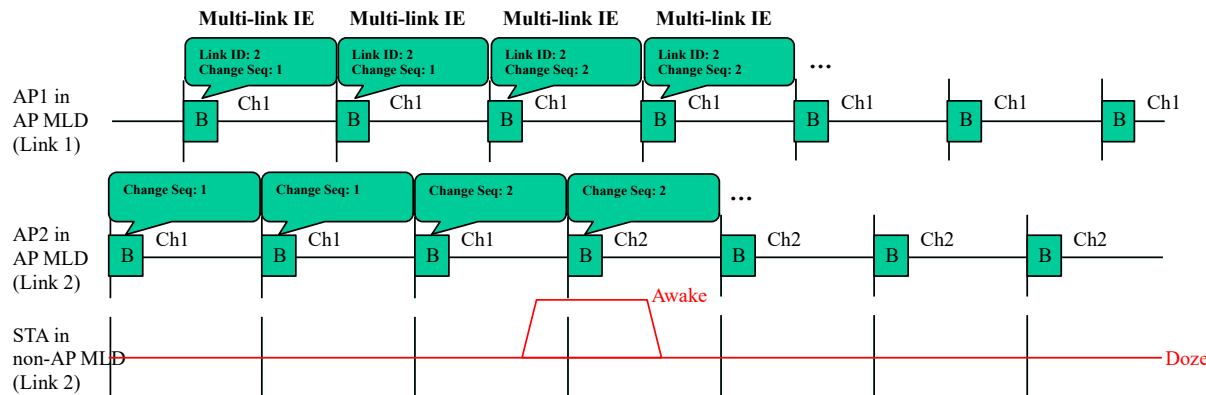
- MLD indications

- An AP of an AP MLD may transmit on a link a frame that carries an indication of buffered data for transmission on other enabled link(s).
- An AP MLD can recommend a non-AP MLD to use one or more enabled links.
- For a link setup between an AP MLD and a non-AP MLD, a non-AP STA operating on that link can send to an AP operating on that link an indication that (an)other non-AP STA(s) within the same non-AP MLD that has(have) transition to doze state is(are) in awake state.



Multi-link power save (3/4)

- Critical updates



For example, a non-AP MLD only monitors the link 1 for the BSS parameter update. A STA in the non-AP MLD is awake to receive on the link 2 the next Beacon frame sent by the AP2 within the AP MLD, after receiving the Change Sequence field set to 2 on the link 1 which is different with the previously received Change Sequence field.

- Some STAs of a non-AP MLD may not monitor its associated BSS parameter update.
- An AP within an AP MLD shall include in the Beacon and Probe Response frames it transmits the Change Sequence fields that indicate changes of system information for other APs within the same AP MLD that increments as the critical update of the reported AP is occurred.

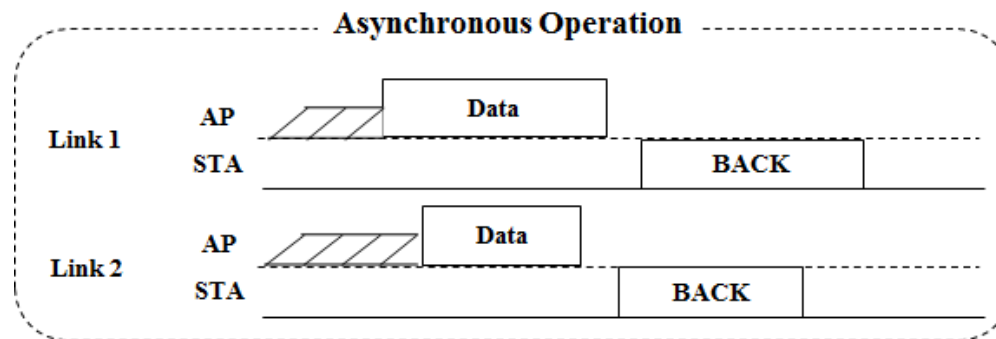
○ Multi-link power save (4/4)

- Multi-link TIM

- When a non-AP MLD made a multi-link setup with an AP MLD, one AID is assigned to the non-AP MLD across all links.
- A bit in a partial virtual bitmap of a TIM element that corresponds to a non-AP MLD is set to 1 if any individually addressed BUs for the non-AP MLD are buffered by the AP MLD.

○ Multi-link channel access (1/2)

- **Asynchronous multi-link channel access**
 - 802.11be allows the following asynchronous multi-link channel access.
 - Each of STAs belonging to an MLD performs a channel access over their links independently in order to transmit frames.
 - Downlink and uplink frames can be transmitted simultaneously over the multiple links.

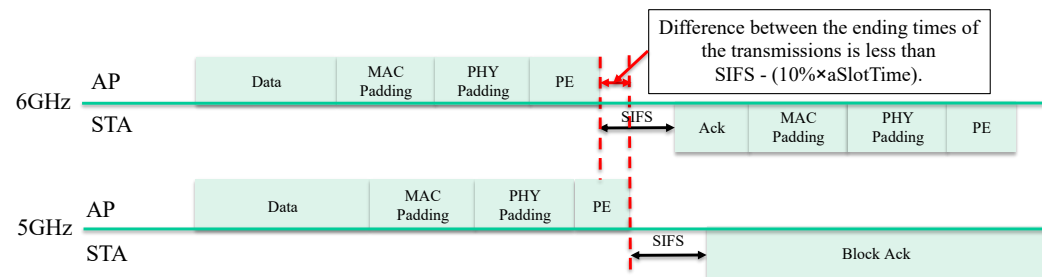
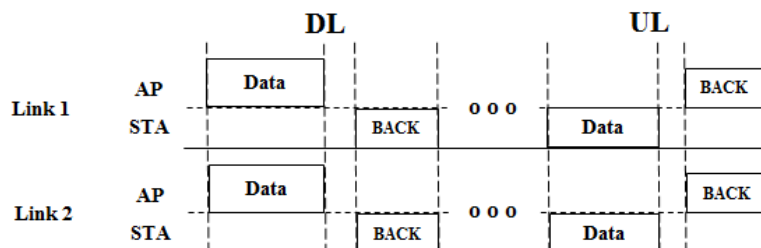


○ Multi-link channel access (2/2)

- Operations for non-STR MLD

- 802.11be shall allow an MLD that has constraints to simultaneously transmit and receive on a pair of links to operate over this pair of links.

- If an AP MLD intends to align the ending time of DL PPDU's carrying a frame soliciting an immediate response simultaneously sent to the same non-STR non-AP MLD on multiple links, the AP MLD shall ensure that the difference between the ending times of transmitting DL PPDU's is less than TBD ($< \text{SIFS}$).
- When a STA in a non-STR MLD receives an RTS addressed to itself, if the NAV of the STA indicates idle but another STA in the same MLD is either a TXOP holder or a TXOP responder, the STA may not respond with a CTS frame.

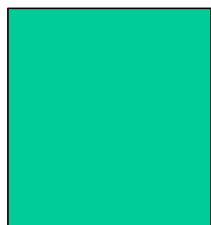


19/1144r6, "Channel access for multi-link operation"
19/1405r7, "Multi-link channel access discussion"
19/1305r4, "Synchronous multi-link operation"

○ TXOP (Trasmit Oppprtunity)

- **BW > 160 MHz and preamble puncturing**
 - **802.11be supports defining a MAC mechanism to protect TXOP for PPDUs with > 160 MHz and/or PPDUs with preamble puncturing.**
 - 802.11be supports transmitting the MU-RTS/RTS and CTS frames in a non-HT duplicate PPDU on 20 MHz subchannels which are not punctured.
 - 802.11be supports indicating BW larger than 160 MHz through scrambler sequence in non-HT or non-HT duplicated frames.

• EHT PPDU examples

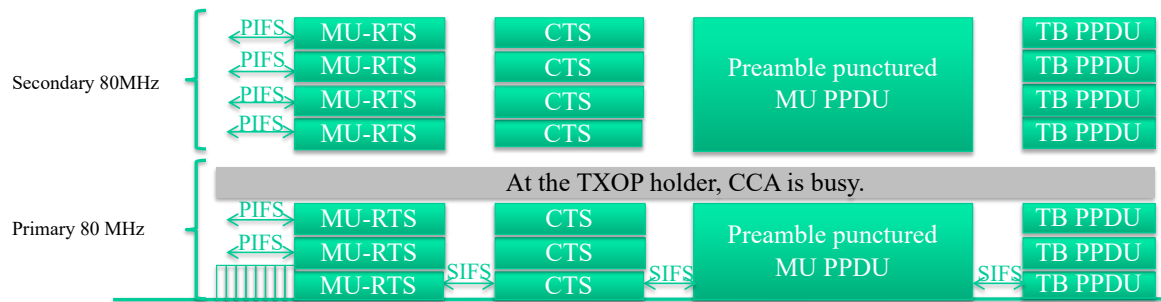


320MHz EHT PPDU at 5GHz or 6GHz band



160+80 MHz EHT PPDU at 5GHz or 6GHz band

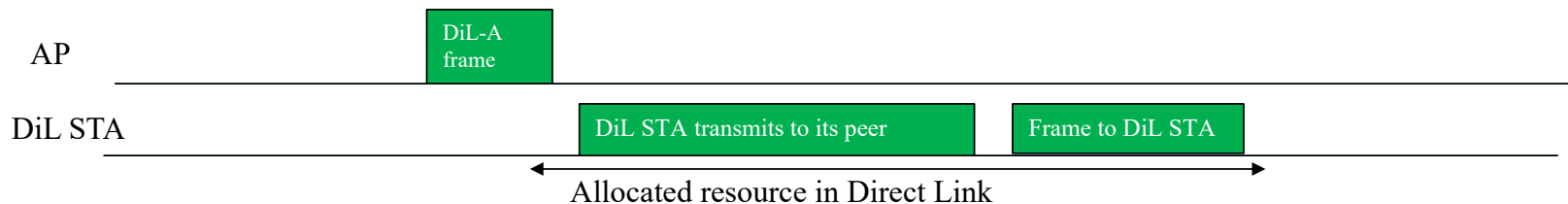
• RTS/CTS procedure example



20/0062r0, "Protection with more than 160MHz PPDU and puncture operation"
 19/2125r2, "EHT RTS and CTS procedure"
 20/0616r0, "Bandwidth indication of 320MHz for non-HT and non-HT duplicate frames"

○ Direct link transmission

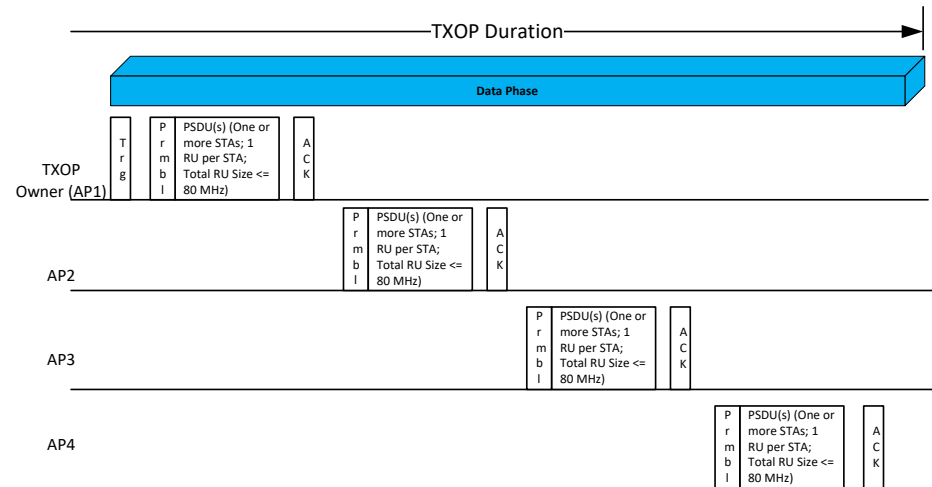
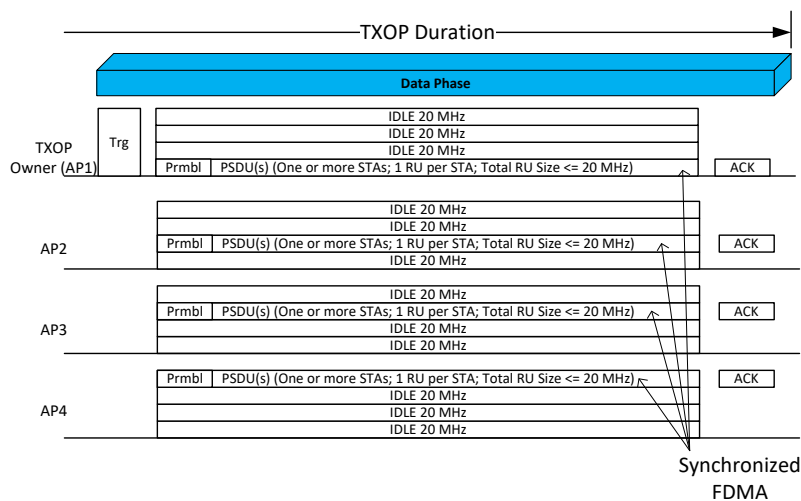
- Direct link transmission
 - 802.11be defines mechanism(s) for an AP to assist a STA that communicates with another STA.
 - 802.11be supports defining a procedure for an AP to share time resource obtained in a TXOP for peer to peer (STA-TO-STA) frame exchanges.



○ Multi-AP operation (1/2)

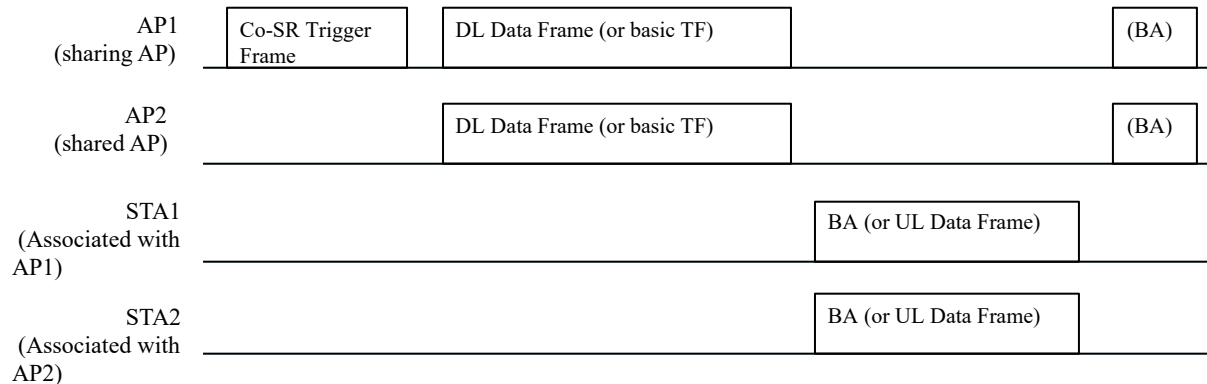
• Coordinated transmission

- 802.11be defines a procedure for an AP to share its frequency/time resources of an obtained TXOP with a set of APs.
- Coordinated OFDMA is supported in 11be, and in a coordinated OFDMA, both DL OFDMA and its corresponding UL OFDMA acknowledgement are allowed.



○ Multi-AP operation (2/2)

- Multi-AP coordination



- **A coordinated spatial reuse operation**

- One AP triggers one or more APs.
- AP1 contends the channel and sends a co-SR Trigger frame including control information.
- AP1 and AP2 transmit data concurrently, when predefined conditions are met.

○ Summary

- IEEE 802.11be (Wi-Fi 7)
- MAC main features
 - Multi-link device
 - Multi-link discovery
 - Multi-link setup
 - TID-to-link mapping
 - Multi-link block ack
 - Multi-link power save
 - Multi-link channel access
 - TXOP (Transmit Opportunity)
 - Direct link transmission
 - Multi-AP operation

THANK YOU

