IEEE P802.11
Wireless LANs

|  |
| --- |
| MLD architecture part 2 |
| Date: 2021-09-15 |
| Author(s): |
| Name | Company | Address | Phone | email |
| Mark Hamilton | Ruckus/CommScope | 350 W. Java DrSunnyvale, CA | +1 303 818 8472 | mark.hamilton2152@gmail.com  |
|  |  |  |  |  |

Abstract

This submission builds upon the MLD architecture presented in 11-21/0577, by adding support for group addressed transmissions from AP MLD, and legacy operation.

R0 – Initial discussion document.

R1 – Added proposed resolution text for the relevant CIDs.

R2 – After discussion of Affiliated STA definition, captured alternate concept that an affiliated STA/AP is defined to provide the communication path between MLDs, without further details.

R3 – Agreed the non-AP STA is either MLD or “legacy” and never a combination (as opposed to the AP MLD, which is a combination). Wording needs to be updated to align with this agreement. Clarified power save state tracking versus power save buffering, w.r.t. upper/lower MAC sublayer functions.

R4 – Updated based on comments from Aug 30 teleconference. Updates are labelled with “8/30”.

R5 – Updates during Sept 9 teleconference (marked with “9/9”).

R6- Updates follow Sept 9 teleconference, based on discussion on that call. Marked with “9/13”.

R7 – Updates per 11-21/0209 review.

R8 – Updates from Sept 14 telecon. Marked with 9/14.

**Introduction**

This document takes the text of 11-21/0577r5 as a baseline, and extends the MLD architecture concepts in that document, to add architectural support for group addressed frames and legacy operation (of affiliated STAs), along with some (mostly) editorial suggestions.

**CC36 CIDs:**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 5171 | Guogang Huang | 3.2 | 41.16 | For the AP MLD, If there are legacy STAs which associate with affiliated APs, then each affiliated AP will have a MAC SAP to LLC, which is identify by the MAC address of the corresponding affiliated AP. | Please add a note below the MLD definition, e.g.Note. For an AP MLD, If there are legacy STAs which associate with each affiliated AP, then each affiliated AP will also have a MAC SAP to LLC, which is identify by the MAC address of the corresponding affiliated AP. | **Revised.****The MAC SAP at an AP serves the DSAF, not LLC. However, the intent of the clarification is agreed.** **Make the changes shown in 11-21/1111, which adds the architectural structure for affiliated APs to the AP MLD concepts.** |
| 5172 | Guogang Huang | 4.9 | 49.44 | Add a subclause 4.9.5 to describe the reference model for MLD and explain the legacy support of the AP MLD | As in comment. | **Revised. Make the changes shown in 11-21/1111, which adds the architectural structure for affiliated APs to the AP MLD concepts.** |
| 5173 | Guogang Huang | 7.1 | 0.00 | Update the figure 7-1 DS architecture, and clarify the number of DS SAPs for an AP MLD especially when there are legacy STAs associated with each affiliated AP | As in comment. | **Revised. Make the changes shown in 11-21/1111, which adds Figure 7-2 to show the DS SAPs, as requested.** |
| 6187 | Michael Montemurro | 4 | 45.01 | In MLO, affiliated APs are able to provide BSS connectivtiy to legacy STAs but there is no description on how this works. Proide a description of how an affiiated AP can service legacy STAs while also operating with an MLD to support MLO. | The commenter is willling to collaborate on a contribution which would add a description to address this comment. | **Revised. Make the changes shown in 11-21/1111, which adds the architectural structure for affiliated APs to the AP MLD concepts.** |
| 7349 | Stephen McCann | 3.2 | 41.12 | A definition of "affiliated" would be useful in clause 3.2 | Add the following definition "Affiliated: A STA and an MLD that are co-located or connected through an existing security relationship." | **Revised. Make the changes shown in 11-21/1111, which adds definitions for affiliated AP and affiliated STA.** |

**Discussion:**

1. **Affiliated STA**:

Multiple places in the TGbe draft and 11-21/0577r5 refer to affiliated STAs/APs (of course). But, this term is never clearly defined. We do have the following definitions (TGbe draft) which imply the concept:

**access point (AP) multi-link device (MLD):** An MLD, where each station (STA) affiliated with the MLD is an AP.

**multi-link device (MLD):** A device that is a logical entity and has more than one affiliated station (STA) and has a single medium access control (MAC) service access point (SAP) to logical link control (LLC), which includes one MAC data service.

**non-access point (non-AP) multi-link device (MLD):** An MLD, where each station (STA) affiliated with the MLD is a non-AP STA.

Concept of affiliated AP/STA?: When an MLD association is done, the affiliated APs/STAs provide the communication path between the MLDs (similarly, the affiliated APs provide the pre-association services for the AP MLD).

There appear to be only two possibilities for the concept being described as “affiliated” STA or AP: either this is a ‘complete’ stack logically parallel and adjacent to the MLD stack, or this concept refers only to the “MLD lower MAC sublayer” that is part of MLD operation. However, consider:

1. If we take it literally that whether affiliated or not, a “STA” or an “AP” fulfills the definition of those terms, then they need to be ‘complete’ in the sense of providing MAC service, and attaching to the DS in the case of an affiliated AP.
2. To support “legacy” operation (non-MLD associations) the affiliated STA/AP needs to be ‘complete’ in the same sense.

Thus, it seems the ‘complete’ stack is the more logical view. This leads to a definition of affiliated STA as something similar to:

**affiliated STA**: A STA that shares MLD lower MAC sublayer components with a co-located non-AP MLD.

And:

**affiliated AP**: An AP that shares MLD lower MAC sublayer components with a co-located AP MLD.

This leads to needing a definition of “MLD lower MAC sublayer” (and therefore MLD upper MAC sublayer). Suggest the following, based on 11-21/0577 wording:

**MLD lower MAC sublayer:** The link-specific components of an affiliated STA or affiliated AP, whose operation is shared with a co-located MLD.

**MLD upper MAC sublayer:** The components of an MLD that perform functionalities that are common across all links supported by the MLD.

NOTE: Per editorial convention, the concepts of MLD upper/lower MAC sublayer are not capitalized. That change to 11-21/0577 is shown in the Proposed Changes, below.

This definition of affiliated STA/AP implies some slight wording changes, as shown in the Proposed Changes, below.

1. **Group addressed MSDU handling and legacy operation:**

**Group addressed MSDU handling:**

11-21/0577 touched on group addressed frames, but only superficially. It mentioned that there are separate GTK/IGTK/BIGTK maintained per link, and that group addressed frame encryption and decryption are done with the GTK for a given link. Further clarification and details are needed, however.

First, it needs to be noted that with separate group keys per link, there needs to be separate key management per link. This implies a separate Authenticator/Supplicant context per link paired with the link’s specific RSNA key management for group keys. Thus, our architectural model for an MLD needs to be extended to add these RSN facilities per link, for the group addressed frames and group key handling.

Note that these RSN facilities are the same ones as used by the affiliated AP for legacy operations (with associated non-MLD peers). See next section…

**Legacy operations:**

Legacy operation of the affiliated APs collocated with an AP is a key feature, which raises some architectural details. In particular, since the MLD lower MAC sublayer is shared between the MLD and legacy upper MAC sublayers, the operation of this sharing needs to be specified where it affects externally visible behavior. To support group addressed security contexts (one set of GTK/IGTK/BIGTK per link), and legacy operation (PTK per peer STA) an AP MLD maintains an Authenticator per link (with legacy association PTKSAs, as well as GTK/IGTK/BIGTK for that link) and an Authenticator for the AP MLD (with PKTSAs per MLD association). These Authenticators cooperate as needed, on key updates, etc.

**Non-AP MLD and legacy non-AP STA:**

On the non-AP MLD, there is no need for this complexity. A non-AP MLD is simply a MLD upper MAC sublayer, and multiple MLD lower MAC sublayers (one for each link). A non-AP device that switches from MLO to legacy operation (when roaming to a legacy AP, for example), retains the upper MAC sublayer and only one lower MAC sublayer, thus switching to operation over a single link, but making the transition invisible to the upper layers. Further, only one Supplicant is modelled in the reference model for the non-AP MLD. However, this Supplicant is enhanced over a legacy non-AP STA, in that it can manage the multiple sets of GTK/IGTK/BIGTK, one set per each link.

Also continued into next section…

**Adding group addressed MSDU handling, and legacy operation:**

To complete the terminology, add a definition for the “upper MAC” that is used outside the MLD, for legacy and group addressed frames. Note that this is simply the legacy (non-MLD) upper MAC, but with extensions as needed to support group addressed traffic for a co-located MLD, if there is one. Also, it is not appropriate to use the word “legacy” in the amendment, since it will be unclear what change this is “legacy” to, as more amendments are added in subsequent years, so suggest calling this “non-MLD” instead of ‘legacy”.

Proposed additional definition:

**non-MLD upper MAC sublayer:** The components of an affiliated AP that perform functionalities above the lower MAC sublayer for link-specific (non-MLD) traffic, and for group addressed MLD traffic.

Then, we can add a reference model figure (new Figure 4-29c, below) that shows how these co-located MLD and non-MLD sublayers relate to each other on an AP, similar to the existing Figure 4-27. Suggest keeping this high-level, however, not showing the separate components for the data plane and management plane (yet), as that gets too complicated in one figure. (We have the new Figure 4-29a to show the data plane/management plan relationships.) As it gets too complicated to show all the planes and connections in one Figure, in clause 5, we can reference this new high-level figure (Figure 4-29c), in combination with Figure 5-2a and Figure 5-1, to explain that the complete view of an AP MLD and its affiliated APs is the combination of these figures.

1. **Minor updates to Figure 5-2a**

Figure 5-2a is slightly modified editorially. The grey boxes showing the upper and lower MAC functionalities will not copy well and the layers of boxes get confusing, so suggest replacing with braces instead. The separation of TX and RX functions in the upper MAC is carried over into the lower MAC, for consistency.

An additional figure and text are added following Figure 5-2a, to introduce the MPDU distribution function at the top of the MLD lower MAC sublayer to support legacy operation (distributing to the MLD or an affiliated AP, based on a mapping from the TA) and the transmission of group addressed frames.

1. **Function(s) of MLD lower MAC sublayer:**

As the MLD lower MAC sublayer comprises only some link-specific, low-level MAC functions (as shown in Figure 5-2a), this component cannot perform many complex MAC functions. Instead, it is actually the non-MLD upper MAC sublayer of an affiliated AP that performs these functions.

The discussion in 4.9.5 of where functions are performed needs to be updated to clarify this. Examples include:

* Maintenance of Link-specific GTK/IGTK/BIGTK (between an AP affiliated with the AP MLD and a STA affiliated with the non-AP MLD)
* Link-specific encryption/decryption/integrity protection and PN assignment using GTK/IGTK/BIGTK (between an AP affiliated with the AP MLD and a STA affiliated with the non-AP MLD)

And, some functions described in 4.9.5 (of 11-21/0577) could be clarified that it is only the *tracking* of this information that is (or could be) performed in the MLD lower MAC sublayer, including:

* Power save state and mode

while power save queuing and timing are managed by the MLD upper MAC sublayer.

1. **Reorganize text from 11-21/0577**

Now that the concepts for MLD are complete (including the “legacy” operations), we can re-visit the organization of the introductory material in clause 4. There are generally three types of material: 1) an introduction to the concepts of multi-link operation between peers; 2) some description, still high-level/reference model, to expand on these architectural concepts at the level of the rest of clause 4, just clarifying concepts but not operational structure and details; 3) details that do get into the operation of the concepts and the detailed components of the stack.

Recommendation: Arrange the text in the new subclause 4.9.5 by introducing the multi-link concepts at a high-level first (the text shaded in red below), and then the reference model that can support this behavior (the text shaded in blue below). Move text shaded in green from clause 4 into clause 5, as this introduces the details of stack components and helps explain Figure 5-2a, and is more relevant where those details are discussed.

**Proposed Changes:**

***Changes proposed by this document are shown with underscore*** ***additions and ~~strikethrough~~ deletions, treating the text from 11-21/0577r5 as baseline.***

***Track changes are used for discussion purposes only, as revisions of this document are reviewed and edited.***

***TGbe editor: Please add the following new section 4.9.5 to the spec:***

***Text shaded in red is to appear first, then the text shaded in blue (and then the added (unshaded) text). The text shaded in green is moved to clause 5, and inserted where noted there. An example of the final order and contents of 4.9.5 appears as an Annex to this document.***

**4.9.5 Reference model for multi-link operation (MLO)**

MLO allows operation over multiple links. The reference model of a multi-link device (MLD) (see 35.3 (Multi-link operation)) is shown in Figure 4-29a (Reference model for an MLD).

NOTE—For simplicity, Figure 4-29a (Reference model for an MLD) depicts the reference model when there are two links, while in general, an MLD can support more than two links.



An MLD manages such communication over multiple links. Communication across different frequency bands/channels can occur simultaneously or not depending on the capabilities of both the AP MLD and the non-AP MLD (see 35.3.13.2 (Simultaneous transmit and receive (STR) operation) and 35.3.13.3 (Nonsimultaneous transmit and receive (NSTR) operation)).

NOTE—The SME boundary top is left open in Figure 4-29a (Reference model for an MLD) to indicate that the SME can contain other functions that are not defined by this standard.

An MLD supports multiple MAC sublayers, coordinated by an SME.

The SME maintains the authentication and association states. The Authenticator and the MAC-SAP of the AP MLD are identified by the same AP MLD MAC address. The Supplicant and the MAC-SAP of the non-AP MLD are identified by the same non-AP MLD MAC address.

The MLO procedures (see 35.3 (Multi-link operation)) allow a pair of MLDs to discover, synchronize, (de)authenticate, (re)associate, disassociate, and manage resources with each other on any common bands or channels that are supported by both MLDs.

As described in 35.3.1 (General), each AP MLD has a single MAC-SAP and each non-AP MLD has a single MAC-SAP. Each AP affiliated with an AP MLD has a ~~different~~ MAC address different from any other AP affiliated with the AP MLD, ~~within the MLD~~ and each STA affiliated with a non-AP MLD has a ~~different~~ MAC address different from any other STA affiliated with the non-AP MLD~~within the MLD~~.

The SME is responsible for coordinating each of the MLMEs of all affiliated STAs, and to maintain an ~~single~~ RSNA key management entity~~, as well as a single~~ and IEEE 802.1X Authenticator or Supplicant in each upper MAC sublayer component, for MLO.

An example of an AP MLD with two links (Link 1 and Link 2) is shown in Figure 4-29b (Example MLD and the affiliated STA communication system). The figure shows a~~A~~n AP MLD with MLD MAC address *M* and the MLD lower MAC sublayers of two affiliated APs (AP1 with MAC address *w* and AP2 with MAC address *x*). The AP MLD is associated with a non-AP MLD with MLD MAC address *P* and the MLD lower MAC sublayers of two affiliated STAs (STA1 with MAC address *y* and STA2 with MAC address z*)* are shown*.* Link 1 is established between AP1 and STA1 and link 2 is established between AP2 and STA2. In general, the MAC address of an MLD and the MAC addresses of the STAs affiliated with the MLD are all different (e.g., *M*, *P*, *w*, *x*, *y*, and *z* have different values).



**Figure 4-29b – Example MLD and the affiliated STA communication system**

The MAC Sublayer is further divided into an MLD ~~U~~upper MAC sublayer and an MLD ~~L~~lower MAC sublayer. The MLD ~~U~~upper MAC sublayer ~~(MLD)~~ performs functionalities that are common across all links, and the MLD ~~L~~lower MAC sublayer (shared with an AP or STA affiliated with the MLD) performs functionalities that are local to each link. Some of the functionalities require joint processing of both the MLD ~~U~~upper MAC sublayer and MLD ~~L~~lower MAC sublayer~~s~~.

An AP MLD always operates co-located with more than one non-MLD APs, one for each physical link, known as affiliated APs. Some behaviors of MLO require the use one or more of these affiliated APs’ stack components. In particular, the affiliated AP MLD upper MAC sublayer components support group addressed traffic, and traffic to or from any non-MLD non-AP STAs. The high-level structure of an AP MLD along with its affiliated APs is shown in Figure 4-29c.



**Figure 4-29c – High-level architecture for AP MLD with affiliated STAs**

The non-AP MLD reference model does not include any non-MLD upper MAC sublayers. A single Supplicant on the non-AP MLD manages the PKTSA, and multiple group key security associations (one set per link). The reference architecture is shown in Figure 4-29d.



**Figure 4-29d – High-level architecture for non-AP MLD with affiliated STAs**

The MLD ~~U~~upper MAC sublayer functions include:

* Authentication, association and reassociation (between an AP MLD and a non-AP MLD)
* Security association (e.g., PMKSA, PTKSA) and distribution of GTK/IGTK/BIGTK
* SN/PN assignment for frames to be encrypted by PTK for unicast frames
* Encryption/decryption using PTK for unicast frames
* Selection of the MLD ~~L~~lower MAC sublayer for transmission (TID-to-link mapping (see 35.3.6.1 (TID-to-link mapping)))
* Reordering of packets to ensure in-order delivery per each BA session
* Block Ack scoreboarding for individually addressed frames (in collaboration with the MLD ~~L~~lower MAC sublayer). Optionally, the MLD ~~U~~upper MAC sublayer delivers the BA record on one link to the MLD ~~L~~lower MAC sublayer of other links)
* MLD-level management information exchange/indication via the MLD ~~L~~lower MAC sublayer

The non-MLD (affiliated) upper MAC sublayer functions include:

* Non-MLD peer operations, above the MLD lower MAC sublayer
* Maintenance of Link-specific GTK/IGTK/BIGTK (between an AP affiliated with the AP MLD and a STA affiliated with the non-AP MLD)
* Link-specific encryption/decryption/integrity protection and PN assignment using GTK/IGTK/BIGTK (between an AP affiliated with the AP MLD and a STA affiliated with the non-AP MLD)
* Link-specific management info exchange/indication (e.g., Beacon)
* Power save state and mode tracking, per-link for MLD peers

The MLD ~~L~~lower MAC sublayer functions include:

* ~~Maintenance of Link-specific GTK/IGTK/BIGTK (between an AP affiliated with the AP MLD and a STA affiliated with the non-AP MLD)~~
* ~~Link-specific encryption/decryption/integrity protection and PN assignment using GTK/IGTK/BIGTK (between an AP affiliated with the AP MLD and a STA affiliated with the non-AP MLD)~~
* ~~Link-specific management info exchange/indication (e.g., Beacon)~~
* Link-specific control info exchange/indication (e.g., RTS/CTS, Acks, NDP, etc.)
* ~~Power save state and mode~~
* MAC address filtering for frame reception
* Block Ack scoreboarding for individually addressed frames (in collaboration with the MLD ~~U~~upper MAC sublayer). Optionally, the MLD ~~L~~lower MAC sublayer receives ~~from the~~ the BA record on the other links from the MLD ~~U~~upper MAC sublayer)

NOTE—The above functionality partitioning is meant for modelling the functionalities of each MAC Sublayer and is not meant for describing the MAC Sublayer for which the actual implementation of each function should reside.

NOTE – The Block Ack scoreboarding maintenance collaborated between the MLD ~~U~~upper MAC sublayer and MLD ~~L~~lower MAC sublayer is implementation dependent.

***TGbe editor: Please modify subclause 5.1.5.1 as follows:***

**5.1.5 MAC data service architecture**

**5.1.5.1 General**

The MAC data plane architecture (i.e., processes that involve transport of all or part of an MSDU) is shown in Figure 5-1 (MAC data plane architecture(11ak)(#2273)) when transparent FST is not being used and shown in Figure 5-2 (MAC data plane architecture (transparent FST)(11ak)(#2467)(#2273)) when transparent FST is being used.

The dotted line box labeled “Role-specific behaviors” is replaced by one of several options, depending on the role of the STA. See the following subclauses

(#4272)During transmission, an MSDU goes through the processes shown in the left-hand side of Figure 5-1 (MAC data plane architecture(11ak)(#2273)). When transparent FST is used, an MSDU first goes, as shown in Figure 5-2 (MAC data plane architecture (transparent FST)(11ak)(#2467)(#2273)), through an additional transparent FST entity that contains a demultiplexing process that forwards the MSDU down to the selected TX MSDU Rate Limiting process, and thence MAC data plane processing as described in the previous sentence. IEEE Std 802.1X-2010 may block the MSDU at the Controlled Port before the preceding processing occurs. Otherwise, at some point, the Data frames that contain all or part of the MSDU are queued per AC/TS.

(#4272)During reception, a received Data frame goes through the processes shown in the right-hand side of of Figure 5-1 (MAC data plane architecture(11ak)(#2273)). Then, one or more MSDUs are delivered to the MAC SAP or, via the DSAF, to either the DS or an IEEE 802.1Q bridge port.(11ak) When transparent FST is used, MSDUs originating from different PHY SAPs go, as shown in Figure 5-2 (MAC data plane architecture (transparent FST)(11ak)(#2467)(#2273)), through a final step of a transparent FST entity that contains a multiplexing process before delivering the MSDU. The IEEE 802.1X -Controlled/Uncontrolled Ports discard any received MSDUs if the Controlled Port is not enabled and if the MSDU does not represent an IEEE 802.1X frame.

(#4272)NOTE—Many of the processes shown in Figure 5-1 (MAC data plane architecture(11ak)(#2273)) also apply to MMPDU flows for the MAC control plane architecture, and the processes shown at the bottom also apply to Control and Extension frames.

When transparent FST is used, the same security keys, sequence counter, and PN counter are used by the MAC data plane to encrypt the MPDU prior to and following an FST, and the same security keys are used to check the integrity and perform the protection of MSDUs. When nontransparent FST is used, independent RSNAs, security keys, sequence counters, and PN counters have to be established for each MAC data plane to be used prior to and following an FST. When transparent FST is used, a single MAC SAP at each peer is presented to the higher layers of that peer for all of the frequency bands/channels that are identified by the same MAC address at that peer. When nontransparent FST is used, different MAC SAPs are presented to higher layers since different MAC addresses are used prior to and following an FST.

**5.1.5.1a Multi-link Operation**

For Multi-link Operation (MLO), one or more links are used for communication between the AP MLD and non-AP MLD after MLD (re)setup as described in 35.3.5 (Multi-link (re)setup)). The MAC data plane architecture of an MLD with *n* links (i.e., processes that involve transport of all or part of an MSDU) is shown in Figure 5-2a (MAC data plane architecture (MLO)).

~~~~



**Figure 5-2a - MAC data plane architecture (MLO) for unicast data frames**

During transmission, an MSDU from the MAC SAP goes through the processes shown in the left-hand side of Figure 5-2a (MAC data plane architecture (MLO)), then through the TID-to-link mapping process (see 35.3.6.1 (TID-to-link mapping)) that forwards the MPDUs down to one of the MLD ~~L~~lower MAC sublayers and then to the corresponding PHY SAP.

Note – TID-to-link mapping negotiation between peer MLDs is an optional feature.

During reception, MPDUs originating from different PHY SAPs first go through an MLD ~~L~~lower MAC sublayer, followed by a merging process, and then go through the rest of the processes in the right-hand side of Figure 5-2a (MAC data plane architecture (MLO)). Then, one or more MSDUs are delivered to the MAC SAP or, via the DSAF to the DS. The IEEE 802.1X Controlled/Uncontrolled Ports discard any received MSDUs if the Controlled Port is not enabled and if the MSDU does not represent an IEEE 802.1X frame.

NOTE—Many of the processes shown in Figure 5-2a (MAC data plane architecture (MLO)) also apply to MLD-level MMPDU flows for the MAC control plane architecture, and the processes shown at the MLD ~~L~~lower MAC sublayer also apply to Control and Extension frames.

When MLO is being used, the same security association (PTKSA) is used to encrypt the unicast MPDUs and MMPDUs prior to transmission on all the links. The same security association (PTKSA) is used to decrypt the unicast MPDUs and MMPDUs received on all the links.

For an AP MLD to support group address transmissions and also non-MLD peer STA associations, Figure 5-2a is combined with *n* affiliated APs, within a structure as shown in Figure 4-29c. The MLD upper MAC sublayer components of the affiliated APs are the same as those for the AP MLD, but handle group addressed security associations (GTK, IGTK and BIGTK), and handle traffic to and from associated non-MLD non-AP STAs with single-link security associations for peerwise keys (PTKs). The overall structure is as shown in Figure 5-2b.



**Figure 5-2b -** **MAC data plane architecture for MLD AP and affiliated APs**

An additional function is added for data MPDU reception to distribute the MPDUs to the appropriate MLD upper MAC sublayer based on the type of association with the peer, which is tracked per TA. MPDUs received from an MLD non-AP STA peer are delivered to the AP MLD upper MAC, and other MPDUs are delivered to the affiliated AP upper MAC for that link.

~~Group-addressed MPDUs are not transmitted by an AP MLD as the affiliated APs will transmit copies of the MSDU on their corresponding links.~~  Group addressed MSDUs at the DS are not transmitted directly by affiliated APs. Instead, the MLD AP processes group addressed MSDUs to the point of assigning a sequence number. The MLD AP and affiliated APs then coordinate to power save buffer (if appropriate), assign packet numbers and encrypt the resulting MPDU in the individual affiliated APs’ stacks. The GTK of ~~a link~~ an affiliated AP is used to encrypt the group addressed frames MPDUs and MMPDUs prior to transmission on the link managed by that affiliated AP. The GTK of ~~a link~~ the corresponding affiliated STA is used to decrypt the group addressed frames MPDUs and MMPDUs received on ~~the~~ a link. Group-addressed MMPDUs generated within the AP MLD upper MAC sublayer shall be transferred to the appropriate affiliated APs for transmission.

NOTE--An implementation must confirm that an MSDU that would otherwise be transmitted to peer MLD STAs is still transmitted, even if group address filtering of multicast MSDUs is being performed such that the MSDU might not be transmitted by the affiliated APs.

***<Insert here, shaded green text from above (in subclause 4.9.5)>***

When MLO is being used, the “Block Ack Scoreboarding” block in the MLD ~~U~~upper MAC sublayer manages the BA status of the MPDUs (of this BA session) that are received on any setup link. The “Block Ack Scoreboarding” block in the MLD ~~L~~lower MAC sublayer manages the BA status of the MPDUs (of this BA session) that are received on this link. It may convey BA status of the MPDUs received on another link if it obtained such info from the other link via the MLD ~~U~~upper MAC sublayer.

<start here next time>

***TGbe editor: Please add this new subclause to the spec (#2239)***

**5.1.5.10 Non-AP MLD role**

The MAC data plane architecture of a non-AP MLD as shown in Figure 5-2a (MAC data plane architecture (MLO) for unicast data frames) is completed by replacing the role-specific behavior block with that shown in Figure 5-11 (Role-specific behavior block for a non-AP MLD). The function of this block in a non-AP MLD is to perform destination address filtering as described in 10.2.7 (MAC data service).

NOTE—In implementations, the DA address filtering function may be done “lower in the stack.” It is shown in the role-specific behavior block location for simplicity, and any implementation choice needs to provide equivalent behavior.



**Figure 5-11 – Role-specific behavior block for a non-AP MLD**

***TGbe editor: Please add this new subclause to the spec (#2239)***

**5.1.5.11 AP MLD role**

In an AP MLD, the MAC data plane architecture as shown in Figure 5-2a (MAC data plane architecture (MLO) for unicast data frames) and Figure 5-2b (MAC data plane architecture for MLD AP and affiliated APs) includes Distribution System (DS) access in its role-specific behavior block, as shown in Figure 5-12 (Role-specific behavior block for an AP MLD). This block provides access to the DS for associated non-AP MLDs as described in 4.5.2.1 (Distribution).

NOTE—This behavior block indicates that there is no access through the controlled port to or from the local ~~upper~~higher-layers (e.g., the LLC sublayer) at an AP MLD. Any such access is logically achieved in the architecture via transition of the DS and Portal to an integrated LAN. In actual implementations, this is likely to be optimized, and Data frames appear to be delivered directly to one or more local LLC sublayer entities on the same physical device as the AP MLD. Such optimization is effectively distributing the functions of the DS and Portal, and it is the responsibility of the implementation to ensure the logical behavior of these entities is maintained.



**Figure 5-12 - Role-specific behavior block for an AP MLD**

***TGbe editor: Please modify subclause 7.1 as follows:***

**7.1 Introduction**

The DS SAP is the interface between the DS SAP service users and the DS SAP service provider. The DS SAP service users are the connected APs, mesh gates, the portal, and AP MLDs. The DS SAP service provider is the DS. Figure 7-1 (DS architecture(#2251)) shows the location of the DS in the IEEE 802.11 architecture. The DS SAP is indicated in this Figure by the lines connecting the DS to its service users. In Figure 7-1 (DS architecture(#2251)), the DS has four users, two APs, a mesh gate, a portal, and an AP MLD, so the DS is shown passing behind the MAC/PHYs of the STAs.



**Figure 7-1 – DS architecture**

The DS SAP interface specification describes the primitives required to get MAC service tuples in and out of the DS and

* update the DS’s mapping of STAs to APs or to mesh gates,
* update the DS’s mapping of non-AP MLDs to AP MLDs

Describing the DS itself or the functions thereof is out of scope of this standard.

The DS SAP actions are as follows:

1. Accept MSDUs (as part of MAC service tuples) from APs, mesh gates, the portal and AP MLDs.
2. Deliver MSDUs (as part of MAC service tuples) to APs, mesh gates, the portal, or the AP MLDs.
3. Accept STA-to-AP mapping updates from the APs.
4. Accept STA-to-mesh gate mapping updates from the mesh gates.
5. Accept non-AP-MLD-to-AP-MLD mapping updates from the AP MLDs.

NOTE—For MLDs, the source address or destination address parameters of the MAC service tuples (see 5.2.3.2 (Semantics of the service primitive)) are set to the MLD MAC address of the non-AP MLD, which is the identity of the non-AP MLD known by the DS.

When the DS delivers the MAC service tuples to an AP, the AP then determines when and how to deliver the MAC service tuples to the AP’s MAC (via the MAC SAP). When the DS delivers the MAC service tuples to a mesh gate, the mesh gate then determines when and how to deliver the MAC service tuples to the mesh gate’s MAC (via the MAC SAP). When the DS delivers the MAC service tuples to an AP MLD through DSAF, the AP MLD then determines when and how to deliver the MAC service tuples to the AP MLD’s MLD ~~U~~upper MAC sublayer (via the MAC SAP).

In the case of an AP MLD and its affiliated APs connected to the DS, there are individual DS SAPs for each affiliated AP and one for the AP MLD, as shown in Figure 7-2. The affiliated APs will each provide a mapping to their associated non-AP STAs, by their MAC addresses. The AP MLD will provide a mapping to its associated non-AP MLDs, by their MLD MAC addresses. Thus, the non-AP devices form distinct sets of MAC addresses, and the DS can deliver any service tuples with a one-to-one mapping of destination address to DS SAP.



**Figure 7-2 – Example DS access for an AP MLD with two affiliated APs**

***TGbe editor: Please modify subclause 35.1 as follows:***

**35. Extremely high throughput (EHT) MAC specification**

**35.1 Introduction**

An EHT STA shall set dot11EHTBaseLineFeaturesImplementedOnly to true.

An EHT STA supports the MAC and MLME functions defined in Clause 35 (Extremely high throughput (EHT) MAC specification) in addition to the MAC functions defined in Clause 26 (High efficiency (HE) MAC specification) and Clause 10 (MAC sublayer functional description), the MLME functions defined in Clause 11 (MLME), and the security functions defined in Clause 12 (Security) except when the functions in Clause 35 (Extremely High Throughput (EHT) MAC specification) supersede the functions in Clause 10 (MAC sublayer functional description), Clause 11 (MLME), Clause 12 (Security), or Clause 26 (High efficiency (HE) MAC specification).

A reference model for MLO is described in subclause 4.9.5 (Reference model for multi-link operation (MLO)).

***Annex – result of reordering of subclause 4.9.5***

**4.9.5 Reference model for multi-link operation (MLO)**

MLO allows operation over multiple links. An MLD manages such communication over multiple links. Communication across different frequency bands/channels can occur simultaneously or not depending on the capabilities of both the AP MLD and the non-AP MLD (see 35.3.13.2 (Simultaneous transmit and receive (STR) operation) and 35.3.13.3 (Nonsimultaneous transmit and receive (NSTR) operation)).

The MLO procedures (see 35.3 (Multi-link operation)) allow a pair of MLDs to discover, synchronize, (de)authenticate, (re)associate, disassociate, and manage resources with each other on any common bands or channels that are supported by both MLDs.

As described in 35.3.1 (General), each AP MLD has a single MAC-SAP and each non-AP MLD has a single MAC-SAP. Each AP affiliated with an AP MLD has a ~~different~~ MAC address different from any other AP affiliated with the AP MLD, ~~within the MLD~~ and each STA affiliated with a non-AP MLD has a ~~different~~ MAC address different from any other STA affiliated with the non-AP MLD~~within the MLD~~.

An example of an AP MLD with two links (Link 1 and Link 2) is shown in Figure 4-29b (Example MLD and the affiliated STA communication system). The figure shows a~~A~~n AP MLD with MLD MAC address *M* and the MLD lower MAC sublayers of two affiliated APs (AP1 with MAC address *w* and AP2 with MAC address *x*). The AP MLD is associated with a non-AP MLD with MLD MAC address *P* and the MLD lower MAC sublayers of two affiliated STAs (STA1 with MAC address *y* and STA2 with MAC address z*)* are shown*.* Link 1 is established between AP1 and STA1 and link 2 is established between AP2 and STA2. In general, the MAC address of an MLD and the MAC addresses of the STAs affiliated with the MLD are all different (e.g., *M*, *P*, *w*, *x*, *y*, and *z* have different values).



**Figure 4-29b – Example MLD and the affiliated STA communication system**

The reference model of a multi-link device (MLD) (see 35.3 (Multi-link operation)) is shown in Figure 4-29a (Reference model for an MLD).

NOTE—For simplicity, Figure 4-29a (Reference model for an MLD) depicts the reference model when there are two links, while in general, an MLD can support more than two links.



NOTE—The SME boundary top is left open in Figure 4-29a (Reference model for an MLD) to indicate that the SME can contain other functions that are not defined by this standard.

An MLD supports multiple MAC sublayers, coordinated by an SME.

The SME maintains the authentication and association states. The Authenticator and the MAC-SAP of the AP MLD are identified by the same AP MLD MAC address. The Supplicant and the MAC-SAP of the non-AP MLD are identified by the same non-AP MLD MAC address.

The SME is responsible for coordinating each of the MLMEs of all affiliated STAs, and to maintain an ~~single~~ RSNA key management entity~~, as well as a single~~ and IEEE 802.1X Authenticator or Supplicant in each upper MAC sublayer component, for MLO.

The MAC Sublayer is further divided into an MLD ~~U~~upper MAC sublayer and an MLD ~~L~~lower MAC sublayer. The MLD ~~U~~upper MAC sublayer ~~(MLD)~~ performs functionalities that are common across all links, and the MLD ~~L~~lower MAC sublayer (shared with an AP or STA affiliated with the MLD) performs functionalities that are local to each link. Some of the functionalities require joint processing of both the MLD ~~U~~upper MAC sublayer and MLD ~~L~~lower MAC sublayer~~s~~.

An MLD always operates co-located with more than one non-MLD STAs, one for each physical link, known as affiliated STAs or affiliated APs. Some behaviors of MLO require the use one or more of these co-located non-MLD stacks’ components. In particular, the co-located non-MLD MAC components support group addressed traffic, and traffic to or from any non-MLD peer STAs. The high-level structure of an MLD along with its affiliated STAs is shown in Figure 4-29c.



**Figure 4-29c – High-level architecture for MLD with affiliated STAs**