7 Connectivity configurations

7.1 Introduction

Clause~~ ~~ 7 describes features that affect EPON connectivity. These features include VLAN configurations, tunneling configurations, and multicast configurations that determine forwarding behavior of OLTs and ONUs. As illustrated in ~~Figure 6-1,~~IEEE Std 1904.1, Figure6-1, the connectivity configurations affect the provisioning of Classifier, Modifier, and CrossConnect functional blocks. This ~~clause~~ Clause does not specify configurations for the Policing/Shaping, Queuing, or Scheduling functional blocks, which affect performance characteristics of flows.

To facilitate the description of various connectivity-related configurations, this ~~clause~~ Clause categorizes each Ethernet Frame as either C-Frame or B-Frame.

A *C-Frame* is a customer's data frame. It starts with `C_DA` and `C_SA` fields. It may contain S-Tags and/or C-Tags. An *untagged* C-Frame contains neither C-Tags nor S-Tags. A *single-tagged* C-Frame contains either a single C-Tag or a single S-Tag. A *double-tagged* C-Frame contains either two C-Tags or an innermost C-Tag and an outermost S-Tag.

A *B-Frame* is a backbone frame. It starts with `B_DA` and `B_SA` fields. A B-Frame always contains an I-Tag and carries a C-Frame as a payload. A B-Frame may contain a B-Tag. A *single-tagged* B-Frame contains only the I-Tag. A *double-tagged* B-Frame contains an I-Tag and a B-Tag.

Note that the above definitions of C-Frame and B-Frame reflect the use of these terms in this standard only and may differ from how similar terms are defined elsewhere.

Editorial Note (to be removed prior to publication): subclause 7.2 material *may* be referenced from IEEE Std 1904.1 verbanim, since it is data rate and EPON generation independent.

7.2 VLAN configurations

This subclause describes EPON VLAN connections, modes, and operations.

A *VLAN connection* defines EPON's end-to-end (Client Interface to Client Interface) VLAN-dependent frame forwarding as well as any related frame transformations.

A VLAN connection is constructed by configuring a *VLAN mode* in the OLT and/or the ONU. A VLAN mode defines transformation and forwarding of a frame within either the ONU or the OLT. In the case of the OLT, a VLAN mode describes transformation and forwarding of a frame between the NNI and OLT_MDI in either downstream or upstream direction. In the case of the ONU, a VLAN mode describes transformation and forwarding of a frame between the UNI and ONU_MDI in either downstream or upstream direction. Commonly used VLAN modes are specified in 7.2.2.

A VLAN mode represents a collection of Classifier rules and associated Modifier actions (*VLAN operations*). VLAN operations are the atomic operations that can be performed on the VLAN tags (C-Tag and S-Tag). Various combinations of rules in the Classifier and VLAN operations in the Modifier may be provisioned on the ONU and OLT to form VLAN modes. Available VLAN operations are specified in 7.2.1.

7.2.1 VLAN operations

This subclause defines the VLAN operations that are applicable in the EPON ONU and OLT. Different VLAN modes, described in 7.2.2, rely on these VLAN operations.

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A VLAN operation is a single, VLAN-related action performed on an Ethernet frame. This action is executed in the Modifier block as the result of the successful match for one of the provisioned rules in the Classifier block. The defined actions include Add Tag, Remove Tag, and Replace Tag Field.

Note that the Add Tag and Remove Tag operations always operate on the entire VLAN tag, while the Replace Tag Field operation may alter either the entire VLAN tag or only one of the subfields of that tag.

7.2.1.1 Add Tag operation

The *Add Tag* operation inserts one VLAN tag into the received frame. The entire VLAN tag is added as one unit (32-bit value), which includes TPID, VLAN ID, Priority, and CFI or DEI flag.

Note that it is not mandatory for this operation to be able to add tags if the resulting frame would have more than two VLAN tags.

The VLAN tag value to be added to a frame is provisioned in the Modifier actionable entry, which is indexed in the output vector of the Classifier. The Classifier passes this vector to the Modifier through ESP_CTRL.

The behavior of the Add Tag operation is different, depending on whether the operation is invoked with the C_TAG, S_TAG, or VLAN_TAG field code. The Modifier does not verify any of the subfield values provisioned as part of the 32-bit VLAN tag value (for example, that a TPID has the correct value).

7.2.1.1.1 Add C-Tag operation

The *Add C-Tag* operation behaves as follows:

- Each untagged frame received from the Classifier block is tagged with a single provisioned C-Tag, and then the frame is transferred to the Policer/Shaper block.
- Results of applying Add C-Tag operation to a frame containing a C-Tag are undefined.
- Each single-tagged frame received from the Classifier block and containing an S-Tag is tagged with an additional provisioned C-Tag, resulting in a double-tagged frame. The C-Tag is added after the S-Tag. The frame is then transferred to the Policer/Shaper block.
- Results of applying Add C-Tag operation to a double-tagged frame are undefined.

Figure 7-1 illustrates the behavior of the Add C-Tag operation of the Modifier.

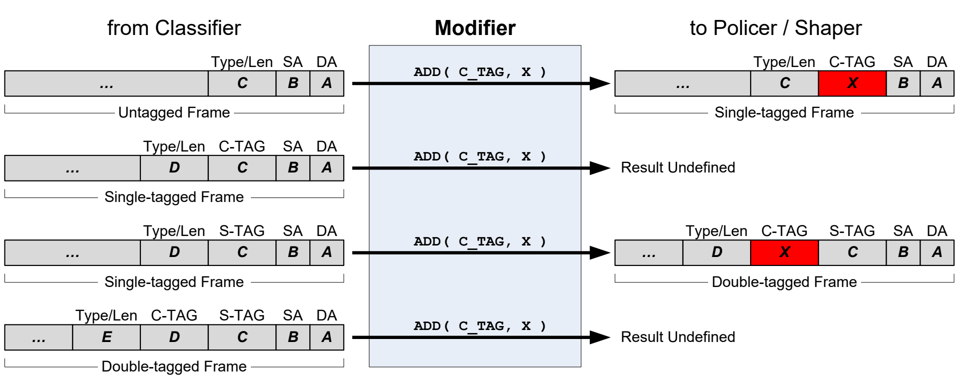

Figure 7-1—Behavior of Add C-Tag operation

7.2.1.1.2 Add S-Tag operation

The *Add S-Tag* operation behaves as follows:

— Each untagged frame received from the Classifier block is tagged with a single provisioned S-Tag, resulting in an S-tagged frame. The frame is then transferred to the Policer/Shaper block.

— Each single-tagged frame received from the Classifier block and containing a C-Tag is tagged with an additional provisioned S-Tag, resulting in a double-tagged frame. The frame is then transferred to the Policer/Shaper block.

— Results of applying Add S-Tag operation to a frame containing an S-Tag are undefined.

— Results of applying Add S-Tag operation to a double-tagged frame are undefined.

Figure 7-2 illustrates the behavior of the Add S-Tag operation of the Modifier.

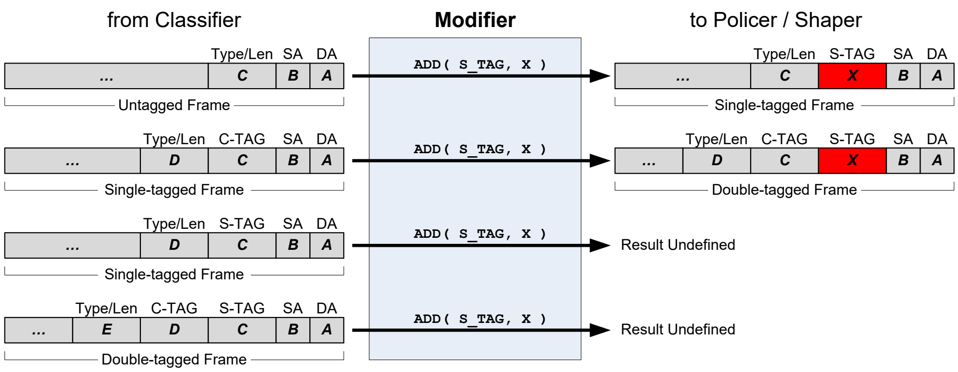

Figure 7-2—Behavior of Add S-Tag operation

7.2.1.1.3 Add VLAN0 operation

The *Add VLAN0* operation adds either C-Tag or S-Tag, depending on the TPID that is provisioned as part of the new VLAN value. The Add VLAN0 operation behaves as follows:

— Each untagged frame received from the Classifier block is tagged with a single provisioned VLAN value, resulting in a C-tagged or an S-tagged frame. The frame is then transferred to the Policer/Shaper block.

— Each single-tagged frame received from the Classifier block and containing a C-Tag is tagged with an additional provisioned Tag, resulting in a double-tagged frame. The new tag is added immediately after the Source MAC address field. The frame is then transferred to the Policer/Shaper block.

— Results of applying Add VLAN0 operation to a frame containing an S-Tag are undefined.

— Results of applying Add VLAN0 operation to a double-tagged frame are undefined.

Figure 7-3 illustrates the behavior of the Add VLAN0 operation of the Modifier.

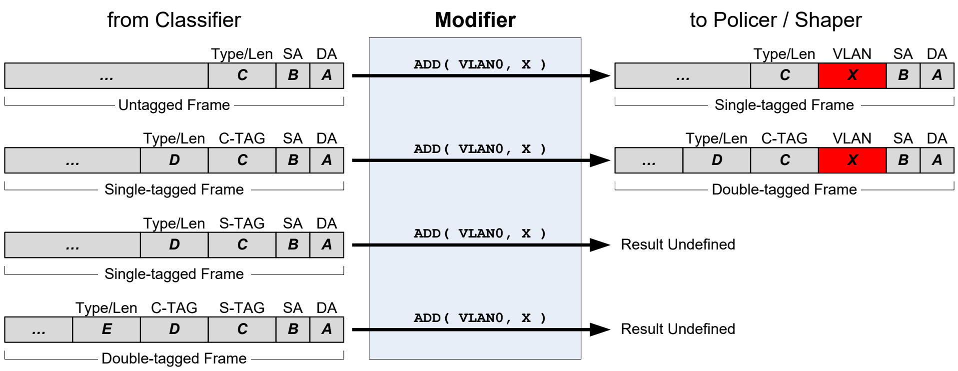

Figure 7-3—Behavior of Add VLAN0 operation

7.2.1.1.4 Add VLAN1 operation

The *Add VLAN1* operation adds either C-Tag or S-Tag, depending on the TPID that is provisioned as part of the new VLAN value. The Add VLAN1 operation behaves as follows:

— Each untagged frame received from the Classifier block is tagged with a single provisioned VLAN value, resulting in a C-tagged or an S-tagged frame. The frame is then transferred to the Policer/Shaper block.

— Each single-tagged frame received from the Classifier block and containing a C-Tag is tagged with an additional provisioned Tag, resulting in a double-tagged frame. The new tag is added immediately after the existing C-Tag. The frame is then transferred to the Policer/Shaper block.

— Each single-tagged frame received from the Classifier block and containing an S-Tag is tagged with an additional provisioned Tag, resulting in a double-tagged frame. The new tag is added immediately after the existing S-Tag. The frame is then transferred to the Policer/Shaper block.

— Results of applying Add VLAN1 operation to a double-tagged frame are undefined.

Figure 7-4 illustrates the behavior of the Add VLAN1 operation of the Modifier.

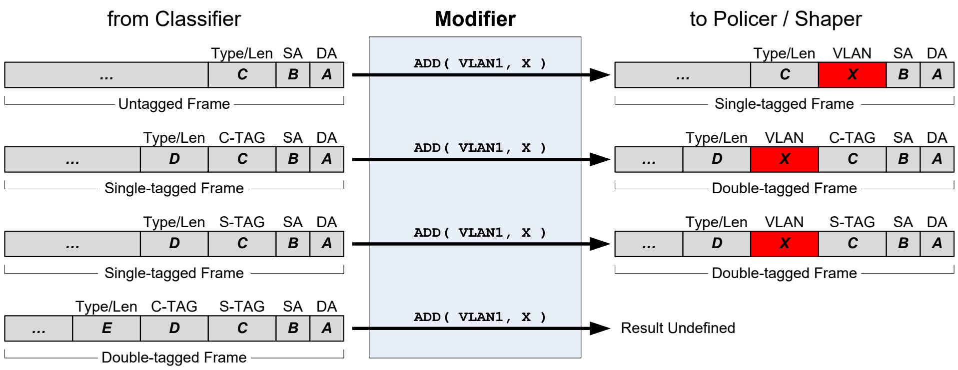

Figure 7-4—Behavior of Add VLAN1 operation

7.2.1.2 Remove Tag operation

The *Remove Tag* operation deletes one VLAN tag in the received frame. The entire VLAN tag is deleted as one unit (32-bit value), which includes TPID, VLAN ID, Priority, and CFI or DEI flag.

The behavior of Remove Tag operation is different, depending on whether the operation is invoked with the C_TAG, S_TAG, or VLAN_TAG field code.

7.2.1.2.1 Remove C-Tag operation

The *Remove C-Tag* operation removes the first encountered C-Tag. It behaves as follows:

- Each untagged frame received from the Classifier block is transferred to the Policer/Shaper block unchanged.
- Each single-tagged frame received from the Classifier block and containing a C-Tag is stripped of its tag. The untagged frame is then transferred to the Policer/Shaper block.
- Each single-tagged frame received from the Classifier block and containing an S-Tag is transferred to the Policer/Shaper block unchanged.
- Each frame received from the Classifier block and containing a C-Tag and an S-Tag is stripped of its C-Tag, resulting in a single-tagged (S-Tag) frame. The frame is then transferred to the Policer/Shaper block.

Figure 7-5 illustrates the behavior of the Remove C-Tag operation of the Modifier.

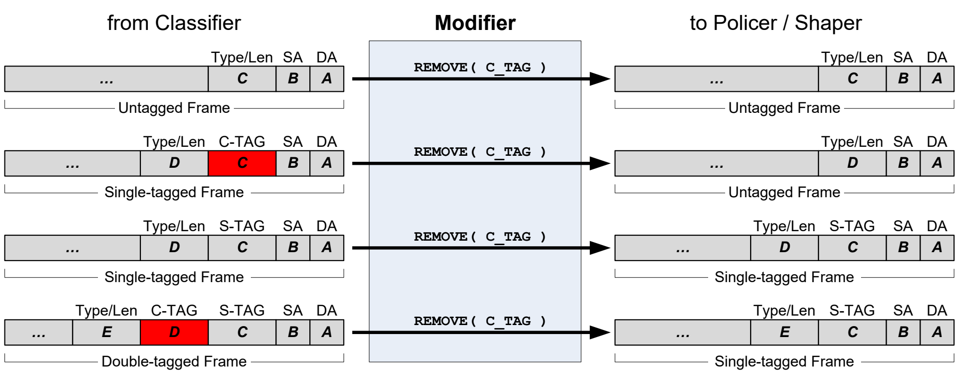

Figure 7-5—Behavior of Remove C-Tag operation

7.2.1.2.2 Remove S-Tag operation

The *Remove S-Tag* operation removes the first encountered S-Tag. It behaves as follows:

- Each untagged frame received from the Classifier block is transferred to the Policer/Shaper block unchanged.
- Each single-tagged frame received from the Classifier block and containing a C-Tag is transferred to the Policer/Shaper block unchanged.
- Each single-tagged frame received from the Classifier block and containing an S-Tag is stripped of its tag. The untagged frame is then transferred to the Policer/Shaper block.

— Each frame received from the Classifier block and containing a C-Tag and an S-Tag is stripped of its S-Tag, resulting in a single-tagged (C-Tag) frame. The frame is then transferred to the Policer/Shaper block.

Figure 7-6 illustrates the behavior of the Remove S-Tag operation of the Modifier.

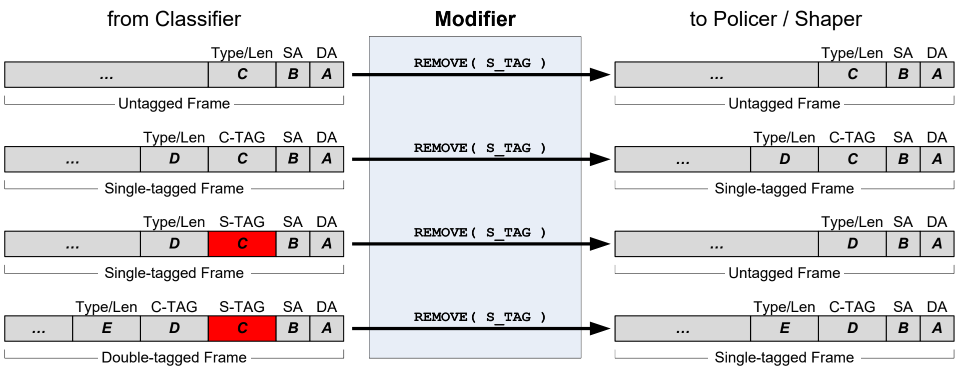

Figure 7-6—Behavior of Remove S-Tag operation

7.2.1.2.3 Remove VLAN0 operation

The *Remove VLAN0* operation removes the first encountered tag (either C-Tag or S-Tag), depending on the format of the incoming frame. The Remove VLAN0 operation behaves as follows:

— Each untagged frame received from the Classifier block is transferred to the Policer/Shaper block unchanged.

— Each single-tagged frame received from the Classifier block and containing a C-Tag is stripped of its tag. The untagged frame is then transferred to the Policer/Shaper block.

— Each single-tagged frame received from the Classifier block and containing an S-Tag is stripped of its tag. The untagged frame is then transferred to the Policer/Shaper block.

— Each frame received from the Classifier block and containing a C-Tag and an S-Tag is stripped of its S-Tag, resulting in a single-tagged (C-Tag) frame. The frame is then transferred to the Policer/Shaper block.

Figure 7-7 illustrates the behavior of the Remove VLAN0 operation of the Modifier.

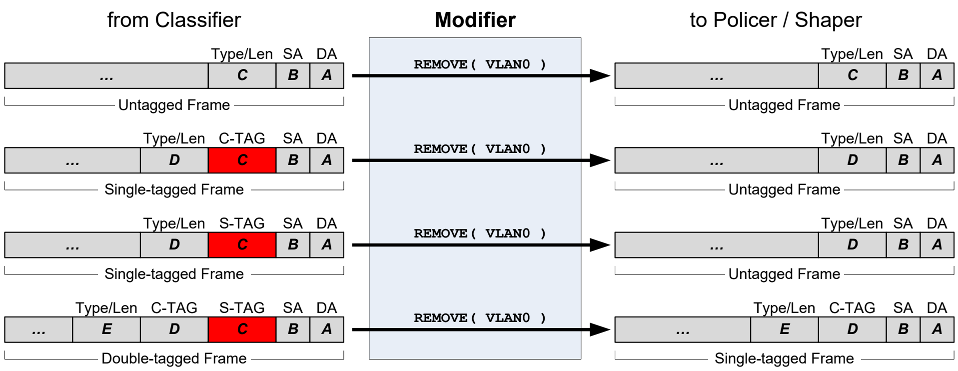

Figure 7-7—Behavior of Remove VLAN0 operation

7.2.1.2.4 Remove VLAN1 operation

The *Remove VLAN1* operation removes the second encountered tag. It behaves as follows:

— Each untagged frame received from the Classifier block is transferred to the Policer/Shaper block unchanged.

— Each single-tagged frame received from the Classifier block and containing a C-Tag is transferred to the Policer/Shaper block unchanged.

— Each single-tagged frame received from the Classifier block and containing an S-Tag is transferred to the Policer/Shaper block unchanged.

— Each frame received from the Classifier block and containing a C-Tag and an S-Tag is stripped of its C-Tag, resulting in a single-tagged (S-Tag) frame. The frame is then transferred to the Policer/Shaper block.

Figure 7-8 illustrates the behavior of the Remove VLAN1 operation of the Modifier.

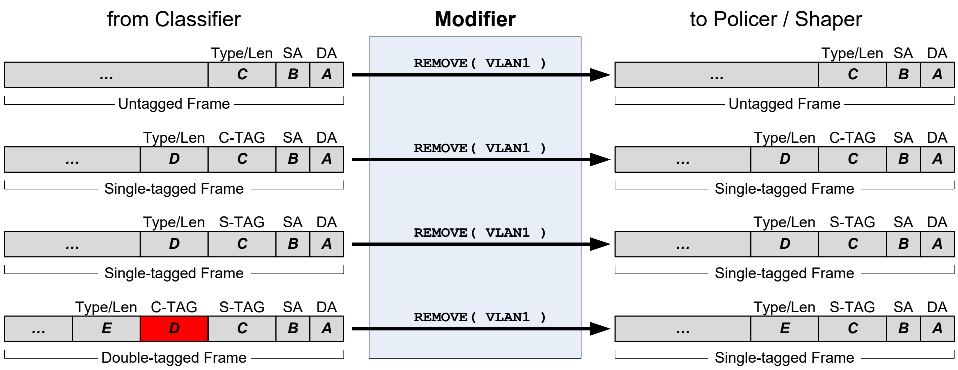

Figure 7-8—Behavior of Remove VLAN1 operation

7.2.1.3 Replace Tag Field operation

The *Replace Tag Field* operation alters the values of the VLAN tags in the received frame.

Note that it is not mandatory for this operation to be able to alter fields beyond two VLAN tags in any single frame.

The Replace Tag Field operation may replace the entire VLAN tag or only one subfield of the VLAN tag. The operation is capable of altering any subfields associated with a specified VLAN tag. These subfields include the following:

- TPID
- VLAN ID
- priority
- drop eligible

Replacement values for these fields are provisioned in the Modifier actionable entry, which is indexed in the output vector of the Classifier. The Classifier passes this vector to the Modifier through ESP_CTRL. The size of the replacement value parameter matches the size of the field being replaced (see ~~6.5.2.1.1).~~IEEE Std 1904.1, 6.5.2.1.1).

The Modifier does not verify the correctness of any of the provisioned replacement. Incorrectly provisioned values may result in a malformed frame.

The following examples show replacement of the entire VLAN tag; however, similar rules apply for replacing only a subfield of the VLAN tag.

7.2.1.3.1 Replace C-Tag operation

The *Replace C-Tag* operation replaces the first encountered C-Tag. It behaves as follows:

- Each untagged frame received from the Classifier block is transferred to the Policer/Shaper block unchanged.
- Each single-tagged frame received from the Classifier block and containing a C-Tag receives a new value of its C-Tag. The frame is then transferred to the Policer/Shaper block.
- Each single-tagged frame received from the Classifier block and containing an S-Tag is transferred to the Policer/Shaper block unchanged.
- Each frame received from the Classifier block and containing a C-Tag and an S-Tag receives a new value of its C-Tag. The frame is then transferred to the Policer/Shaper block.

Figure 7-9 illustrates the behavior of the Replace C-Tag operation of the Modifier.

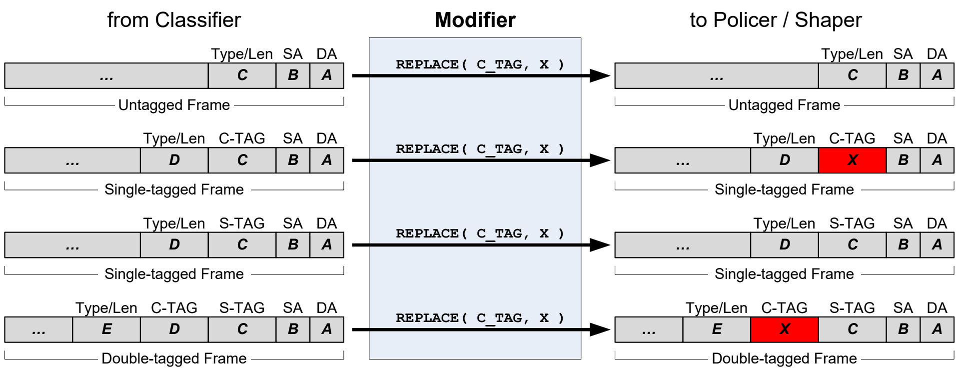

Figure 7-9—Behavior of Replace C-Tag operation

7.2.1.3.2 Replace S-Tag operation

The *Replace S-Tag* operation replaces the first encountered S-Tag. It behaves as follows:

- Each untagged frame received from the Classifier block is transferred to the Policer/Shaper block unchanged.
- Each single-tagged frame received from the Classifier block and containing a C-Tag is transferred to the Policer/Shaper block unchanged.
- Each single-tagged frame received from the Classifier block and containing an S-Tag receives a new value of its S-Tag. The frame is then transferred to the Policer/Shaper block.
- Each frame received from the Classifier block and containing a C-Tag and an S-Tag receives a new value of its S-Tag. The frame is then transferred to the Policer/Shaper block.

Figure 7-10 illustrates the behavior of the Replace S-Tag operation of the Modifier.

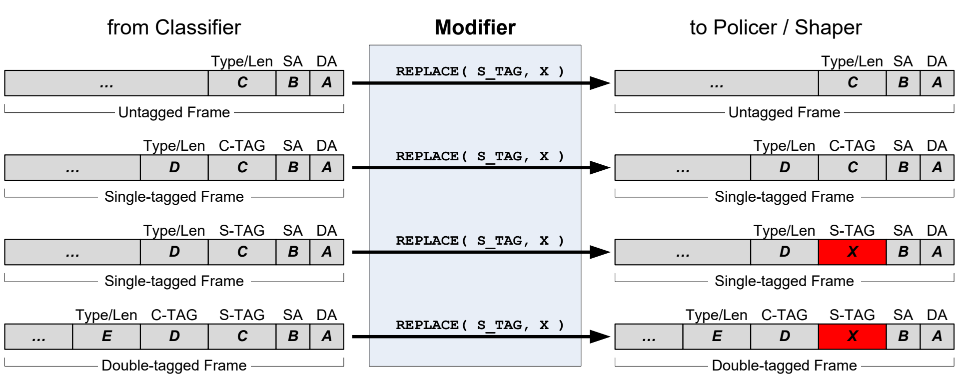

Figure 7-10—Behavior of Replace S-Tag operation

7.2.1.3.3 Replace VLAN0 operation

The *Replace VLAN0* operation replaces the value of the first encountered tag (either C-Tag or S-Tag), depending on the format of the incoming frame. The Replace VLAN0 operation behaves as follows:

— Each untagged frame received from the Classifier block is transferred to the Policer/Shaper block unchanged.

— Each single-tagged frame received from the Classifier block and containing a C-Tag receives a new value of its C-Tag. The frame is then transferred to the Policer/Shaper block.

— Each single-tagged frame received from the Classifier block and containing an S-Tag receives a new value of its S-Tag. The frame is then transferred to the Policer/Shaper block.

— Each frame received from the Classifier block and containing a C-Tag and an S-Tag receives a new value of its S-Tag. The frame is then transferred to the Policer/Shaper block.

Figure 7-11 illustrates the behavior of the Replace VLAN0 operation of the Modifier.

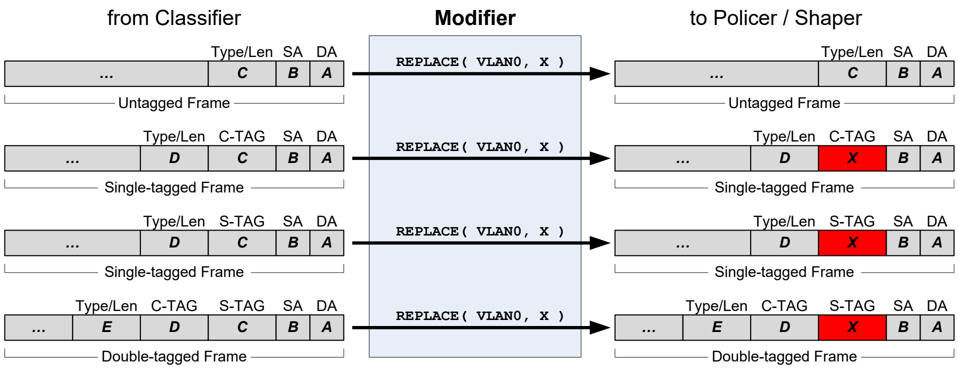

Figure 7-11—Behavior of Replace VLAN0 operation

7.2.1.3.4 Replace VLAN1 operation

The *Replace VLAN1* operation replaces the value of the second encountered tag. It behaves as follows:

— Each untagged frame received from the Classifier block is transferred to the Policer/Shaper block unchanged.

— Each single-tagged frame received from the Classifier block and containing a C-Tag is transferred to the Policer/Shaper block unchanged.

— Each single-tagged frame received from the Classifier block and containing an S-Tag is transferred to the Policer/Shaper block unchanged.

— Each frame received from the Classifier block and containing a C-Tag and an S-Tag receives a new value of its C-Tag. The frame is then transferred to the Policer/Shaper block.

Figure 7-12 illustrates the behavior of the Replace VLAN1 operation of the Modifier.

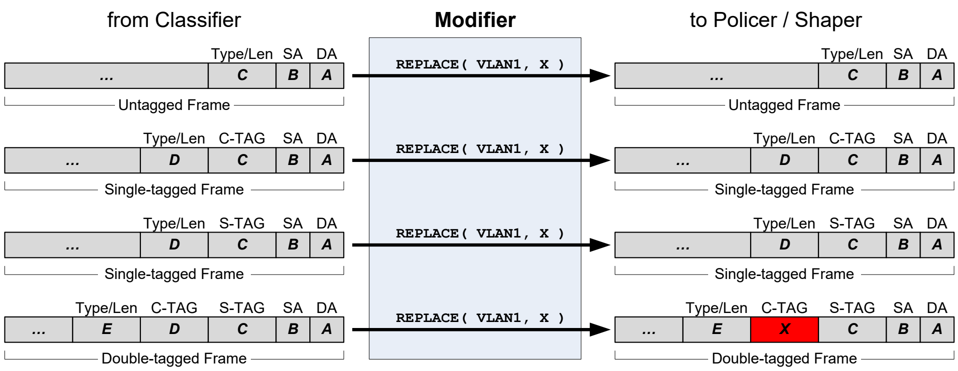

Figure 7-12—Behavior of Replace VLAN1 operation

7.2.1.4 Double-tagging operations

Some VLAN modes may require VLAN operations performed on more than one VLAN tag or on several fields of one VLAN Tag. This functionality is achieved by provisioning several elements (operations) for a single Modifier entry.

Any VLAN operations may be combined in a single Modifier entry. This standard does not mandate the minimum or the maximum number of elements that can be provisioned for a single Modifier entry.

The following examples illustrate a few typical configurations of Modifier entries:

Example 1: A Modifier entry [m1] is provisioned to remove two tags from a frame:

```
[m1:0]: REMOVE(VLAN0)

[m1:1]: REMOVE(VLAN0)
```

Example 2: A Modifier entry [m2] is provisioned to replace VID in C-Tag with a value X (X is a 12-bit value) and adds S-Tag with a value Y (Y is a 32-bit value):

```
[m2:0]: REPLACE(C_VID,X)

[m2:1]: ADD(S_TAG,Y)
```

7.2.2 VLAN modes

This subclause defines VLAN modes that are used to establish VLAN-dependent connectivity for various types of services in EPON. A VLAN mode defines VLAN-dependent transformation and forwarding of a frame within either the ONU or the OLT. In the case of the OLT, a VLAN mode covers transformation and forwarding of a frame between the NNI and OLT_MDI in the downstream and upstream directions. In the case of the ONU, a VLAN mode covers transformation and forwarding of a frame between the UNI and ONU_MDI in the downstream and upstream directions.

All VLAN modes are defined in terms of Classifier rules and their associated Modifier actions (VLAN operations). Field codes, which are used as arguments in the Classifier rules and Modifier actions, are described in ~~6.5.2.1.1.~~IEEE Std 1904.1, 6.5.2.1.1. Individual VLAN operations are specified in 7.2.1. The rules that comprise a VLAN mode are shown in order of their priority and are executed sequentially until the first matched rule is found.

7.2.2.1 Device-based VLAN modes

In the device-based VLAN modes, each EPON device is assigned a specific VLAN mode as defined in the following subclauses.

A C-OLT shall support all of the following VLAN modes:

- Transparent VLAN mode (see 7.2.2.1.1)
- Tagging VLAN mode (see 7.2.2.1.3)
- Translation VLAN mode (see 7.2.2.1.5)

A C-OLT shall be able to operate in at least one VLAN mode, as provisioned by the NMS.

A C-ONU shall support all of the following VLAN modes:

- Transparent VLAN mode (see 7.2.2.1.2)
- Tagging VLAN mode (see 7.2.2.1.4)
- ToS/CoS Conversion VLAN mode (see 7.2.2.1.6)

A C-ONU shall be able to operate in at least one VLAN mode, as provisioned and configured using the Type/Length/Values (TLVs) defined in 14.3.1.5.

Note that all of the defined device-based VLAN modes may operate on single-tagged ~~(IEEE Std 802.1Q compliant)~~ or double-tagged (IEEE Std 802.~~1ad™~~ 1Q compliant) frames.

7.2.2.1.1 OLT Transparent VLAN mode

In the *OLT Transparent* VLAN mode, the upstream and downstream ESPs are provisioned to not modify VLAN tags in the forwarded frames. This VLAN mode is provisioned by the NMS.

In the downstream direction at the OLT_LI, each MAC Client output port is associated with a separate MAC instance and, by extension, with a unique LLID. Each frame is forwarded to the output port according to the IEEE Std 802.1Q bridging function. A specific output port is selected according to the Destination MAC address of the frame. The rules for the association of the MAC addresses to the ports are set in the Classifier according to the MAC Learning function that monitors the source addresses of the upstream frames coming from each port. Any frame, tagged or untagged, whose address was learned is forwarded to the associated output port without any modifications. Any frame whose DA was not learned is flooded (i.e., forwarded to the downstream output port associated with the single-copy broadcast (SCB) MAC/broadcast LLID).

The upstream ESP in the OLT Transparent VLAN mode is configured to forward the received tagged or untagged frame to the output port without any changes. The MAC Learning function monitors the upstream traffic and learns the Source MAC addresses of the incoming frames for each input port. This function then generates the necessary rules to forward downstream frames to proper output ports based on learned associations.

In this mode, in the downstream direction, the OLT shall apply rules and actions as illustrated in Table 7-1.

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Table 7-1—Classifier rules and Modifier actions for downstream ESP in the OLT Transparent VLAN mode[a]

Classifier rules	Modifier actions	Description
IF (C_DA == LA_1) THEN <m_0,…,x_1>	[m_0]: none	The output vector of each rule directs the frame to the CrossConnect entry (x_n) that forwards the frame further to an output port associated with the given value of C_DA through MAC Learning. These rules are generated locally as a result of MAC Learning function.
...		
IF (C_DA == LA_n) THEN <m_0,…,x_n>		
IF (true) THEN <m_0,…,x_B>	[m_0]: none	A frame whose DA value does not match any of the learned MAC addresses is flooded to all ONUs. To flood a frame, OLT forwards it to CrossConnect entry x_B associated with the SCB MAC/broadcast LLID. Multicast frames are also matched by this rule.

[a] LA_1-LA_n are learned MAC addresses of the CPE devices, acquired by the MAC Learning function operating on the upstream traffic.

In the Transparent VLAN mode, in the upstream direction, the OLT shall apply rules and actions as illustrated in Table 7-2.

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Table 7-2—Classifier rules and Modifier actions for upstream ESP in the OLT Transparent VLAN mode

Classifier rules	Modifier actions	Description
IF (true) THEN <m_0,…,x_0>	[m_0]: none	The upstream frame is forwarded to a provisioned CrossConnect entry x_0 associated with an upstream output port.

7.2.2.1.2 ONU Transparent VLAN mode

In the *ONU Transparent* VLAN mode, the upstream and downstream ESPs are provisioned to not modify VLAN tags in the forwarded frames. This VLAN mode is provisioned using the *VLAN Mode* TLV (0xB7/0x00-0B) for Transparent VLAN mode (`VlanMode` value 0x01), as defined in 14.3.1.5.

In the downstream direction, the behavior of the ONU Transparent VLAN mode depends on whether VLAN-based multicast filtering is enabled. If VLAN-based multicast filtering is enabled, in addition to filtering based on multicast VID values, the ONU also filters downstream frames based on unicast VID values, provisioned using the *PON-VID Value* TLV (0xB7/0x00-15), as defined in 14.3.1.13. If VLAN-based multicast filtering is disabled, the ONU transparently passes downstream frames. The ONU is able to filter multicast frames based on Destination MAC address, independent of VLAN-based multicast filtering. The Classifier rules for VLAN-based multicast filtering are described in 7.4.2.3. The Classifier rules for MAC-address-based filtering are described in 7.4.2.4.

The upstream ESP in the ONU Transparent VLAN mode is configured to forward each received tagged or untagged frame to the output port without any changes. Any frame whose destination address was learned on the same input port from where it arrived is discarded.

In this mode, in the downstream direction, when VLAN-based multicast filtering is disabled, the ONU shall apply rules and actions as illustrated in Table 7-3.

Table 7-3—Classifier rules and Modifier actions for downstream ESP in the ONU Transparent VLAN mode, with VLAN-based multicast filtering disabled[a]

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Classifier rules	Modifier actions	Description
When multicast frame filtering based on MAC address is enabled, the relevant rules are inserted here. The rules for multicast filtering mode with static MAC address registration are specified in Table 7-34. The rules for multicast filtering mode with dynamic MAC address registration are specified in Table 7-35.		
IF (true) THEN <m_0,…,x_k>	[m_0]: none	The downstream frame is forwarded to a provisioned CrossConnect entry x_k associated with the downstream output port.

[a] This table illustrates the behavior of an ONU with a single downstream output port (x_k) associated with a single UNI port. In the case of an ONU containing multiple UNI ports, the port selection is done by matching the DA field of the downstream frame with MAC addresses learned on each UNI by the MAC Learning function.

When VLAN-based multicast filtering is enabled, the ONU shall apply rules and actions as illustrated in Table 7-4.

Table 7-4—Classifier rules and Modifier actions for downstream ESP in the ONU Transparent VLAN mode, with VLAN-based multicast filtering enabled[a, b]

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Classifier rules	Modifier actions	Description
When multicast frame filtering based on MAC address is enabled, the relevant rules are inserted here. The rules for multicast filtering mode with static MAC address registration are specified in Table 7-34. The rules for multicast filtering mode with dynamic MAC address registration are specified in Table 7-35.		
The rules for VLAN-based multicast filtering, as specified in Table 7-33, are inserted here.		
IF (VLAN0_VID == V_1) THEN <m_0,…,x_k>	[m_0]: none	The ONU accepts a tagged frame if the VID of the frame is provisioned as one of the allowed VIDs. The frame is forwarded to a provisioned CrossConnect entry x_k unmodified.
...		
IF (VLAN0_VID == V_n) THEN <m_0,…,x_k>		

[a] V_1–V_n are provisioned 12-bit values that represent the VIDs provisioned using *PON-VID Value* TLV (0xB7/0x00-15), as defined in 14.3.1.13.

[b] This table illustrates the behavior of an ONU with a single downstream output port (xk) associated with a single UNI port. In the case of an ONU containing multiple UNI ports, the port selection is done by matching the DA field of the downstream frame with MAC addresses learned on each UNI by the MAC Learning function.

In the Transparent VLAN mode, in the upstream direction, the ONU shall apply rules and actions as illustrated in Table 7-5.

Table 7-5—Classifier rules and Modifier actions for upstream ESP in the ONU Transparent VLAN mode[a, b]

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Classifier rules	Modifier actions	Description
IF (port == [i_U] AND DA == LA_1) THEN drop	N/A	The upstream frame whose destination address matches any of the CPE MAC addresses (LA_1-LA_n) learned to be behind the upstream input port [i_U] is discarded. These rules are generated locally as a result of MAC Learning function.
...		
IF (port == [i_U] AND DA == LA_n) THEN drop		
IF (port == [i_U]) THEN <m_0,…,x_k>	[m_0]: none	The upstream frame whose destination address does not match any of the CPE MAC addresses is forwarded to a provisioned CrossConnect entry x_k associated with an upstream output port.

[a] [i_U] represents an upstream input port (an entry of the Input functional block).

[b] LA_1-LA_n are learned MAC addresses of the CPE devices, acquired by the MAC Learning function operating on the upstream traffic.

7.2.2.1.3 OLT Tagging VLAN mode

In the *OLT Tagging* VLAN mode, the upstream ESP is provisioned to add a VLAN tag to each upstream frame, and the downstream ESP is provisioned to remove a VLAN tag from each downstream frame. This VLAN mode is provisioned by the NMS.

In the OLT, each downstream output port and each upstream input port are associated with a separate MAC instance and, by extension, with a unique LLID. The Tagging VLAN mode associates a unique VID value with each LLID.

In the downstream direction, the OLT directs the frame to the appropriate downstream output port based on the VID value of the received frame. The OLT removes the outer VLAN tag before forwarding the frame to an ONU. The OLT discards all untagged downstream frames as well as any frame with an unknown VID value (i.e., VID value not associated with any of the output ports in this OLT).

In the upstream direction, the OLT inserts a VLAN tag with VID associated with the given upstream input port. The OLT shall be capable of either discarding all tagged frames received from the upstream input port or discarding only the tagged frames with an unknown VLAN tag (i.e., any frame with VID not matching the VID provisioned for the input port from which the frame was received). If the OLT is configured to discard only the frames with the unknown VLAN tag, then any frame with a known VLAN tag (i.e., with VID matching the VID provisioned for the input port from which the frame was received) is forwarded without any modifications.

The Tagging VLAN mode may operate on either C-Tags or S-Tags. In this mode, in the downstream direction, the OLT shall apply rules and actions as illustrated in Table 7-6.

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Table 7-6—Classifier rules and Modifier actions for downstream ESP in the OLT Tagging VLAN mode[a]

Classifier rules	Modifier actions	Description
IF (!exists(VLAN0)) THEN drop	N/A	The untagged downstream frame is discarded.

IF (VLAN0_VID == 0) THEN drop	N/A	The priority-tagged frame is discarded. Priority-tagged frames are defined in IEEE Std 802.1Q, 3.158.
When multicast frame filtering based on VLAN is enabled, the relevant rules are inserted here. The rules for VLAN-based multicast filtering are specified in Table 7-32.		
IF (VLAN0_VID == V_1) THEN <m_i,…,x_1>	[m_i]: REMOVE(VLAN0)	These rules seek frames with known (provisioned) VID values. The output vector of each rule directs the frame to the CrossConnect entry (x_n) that forwards the frame further to an output port associated with the given VID value of outermost VLAN tag. The outermost VLAN tag is removed before the frame is forwarded.
...		
IF (VLAN0_VID == V_n) THEN <m_i,…,x_n>		

[a] V_1-V_n are provisioned 12-bit values representing the expected VIDs in the downstream frames.

In the Tagging VLAN mode, in the upstream direction, the OLT shall apply rules and actions as illustrated in Table 7-7.

Table 7-7—Classifier rules and Modifier actions for upstream ESP in the OLT Tagging VLAN mode[a, b]

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Classifier rules	Modifier actions	Description
IF (port == [i_{U1}] AND !exists(VLAN0)) THEN <m_1,…,x_k>	[m_1]: ADD(VLAN0,V_1);	The untagged upstream frame receives a VLAN tag with a VID value associated with the input port from which this frame was received.
...	...	
IF (port == [i_{Un}] AND !exists(VLAN0)) THEN <m_n,…,x_k>	[m_n]: ADD(VLAN0,V_n);	
IF (port == [i_{U1}] AND VLAN0_VID == V_1) THEN <m_0,…,x_k>	[m_0]: none	These rules are optional. If these rules are provisioned, the OLT accepts all upstream frames tagged with the predetermined VID values and forwards these frames without any modifications. If these rules are not provisioned, the OLT discards all tagged upstream frames.
...		
IF (port == [i_{Un}] AND VLAN0_VID == V_n) THEN <m_0,…,x_k>		
IF (exists(VLAN0)) THEN drop	N/A	The tagged upstream frame is discarded.

[a] [i_{U1}]-[i_{Un}] are upstream input port (entries of the Input functional block).

[b] V_1-V_n are 32-bit values associated with upstream input ports [i_{U1}]-[i_{Un}]. These values allow identification of the subscriber using VLAN ID. The 32-bit value consists of a VID value provisioned by NMS and the vendor-specified default values for TPID, PCP, and DEI.

7.2.2.1.4 ONU Tagging VLAN mode

In the *ONU Tagging* VLAN mode, the downstream ESP is configured to filter each received frame based on the provisioned values of the VLAN0_VID field or the DA field and to remove the VLAN tag before passing the frame to the Policer/Shaper block. This VLAN mode shall be provisioned using the *VLAN Mode* TLV (0xB7/0x00-0B) for Tagging VLAN mode (`VlanMode` value 0x02), as defined in 14.3.1.5.

The downstream ESP discards each untagged frame received from the downstream input port. Additionally, if VLAN-based multicast filtering is enabled, the ONU also discards any multicast frame with VID not matching any of the provisioned VIDs. If MAC-address-based filtering is enabled, the ONU discards any multicast frame with Destination MAC address not matching any of the provisioned MAC addresses. The ONU removes the outermost VLAN tag from the accepted frames before forwarding them to the egress port.

The upstream ESP in the ONU Tagging VLAN mode is configured to add a provisioned C-Tag or S-Tag. The VLAN tag to be added consists of a provisioned VID value and the default values for TPID, PCP, and DEI. The VID is provisioned using the *PON-VID Value* TLV (0xB7/0x00-15), as defined in 14.3.1.13.

In the ONU Tagging VLAN mode, in the downstream direction, when VLAN-based multicast filtering is disabled, the ONU shall apply rules and actions as illustrated in Table 7-8. The ONU is able to filter any multicast frame based on Destination MAC address.

Table 7-8—Classifier rules and Modifier actions for downstream ESP in the ONU Tagging VLAN mode, with VLAN-based multicast filtering disabled[a]

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Classifier rules	Modifier actions	Description
IF (!exists(VLAN0)) THEN drop	N/A	The untagged downstream frame is discarded.
When multicast frame filtering based on MAC address is enabled, the relevant rules are inserted here. The rules for multicast filtering mode with static MAC address registration are specified in Table 7-34. The rules for multicast filtering mode with dynamic MAC address registration are specified in Table 7-35.		
IF (exists (VLAN0)) THEN <m_i,…,x_k>	[m_i]: REMOVE(VLAN0)	The downstream frame with the outermost VLAN tag that was not filtered out (discarded) by the preceding rules is forwarded to provisioned CrossConnect entry x_k after the outermost VLAN tag is removed.

[a] This table illustrates the behavior of an ONU with a single downstream output port (x_k) associated with a single UNI port. In the case of an ONU containing multiple UNI ports, the port selection is done by matching the DA field of the downstream frame with MAC addresses learned on each UNI by the MAC Learning function.

In the ONU Tagging VLAN mode, in the downstream direction, when VLAN-based multicast filtering is enabled, the ONU shall apply rules and actions as illustrated in Table 7-9. The ONU is able to filter any multicast frame based on VID or Destination MAC address.

Table 7-9—Classifier rules and Modifier actions for downstream ESP in the ONU Tagging VLAN mode, with VLAN-based multicast filtering enabled[a, b]

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Classifier rules	Modifier actions	Description
IF (!exists(VLAN0)) THEN drop	N/A	The untagged downstream frame is discarded.
When multicast frame filtering based on MAC address is enabled, the relevant rules are inserted here. The rules for multicast filtering mode with static MAC address registration are specified in Table 7-34. The rules for multicast filtering mode with dynamic MAC address registration are specified in Table 7-35.		

When multicast frame filtering based on VLAN is enabled, the relevant rules are inserted here. The rules for VLAN-based multicast filtering are specified in Table 7-33.		
IF (VLAN0_VID == V_1) THEN <m_i,…,x_k>	[m_i]: REMOVE(VLAN0)	The downstream frame with the outermost VLAN tag matching one of the provisioned VIDs (V_1-V_n) that was not filtered out (discarded) by the preceding rules is forwarded to a provisioned CrossConnect entry x_k after the outermost VLAN tag is removed.
...		
IF (VLAN0_VID == V_n) THEN <m_i,…,x_k>		

[a] V_1-V_n are provisioned 12-bit values that represent the VIDs to be accepted by a given ESP.

[b] This table illustrates the behavior of an ONU with a single downstream output port (x_k) associated with a single UNI port. In the case of an ONU containing multiple UNI ports, the port selection is done by matching the DA field of the downstream frame with MAC addresses learned on each UNI by the MAC Learning function.

In the Tagging VLAN mode, in the upstream direction, the ONU shall apply rules and actions as illustrated in Table 7-10.

Table 7-10—Classifier rules and Modifier actions for upstream ESP in the ONU Tagging VLAN mode[a, b, c]

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Classifier rules	Modifier actions	Description
IF (exists(VLAN0) AND VLAN0_VID != 0) THEN drop	N/A	The VLAN-tagged C-Frame is discarded. VLAN-tagged frames are defined in IEEE Std 802.1Q, 3.262.
IF (exists(VLAN0) AND VLAN0_VID == 0) THEN drop	N/A	The Priority-tagged C-Frame is discarded. Priority-tagged frames are defined in IEEE Std 802.1Q, 3.158. This rule is optional and implementation dependent. If this rule is not implemented, the priority-tagged frame is processed as an untagged frame by the subsequent rules.
IF (port == [i_U] AND DA == LA_1) THEN drop	N/A	The upstream frame whose destination address matches any of the CPE MAC addresses (LA_1-LA_n) learned to be behind the upstream input port [i_U] is discarded. These rules are generated locally as a result of MAC Learning function.
...		
IF (port == [i_U] AND DA == LA_n) THEN drop		
IF (port == [i_U]) THEN <m_i,…,x_k>	[m_i]: ADD(VLAN0,V_1);	The upstream untagged frame whose destination address does not match any of the CPE MAC addresses receives a VLAN tag with a provisioned value of V_1 and is forwarded to a provisioned CrossConnect entry x_k associated with an upstream output port.

[a] `[i`$_U$`]` represents an upstream input port (an entry of the Input functional block).

[b] LA_1-LA_n are learned MAC addresses of the CPE devices, acquired by the MAC Learning function operating on the upstream traffic.

[c] V_1 is a 32-bit value representing C-Tag or S-Tag to be added to upstream frame. The 32-bit value consists of a provisioned VID value and the vendor-specified default values for TPID, PCP, and DEI. The VID is provisioned using the *PON-VID Value* TLV (0xB7/0x00-15), as defined in 14.3.1.13.

7.2.2.1.5 OLT Translation VLAN mode

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In the *OLT Translation* VLAN mode, the upstream ESP is provisioned to change the user-side VID value in each incoming frame to the associated value of the network-side VID. The downstream ESP is provisioned to change the network-side VID value in each incoming frame to the associated value of the user-side VID. This VLAN mode is provisioned by the NMS.

In the OLT, each downstream output port and each upstream input port are associated with a separate MAC instance and, by extension, with a unique LLID. The Translation VLAN mode associates a unique VID value with each LLID.

In the downstream direction, the OLT directs the frame to the appropriate downstream output port based on the VID value of the received frame. The OLT replaces the network-side VID value with an associated user-side VID value before forwarding the frame to an ONU. The OLT discards all untagged downstream frames as well as any frame with an unknown VID value (i.e., VID value not associated with any of the output ports in this OLT).

In the upstream direction, the OLT replaces the user-side VID value with an associated network-side VID value. The OLT discards all untagged frames received from the upstream input port as well as any tagged frame with an unknown VLAN tag (i.e., VID value not matching the VID provisioned for the input port from which the frame was received).

The Translation VLAN mode may operate on either C-Tags or S-Tags. In this mode, in the downstream direction, the OLT shall apply rules and actions as illustrated in Table 7-11.

Table 7-11—Classifier rules and Modifier actions for downstream ESP in the OLT Translation VLAN mode[a–d]

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Classifier rules	Modifier actions	Description
`IF (!exists(VLAN0)) THEN drop`	`N/A`	The untagged downstream frame is discarded.
`IF (VLAN0_VID == 0) THEN drop`	`N/A`	The Priority-tagged frame is discarded. Priority-tagged frames are defined in IEEE Std 802.1Q, 3.158.
`IF (VLAN0_VID ==` VN_1`) THEN <`m_1`,…,`x_1`>`	`[`m_1`]: REPLACE(VLAN0_VID,` VU_1`)`	These rules seek frames with known (provisioned) network-side VID values. The output vector of each rule directs the frame to the CrossConnect entry (x_n) that forwards the frame further to an output port associated with the given VID value of outermost VLAN tag. The outermost VID value is replaced with a provisioned user-side VID value (translated) before the frame is forwarded.
`...`	`...`	
`IF (VLAN0_VID ==` VN_n`) THEN <`m_n`,…,`x_n`>`	`[`m_n`]: REPLACE(VLAN0_VID,` VU_n`)`	

IF (VLAN0_VID == VM_1) THEN <m_1, …, x_B>	[m_1]: REPLACE(VLAN0_VID, VW_1)	These rules are optionally provisioned to support multicast VLAN. To support multicast VLAN, the OLT forwards any frame with VLAN tag of a specific set (VM_1–VM_m) to the broadcast LLID. The output vector of this rule directs the frame to the CrossConnect entry (x_B) that forwards the frame further to an output port associated with the SCB MAC. The outermost VID value is replaced with a provisioned value (translated) before the frame is forwarded.
...	...	
IF (VLAN0_VID == VM_m) THEN <m_m, …, x_B>	[m_m]: REPLACE(VLAN0_VID, VW_m)	

[a] VN_1–VN_n are provisioned 12-bit values representing the expected network-side VIDs in the downstream frames.

[b] VM_1–VM_m are provisioned 12-bit values representing the set of allowed network-side multicast VIDs in the downstream frames.

[c] VU_1–VU_n are provisioned 12-bit values representing the user-side VIDs in the downstream frames (post-translation).

[d] VW_1–VW_m are provisioned 12-bit values representing the user-side multicast VIDs in the downstream frames (post-translation).

In the Translation VLAN mode, in the upstream direction, the OLT shall apply rules and actions as illustrated in Table 7-12.

Table 7-12—Classifier rules and Modifier actions for upstream ESP in the OLT Translation VLAN mode[a, b]

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Classifier rules	Modifier actions	Description
IF (!exists(VLAN0)) THEN drop	N/A	The untagged upstream frame is discarded.
IF (VLAN0_VID == VU_1) THEN <m_1, …, x_k>	[m_1]: REPLACE(VLAN0_VID, VN_1);	These rules seek frames with known (provisioned) user-side VID values. The output vector of each rule directs the frame to the CrossConnect entry (x_k) that forwards the frame further to an output port associated with the NNI. The outermost VID value is replaced with a provisioned network-side VID value (translated) before the frame is forwarded.
...	...	
IF (VLAN0_VID == VU_n) THEN <m_n, …, x_k>	[m_n]: REPLACE(VLAN0_VID, VN_n);	

[a] VU_1–VU_n are provisioned 12-bit values representing the expected user-side VIDs in the upstream frames.

[b] VN_1–VN_n are provisioned 12-bit values representing the network-side VIDs in the upstream frames (post-translation). These values are associated with upstream input ports (entries of the Input functional block) and allow identification of subscriber using VLAN ID.

7.2.2.1.6 ONU ToS/CoS Conversion VLAN mode

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In the *ONU ToS/CoS Conversion* VLAN mode, the downstream ESP is configured to filter each received frame based on the provisioned values of the C_VID field or the DA field and to remove the C-Tag before passing the frame to the Policer/Shaper block.

The ONU discards all untagged frames received from the ingress port. Additionally, if VLAN-based multicast filtering is enabled, the ONU also discards any multicast frame with VID not matching any of the provisioned VIDs. If MAC-address-based filtering is enabled, the ONU discards any multicast frame with Destination MAC address not matching any of the provisioned MAC addresses. The ONU removes the outermost VLAN tag from the accepted frames before forwarding them to the egress port.

The upstream ESP in the ONU ToS/CoS Conversion VLAN mode is configured to add a C-Tag with a provisioned value of VID and to transfer the value of IPv4 ToS or IPv6 TC of the received frame into the C_PCP field. The VID to be added is provisioned using the *PON-VID Value* TLV (0xB7/0x00-15), as defined in 14.3.1.13. The value of IPv4 ToS or IPv6 TC field is transferred into the C_PCP field using a provisioned mapping function. The default behavior of this function is direct copying. Other mapping functions may be provisioned using the *ToS/CoS Conversion Table* TLV (0xB7/0x00-35), as defined in 14.3.1.33.

This VLAN mode is provisioned using the *VLAN Mode* TLV (0xB7/0x00-0B) for ToS/CoS Conversion VLAN mode(IPv4) (`VlanMode` value 0x03), for ToS/CoS Conversion VLAN mode(IPv6) (`VlanMode` value 0x04), and for ToS/CoS Conversion VLAN mode(IPv4/IPv6) (`VlanMode` value 0x05), as defined in 14.3.1.5.

In the ToS/CoS Conversion VLAN mode, in the downstream direction, the ONU's behavior is identical to the ONU's behavior in Tagging VLAN mode (see 7.2.2.1.4). The ONU shall apply rules and actions as illustrated in Table 7-8 and Table 7-9. The ONU is able to filter multicast frames based on VID or Destination MAC address.

In the ToS/CoS Conversion VLAN mode, in the upstream direction, the ONU shall apply rules and actions as illustrated in Table 7-13.

Table 7-13—Classifier rules and Modifier actions for upstream ESP in the ONU ToS/CoS Conversion VLAN mode[a, b]

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Classifier rules	Modifier actions	Description
IF (exists(VLAN0) AND VLAN0_VID != 0) THEN drop	N/A	The VLAN-tagged C-Frame is discarded. VLAN-tagged frames are defined in IEEE Std 802.1Q, 3.262.
IF (exists(VLAN0) AND VLAN0_VID == 0) THEN drop	N/A	The Priority-tagged C-Frame is discarded. Priority-tagged frames are defined in IEEE Std 802.1Q, 3.158. This rule is optional and implementation dependent. If this rule is not implemented, the priority-tagged frame is processed as an untagged frame by the subsequent rules.
IF (port == [i_U] AND DA == LA_1) THEN drop	N/A	The upstream frame whose destination address matches any of the CPE MAC addresses (LA_1-LA_n) learned to be behind the upstream input port [i_U] is discarded. These rules are generated locally as a result of MAC Learning function.
...		
IF (port == [i_U] AND DA == LA_n) THEN drop		

Classifier rules	Modifier actions	Description
IF (exists(IPv4_ToS) AND MASK(IPv4_ToS,0,3) == 0) THEN $<m_i,\ldots,x_k>$	$[m_i]$: ADD(VLAN0, V_1); REPLACE(VLAN0_PCP, W_0)	The untagged upstream C-Frame with an IPv4 header receives a VLAN tag with pre-provisioned VID and PCP value (W_0–W_7) derived from the IPv4_ToS field per the provisioned ToS/CoS conversion table. The frame is then forwarded to provisioned CrossConnect entry x_k.
...	...	
IF (exists(IPv4_ToS) AND MASK(IPv4_ToS,0,3) == 7) THEN $<m_j,\ldots,x_k>$	$[m_j]$: ADD(VLAN0, V_1); REPLACE(VLAN0_PCP, W_7)	
IF (exists(IPv6_TC) AND MASK(IPv6_TC,0,3) == 0) THEN $<m_k,\ldots,x_k>$	$[m_k]$: ADD(VLAN0, V_1); REPLACE(VLAN0_PCP, W_0)	The untagged upstream C-Frame with an IPv6 header receives a VLAN tag with pre-provisioned VID and PCP value (W_0–W_7) derived from the IPv6_TC field per the provisioned ToS/CoS conversion table. The frame is then forwarded to a provisioned CrossConnect entry x_k.
...	...	
IF (exists(IPv6_TC) AND MASK(IPv6_TC,0,3) == 7) THEN $<m_l,\ldots,x_k>$	$[m_l]$: ADD(VLAN0, V_1); REPLACE(VLAN0_PCP, W_7)	
IF (true) THEN $<m_m,\ldots,x_k>$	$[m_m]$: ADD(VLAN0, V_1); REPLACE(VLAN0_PCP, 0)	The untagged upstream C-Frame that does not carry an IPv4 or IPv6 packet receives a VLAN tag with pre-provisioned VID and PCP value of 0. The frame is then forwarded to a provisioned CrossConnect entry x_k.

[a] V_1 is a 32-bit value that represents the VLAN tag to be added by a given ESP. The 32-bit value consists of a VID value provisioned using the *PON-VID Value* TLV (0xB7/0x00-15), as defined in 14.3.1.13, and the vendor-specified default values for TPID, PCP, and DEI.

[b] W_0–W_7 are provisioned 3-bit values that comprise ToS-to-CoS mapping function. These values are provisioned using *ToS/CoS Conversion Table* TLV (0xB7/0x00-35), as defined in 14.3.1.33.

7.2.2.1.7 Default configuration

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The OLT preserves the last provisioned configuration for VLAN mode and VLAN IDs in the nonvolatile memory. Upon the power-up, reset, or restart caused by local or remote signaling, the OLT shall use the last provisioned VLAN mode and VLAN IDs for all LLIDs.

The ONU preserves the last provisioned configuration for VLAN mode, VLAN IDs, and the ToS/CoS conversion table in the nonvolatile memory. Upon the power-up, reset, or deregistration, the ONU shall use the last provisioned VLAN mode, VLAN IDs, and the ToS/CoS conversion table.

7.2.2.1.8 Device-based VLAN management

The management of the VLAN modes specified for the ONU-based VLAN modes in 7.2.2.1 uses the standard set of eOAMPDUs to perform attribute read/set operations using the *eOAM_Get_Request*/*eOAM_Get_Response* for reading and *eOAM_Set_Request*/*eOAM_Set_Response* for setting the specific attribute.

The managed objects associated with VLAN management for this profile are defined in 14.3.1.5, 14.3.1.13, and 14.3.1.33. These TLVs shall be used for management and configuration of unicast VLANs only.

The existing VLAN mode configuration for the given ONU shall be overwritten every time a new TLV is received.

7.2.2.2 Port-based VLAN modes

In the port-based VLAN modes, each of the ONU UNI ports is assigned one and only one specific mode defined in the following subclauses, as configured using the TLVs defined in 14.2.2.21. A single C-OLT shall be able to support all VLAN modes specified below and shall be able to operate in at least one VLAN mode, as configured by the NMS. A single C-ONU shall be able to support all VLAN modes specified below and shall be able to operate in at least one VLAN mode, as configured by the OLT. A new mode provisioned by the OLT for a given C-ONU port overrides the previously configured VLAN mode.

Five port-based VLAN modes are defined in this profile:

- Transparent VLAN mode (see 7.2.2.2.1)
- Tagging VLAN mode (see 7.2.2.2.2)
- Translation VLAN mode (see 7.2.2.2.3)
- Filtering VLAN mode (see 7.2.2.2.4)
- N:1 Aggregation VLAN mode (see 7.2.2.2.5)

For all port-based VLAN modes, the term *frame* is used to indicate either a B-Frame or a C-Frame, depending on the type of frame transmitted by the subscriber or received from the network. No port-based VLAN mode verifies whether the frame is a B-Frame or a C-Frame.

7.2.2.2.1 Transparent VLAN mode

In the *Transparent* VLAN mode, the upstream and downstream ESPs are provisioned to not modify VLAN tags in the forwarded frames. This VLAN mode in the ONU shall be provisioned by the OLT using the *Port VLAN* TLV (0xC7/0x00-21) for Transparent VLAN mode (the sub-attribute *aPortVLAN.sVLANmode* set to value of `transparent`), as defined in 14.2.2.21.

In the upstream direction, each received tagged or untagged frame is forwarded to the output port without any changes. The MAC Learning function monitors the upstream traffic and learns the Source MAC addresses of frames received from each input port. This function then creates in the Classifier the necessary rules to forward downstream frames to proper output ports based on learned association between the MAC address and the port. The upstream frame whose Destination MAC address matches a MAC address learned on the same port is discarded.

In the downstream direction, each frame is forwarded to the output port according to the IEEE Std 802.1Q bridging function. A specific output port is selected according to the Destination MAC address of the frame. The rules for the association of the Destination MAC addresses to specific ports are described via Classifier rules, created by the MAC Learning function. A frame whose Destination MAC address was learned is then forwarded to the associated output port without any modifications. A frame whose Destination MAC address was not learned is discarded.

When configured in the Transparent VLAN mode, the downstream ESPs at the OLT and the ONU shall apply rules and actions as illustrated in Table 7-14.

Table 7-14—Classifier rules and Modifier actions for downstream ESP in the Transparent VLAN mode[a]

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<table>
<tr><th>Classifier rules</th><th>Modifier actions</th><th>Description</th></tr>
<tr><td colspan="3">When multicast frame filtering is enabled, the relevant rules are inserted here. The rules for multicast filtering are specified in Table 7-36 for OLT and Table 7-37 for ONU for the multicast transport based on VLAN and MAC group address and in Table 7-38 for OLT and Table 7-39 for ONU for the multicast transport based on VLAN and IP group address.</td></tr>
<tr><td>IF (DA == LA_1)
THEN $\langle m_0, \ldots, x_1 \rangle$</td><td rowspan="3">[$m_0$]: none</td><td rowspan="3">The output vector of each rule directs the frame to the CrossConnect entry (x_n) that forwards the frame further to an output port associated with the given value of DA through MAC Learning. These rules are generated locally as a result of MAC Learning function.</td></tr>
<tr><td>...</td></tr>
<tr><td>IF (DA == LA_n)
THEN $\langle m_0, \ldots, x_n \rangle$</td></tr>
</table>

[a] LA_1-LA_n represent n MAC addresses of the CPE devices, acquired by the MAC Learning function operating on the upstream traffic.

When configured in the Transparent VLAN mode, the upstream ESPs at the OLT and the ONU shall apply rules and actions as illustrated in Table 7-15.

Table 7-15—Classifier rules and Modifier actions for upstream ESP in the Transparent VLAN mode[a, b]

Classifier rules	Modifier actions	Description
IF (port == [i_U] AND DA != LA_1 AND ... DA != LA_n) THEN $\langle m_0, \ldots, x_k \rangle$	[m_0]: none	The upstream frame whose destination address does not match any of the CPE MAC addresses (LA_1-LA_n) learned to be behind input port [i_U] is forwarded to a provisioned CrossConnect entry x_k associated with an upstream output port. This rule is generated locally as a result of MAC Learning function.

[a] [i_U] represents an upstream input port (an entry of the Input functional block).

[b] LA_1-LA_n represent n MAC addresses of the CPE devices, acquired by the MAC Learning function operating on the upstream traffic.

7.2.2.2.2 Tagging VLAN mode

In the *Tagging* VLAN mode, the upstream ESP is provisioned to add a VLAN tag to upstream frames, and the downstream ESP is provisioned to remove a VLAN tag from downstream frames.

In the downstream direction, the OLT and ONU direct each frame to the appropriate downstream output port based on the VLAN tag value of the received frame. The downstream ESP removes the outer VLAN tag before forwarding the frame to the egress port. All untagged downstream frames as well as all frames with an unknown VID value (i.e., VID value not associated with any of the output ports in this OLT) are discarded.

In the upstream direction, the OLT and ONU insert a VLAN tag with a value associated with the given upstream input port. All tagged frames received from the upstream input port are discarded.

When configured in the Tagging VLAN mode, the downstream ESPs at the OLT and the ONU shall apply rules and actions as illustrated in Table 7-16.

Table 7-16—Classifier rules and Modifier actions for downstream ESP in the Tagging VLAN mode[a]

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Classifier rules	Modifier actions	Description
IF (!exists(VLAN0)) THEN drop	N/A	The untagged downstream frame is discarded.
IF (exists(VLAN1)) THEN drop	N/A	The double-tagged frame is discarded.
When multicast frame filtering is enabled, the relevant rules are inserted here. The rules for multicast filtering are specified in Table 7-36 for OLT and Table 7-37 for ONU for the multicast transport based on VLAN and MAC group address and in Table 7-38 for OLT and Table 7-39 for ONU for the multicast transport based on VLAN and IP group address.		
IF (VLAN0 == DV_1) THEN <m_i, …, x_1>	[m_i]: REMOVE(VLAN0)	These rules seek frames with known (provisioned) VLAN tag values. The output vector of each rule directs the frame to the CrossConnect entry (x_n) that forwards the frame further to an output port associated with the given VLAN value DV_n representing the given Default VLAN. The VLAN tag is removed before the frame is forwarded.
...		
IF (VLAN0 == DV_n) THEN <m_i, …, x_n>		

[a] DV_1–DV_n represent n provisioned 32-bit Default VLAN tag values associated with downstream output ports. There shall be one Default VLAN tag value provisioned for each downstream output port configured to operate in the Tagging VLAN mode.

When configured in the Tagging VLAN mode, the upstream ESPs at the OLT and the ONU shall apply rules and actions as illustrated in Table 7-17.

Table 7-17—Classifier rules and Modifier actions for upstream ESP in the Tagging VLAN mode[a, b, c]

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Classifier rules	Modifier actions	Description
IF (exists(VLAN0)) THEN drop	N/A	The tagged frame is discarded.
IF (port == [i_{U1}] AND DA != LA_1 AND ... DA != LA_k AND) THEN <m_1, …, x_j>	[m_1]: ADD(VLAN0, DV_1);	The upstream untagged frame whose destination address does not match any of the CPE MAC addresses (LA_1–LA_m) learned to be behind input port [i_{Un}] receives a VLAN tag with a value associated with the input port from which this frame was received (Default VLAN value). The frame is then forwarded to a provisioned CrossConnect entry x_j associated with an upstream output port.
...	...	
IF (port == [i_{Un}] AND DA != LA_1 AND ... DA != LA_m AND) THEN <m_n, …, x_j>	[m_k]: ADD(VLAN0, DV_k);	

[a] [i_{U1}]-[i_{Un}] are upstream input port (entries of the Input functional block).

[b] LA_1–LA_m represent m MAC addresses of devices learned by the MAC Learning function to be behind input port [i_{Un}].

[c] DV_1–DV_k represent n provisioned 32-bit Default VLAN tag values associated with upstream input ports. There shall be one Default VLAN tag value provisioned for each upstream input port configured to operate in the Tagging VLAN mode.

This VLAN mode in the ONU shall be provisioned by the OLT using the *Port VLAN* TLV (0xC7/0x00-21) for Tagging VLAN mode (the sub-attribute *aPortVLAN.sVLANmode* set to value of `tagging`), as defined in 14.2.2.21.

7.2.2.2.3 Translation VLAN mode

In the *Translation* VLAN mode for downstream ESPs, the MAC Client at the ONU or OLT is provisioned to

— Strip the outermost VLAN tag from a forwarded frame if the VLAN tag matches the provisioned Default VLAN tag;

— Translate the VID in the VLAN tag of an incoming frame to a provisioned value if the VLAN tag matches one of the provisioned Source VLAN tags;

— Discard all other frames in this ESP.

When configured in the Translation VLAN mode, the downstream ESPs at the OLT and the ONU shall apply rules and actions as illustrated in Table 7-18.

Table 7-18—Classifier rules and Modifier actions for downstream ESP in the Translation VLAN mode[a–d]

<table>
<tr><th>Classifier rules</th><th>Modifier actions</th><th>Description</th></tr>
<tr><td>IF (!exists(VLAN0)) THEN drop</td><td>N/A</td><td>The untagged frame is discarded.</td></tr>
<tr><td>IF (exists(VLAN1)) THEN drop</td><td>N/A</td><td>The double-tagged frame is discarded.</td></tr>
<tr><td colspan="3"><u>*Editorial Note (to be removed prior to publication): reference to aOnuMulticastLlid removed per tf4_2106_kramer_4a.pdf*</u>
When multicast frame filtering is enabled, the relevant rules are inserted here. The rules for multicast filtering are specified in Table 7-36 for OLT and Table 7-37 for ONU for the multicast transport based on VLAN and MAC group address and in Table 7-38 for OLT and ~~Table 7-39~~<u>**TBD**</u> for ONU for the multicast transport based on VLAN and IP group address.</td></tr>
<tr><td>IF (VLAN0 == DV_1) THEN $\langle m_i, \ldots, x_1 \rangle$</td><td rowspan="3">[$m_i$]: REMOVE (VLAN0)</td><td rowspan="3">These rules seek frames with known (provisioned) VLAN tag values. The output vector of each rule directs the frame to the CrossConnect entry (x_n) that forwards the frame further to an output port associated with the given VLAN value DV_n representing the given Default VLAN. The VLAN tag is removed before the frame is forwarded.</td></tr>
<tr><td>...</td></tr>
<tr><td>IF (VLAN0 == DV_n) THEN $\langle m_i, \ldots, x_n \rangle$</td></tr>
<tr><td>IF (VLAN0 == SV_1) THEN $\langle m_j, \ldots, x_1 \rangle$</td><td>[$m_j$]: REPLACE (VLAN0_VID, TV_1)</td><td rowspan="3">The single-tagged frame with a VLAN tag matching one of the provisioned Source VLAN tag values SV_1–SV_m has the VLAN tag VID replaced with a corresponding provisioned VLAN tag VID value of TV_x (x = 1 to m) and is forwarded to a provisioned CrossConnect entry x_m.</td></tr>
<tr><td>...</td><td>...</td></tr>
<tr><td>IF (VLAN0 == SV_m) THEN $\langle m_k, \ldots, x_m \rangle$</td><td>[$m_k$]: REPLACE (VLAN0_VID, TV_m)</td></tr>
</table>

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[a] DV_1–DV_n represent n provisioned 32-bit Default VLAN tag values associated with downstream output ports. There shall be one Default VLAN tag value provisioned for each downstream output port configured to operate in the Translation VLAN mode.

[b] SV_1–SV_m represent m provisioned 32-bit Source (input) VLAN tag values.

[c] TV_1–TV_m represent m provisioned 12-bit Target (egress) VLAN tag VID values. There is a one-to-one correspondence between SV_x (x = 1 to m) and TV_x (x = 1 to m). There are in total m Target–Source VLAN tag pairs provisioned on a device.

[d] A Source VLAN tag SV_x (x = 1 to m) and a Target VLAN tag TV_x (x = 1 to m) may have the same value, if so provisioned by the operator.

In the Translation VLAN mode for upstream ESPs, the MAC Client at the ONU or OLT is provisioned to

- Add a Default VLAN tag to each incoming, untagged frame;
- Translate the VID in the VLAN tag of an incoming, single-tagged frame to a provisioned value if the VLAN tag matches one of the provisioned Source VLAN tags, as configured by the operator;
- Discard all other frames in this ESP.

When configured in the Translation VLAN mode, the upstream ESPs at the OLT and the ONU shall apply rules and actions as illustrated in Table 7-19.

Table 7-19—Classifier rules and Modifier actions for upstream ESP in the Translation VLAN mode[a–e]

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Classifier rules	Modifier actions	Description
IF (exists(VLAN1) THEN drop	N/A	The double-tagged frame is discarded.
IF (port == [i_{U1}] AND !exists(VLAN0)) THEN <m_1, …, x_k>	[m_1]: ADD (VLAN0, DV_1)	A VLAN tag is added to the upstream untagged frame. The value of the VLAN tag is associated with the input port [i_{Un}] from which this frame was received (Default VLAN value). The frame is then forwarded to a provisioned CrossConnect entry x_k associated with an upstream output port.
...	...	
IF (port == [i_{Un}] AND !exists(VLAN0)) THEN <m_i, …, x_k>	[m_i]: ADD (VLAN0, DV_n)	
IF (port == [i_{U1}] AND VLAN0 == SV_1) THEN <m_j, …, x_k>	[m_j]: REPLACE (VLAN0_VID, TV_1)	The single-tagged frame, received from the input port [i_{Un}], with a VLAN tag matching one of the provisioned Source VLAN tags (SV_1–SV_k) for the given input port [i_{Un}], has the VLAN tag VID replaced with a corresponding provisioned Target VID value of TV_x (x = 1 to k) and is forwarded to a provisioned CrossConnect entry x_k associated with an upstream output port.
...	...	
IF (port == [i_{Un}] AND VLAN0 == SV_k) THEN <m_k, …, x_k>	[m_k]: REPLACE (VLAN0_VID, TV_k)	

[a] [i_{U1}]–[i_{Un}] are upstream input port (entries of the Input functional block).

[b] DV_1–DV_n represent n provisioned 32-bit Default VLAN tag values associated with upstream input ports. There shall be one Default VLAN tag value provisioned for each upstream input port configured to operate in the Translation VLAN mode.

[c] SV_1–SV_k represent k provisioned 32-bit Source (input) VLAN tag values.

[d] TV_1–TV_k represent k provisioned 12-bit Target (egress) VLAN tag VID values. There is a one-to-one correspondence between SV_x (x = 1 to k) and TV_x (x = 1 to k). There are in total k Target–Source VLAN tag pairs provisioned on a device.

[e] The Source VLAN tag SV_x (x = 1 to k) and the Target VLAN tag TV_x (x = 1 to k) may have the same value, if so provisioned by the operator.

This VLAN mode in the ONU shall be provisioned by the OLT using the *Port VLAN* TLV (0xC7/0x00-21) for Translation VLAN mode (the sub-attribute *aPortVLAN.sVLANmode* set to value of `translation`), as defined in 14.2.2.21.

7.2.2.2.4 Filtering VLAN mode

In the *Filtering* VLAN mode for downstream ESPs, the MAC Client at the ONU or OLT is provisioned to

- Strip the VLAN tag from an incoming single-tagged frame if that VLAN tag matches the provisioned Default VLAN tag;
- Forward a single-tagged frame unmodified to the output port if that VLAN tag value matches one of the Permitted VLAN tags (as configured by the operator);
- Discard all other downstream frames in this ESP.

When configured in the Filtering VLAN mode, the downstream ESPs at the OLT and the ONUs shall apply rules and actions as illustrated in Table 7-20.

Table 7-20—Classifier rules and Modifier actions for downstream ESP in the Filtering VLAN mode[a, b]

<table>
<tr><th>Classifier rules</th><th>Modifier actions</th><th>Description</th></tr>
<tr><td>IF (!exists(VLAN0))
THEN drop</td><td>N/A</td><td>The untagged frame is discarded.</td></tr>
<tr><td>IF (exists(VLAN1)
THEN drop</td><td>N/A</td><td>The double-tagged frame is discarded.</td></tr>
<tr><td colspan="3">When multicast frame filtering is enabled, the relevant rules are inserted here. The rules for multicast filtering are specified in Table 7-36 for OLT and Table 7-37 for ONU for the multicast transport based on VLAN and MAC group address and in Table 7-38 for OLT and Table 7-39 for ONU for the multicast transport based on VLAN and IP group address.</td></tr>
<tr><td>IF (VLAN0 == DV_1)
THEN <m_i,…,x_1></td><td rowspan="3">[m_i]:
REMOVE (VLAN0)</td><td rowspan="3">These rules seek frames with known (provisioned) VLAN tag values. The output vector of each rule directs the frame to the CrossConnect entry (x_n) that forwards the frame further to an output port associated with the given VLAN value DV_n representing the given Default VLAN. The VLAN tag is removed before the frame is forwarded.</td></tr>
<tr><td>...</td></tr>
<tr><td>IF (VLAN0 == DV_n)
THEN <m_i,…,x_n></td></tr>
<tr><td>IF (VLAN0 == PV_1)
THEN <m_0,…,x_1></td><td rowspan="3">[m_0]: none</td><td rowspan="3">The single-tagged frame with a VLAN tag matching one of the provisioned Permitted VLAN tag values (PV_1–PV_m) is forwarded unmodified to a provisioned CrossConnect entry x_m.</td></tr>
<tr><td>...</td></tr>
<tr><td>IF (VLAN0 == PV_m)
THEN <m_0,…,x_m></td></tr>
</table>

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[a] DV_1–DV_n represent n provisioned 32-bit Default VLAN tag values associated with downstream output ports. There shall be only one Default VLAN tag value provisioned for each downstream output port configured to operate in the Filtering VLAN mode.

[b] PV_1–PV_m represent m provisioned 32-bit Permitted VLAN tag values.

In the Filtering VLAN mode for upstream ESPs, the MAC Client at the ONU or OLT is provisioned to

- Add a Default VLAN tag to each incoming untagged frame;
- Forward an incoming, single-tagged frame unmodified to the output port if the VLAN tag matches one of the Permitted VLAN tags (as configured by the operator);
- Discard all other upstream frames in this ESP.

When configured in the Filtering VLAN mode, the upstream ESPs at the OLT and the ONU shall apply rules and actions as illustrated in Table 7-21.

Table 7-21—Classifier rules and Modifier actions for upstream ESP in the Filtering VLAN mode[a, b, c]

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Classifier rules	Modifier actions	Description
IF (exists(VLAN1) THEN drop	N/A	The double-tagged frame is discarded.
IF (port == [i_{U1}] AND !exists(VLAN0)) THEN <m_1,…,x_k>	[m_i]: ADD (VLAN0,DV_1)	A VLAN tag is added to the upstream untagged frame. The value of the VLAN tag is associated with the input port [i_{Un}] from which this frame was received (Default VLAN value). The frame is then forwarded to a provisioned CrossConnect entry x_k associated with an upstream output port.
...	...	
IF (port == [i_{Un}] AND !exists(VLAN0)) THEN <m_i,…,x_k>	[m_i]: ADD (VLAN0,DV_n)	
IF (port == [i_{U1}] AND VLAN0 == PV_1) THEN <m_0,…,x_k>	[m_0]: none	The single-tagged frame, received from the input port [i_{Un}], with the VLAN tag matching one of the provisioned Permitted VLAN tag values (PV_1–PV_k), is forwarded unmodified to a provisioned CrossConnect entry x_k.
...		
IF (port == [i_{U1}] AND VLAN0 == PV_k) THEN <m_0,…,x_k>		

[a] [i_{U1}]-[i_{Un}] are upstream input port (entries of the Input functional block).

[b] DV_1–DV_n represent n provisioned 32-bit Default VLAN tag values associated with upstream input ports. There shall be one Default VLAN tag value provisioned for each upstream input port configured to operate in the Filtering VLAN mode.

[c] PV_1–PV_k represent k provisioned 32-bit Permitted VLAN values associated with the given upstream input port [i_{Un}].

This VLAN mode in the ONU shall be provisioned by the OLT using the *Port VLAN* TLV (0xC7/0x00-21) for the Filtering VLAN mode (the sub-attribute *aPortVLAN.sVLANmode* set to value of filtering), as defined in 14.2.2.21.

7.2.2.2.5 N:1 Aggregation VLAN mode

The *N:1 Aggregation* VLAN mode aggregates multiple customer VLAN values, referred to as Source VLANs, to a single operator-assigned VLAN value, referred to as Trunk VLAN. A device may be provisioned to use multiple Trunk VLANs, with multiple Source VLANs mapped to each Trunk VLAN. A different number of Source VLANs may be associated with each Trunk VLAN. The association of Source VLANs and Trunk VLANs is provisioned by the operator.

In the upstream direction, a Source VID is replaced by an associated Trunk VID. In addition, a MAC Learning function observes upstream data frames and builds an association of the Source VLANs, source port (upstream input port), and Source MAC addresses (SA). Based on this association, the device generates Classifier rules used in the downstream direction (see ~~6.5.2.2.6).~~IEEE Std 1904.1, 6.5.2.2.6).

In the downstream direction, the Trunk VID is replaced with a Source VID. A specific value of Source VID is selected based on the destination MAC address (DA) of a frame using the set of rules generated by the MAC Learning function. These rules direct frames to the CrossConnect entry that forwards them to a port associated with the given DA value (as part of the MAC Learning process).

The MAC Learning function can add, remove, and modify the downstream forwarding rules dynamically.

In the N:1 Aggregation VLAN mode for downstream ESPs, the MAC Client at the ONU or OLT is provisioned to

— Strip the VLAN tag from an incoming, single-tagged frame if the VLAN tag matches the provisioned Default VLAN tag;

— Translate the VID in an incoming, single-tagged frame into a Source VID as directed by the MAC Learning function if the VLAN tag matches one of the provisioned Trunk VLAN tags and the DA value matches one of the learned SA values;

— Discard all other frames in this ESP.

When configured in the N:1 Aggregation VLAN mode, the downstream ESPs at the OLT and the ONU shall apply rules and actions as illustrated in Table 7-22.

Table 7-22—Classifier rules and Modifier actions for downstream ESPs in the N:1 Aggregation VLAN mode[a–f]

Classifier rules	Modifier actions	Description
`IF (!exists(VLAN0)) THEN drop`	`N/A`	The untagged frame is discarded.
`IF (exists(VLAN1)) THEN drop`	`N/A`	The double-tagged frame is discarded.
When multicast frame filtering is enabled, the relevant rules are inserted here. The rules for multicast filtering are specified in Table 7-36 for OLT and Table 7-37 for ONU for the multicast transport based on VLAN and MAC group address and in Table 7-38 for OLT and Table 7-39 for ONU for the multicast transport based on VLAN and IP group address.		

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Classifier rules	Modifier actions	Description
IF (exists(VLAN0) AND VLAN0 == DV_1)) THEN <m_i,…,x_1>	[m_i]: REMOVE (VLAN0)	These rules seek frames with known (provisioned) VLAN tag values. The output vector of each rule directs the frame to the CrossConnect entry (x_n) that forwards the frame further to an output port associated with the given VLAN value DV_n representing the given Default VLAN. The VLAN tag is removed before the frame is forwarded.
...		
IF (exists(VLAN0) AND VLAN0 == DV_n) THEN <m_i,…,x_n>		
IF (exists(VLAN0) AND VLAN0 != TV_1 AND ... VLAN0 != TV_m) THEN drop	N/A	The single-tagged frame with a VLAN tag not matching either the provisioned Default VLAN tag (DV_1–DV_n) or any of the provisioned Trunk VLANs (TV_1–TV_m) is discarded.
IF (exists(VLAN0) AND VLAN0 == RV_1 AND DA == LSA_1) THEN <m_j,…,x_1>	[m_j]: REPLACE (VLAN0_VID, SV_1)	The single-tagged frame with the a VLAN tag matching one of the provisioned Trunk VLAN tags (RV_1–RV_m) and the DA matching one of the MAC addresses learned in the upstream direction (LSA_1–LSA_n) has the VID replaced with a provisioned Source VID value SV_m associated with the given TV_m and DA values. The output vector of each rule directs the frame to the CrossConnect entry (x_n) that forwards the frame further to an output port associated with the given value of DA through MAC Learning. These rules are generated locally as a result of MAC Learning function.
...	...	
IF (exists(VLAN0) AND VLAN0 == RV_m AND DA == LSA_n) THEN <m_k,…,x_n>	[m_k]: REPLACE (VLAN0_VID, SV_m)	

[a] DV_1–DV_n represent n provisioned 32-bit value Default VLAN tag values associated with downstream output ports. There shall be one Default VLAN tag value provisioned for each downstream output port configured to operate in the Tagging VLAN mode.

[b] SV_1–SV_m represent m provisioned 12-bit Source VID values.

[c] TV_1–TV_m represent m provisioned 32-bit Trunk VLAN values.

[d] RV_1–RV_m represent m provisioned 12-bit Trunk VID values.

[e] The Source VLAN tag SV_x (x = 1 to k) and the Trunk VLAN tag RV_x (x = 1 to k) may have the same value, if so provisioned by the operator.

[f] LSA_1–LSA_n represent SAs of the CPE devices, acquired by the MAC Learning function operating on the upstream traffic.

In the N:1 Aggregation VLAN mode for upstream ESPs, the MAC Client at the ONU or OLT is provisioned to

— Add a Default VLAN tag to each incoming untagged frame;

— Translate the VLAN tag VID into a provisioned Trunk VID if the VLAN tag of an incoming single-tagged frame matches one of the provisioned Source VLAN tags;

— Discard all other frames in this ESP.

When configured in the N:1 Aggregation VLAN mode, the upstream ESPs at the OLT and the ONU shall apply rules and actions as illustrated in Table 7-23.

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Table 7-23—Classifier rules and Modifier actions for upstream ESPs in the N:1 Aggregation VLAN mode[a–e]

Classifier rules	Modifier actions	Description
IF (exists(VLAN1) THEN drop	N/A	The double-tagged frame is discarded.
IF (port == [i_{U1}] AND !exists(VLAN0)) THEN <m_g, …, x_k>	[m_g]: ADD (VLAN0, DV_1)	A VLAN tag is added to the upstream untagged frame. The value of the VLAN tag is associated with the input port [i_{Un}] from which this frame was received (Default VLAN value). The frame is then forwarded to a provisioned CrossConnect entry x_k associated with an upstream output port.
...	...	
IF (port == [i_{Un}] AND !exists(VLAN0)) THEN <m_h, …, x_k>	[m_h]: ADD (VLAN0, DV_n)	
IF (port == [i_{U1}] AND VLAN0 == SV_1) THEN <m_i, …, x_k>	[m_i]: REPLACE (VLAN0_VID, RV_1)	The single-tagged frame, received from the input port [i_{Un}], with the VLAN tag matching any of the Source VLAN tags (SV_1–SV_k) for the given input port [i_{Un}], has the VLAN tag VID replaced with a provisioned Trunk VID value of RV_x, (x = 1 to m) and is forwarded to a provisioned CrossConnect entry x_k associated with an upstream output port.
...	...	
IF (port == [i_{Un}] AND VLAN0 == SV_k) THEN <m_j, …, x_k>	[m_j]: REPLACE (VLAN0_VID, RV_m)	

[a] [i_{U1}]–[i_{Un}] are upstream input port (entries of the Input functional block).

[b] DV_1–DV_n represent n provisioned 32-bit Default VLAN tag values associated with upstream input ports. There shall be one Default VLAN tag value provisioned for each upstream input port configured to operate in the N:1 Aggregation VLAN mode.

[c] SV_1–SV_k represent k provisioned 32-bit Source VLAN tag values.

[d] RV_1–RV_m represent m provisioned 12-bit Trunk VLAN VID values.

[e] The Source VLAN tag SV_x (x = 1 to k) and the Trunk VLAN tag RV_x (x = 1 to m) may have the same value, if so provisioned by the operator.

This VLAN mode in the ONU shall be provisioned by the OLT using the *Port VLAN* TLV (0xC7/0x00-21) for N:1 Aggregation VLAN mode (the sub-attribute *aPortVLAN.sVLANmode* set to value of aggregation), as defined in 14.2.2.21.

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7.2.2.2.6 Default configuration

Upon power-up, reboot, or restart caused by local or remote signaling, the OLT shall be configured to use the Transparent VLAN mode for all ESPs associated with the active ONUs.

Upon power-up, reboot, or deregistration, the ONU shall be configured to use the Transparent VLAN mode for all ESPs associated with the configured UNI ports.

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7.2.2.2.7 Port-based VLAN management

The management of the VLAN modes~~ specified for this profile~~ relies on *eOAM_Get_Request*/*eOAM_Get_Response* eOAMPDUs for reading and *eOAM_Set_Request*/*eOAM_Set_Response* eOAMPDUs for setting the specific VLAN-related attributes. The VLAN-related attributes for this profile use the *Port VLAN* TLV (0xC7/0x00-21) (see 14.2.2.21) to manage the VLAN modes for specific UNI ports.

All VLAN operation modes ~~specified for this profile~~ are UNI port-based. Each instance of the *Port VLAN* TLV (0xC7/0x00-21) shall contain VLAN configuration for only one UNI port, as indicated by the *Object_ID* TLV (0x37/varies), as defined in 14.2.3.1, preceding the *Port VLAN* TLV (0xC7/0x00-21). The *Port VLAN* TLV (0xC7/0x00-21) shall be used for management and configuration of unicast VLANs only.

Each UNI port shall be associated with only one VLAN mode (i.e., it is not permitted for a single port to be associated with more than one VLAN mode).

The existing VLAN mode configuration for the given UNI port shall be overwritten every time the *Port VLAN* TLV (0xC7/0x00-21) is received. As a result, the VLAN configuration mode for the given UNI port cannot be extended by adding new entries to the existing configuration tables. Every time a change in the VLAN configuration mode for the given UNI port is needed, a complete VLAN mode configuration needs to be sent to the ONU in question, replacing the previously existing configuration.

7.2.2.2.8 MAC aging function

ONUs and OLTs complying with this profile support a limited number of MAC address entries, learned through the MAC learning function provided by the Classifier block or provisioned by the operator using other mechanisms. The limitation in question is typically hardware related, due to constraints in the size of available memory rather than constraints in the MAC learning function or the provisioning model defined in this standard.

To avoid a lockdown of the MAC address table, its overflow and loss of MAC address information, and rejection of new MAC addresses because of the lack of available storage space and to prevent certain types of network attacks, individual MAC addresses are aged and consequently removed from the MAC address table if they are not refreshed for a predefined period of time. A typical implementation maintains a timer associated with each MAC address, counting from a certain provisioned default value toward zero. When this timer reaches zero, the MAC address associated with this timer is considered to be aged and consequently is removed from the MAC address table. This timer is reset to its default value every time this MAC address is observed by the MAC learning function, extending the validity of the given MAC address.

ONUs and OLTs complying with this profile shall support the MAC aging function, as described above. The configuration of this function on the OLT is the responsibility of the NMS and remains outside the scope of this standard. The OLT should configure this function on the ONU using the *MAC Aging Time Configuration* TLV (0xC7/0x00-A4), as defined in 14.2.2.33, including the administrative status of this function (enabled/disabled) and the MAC aging period, when MAC aging is enabled. The duration of the MAC address validity period may be configured by the operator to an arbitrary value. Unless otherwise configured by the operator, the ONU and OLT shall enable the MAC aging functions. When the MAC aging function is enabled, the ONU and OLT shall use the default duration of the MAC aging timeout of 300 seconds unless configured otherwise by the operator.

7.2.2.3 Provider Bridging (PB) VLAN modes

In the PB VLAN modes, each of the ONU UNI ports is assigned one and only one specific mode defined in the following subclauses, as configured using a combination of the *Port Ingress Rule* TLV (~~0xD7~~0xDB/0x05-01), the *Custom Field* TLV (~~0xD7~~0xDB/0x05-02), the *Alternative C-TPID* TLV (~~0xD7~~0xDB/0x05-03), and the *Alternative S-TPID* TLV (~~0xD7~~0xDB/0x05-04), as defined in 14.4.3.6.4 and its subclauses. A single C-OLT shall be able to support all PB VLAN modes specified below and shall be able to operate in at least one PB VLAN mode, as configured by the NMS. A single C-ONU shall be able to configure any of the PB VLAN modes on any of UNIs. Each UNI shall operate in one and only one PB VLAN mode at a time, as configured by the OLT. When an ONU is provisioned with a specific PB VLAN mode for a specific UNI, the previously existing configuration for this UNI is overwritten. Two PB VLAN modes are defined in this profile:

— Transport PB VLAN mode

— Encapsulation PB VLAN mode

7.2.2.3.1 Transport PB VLAN mode

In the *Transport* PB VLAN mode for upstream and downstream, ESPs at the ONU and OLT are provisioned to transfer incoming S-tagged C-Frames matching the provisioned Classifier rules to the output port. At the OLT, the upstream and downstream ESPs may be additionally configured to perform TPID translation for S-TPID, as provisioned by the operator.

When configured in the Transport PB VLAN mode, the downstream and upstream ESPs at the OLT shall apply rules and actions as illustrated in Table 7-24.

Table 7-24—Classifier rules and Modifier actions for downstream and upstream ESPs in the OLT Transport PB VLAN mode[a–d]

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Classifier rules	Modifier actions	Description
When multicast frame filtering is enabled, the relevant rules are inserted here. The rules for multicast filtering and forwarding based on LLID and IP multicast address are specified in Table 7-~~40~~32 for the OLT and in Table 7-~~41~~33 for the ONU.		
IF (!exists(I_TAG) AND exists(S_TAG) AND S_VID == $SVID_1$) THEN <m_0,…,x_1>	[m_0]: none	If provisioned, this set of rules implements the Transport PB VLAN mode without TPID translation. All S-tagged C-Frames (not subject to TPID translation) are forwarded to the provisioned CrossConnect entry x_k associated with a downstream output port [o_k]. The output port [o_k] is selected based on a configured SVID value ($SVID_k$).
...		
IF (!exists(I_TAG) AND exists(S_TAG) AND S_VID == $SVID_k$) THEN <m_0,…,x_k>		

Classifier rules	Modifier actions	Description
IF (!exists(I_TAG) AND exists(S_TAG) AND S_TPID == STPID$_{S1}$ AND S_VID == SVID$_1$) THEN <m$_i$,…,x$_1$>	[m$_i$]: REPLACE (S_TPID, STPID$_{T1}$)	If provisioned, this set of rules implements the Transport PB VLAN mode with the TPID translation. An S-tagged C-Frame with the S-TPID matching a provisioned value of STPID$_{Sm}$ has the S-TPID replaced with a provisioned value of STPID$_{Tm}$ and is then forwarded to the provisioned CrossConnect entry x$_k$ associated with a downstream output port [o$_k$]. The output port [o$_k$] is associated with the specific value of S-VID (SVID$_k$).
...		
IF (!exists(I_TAG) AND exists(S_TAG) AND S_TPID == STPID$_{Sm}$ AND S_VID == SVID$_k$) THEN <m$_m$,…,x$_k$>	[m$_m$]: REPLACE (S_TPID, STPID$_{Tm}$)	

[a] SVID$_k$ represents a provisioned 12-bit S-VID value to be associated with the specific instance of service provisioned on the given output port [o$_k$].

[b] STPID$_{Sm}$ represents a provisioned 16-bit-wide source value of the S-TPID field to be translated into the target S-TPID (STPID$_{Tm}$) using the TPID translation mechanism.

[c] STPID$_{Tm}$ represents a provisioned 16-bit-wide target value of the S-TPID field to which the source value of the S-TPID (STPID$_{Sm}$) is being translated using the TPID translation mechanism.

[d] A single SVID$_k$ value may be shared by multiple STPID$_{Sm}$ values, i.e., the same SVID$_k$ value may be used with various source STPID$_{Sm}$ values. There are no requirements regarding translation between STPID$_{Sm}$ values and STPID$_{Tm}$ values, which are independent from the SVID$_k$ numbering space.

When configured to operate in the Transport PB VLAN mode, the downstream and upstream ESPs at the ONU shall apply rules and actions as illustrated in Table 7-25.

Table 7-25—Classifier rules and Modifier actions for downstream and upstream ESPs in the ONU Transport PB VLAN mode[a]

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Classifier rules	Modifier actions	Description
When multicast frame filtering is enabled, the relevant rules are inserted here. The rules for multicast filtering and forwarding based on LLID and IP multicast address are specified in Table 7-~~40~~32 for the OLT and in Table 7-~~41~~33 for the ONU.		
IF (!exists(I_TAG) AND exists(S_TAG) AND S_VID == SVID$_1$) THEN <m$_0$,…,x$_1$>)	[m$_0$]: none	An S-tagged C-Frame is forwarded to the provisioned CrossConnect entry x$_k$ associated with an output port [o$_k$], where the output port is selected based on a configured S-VID$_k$ value (SVID$_k$).
...		
IF (!exists(I_TAG) AND exists(S_TAG) AND S_VID == SVID$_k$) THEN <m$_0$,…,x$_k$>)		

[a] SVID$_k$ represents a provisioned 12-bit S-VID value associated with the specific instance of service provisioned on the given output port [o$_k$].

7.2.2.3.2 Encapsulation PB VLAN mode

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In the *Encapsulation* PB VLAN mode, the upstream and downstream ESPs at the OLT are provisioned to transfer incoming S-tagged C-Frames matching the provisioned Classifier rules to the output port. The upstream and downstream ESPs may be additionally configured to perform TPID translation for S-TPID, as provisioned by the operator.

In the Encapsulation PB VLAN mode, the upstream ESPs at the ONU are provisioned to perform encapsulation by adding an S-Tag to incoming C-Frames or adding an S-Tag and C-Tag to incoming untagged C-Frames matching the provisioned Classifier rules. The downstream ESPs at the ONU are provisioned to perform decapsulation by stripping the S-Tag or the S-Tag and C-Tag from frames matching the provisioned Classifier rules.

When configured in the Encapsulation PB VLAN mode, the downstream and upstream ESPs at the OLT shall apply rules and actions as illustrated in Table 7-24.

When configured in the Encapsulation PB VLAN mode, the downstream ESP at the ONU shall apply rules and actions as illustrated in Table 7-26.

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Table 7-26—Classifier rules and Modifier actions for downstream ESPs in the ONU Encapsulation PB VLAN mode [a]

<table>
<tr><th>Classifier rules</th><th>Modifier actions</th><th colspan="2">Description</th></tr>
<tr><td colspan="4">When multicast frame filtering is enabled, the relevant rules are inserted here. The rules for multicast filtering and forwarding based on LLID and IP multicast address are specified in Table 7-~~40~~32 for the OLT and in Table 7-~~41~~33 for the ONU.</td></tr>
<tr><td>IF (exists(S_TAG) AND exists(C_TAG) AND S_VID == $SVID_1$) THEN <m_i,…,x_1></td><td rowspan="3">[m_i]: REMOVE (S_TAG); REMOVE (C_TAG)</td><td rowspan="3">An S&C-tagged C-Frame is stripped of the S-Tag and C-Tag and then forwarded to the provisioned CrossConnect entry x_k associated with a downstream output port [o_k]. The output port [o_k] is selected based on a configured S-VID value ($SVID_k$).</td><td rowspan="6">Only one set of rules shall be configured at any time.</td></tr>
<tr><td>...</td></tr>
<tr><td>IF (exists(S_TAG) AND exists(C_TAG) AND S_VID == $SVID_k$) THEN <m_i,…,x_k></td></tr>
<tr><td>IF (exists(S_TAG) AND S_VID == $SVID_1$) THEN <m_j,…,x_1></td><td rowspan="3">[m_j]: REMOVE (S_TAG)</td><td rowspan="3">An S-tagged C-Frame is stripped of the S-Tag and forwarded to the provisioned CrossConnect entry x_k associated with a downstream output port [o_k]. The output port [o_k] is selected based on a configured S-VID value ($SVID_k$).
These C-Frames may be C-tagged.</td></tr>
<tr><td>...</td></tr>
<tr><td>IF (exists(S_TAG) AND S_VID == $SVID_k$) THEN <m_j,…,x_k></td></tr>
</table>

[a] $SVID_k$ represents a provisioned 12-bit S-VID value associated with the specific instance of service provisioned on the given output port [o_k].

When configured in the Encapsulation PB VLAN mode, the upstream ESPs at the ONU shall apply rules and actions as illustrated in Table 7-27.

Table 7-27—Classifier rules and Modifier actions for upstream ESPs in the ONU Encapsulation PB VLAN mode [a,b]

Classifier rules	Modifier actions	Description
`IF (!exists(I_TAG) AND !exists(C_TAG) AND !exists(S_TAG)) THEN <`m_j`,…,`x_k`>`	`[`m_j`]: ADD (VLAN0,S1); ADD (VLAN0,C1)`	An untagged C-Frame is tagged with a C-Tag and S-Tag as provisioned by the operator and then forwarded to the output port `[`o_k`]`.
`IF (!exists(I_TAG) AND !exists(S_TAG)) THEN <`m_i`,…,`x_k`>`	`[`m_i`]: ADD (VLAN0,S1)`	An untagged or C-tagged C-Frame is tagged with outermost VLAN tag `S1` and then forwarded to the output port `[`o_k`]`.

[a] `S1` represents a provisioned 32-bit S-Tag to be added to frames originating from the given input port `[`i_1`]`.

[b] `C1` represents a provisioned 32-bit C-Tag to be added to frames originating from the given input port `[`i_1`]`.

7.2.2.3.3 MAC-Source-Address-based admission control function

The MAC-Source-Address-based admission control function operating on the selected ONU UNI port in the upstream direction controls which frames received from ONU UNI ports are admitted for upstream transmission.

When the MAC-Source-Address-based admission control function for the given UNI port is disabled, all frames received from the ONU UNI port are admitted for upstream transmission.

When the MAC-Source-Address-based admission control function for the given UNI port is enabled, the ONU shall drop any frame received from the ONU UNI port if the MAC Source Address for such a frame is not present in the MAC address admission control table on the ONU. This table is configured through provisioning.

Editorial Note (to be removed prior to publication): subclause 7.3 material *may* be referenced from IEEE Std 1904.1 verbanim, since it is data rate and EPON generation independent.

7.3 Tunneling configurations

This subclause describes EPON tunneling connections, modes, and operations.

A *tunneling connection* defines EPON's end-to-end (Client Interface to Client Interface) Backbone-Service-Instance-dependent frame forwarding as well as any related frame transformations.

A tunneling connection is constructed by configuring a *tunneling mode* in the OLT and/or the ONU. A tunneling mode defines transformation and forwarding of a frame within either the ONU or the OLT. In the case of the OLT, a tunneling mode describes transformation and forwarding of a frame between the NNI and OLT_MDI in either the downstream or upstream direction. In the case of the ONU, a tunneling mode describes transformation and forwarding of a frame between the UNI and ONU_MDI in either the downstream or upstream direction. Tunneling modes are represented by a collection of Classifier rules and associated Modifier actions. Commonly used tunneling modes are specified in 7.3.2.

A tunneling mode represents a collection of Classifier rules and associated Modifier actions (*tunneling operations*). Tunneling operations are the atomic operations that can be performed on the tunneling tags (I-

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Tag and B-Tag). Various combinations of rules in the Classifier and tunneling operations in the Modifier may be provisioned on the ONU and OLT to form tunneling modes. Available tunneling operations are specified in 7.3.1. For all tunneling operations, the term *frame* is used to indicate a B-Frame.

7.3.1 Tunneling operations

This subclause defines the tunneling operations that are applicable in the EPON ONU and OLT. Different tunneling modes, described in 7.3.2, rely on these tunneling operations.

A tunneling operation is a single, Backbone-Service-Instance-related action performed on an Ethernet frame. This action is executed in the Modifier block as the result of the successful match for one of the provisioned rules in the Classifier block. The defined actions include Add Tag, Remove Tag, and Replace Tag Field.

Note that the Add Tag and Remove Tag operations always operate on the entire selected tag, while the Replace Tag Field operation may alter either the entire selected tag or only one of subfields of that tag.

7.3.1.1 Add Tag operation

The *Add Tag* operation shall be capable of inserting one tag into the received frame. The entire tag is added as one unit (32-bit value for B-Tag or 144-bit value for I-Header). Subfields of the B-Tag and I-Header are listed in ~~Table 6-1.~~IEEE Std 1904.1, Table 6-1.

The tag value to be added to a frame is provisioned in the Modifier actionable entry, which is indexed in the output vector of the Classifier. The Classifier passes this vector to the Modifier through ESP_CTRL.

The behavior of the Add Tag operation is different, depending on whether the operation is invoked with the B-Tag or I-Header field code. The Modifier does not validate any subfield values provisioned as part of the tag value (for example, that a TPID has the correct value).

7.3.1.1.1 Add I-Header operation

The *Add I-Header* operation behaves as follows:

- Each frame received from the Classifier block without an I-Tag is tagged with a single provisioned I-Tag, B-SA, and B-DA, and then the frame is transferred to the Policer/Shaper block.
- Results of applying Add I-Header operation to a frame already containing an I-Tag are undefined.
- Results of applying Add I-Header operation to a frame already containing an I-Tag and a B-Tag are undefined.

Figure 7-13 illustrates the behavior of the Add I-Header operation of the Modifier.

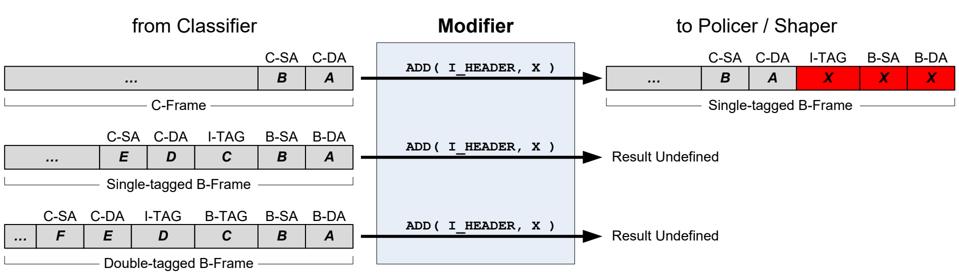

Figure 7-13—Behavior of Add I-Header operation

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7.3.1.1.2 Add B-Tag operation

The *Add B-Tag* operation behaves as follows:

— Results of applying Add B-Tag operation to a frame not containing an I-Tag are undefined.

— Each frame received from the Classifier block without a B-Tag but with I-Tag is tagged with a single provisioned B-Tag, resulting in a B-tagged frame. The frame is then transferred to the Policer/Shaper block.

— Results of applying Add B-Tag operation to a frame containing a B-Tag are undefined.

Figure 7-14 illustrates the behavior of the Add B-Tag operation of the Modifier.

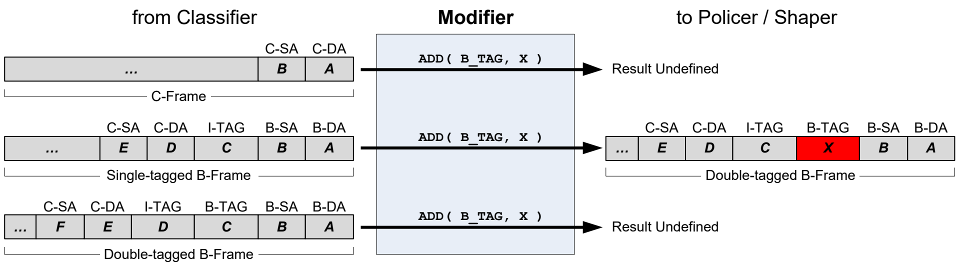

Figure 7-14—Behavior of Add B-Tag operation

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7.3.1.2 Remove Tag operation

The *Remove Tag* operation shall be capable of deleting one selected tag in the received frame. The entire selected tag is deleted as one unit (32-bit value for B-Tag or 144-bit value for I-Header). Subfields of the B-Tag and I-Header are listed in ~~Table 6-1.~~IEEE Std 1904.1, Table 6-1.

The behavior of Remove Tag operation is different, depending on whether the operation is invoked with the B-Tag or I-Header field code.

7.3.1.2.1 Remove I-Header operation

The *Remove I-Header* operation removes the first encountered B-DA, B-SA, and I-Tag. It behaves as follows:

— Each frame received from the Classifier block and not containing an I-Tag is transferred to the Policer/Shaper block unchanged.

— Each frame received from the Classifier block and containing an I-Tag and not containing a B-Tag is stripped of the I-Tag, B-DA, and B-SA and then transferred to the Policer/Shaper block.

— Results of applying Remote I-Header operation to a frame containing a B-Tag are undefined.

Figure 7-15 illustrates the behavior of the Remove I-Header operation of the Modifier.

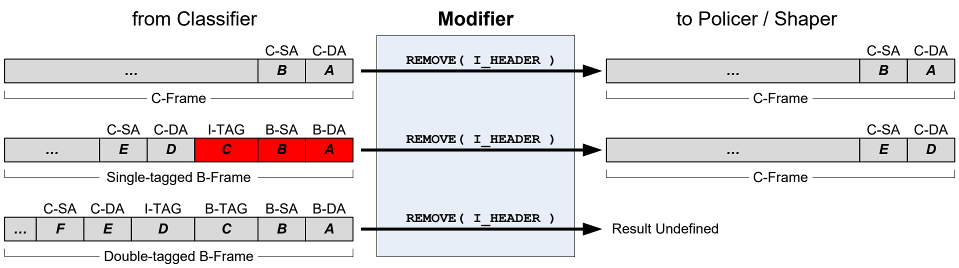

Figure 7-15—Behavior of Remove I-Header operation

7.3.1.2.2 Remove B-Tag operation

The *Remove B-Tag* operation removes the first encountered B-Tag. It behaves as follows:

- Each frame received from the Classifier block and not containing an I-Tag is transferred to the Policer/Shaper block unchanged.
- Each frame received from the Classifier block and containing an I-Tag and not containing a B-Tag is transferred to the Policer/Shaper block unchanged.
- Each frame received from the Classifier block and containing a B-Tag and an I-Tag is stripped of the B-Tag and then transferred to the Policer/Shaper block. The resulting frame contains I-Tag, B-SA, and B-DA.

Figure 7-16 illustrates the behavior of the Remove B-Tag operation of the Modifier.

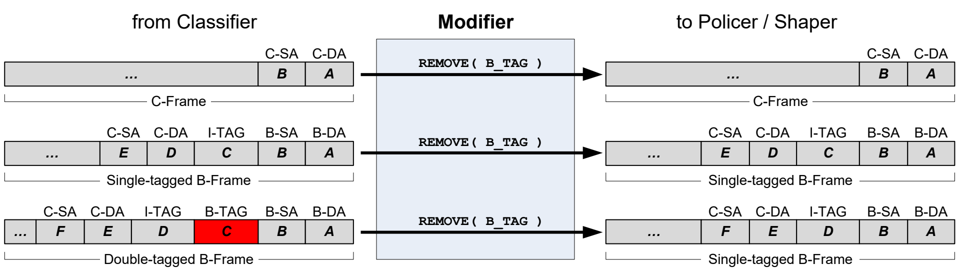

Figure 7-16—Behavior of Remove B-Tag operation

7.3.1.3 Replace Tag operation

The Replace Tag operation shall be capable of altering the values of the tags in the received frame.

The Replace Tag operation may replace the entire selected tag or only one subfield of B-Tag, I-Tag, or I-Header fields. The operation shall be capable of altering the following subfields: B-DA, B-SA, B-TPID, B-PCP, B-DEI, B-VID, I-TPID, I-PCP, I-DEI, I-UCA, I-RES, and I-SID.

Replacement values for these fields are provisioned in the Modifier actionable entry, which is indexed in the output vector of the Classifier. The Classifier passes this vector to the Modifier through ESP_CTRL. The size of the replacement value parameter shall match the size of the field being replaced (see ~~6.5.2.1.1).~~IEEE Std 1904.1, 6.5.2.1.1).

The Modifier does not verify the correctness of any of the provisioned replacement. Incorrectly provisioned values may result in a malformed frame.

The following examples show replacement of the entire selected tag; however, similar rules apply for replacing only a subfield of the selected tag.

7.3.1.3.1 Replace I-Header operation

The Replace I-Header operation replaces the first encountered B-DA, B-SA, and I-Tag. It behaves as follows:

- Each frame received from the Classifier block and not containing an I-Tag is transferred to the Policer/Shaper block unchanged.
- Each frame received from the Classifier block and containing an I-Tag receives new values for its `B_DA`, `B_SA`, and `I_Tag` fields and is then transferred to the Policer/Shaper block.

Figure 7-17 illustrates the behavior of the Replace I-Header operation of the Modifier.

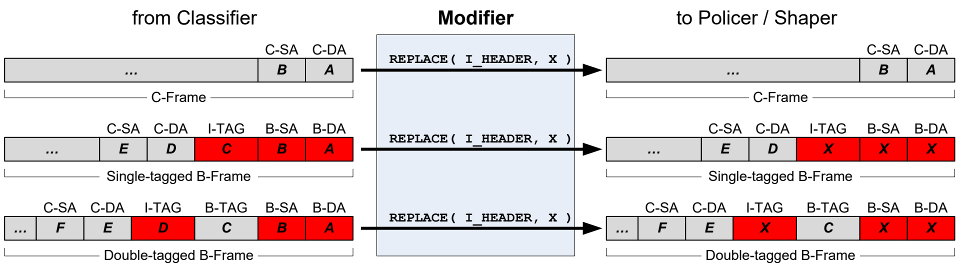

Figure 7-17—Behavior of Replace I-Header operation

7.3.1.3.2 Replace I-Tag operation

The Replace I-Tag operation replaces the first encountered I-Tag. It behaves as follows:

- Each frame received from the Classifier block and not containing an I-Tag is transferred to the Policer/Shaper block unchanged.
- Each frame received from the Classifier block and containing an I-Tag receives a new value for its I-Tag and is then transferred to the Policer/Shaper block.

Figure 7-18 illustrates the behavior of the Replace I-Tag operation of the Modifier.

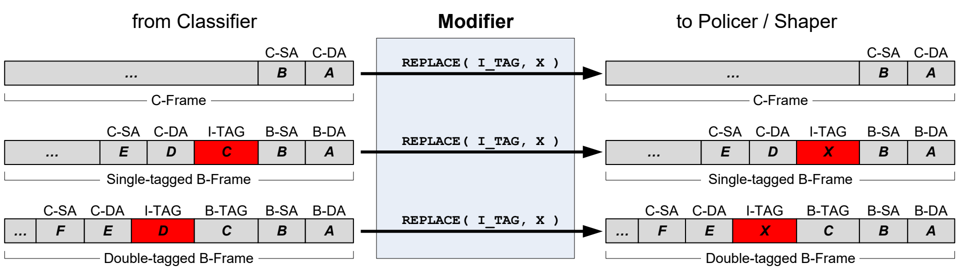

Figure 7-18—Behavior of Replace I-Tag operation

7.3.1.3.3 Replace B-Tag operation

The *Replace B-Tag* operation replaces the first encountered B-Tag. It behaves as follows:

- Each frame received from the Classifier block and not containing an I-Tag is transferred to the Policer/Shaper block unchanged.
- Each frame received from the Classifier block and containing an I-Tag and not containing a B-Tag is transferred to the Policer/Shaper block unchanged.
- Each frame received from the Classifier block and containing an I-Tag and a B-Tag receives a new value for its B-Tag and is then transferred to the Policer/Shaper block. The resulting frame contains an I-Tag and a B-Tag.

Figure 7-19 illustrates the behavior of the Replace B-Tag operation of the Modifier.

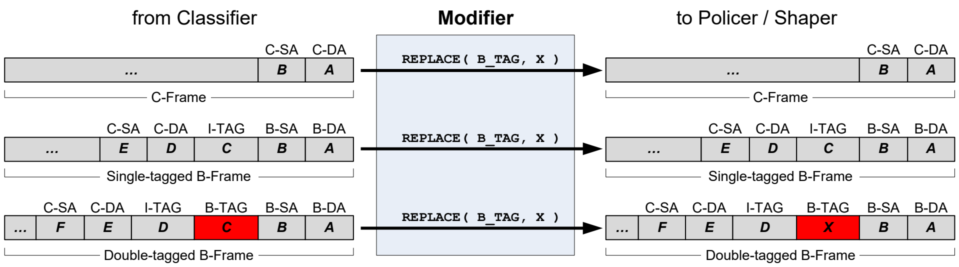

Figure 7-19—Behavior of Replace B-Tag operation

7.3.1.4 Double-tagging operations

Some tag modes may require tag operations performed on more than one selected tag, or on several fields of one selected tag. This functionality is achieved by provisioning several elements (operations) for a single Modifier entry.

Any tag operations may be combined in a single Modifier entry. This standard does not mandate the minimum or the maximum number of elements that can be provisioned for a single Modifier entry.

The following examples illustrate a few typical configurations of Modifier entries:

Example 1: Modifier entry [m1] is provisioned to remove two tags from a frame:

```
[m1:0]: REMOVE (B_TAG)

[m1:1]: REMOVE (I_HEADER)
```

Example 2: Modifier entry [m2] is provisioned to replace I-SID in the I-Tag with a value X (X is a 24-bit value) and adds a B-Tag with a value Y (Y is a 32-bit value):

```
[m2:0]: REPLACE (I_SID, X)

[m2:1]: ADD (B_TAG, Y)
```

7.3.2 Tunneling modes

This subclause defines tunneling modes, which are used to define Backbone-Service-Instance-dependent connectivity for various types of services in EPON. A tunneling mode defines transformation and forwarding of a frame within either the ONU or the OLT.

In the case of the OLT, a tunneling mode covers transformation and forwarding of a frame between the NNI and OLT_MDI in either the downstream or upstream direction. In the case of the ONU, a tunneling mode covers transformation and forwarding of a frame between the UNI and ONU_MDI in either the downstream or upstream direction.

All tunneling modes are defined in terms of Classifier rules and their associated Modifier actions (tunneling operations). Field codes used as arguments in the Classifier rules and Modifier actions are described in ~~6.5.2.1.1.~~IEEE Std 1904.1, 6.5.2.1.1. Individual tunneling operations are specified in 7.3.1. The rules that comprise a tunneling mode are shown in order of their priority and are executed sequentially until the first matched rule is found.

A frame is considered to have an I-Tag if its I-TPID matches one of the I-TPID values provisioned by the operator. A frame is considered to have a B-Tag if its B-TPID matches one of the B-TPID values provisioned by the operator.

In the tunneling modes, each of the ONU UNI ports is assigned one and only one specific mode defined in the following subclauses, as configured using a combination of the *Port Ingress Rule* TLV (~~0xD7~~0xDB/0x05-01), the *Custom Field* TLV (~~0xD7~~0xDB/0x05-02), the *Alternative C-TPID* TLV (~~0xD7~~0xDB/0x05-03), and the *Alternative S-TPID* TLV (~~0xD7~~0xDB/0x05-04), as defined in 14.4.3.6 and its subclauses. A single C-OLT shall be able to support all tunneling modes specified below and shall be able to operate in at least one tunneling mode, as configured by the NMS. A single C-ONU shall be able to configure any of the tunneling modes on any of the UNIs. Each UNI shall operate in one and only one tunneling mode at a time, as configured by the OLT. In essence, every time an ONU is provisioned with a specific tunneling mode for the specific UNI, the previously existing configuration for this UNI is overwritten.

7.3.2.1 Transport mode

In the *Transport* tunneling mode for upstream ESPs, the MAC Client at the ONU or OLT is provisioned to transfer incoming I-tagged B-Frames or B&I-tagged B-Frames matching the provisioned Classifier rules to the output port. The MAC Client at the OLT may be additionally configured to perform TPID translation for I-TPID, B-TPID, or both I-TPID and B-TPID, as provisioned by the operator.

In the Transport tunneling mode for downstream ESPs, the MAC Client at the ONU or OLT is provisioned to transfer any incoming I-tagged B-Frames or B&I-tagged B-Frames matching the provisioned Classifier rules to the output port. The MAC Client at the OLT may be additionally configured to perform TPID translation for I-TPID, B-TPID, or both I-TPID and B-TPID, as provisioned by the operator.

When configured in the Transport tunneling mode, the downstream and upstream ESPs at the OLT shall apply rules and actions as illustrated in Table 7-28.

Table 7-28—Classifier rules and Modifier actions for downstream and upstream ESPs in the OLT Transport tunneling mode[a–h]

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<table>
<tr><th>Classifier rules</th><th>Modifier actions</th><th>Description</th></tr>
<tr><td colspan="3">When multicast frame filtering is enabled, the relevant rules are inserted here. The rules for multicast filtering and forwarding based on LLID and IP multicast address are specified in Table 7-~~40~~32 for the OLT and in Table 7-~~41~~33 for the ONU.</td></tr>
<tr><td>IF (exists(I_TAG) AND
I_SID == $ISID_1$)
THEN <m_0,…,x_1></td><td rowspan="3">[m_0]:
none</td><td rowspan="3">If provisioned, this set of rules implements the Transport tunneling mode without the I-TPID translation.
All B-Frames (not subject to I-TPID translation) are forwarded to the provisioned CrossConnect entry x_k associated with a downstream output port [o_k]. The output port [o_k] is selected based on a configured I-SID_k value ($ISID_k$).</td></tr>
<tr><td>...</td></tr>
<tr><td>IF (exists(I_TAG) AND
I_SID == $ISID_k$)
THEN <m_0,…,x_k></td></tr>
<tr><td>IF (exists(I_TAG) AND
I_TPID == $ITPID_{S1}$ AND
I_SID == $ISID_1$)
THEN <m_{i1},…,x_1></td><td>[m_{i1}]:
REPLACE (I_TPID,
$ITPID_{T1}$)</td><td rowspan="3">If provisioned, this set of rules implements the Transport tunneling mode with the I-TPID translation. A B-Frame with the I-TPID matching a provisioned value of $ITPID_{Sm}$ has the I-TPID replaced with a provisioned value of $ITPID_{Tm}$ and is then forwarded to the provisioned CrossConnect entry x_k associated with a downstream output port [o_k]. The output port [o_k] is associated with the specific value of I-SID ($ISID_k$).</td></tr>
<tr><td colspan="2">...</td></tr>
<tr><td>IF (exists(I_TAG) AND
I_TPID == $ITPID_{Sm}$ AND
I_SID == $ISID_k$)
THEN <m_j,…,x_k></td><td>[m_{i2}]:
REPLACE (I_TPID,
$ITPID_{Tm}$)</td></tr>
<tr><td>IF (exists(B_TAG) AND
B_TPID == $BTPID_{S1}$ AND
I_SID == $ISID_1$)
THEN <m_i,…,x_1></td><td>[m_i]:
REPLACE (B_TPID,
$BTPID_{T1}$)</td><td rowspan="3">If provisioned, this set of rules implements the Transport tunneling mode with the B-TPID translation. A double-tagged B-Frame with the B-TPID matching a provisioned value of $BTPID_{Sn}$ has the B-TPID replaced with a provisioned value of $BTPID_{Tn}$ and is then forwarded to the provisioned CrossConnect entry x_k associated with a downstream output port [o_k]. The output port [o_k] is associated with the specific value of I-SID ($ISID_k$).</td></tr>
<tr><td colspan="2">...</td></tr>
<tr><td>IF (exists(B_TAG) AND
B_TPID == $BTPID_{Sn}$ AND
I_SID == $ISID_k$)
THEN <m_m,…,x_k></td><td>[m_m]:
REPLACE (B_TPID,
$BTPID_{Tn}$)</td></tr>
</table>

Classifier rules	Modifier actions	Description
IF (exists(B_TAG) AND B_TPID == BTPID$_{S1}$ AND I_TPID == ITPID$_{S1}$ AND I_SID == ISID$_{1}$) THEN <m$_{i}$, …, x$_{1}$>	[m$_{i}$]: REPLACE (B_TPID, BTPID$_{T1}$); REPLACE (I_TPID, ITPID$_{T1}$)	If provisioned, this set of rules implements the Transport tunneling mode with the I-TPID and B-TPID translation. The double-tagged B-Frame with the B-TPID matching a provisioned value of BTPID$_{Sk}$ and I-TPID matching a provisioned value of ITPID$_{Sk}$ has these TPID values replaced with the provisioned values of BTPID$_{Tk}$ and ITPID$_{Tk}$, respectively. Then it is forwarded to the provisioned CrossConnect entry x$_{k}$ associated with a downstream output port [o$_{k}$]. The output port [o$_{k}$] is associated with the specific value of I-SID (ISID$_{K}$).
...		
IF (exists(B_TAG) AND B_TPID == BTPID$_{Sn}$ AND I_TPID == ITPID$_{Sm}$ AND I_SID == ISID$_{k}$) THEN <m$_{m}$, …, x$_{k}$>	[m$_{m}$]: REPLACE (B_TPID, BTPID$_{Tn}$); REPLACE (I_TPID, ITPID$_{Tm}$)	

[a] ISID$_{k}$ is a provisioned 24-bit value representing the I-SID configured to be associated with the specific instance of service provisioned on the given output port [o$_{k}$].

[b] ITPID$_{Sm}$ is a provisioned 16-bit-wide value representing the source value of the I-TPID field to be translated into the target I-TPID (ITPID$_{Tm}$) using the TPID translation mechanism.

[c] ITPID$_{Tm}$ is a provisioned 16-bit-wide value representing the target value of the I-TPID field to which the source value of the I-TPID (ITPID$_{Sm}$) is being translated using the TPID translation mechanism.

[d] BTPID$_{Sn}$ is a provisioned 16-bit-wide value representing the source value of the B-TPID field to be translated into the target B-TPID (BTPID$_{Tn}$) using the TPID translation mechanism.

[e] BTPID$_{Tn}$ is a provisioned 16-bit-wide value representing the target value of the B-TPID field to which the source value of the B-TPID (BTPID$_{Sn}$) is being translated using the TPID translation mechanism.

[f] In the case of I-TPID translation, a single ISID$_{k}$ value may be shared by multiple ITPID$_{Sm}$ values (i.e., the same ISID$_{k}$ value may be used with various source ITPID$_{Sm}$ values). There are no requirements regarding translation between ITPID$_{Sm}$ values and ITPID$_{Tm}$ values, which are independent from the ISID$_{k}$ numbering space.

[g] In the case of B-TPID translation, a single ISID$_{k}$ value may be shared by multiple BTPID$_{Sn}$ values (i.e., the same ISID$_{k}$ value may be used with various source BTPID$_{Sn}$ values). There are no requirements regarding translation between BTPID$_{Sn}$ values and BTPID$_{Tn}$ values, which are independent from the ISID$_{k}$ numbering space.

[h] In the case of I-TPID and B-TPID translation, a single ISID$_{k}$ value may be shared by multiple BTPID$_{Sn}$ and ITPID$_{Sm}$ values (i.e., the same ISID$_{k}$ value may be used with various source BTPID$_{Sn}$ and ITPID$_{Sm}$ values). There are no requirements regarding translation between BTPID$_{Sn}$ values and BTPID$_{Tn}$ values as well as ITPID$_{Sm}$ values and ITPID$_{Tm}$ values, which are independent from the ISID$_{k}$ numbering space.

When configured to operate in the Transport tunneling mode, the downstream and upstream ESPs at the ONU shall apply rules and actions as illustrated in Table 7-29.

Table 7-29—Classifier rules and Modifier actions for downstream and upstream ESPs in the ONU Transport tunneling mode[a]

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Classifier rules	Modifier actions	Description
When multicast frame filtering is enabled, the relevant rules are inserted here. The rules for multicast filtering and forwarding based on LLID and IP multicast address are specified in Table 7-~~40~~32 for the OLT and in Table 7-~~41~~33 for the ONU.		
IF (exists(I_TAG) AND I_SID == $ISID_1$) THEN <m_0,…,x_1>	[m_0]: none	A B-Frame is forwarded to the provisioned CrossConnect entry x_k associated with an output port [o_k]. The output port [o_k] is selected based on a configured I-SID$_k$ value ($ISID_k$).
...		
IF (exists(I_TAG) AND I_SID == $ISID_k$) THEN <m_0,…,x_k>		

[a] $ISID_k$ is a provisioned 24-bit value representing the I-SID configured to be associated with the specific instance of service provisioned on the given output port [o_k].

7.3.2.2 Encapsulation mode

In the *Encapsulation* tunneling mode, the upstream and downstream ESPs at the OLT are provisioned to transfer incoming I-tagged B-Frames or B&I-tagged B-Frames matching the provisioned Classifier rules to the output port. The upstream and downstream ESP may be additionally configured to perform TPID translation for I-TPID, B-TPID, or both I-TPID and B-TPID, as provisioned by the operator.

In the Encapsulation tunneling mode, the upstream ESPs at the ONU are provisioned to perform encapsulation by adding an I-Header to the incoming C-Frames, B-Tag to the incoming I-tagged B-Frames, or I-Header and B-Tag to the incoming C-Frames matching the provisioned Classifier rules. The downstream ESPs at the ONU are provisioned to perform decapsulation by stripping the I-Header, B-Tag, or I-Header and B-Tag from frames matching the provisioned Classifier rules.

When configured in the Encapsulation tunneling mode, the downstream and upstream ESPs at the OLT shall apply rules and actions as illustrated in Table 7-28.

When configured in the Encapsulation tunneling mode, the downstream ESP at the ONU shall apply rules and actions as illustrated in Table 7-30.

Table 7-30—Classifier rules and Modifier actions for downstream ESPs in the ONU Encapsulation tunneling mode[a]

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Classifier rules	Modifier actions	Description
When multicast frame filtering is enabled, the relevant rules are inserted here. The rules for multicast filtering and forwarding based on LLID and IP multicast address are specified in Table 7-~~40~~32 for the OLT and in Table 7-~~41~~33 for the ONU.		
IF (exists(I_TAG) AND !exists(B_TAG) AND I_SID == $ISID_1$) THEN <m_i,…,x_1>	[m_i]: REMOVE (I_HEADER)	A single-tagged B-Frame is stripped of the I-Header and forwarded to the provisioned CrossConnect entry x_k associated with a downstream output port [o_k]. The output port [o_k] is selected based on a configured I-SID$_k$ value ($ISID_k$).
...		
IF (exists(I_TAG) AND !exists(B_TAG) AND I_SID == $ISID_k$) THEN <m_i,…,x_k>		

<table>
<tr><th>Classifier rules</th><th>Modifier actions</th><th colspan="2">Description</th></tr>
<tr><td>IF (exists(B_TAG) AND I_SID == $ISID_1$) THEN <m_i,…,x_1></td><td rowspan="3">[m_i]: REMOVE (B_TAG)</td><td rowspan="3">If provisioned, this set of rules implements the Provider Backbone Bridging (PBB) encapsulation mode with stripping B-Tag.
A double-tagged B-Frame is stripped of the B-Tag field and forwarded to the provisioned CrossConnect entry x_k associated with a downstream output port [o_k]. The output port [o_k] is selected based on a configured I-SID$_k$ value ($ISID_k$).</td><td rowspan="6">Only one set of rules shall be configured at any time.</td></tr>
<tr><td>...</td></tr>
<tr><td>IF (exists(B_TAG) AND I_SID == $ISID_k$) THEN <m_i,…,x_k></td></tr>
<tr><td>IF (exists(B_TAG) AND I_SID == $ISID_1$) THEN <m_i,…,x_1></td><td rowspan="3">[m_i]: REMOVE (B_TAG); REMOVE (I_HEADER)</td><td rowspan="3">If provisioned, this set of rules implements the PBB encapsulation mode with stripping B-Tag and I-Header.
A double-tagged B-Frame is stripped of the I-Header and B-Tag fields and forwarded to the provisioned CrossConnect entry x_k associated with a downstream output port [o_k]. The output port [o_k] is selected based on a configured I-SID$_k$ value ($ISID_k$).</td></tr>
<tr><td>...</td></tr>
<tr><td>IF (exists(B_TAG) AND I_SID == $ISID_k$) THEN <m_i,…,x_k></td></tr>
</table>

[a] $ISID_k$ is a provisioned 24-bit value representing the I-SID configured to be associated with the specific instance of service provisioned on the given output port [o_k].

When configured in the Encapsulation tunneling mode, the upstream ESP at the ONU shall apply rules and actions as illustrated in Table 7-31.

Table 7-31—Classifier rules and Modifier actions for upstream ESP in the ONU Encapsulation tunneling mode[a, b]

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<table>
<tr><th>Classifier rules</th><th>Modifier actions</th><th colspan="2">Description</th></tr>
<tr><td rowspan="2">IF (!exists(I_TAG)) THEN <m_i,…,x_k></td><td>[m_i]: ADD (I_HEADER,I1)</td><td>A C-Frame is tagged by adding the I-Header and then forwarded to the output port [o_k].</td><td rowspan="2">Only one rule shall be configured at any time.</td></tr>
<tr><td>[m_i]: ADD (I_HEADER,I1); ADD (B_TAG,B1)</td><td>A C-Frame is tagged by adding the I-Header and B-Tag and then forwarded to the output port [o_k].</td></tr>
<tr><td>IF (exists(I_TAG) AND !exists(B_TAG)) THEN <m_j,…,x_k></td><td>[m_j]: ADD (B_TAG,B1)</td><td colspan="2">If provisioned, this rule adds B-Tag to a single-tagged (I-tagged only) B-Frame and then forwards the frame to the output port [o_k].</td></tr>
</table>

[a] B1 is a provisioned 32-bit value representing the B-Tag configured to be added by the operator to frames originating from the given input port [i_1].

[b] `I1` is a provisioned 144-bit value representing the I-Header configured to be added by the operator to frames originating from the given input port [i_1].

7.4 Multicast configurations

7.4.1 Introduction

This subclause describes *EPON multicast connectivity*, which refers to EPON's ability to deliver identical copies of a frame from the OLT's input port located at the OLT_CI to a group of ONU's output ports located at ONU_CI.

In general, establishing multicast operation in EPON involves three steps, as shown in Figure 7-20. In the first step, a multicast client issues a request to join a multicast group. In the second step, the EPON multicast transport channel is provisioned by configuring Classifier and Modifier at the OLT and the ONU. The provisioning may involve establishing a new multicast-bearing ESP at the OLT or the ONU, or just adding an additional destination output port to already existing ESP. Finally, in the third step, the multicast data is transported over EPON to the multicast clients.

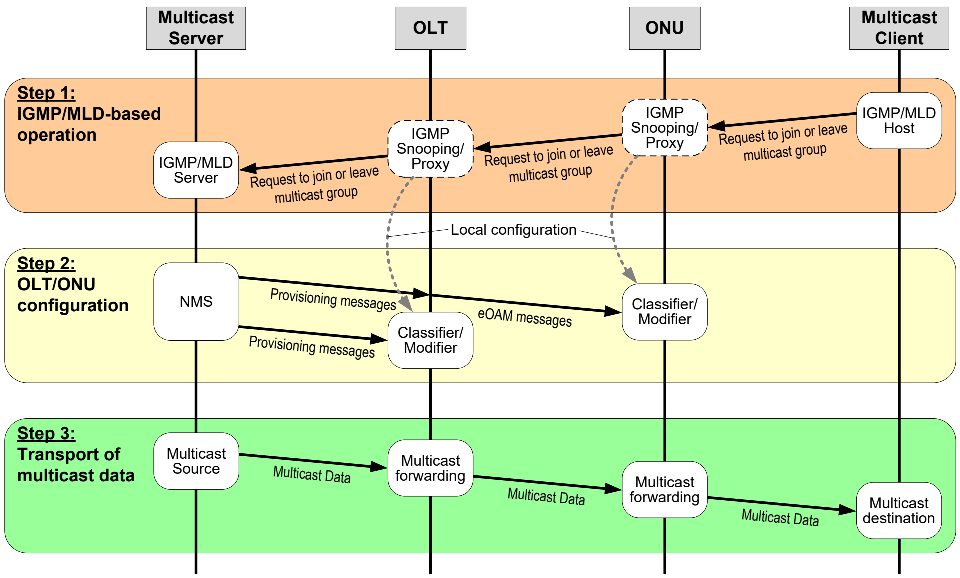

Figure 7-20—Steps establishing multicast operation in EPON

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~~Several methods to establish multicast connectivity are defined:~~

- Multicast ~~based on VLAN and/or MAC~~ group ~~address (see 7.4.2)~~
- ~~Multicast based on combined VLAN and group address with no authorization control (see 7.4.3)~~
- ~~Multicast based on combined VLAN and group address with authorization control (see 7.4.4)~~
- ~~Multicast based on combined LLID and IP group address (see 7.4.5)~~

~~All these methods specify multicast control and multicast transport requirements.~~

~~Multicast~~ control requirements cover methods and protocols used to create and delete multicast groups and to add or remove destination output ports to and from the existing multicast groups (see step 1 in Figure 7-20). The methods to control multicast groups employ IGMP and/or MLD protocols and expect the multicast clients to initiate the process of joining or leaving the multicast groups. The multicast group control requirements are specified in 7.4.3.

~~Multicast transport requirements specify~~Once the new or changed multicast group membership is determined in step 1, the multicast transport mechanisms need to be configured to support this multicast group. Subclause 7.4.4 describes various methods to establish the multicast transport channels and the associated configurations of the ONU and the OLT (see step 2 in Figure 7-20).

It is possible to establish multicast operation solely by the decision of the operator, without involving step 1. In such directly-provisioned multicast configuration, group membership is established by the NMS without any requests from the multicast clients and without employing IGMP/MLD~~. Any multicast transport method can be established by a direct provisioning by the NMS.~~ (see 7.4.3.1).

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The multicast transport mechanisms that allow frames to be delivered to all ONUs belonging to a given multicast group (see step 3 in Figure 7-20) are explained in 7.4.2.

In this subclause, the term *multicast server* is used to denote collectively a multicast server (source of multicast data frames) and a multicast router (source and destination of multicast control frames), the functionality of which may be geographically or logically distinct. The term *multicast client* is used to denote a recipient of multicast data whose membership in a multicast group can be controlled independently.

The term *group address* represents either the MAC multicast group address or the ~~IP~~IPv4/IPv6 multicast group address.

~~7.4.1.1~~7.4.2 Multicast transport mechanisms

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The EPON multicast ~~connectivity~~transport includes *inter-ONU multicast* (i.e., data frame being sent to a subset of ONUs connected to a given OLT) and *intra-ONU multicast* (i.e., data frame being ~~duplicated~~replicated to a subset of ~~output~~service ports within a given ONU).

Intrinsically, in the downstream direction, the P2MP architecture of EPON is a broadcasting medium. As a result, without any additional filtering, a single data frame transmitted by the OLT is received by every ONU. EPON, in most cases, uses the broadcasting properties of its medium to achieve efficient single-copy inter-ONU multicast. ~~The multicast filtering may be based on LLID,~~Inter-ONU multicast transport typically employs P2MP logical links (i.e., multicast LLIDs) to ensure that a multicast frame is accepted by multiple ONUs (see 7.4.2.1). In addition to the LLID field, the multicast filtering may be based on MAC address, VLAN tags, IP address, or a combination of these fields.

Intra-ONU multicast is achieved by configuring a multicast ESP that ~~duplicates~~replicates a received frame into ~~the~~ multiple ~~Queues~~downstream queues, thus delivering ~~them~~a copy of each multicast frame to multiple output ports~~.~~ (see 7.4.2.2).

7.4.2.1 Multicast LLID

A P2MP logical link binds a single MAC instance at the OLT to multiple MAC instances in different ONUs. A dowstream frame transmited by the OLT into a P2MP logical link is delivered to a set of ONUs (see 4.5).

To establish a P2MP logical link, the NMS provisions multiple ONUs to accept the same LLID value, which is refered to as *multicast LLID* (mLLID). A downstream frame sent to such P2MP logical link (i.e., forwarded to the MAC associated with the mLLID) gets delivered to all the ONUs in the given multicast group (i.e., all ONUs that were provisioned to accept this mLLID value).

From the OLT perspective, an mLLID represents a logical channel that delivers frames to a set of ONUs. To serve multicast traffic to a multicast group, the OLT forwards a single copy of each multicast frame to a PON-facing MAC instance associated with the mLLID provisioned for this multicast group.

ONUs are unaware if an LLID is unicast or multicast (i.e., ONUs are unaware whether the same LLID value has been provisioned in other ONUs). At the ONU, there is no distinction in handling the multicast LLID vesus handling the unicast unidirectional LLID.

In some configurations, the logical channel formed by the mLLID is dedicated to a single multicast session. In such configurations, the mLLID value uniquely identifies an individual multicast session and the ONU classification rules may classify multicast frames solely by the mLLID value.

In other configurations, an mLLID logical channel is allocated for a set of multicast sessions. In such configurations, an individual multicast session is identified by a combination of mLLID value and values of some other fields, typically IP Group DA and/or IP SA. Correspondingly, the ONU classification rules may require multiple fields to classify frames as belonging to individual multicast sessions.

Different types of LLIDs (PLID, MLID, and ULID) may be provisioned as multicast LLIDs (see 4.5). Only the multicast ULID is used for delivery of multicast user traffic.

7.4.2.1.1 Multicast PLID

A multicast PLID (mPLID) is used to deliver MPCPDUs to a set of ONUs. Only unidirectional (downstream-only) PLID may be provisioned as mPLID (see 7.4.4.1). At the ONU, the MPCPDUs received in envelopes with mPLID are passed to the same receive queue as MPCPDUs received in envelopes with the primary PLID.

Note that the downstream MPCPDUs sent in envelopes with mPLIDs are typically delivered to multiple ONUs, and therefore the `Timesamp` values in these MPCPDUs are not pre-compensated for the individual ONU's RTTs. Consequently, an ONU shall not attempt to synchronize its local MPCP clock using the `Timestamp` values from the MPCPDUs received over the unidirectional PLIDs.

7.4.2.1.2 Multicast MLID

A multicast MLID (mMLID) is used to deliver OAMPDUs, CCPDUs, or VLCPDUs (if supported) to a set of ONUs. Only unidirectional (downstream-only) MLID may be provisioned as mMLID (see 7.4.4.1). At the ONU, the management PDUs received in envelopes with mMLID are passed to the same receive queue as the PDUs received in envelopes with the primary MLID. If a management PDU requires a response from an ONU, such response shall be transmitted in an envelope with the primary MLID.

7.4.2.1.3 Multicast ULID

A multicast ULID (mULID) is used to deliver user (data) frames to a set of ONUs. Both bidirectional and unidirectional (downstream-only) ULID may be provisioned as mULID (see 7.4.4.1). At the ONU, the downstream user frames received in envelopes with mULID are passed to the Classifier, just like the data frames received in envelopes with unicast ULIDs. ONUs may transmit upstream data frames in envelopes with mULID, if they were granted to do so, and if the mULID value was provisioned as the bidirectional ULID.

7.4.2.1.4 Broadcast LLID

An LLID that delivers downstream frames to all ONUs connected to a given OLT PON port is called a *broadcast LLID* (bLLID). bLLID is a special case of multicast LLID and it follows the same provisioning principles as described in 7.4.2.1.1–7.4.2.1.3. Additionally, the IEEE Std 802.3 specification defines two bLLID values that are enabled at the ONUs and the OLT without explicit provisioning (see IEEE Std 802.3, 144.3.5):

— `BCAST_PLID` (0x00-02): PLID value reserved for MPCPDU broadcast

— `BCAST_MLID` (0x00-03): MLID value reserved for broadcast of management frames (OAMPDUs, CCPDUs, and optionally, VLCPDUs).

~~7.4.1.1.1~~7.4.2.2 Multicast ESP

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A multicast EPON Srevice Path (ESP) is ~~an ESP~~a data path that directs each ~~received~~matching frame to a CrossConnect entry for which multiple elements (multiple queues) are provisioned, as illustrated in Figure 7-21.

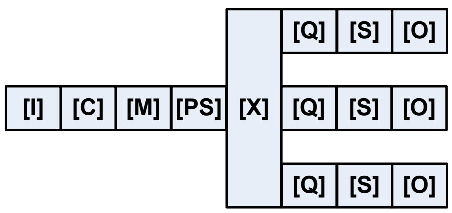

Figure 7-21—Multicast ESP

Generally, to achieve multicast connectivity in EPON, a unicast ESP is provisioned at the OLT, and multicast ESPs are provisioned in target ONUs. The Modifier entry in the unicast ESP at the OLT may be provisioned to insert into each frame traversing that ESP a field (typically a VLAN tag or an IP multicast address) with a specific value, identifying the given multicast group. The Classifiers in the ONUs that belong to this multicast group are provisioned to direct each received frame with the same specific value of the multicast tag to the multicast ESP. The multicast ESP in the ONU forwards the received multicast frame to multiple downstream output ports. (i.e., service ports). This is illustrated in Figure 7-22.

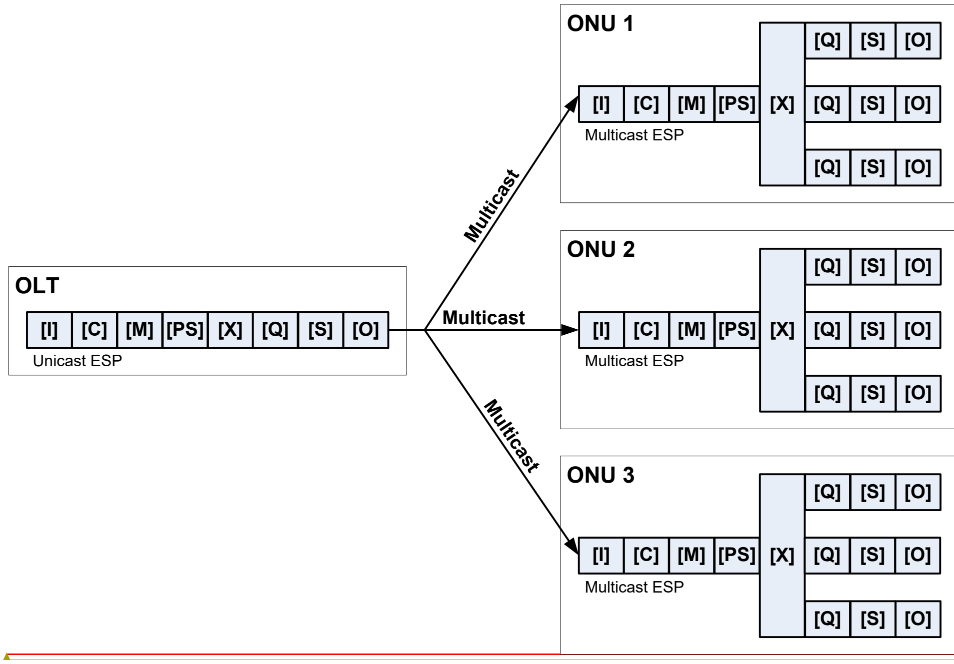

Figure 7-22—Multicast configuration using unicast ESP in the OLT and multicast ESPs in the ONUs

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It is also possible may be necessary to provision a multicast ESP at the OLT. This may be necessary in several situations , e.g., in a situation when an OLT operates at both 1 Gb/s anda multicast group combines 10 Gb/s downstream line rates as when 1G-EPON and 10G-EPON coexist on the same outside plant (see Figure 7-23).ONUs with 25 Gb/s and/or 50 Gb/s ONUs. In this case, the CrossConnect at the OLT may be provisioned to duplicate each multicast frame to 1G-EPON and 10G-EPON SCB channels.10G-EPON and 25G-EPON P2MP logical links (see Figure 7-23). The 50 Gb/s ONUs may receive multicast traffic on a 25 Gb/s P2MP logical link together with 25 Gb/s ONUs, or on a separate 50 Gb/s P2MP logical link (see 7.4.2.3).

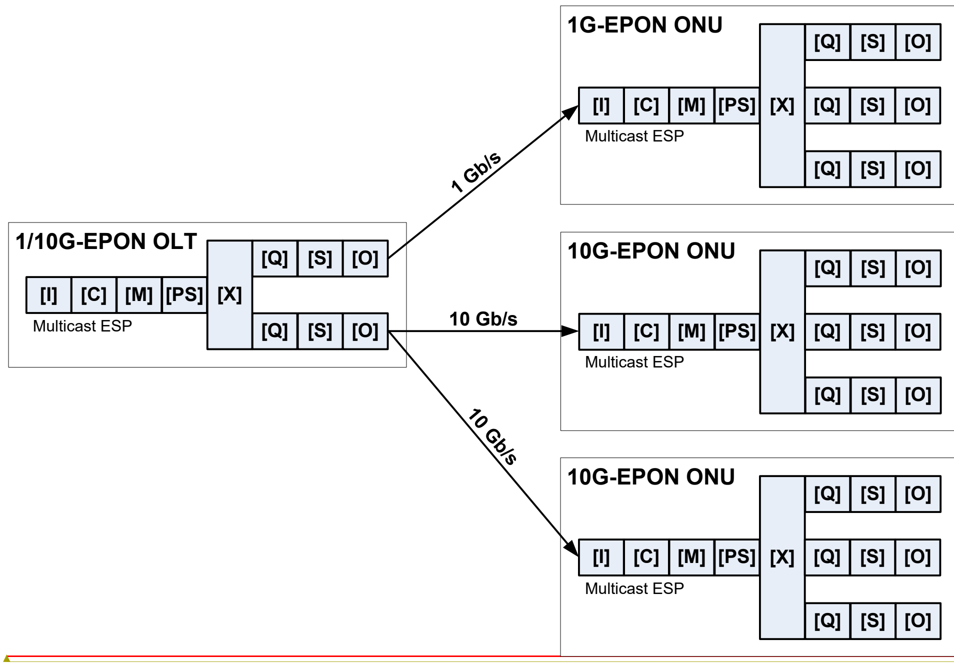

Figure 7-23—Multicast ESP in 1/10G-EPON OLT

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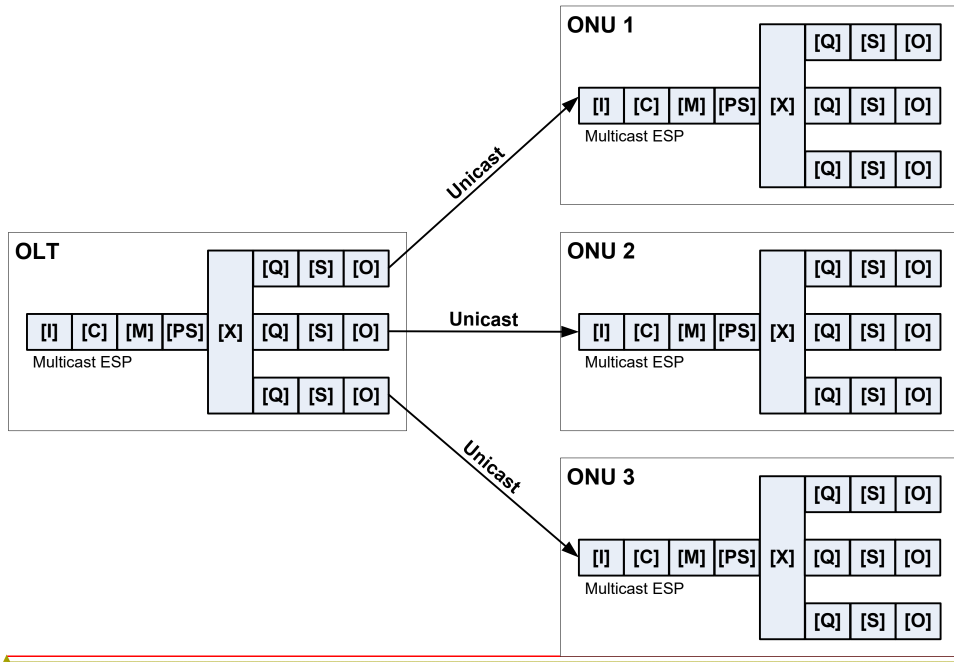
It is also possible to use multicast ESP at the OLT in order to eliminate inter-ONU multicast. In this case, EPON multicast connectivity is achieved by duplicating each multicast frame at the OLT into multiple queues and delivering a separate copy of the frame to each ONU using previously established unicast channelsP2P logical links, as shown in Figure 7-24. This method allows independent encyption of each ONU's traffic (including the multicast traffic), however it consumes more downstream bandwidth than the single-copy multicast method utilizing the mLLD.



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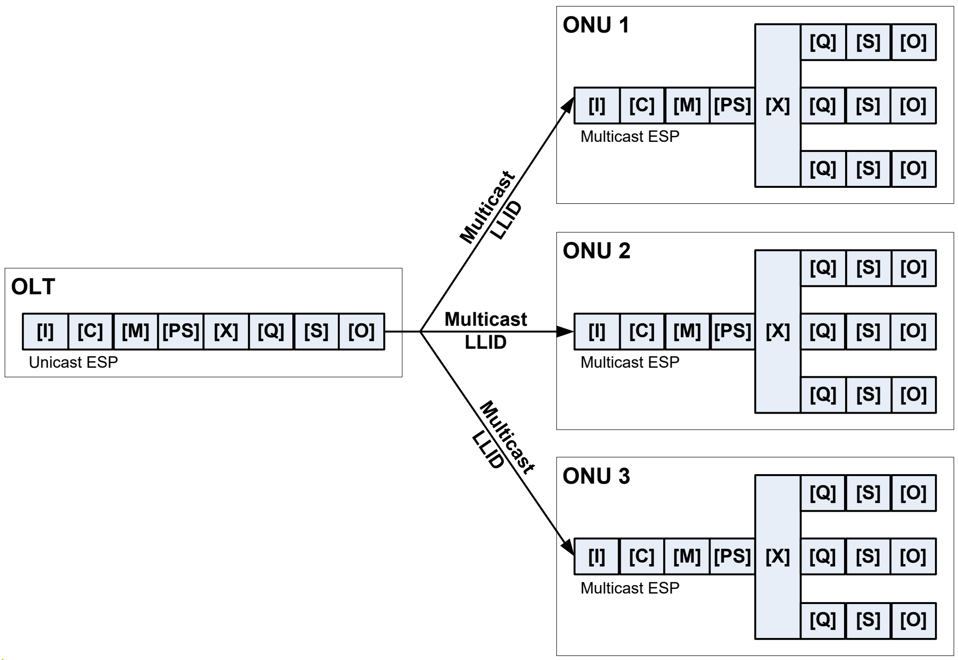

Figure 7-22—Multicast configuration using unicast ESP in the OLT and multicast ESPs in the ONUs

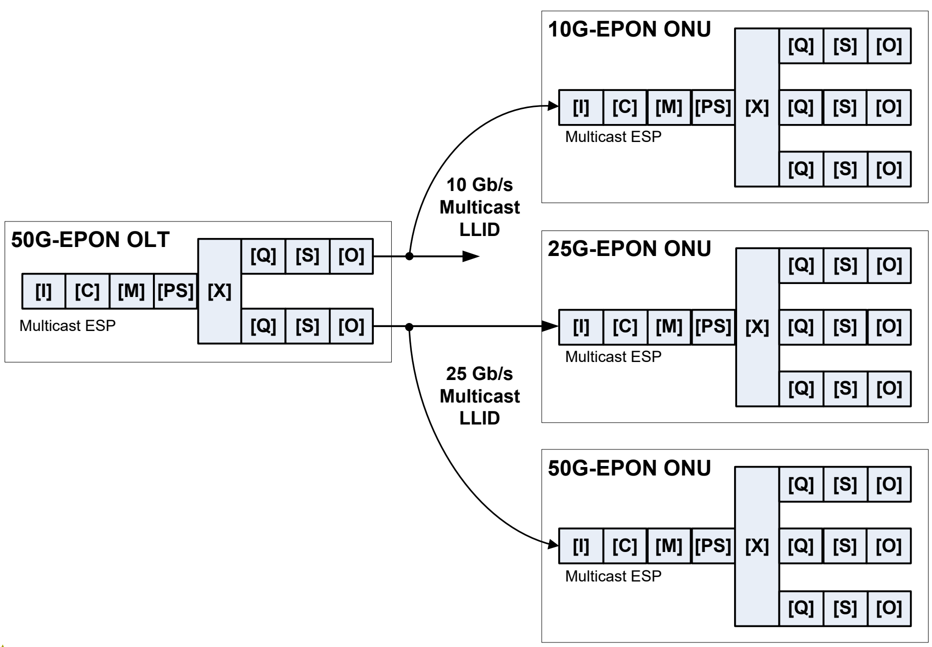

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Figure 7-23—Multicast ESP at the OLT to support 10G-EPON and 25/50G-EPON ONUs

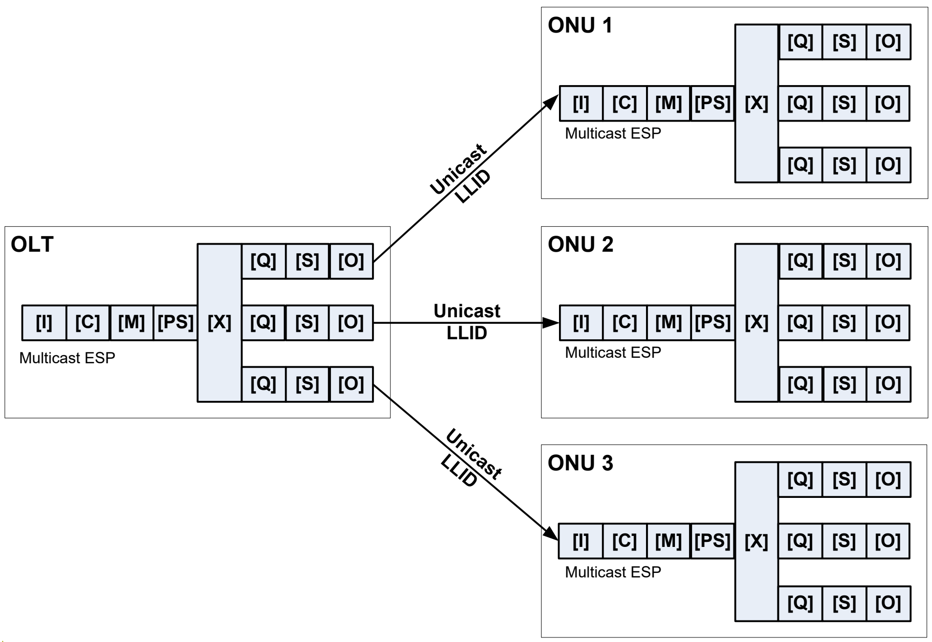

Figure 7-24—Multicast connectivity without inter-ONU multicast

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~~7.4.1.1.2~~7.4.2.3 ~~1G~~25G-EPON/~~10G~~ and 50G-EPON coexistence ~~requirements~~

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~~All~~The multicast transport ~~methods~~method described in this subclause ~~support 1G~~supports 25G-EPON/~~10G~~50G-EPON coexistence, i.e., an ability to ~~include 1~~combine 25 Gb/s ONUs and ~~10~~50 Gb/s ONUs into a single multicast group. ~~When a~~ Two methods are possible for supporting such multicast group ~~includes clients~~.

One method is to use a single P2MP logical link, i.e., to provision the same mLLID value to be accepted by all ONUs belonging to the given multicast group. Under this method, a unicast ESP is provisioned at the OLT, which transmits a single copy of each multicast frame. However the data rate of the multicast stream is limited to 25 Gb/s, even for the 50G-EPON ONUs that are ~~connected to both 1~~able to receive at the rate of 50 Gb/s. This method is illustrated in Figure 7-22.

The other method to combine 25 Gb/s ONUs and ~~10~~50 Gb/s ONUs~~, the OLT employs~~ into a single multicast group is to allocate separate P2MP logical links for the 25 Gb/s ONUs and 50 Gb/s ONUs. In this method, a multicast ESP ~~that~~at the OLT duplicates multicast frames ~~to~~into two ~~output ports~~separate logical links: one ~~associated~~transmitting only to 25 Gb/s ONUs, and the other transmitting only to 50 Gb/s ONUs. This method uses different mLLID values for 25 Gb/s ONUs and 50 Gb/s ONUs. The mLLID that is provisioned for the 50 Gb/s ONUs is able to transmit data at a rate of 50 Gb/s. This method is illustrated in Figure 7-23.

The latter method may also be extended to support multicast groups that combine 1G-EPON and 10G-EPON ONUs (per IEEE Std 1904.1) with ~~the 1 Gb/s downstream channel and the other associated with the 10 Gb/s downstream channel, as illustrated in Figure 7-23.~~25G-EPON and 50G-EPON ONUs, though such cross-generation multicast support is outside the scope of this standard.

In the multicast transport methods described in 7.4.2, 7.4.3, and 7.4.4, multicast transmission utilizes broadcast LLIDs. In these methods, if a multicast group includes 1 Gb/s and 10 Gb/s ONUs, the OLT shall duplicate multicast frames to two output ports: one connected to 1G-EPON broadcast LLID 0x7F-FF and the other one connected to 10G-EPON broadcast LLID 0x7F-FE (see IEEE Std 802.3, 76.2.6.1.3.2). To duplicate a multicast frame to two output ports, the OLT instantiates a multicast ESP, as shown in Figure 7-23.

In the multicast transport method described in 7.4.5, multicast transmission utilizes provisioned multicast LLIDs. Using this method, if a multicast group includes 1 Gb/s and 10 Gb/s ONUs, the OLT shall duplicate multicast frames to two output ports: one connected to 1G-EPON multicast LLID and the other one connected to 10G-EPON multicast LLID. Both LLIDs may be provisioned to have the same or different values.

In any of the specified multicast transport methods, if all multicast clients with membership in a specific multicast group are connected to the same ONU type (1G-EPON or 10G-EPON ONU), the OLT shall forward multicast frames for the given multicast group using a unicast ESP (see Figure 7-22) associated with either the broadcast LLID (for methods described in 7.4.2, 7.4.3, and 7.4.4) or multicast LLID (for the method described in 7.4.5).

7.4.1.1.37.4.2.4 ONU-sourced multicast transport

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ONU-sourced multicast may be supported by configuring the ONU to transfer any multicast frames to the OLT using an upstream unicast channelP2P logical link and configuring the OLT to recognize such frames (based on VLAN value or multicast group address, or a combination of both) and to forward such frames into a downstream multicast channelP2MP logical link. This configuration is illustrated in IEEE Std 1904.1, Figure 6-7.

7.4.2 Multicast based on VLAN and/or MAC group address

7.4.2.1 Operation outline

In the multicast method based on VLAN and/or MAC group address, the OLT acts as a client (host) at the OLT NNI toward the upstream network and as a server at the OLT_MDI toward the PON for the multicast protocol. The OLT is responsible for provisioning the VLAN and MAC addresses in the ONU multicast forwarding table using eOAM.The OLT handles all IGMP/MLD requests from the multicast clients on the given EPON, and the ONU filters the multicast data stream as instructed by the OLT through eOAM. The advantages of this model are that the multicast protocol is reconfigurable simply by changing OLT firmware and it is unnecessary for the ONU to handle complicated functions, such as snooping and proxy multicast subscriber tables.

The operation of this multicast method is described as follows:

a) The ONU forwards IGMP/MLD messages between UNI and ONU_MDI without any processing.

b)7.4.3 The OLT, which acts as a host for OLT NNI toward the upstream network and as a server for OLT_MDI toward the PON, receives the IGMP/MLD messages and updates its multicast control table. The OLT is performing an IGMP/MLD proxy function.

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c) Upon receipt of a *JOIN* request from an IGMP/MLD host for a channel viewable through IP television (IPTV),

1) The OLT updates the multicast control table and delivers the multicast traffic toward the single copied multicast channel; if the OLT is not already receiving the requested multicast traffic, it issues a *JOIN* request to the multicast server;

2) The OLT sends the eOAM message to the ONU that the IGMP/MLD host belongs to; and

3) The ONU receives the eOAM message and configures the multicast forwarding table to forward the multicast stream to the UNI.

d) Upon receipt of a *LEAVE* request from an IGMP/MLD host for the currently active IPTV channel,

1) The OLT generates and transmits an IGMP/MLD *QUERY* message to discover remaining IGMP/MLD hosts that are to keep their participation status as active;

2) In the case where the OLT receives no *IGMP Membership REPORT* message from any IGMP/MLD hosts that belong to the same ONU as the leaving host is connected to, the OLT updates the multicast control table and sends the eOAM message to that ONU to deactivate the entry in the multicast forwarding table. In the case where the OLT receives no *IGMP Membership REPORT* messages from any IGMP/MLD hosts that belong to any ONUs, the OLT updates the multicast control table and terminates the forwarding of the pertinent multicast stream. The OLT generates a *LEAVE* message to the upstream network and transmits it to the multicast server, indicating that there is no host that is participating in the group; and

3) The ONU receives the eOAM message and configures the multicast forwarding table to halt transmission of the multicast stream to the UNI.

The operation of the multicast method based on VLAN and/or MAC group address is illustrated in Figure 7-25.

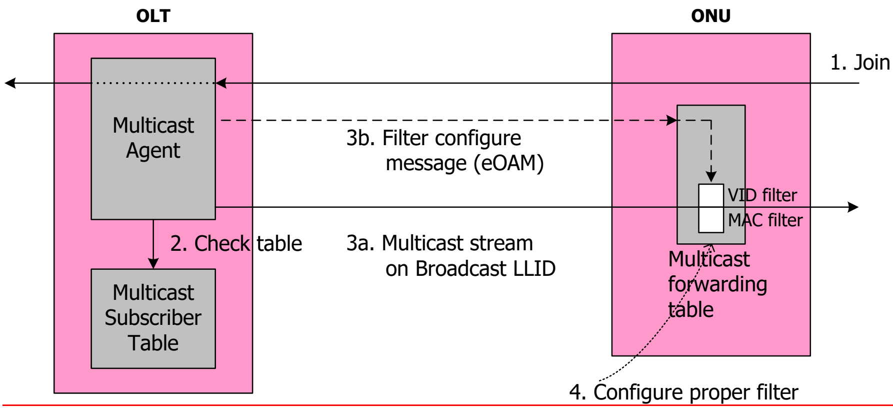

Figure 7-25—Operation of the multicast method based on VLAN and/or MAC group address

7.4.2.1.1 OLT-based multicast management

The management of the multicast method based on VLAN and/or MAC group address uses the standard set of eOAMPDUs to perform attribute read/set operations using the *eOAM_Get_Request*/*eOAM_Get_Response* for reading and *eOAM_Set_Request*/*eOAM_Set_Response* for setting the specific attribute.

The VLAN-based multicast filtering mode is managed using TLVs defined in 14.3.1.11 and 14.3.1.12. The MAC-address-based multicast filtering mode is managed using eOAMPDUs defined in 13.3.3.8. The TLV defined in 14.3.1.15 is used for discovery of the ONU's filtering capabilities.

7.4.2.2 MLD-based multicast control

7.4.2.2.1 ONU requirements

The ONU shall forward all MLD messages and should forward all IGMP messages received at the UNI to the ONU_MDI without any processing.

7.4.2.2.2 OLT requirements

The following list of requirements is needed for the OLT to support this mode:

a) The OLT should support multicast operation on the 1G-EPON and 10G-EPON coexistence PON link. In this case, it is possible to provision multicast ESP for both 1 Gb/s and 10 Gb/s downstream line rate and to duplicate multicast frames at the CrossConnect to 1G-EPON and 10G-EPON SCB channels. The OLT shall implement a multicast forwarding table to select the multicast traffic forwarding on the SCB channels.

b) The OLT shall support multicast traffic control for IPv6 and MLDv2 proxy and should support multicast forwarding control for IPv4 and IGMPv3 proxy.

c) The OLT shall implement a multicast control table for the purpose of maintaining information regarding supported multicast groups, including the membership status for each group.

d) The OLT shall be capable of provisioning registered ONUs via the eOAM messages as described below.

   1) The OLT sets the VLAN tag filter configuration using the *VLAN Tag Filter* TLV (0xB7/0x00-13), as defined in 14.3.1.11, which is used to enable or disable VLAN Tag filter. VLAN Tag filter identifies the VLAN ID of a multicast frame and controls transmission of the multicast traffic to the UNI port by examining the VLAN ID. The `VlanTagFilter` field is used to configure the TPID that is to be handled as a VLAN Tag frame in addition to the conventional VLAN Tag with TPID 0x81-00.

   2) The OLT sets the VLAN tag filter value using the *VLAN Tag Filter value* TLV (0xB7/0x00-14), as defined in 14.3.1.12, which is used by the OLT to configure the VLAN ID values that are to be forwarded to the UNI port when VLAN Tag filter is enabled. The "Set all entries in bulk" action is used to overwrite all the entries of the table in the ONU. If the VLAN IDs in the `VlanId` field exist in the ONU table, the ONU keeps them; otherwise, the ONU adds them. If the VLAN IDs in the ONU table are not designated in the `VlanId` field, the ONU removes the entries.

   3) The OLT discovers filter capabilities for each ONU by using the *Supported Multicast Filter Operation* TLV (0xB7/0x00-17), as defined in 14.3.1.15.

   4) Using the *DefaultFilter* eOAMPDU defined in 13.3.3.8, the OLT configures the parameters for MAC address based multicast filtering, and the ONU informs the OLT of its configured L2-address-based multicast filtering.

7.4.2.3 Multicast transport based on VLAN

In the *VLAN-based multicast filtering* mode, each multicast group present in an EPON is uniquely identified by a VLAN value. The VLAN-based multicast filtering mode is provisioned via eOAM messages by the OLT, using the *VLAN Tag Filter* TLV (0xB7/0x00-13) and the *VLAN Tag Filter Value* TLV (0xB7/0x00-14), as defined in 14.3.1.11 and 14.3.1.12, respectively.

The *VLAN Tag Filter* TLV (0xB7/0x00-13) is used to enable or disable the VLAN-based multicast filtering mode and to configure whether the VLAN matching is done only on the VID value or on a combination of

VID and TPID values. If TPID matching is enabled, only one TPID value is provisioned per ONU. The *VLAN Tag Filter Value* TLV (0xB7/0x00-14) is used to provision or clear the VID values used to identify multicast groups.

7.4.2.3.17.4.3.1.1 OLT forwarding behavior

In the VLAN-based multicast filtering mode, multicast frames arrive at the NNI tagged with VLAN tags uniquely identifying the multicast group to which each frame belongs. Based on the value of the VLAN tags, the OLT filters the incoming frames to determine whether these frames are passed to the ONUs or discarded.

To forward the multicast traffic, an OLT that supports only 1 Gb/s downstream channels, or only 10 Gb/s downstream channels, employs a unicast ESP, as shown in Figure 7-22. An OLT that supports both 1 Gb/s and 10 Gb/s downstream channels employs a multicast ESP that duplicates frames to two output ports: one associated with 1 Gb/s SCB MAC and the other associated with 10 Gb/s SCB MAC, as illustrated in Figure 7-23.

In the VLAN-based multicast filtering mode, in the downstream direction, the OLT shall apply rules and actions as illustrated in Table 7-32.

Table 7-32—Classifier rules and Modifier actions for downstream ESP in the OLT VLAN-based multicast filtering mode[a-e]

Classifier rules	Modifier actions	Description
`IF (exists(VLAN0) AND VLAN0_VID == MVID`$_1$`) THEN <m`$_1$`,…,x`$_B$`>`	Option 1: `[m`$_1$`]: REMOVE(VLAN0)` Option 2: `[m`$_1$`]: REPLACE( VLAN0_VID,UVID`$_1$`)`	To support VLAN-based multicast filtering, the OLT forwards any frame with VLAN tag of a specific set (`MVID`$_1$–`MVID`$_n$) to the broadcast LLID. The output vector of this rule directs the frame to the CrossConnect entry (x_B) that forwards the frame further to an output port associated with the SCB MAC.
. . .	. . .	
`IF (exists(VLAN0) AND VLAN0_VID == MVID`$_n$`) THEN <m`$_1$`,…,x`$_B$`>`	Option 1: `[m`$_1$`]: REMOVE(VLAN0)` Option 2: `[m`$_1$`]: REPLACE( VLAN0_VID,UVID`$_1$`)`	

[a] `MVID`$_1$–`MVID`$_n$ are provisioned 12-bit values representing the set of allowed network-side multicast VIDs in the downstream frames.

[b] `UVID`$_k$ is a provisioned 12-bit value representing the user-side VID associated with a specific network-side VID (`MVID`$_k$). There is a one-to-one mapping of user-side VIDs (`UVID`$_1$–`UVID`$_n$) and network-side VIDs (`MVID`$_1$–`MVID`$_n$). Here, the network-side VIDs (`MVID`$_1$–`MVID`$_n$) represent the allowed set of the multicast VIDs.

[c] x_B represents the CrossConnect entry that forwards the frame to an output port associated with the SCB MAC. When the OLT supports 1 Gb/s and 10 Gb/s downstream channels, the x_B entry is provisioned to duplicate frames to two output ports: one associated with 1 Gb/s SCB MAC and the other associated with 10 Gb/s SCB MAC.

[d] Option 1 of the Modifier action is selected when the OLT is configured to use the Tagging VLAN mode (see 7.2.2.1.3). In the Tagging VLAN mode, the OLT removes the outermost VLAN tag before forwarding the frame to a CrossConnect entry associated with the SCB MAC(s).

[e] Option 2 of the Modifier action is selected when the OLT is configured to use the Translation VLAN mode (see 7.2.2.1.5). In the Translation VLAN mode, the OLT replaces the network-side VID value with an associated user-side VID value (`UVID`$_k$) before forwarding the frame to a CrossConnect entry associated with the SCB MAC(s).

NOTE—VLAN-based multicast filtering is not used at the OLT when the OLT is configured to operate in Transparent VLAN mode (see 7.2.2.1.1).

7.4.2.3.2 ONU forwarding behavior

In the VLAN-based multicast filtering mode, in the downstream direction, the ONU shall apply rules and actions as illustrated in Table 7-33. The rules associated with the VLAN-based multicast filtering mode may be combined with the rules for multicast filtering based on MAC group addresses (see 7.4.2.4).

Table 7-33—Classifier rules and Modifier actions for the ONU VLAN-based multicast filtering mode[a–d]

Classifier rules	Modifier actions	Description
`IF (!exists(VLAN0)) THEN drop`	N/A	Untagged frames are discarded.

`IF (VLAN0_VID == MVID`$_1$`) THEN <`$m_j, \ldots, x_1$`>`	Option 1:
	`[`m_j`]: none`
	
	Option 2:
	`[`m_j`]: REMOVE(VLAN0)`
		In the VLAN-based multicast filtering mode, if the outermost VID of the frame matches one of the allowed multicast VIDs (`MVID`$_1$–`MVID`$_n$), the ONU forwards the frame to the CrossConnect entry x_k associated with the given `MVID` value.

`...`		
`IF (VLAN0_VID == MVID`$_n$`) THEN <`$m_j, \ldots, x_n$`>`		

[a] `MVID`$_1$–`MVID`$_n$ are 12-bit values that represent the provisioned multicast VIDs to be accepted by a given ESP.

[b] x_1–x_n are the downstream CrossConnect entries provisioned to support multicast transport. Each CrossConnect entry x_k is associated with a multicast VID value `MVID`$_k$. Depending on the set of UNIs that are included in each multicast group, the CrossConnect entries may include one element (i.e., multicast frames are forwarded to a single UNI) or multiple elements (i.e., multicast frames are duplicated to multiple UNIs in the given ONU).

[c] Option 1 of the Modifier action is selected when the ONU is configured to use the Transparent VLAN mode (see 7.2.2.1.2). In the Transparent VLAN mode, the ONU passes the unmodified frame to a CrossConnect entry associated with the given multicast group, identified by the `MVID` value.

[d] Option 2 of the Modifier action is selected when the ONU is configured to use the Tagging (see 7.2.2.1.4) or the ToS/CoS Conversion VLAN modes (see 7.2.2.1.6). In the Tagging or the ToS/CoS Conversion VLAN modes, the ONU removes the outermost VLAN tag before forwarding the frame to a CrossConnect entry associated with the given multicast group, identified by the `MVID` value.

7.4.2.4 Multicast transport based on MAC group address

In the *MAC-address-based multicast filtering* mode, each multicast group present in an EPON is uniquely identified by a value of MAC destination address. The MAC-address-based multicast filtering mode shall be provisioned via eOAM messages by the OLT, using the *DefaultFilter* eOAMPDU defined in 13.3.3.8.

MAC-address-based multicast filtering may employ static MAC address registration (see 7.4.2.4.1) or dynamic MAC address registration (see 7.4.2.4.2).

7.4.2.4.1 Static MAC address registration

In the static MAC address based registration method, multicast addresses available at the ONU are provisioned by the OLT using the *DefaultFilter* eOAMPDU. For each of the available addresses, the OLT also provisions the status flag, which can have values of `pass` or `drop`. The target range of MAC address that is handled in this filtering mode is 0x33-33-00-01-00-00 through 0x33-33-FE-FF-FF-FF. When the status is `pass`, the frame with the DA matching the provisioned MAC destination group address is passed to other rules that are associated with a selected VLAN mode. If the status is `drop`, the frames with the matching MAC address are discarded.

In the MAC-address-based multicast filtering mode with static MAC address registration, in the downstream direction, the ONU shall apply rules and actions as illustrated in Table 7-34. The rules associated with the MAC-address-based multicast filtering mode may be combined with the rules for multicast filtering based on VLAN values (see 7.4.2.3).

Table 7-34—Classifier rules and Modifier actions for downstream ESP in the ONU MAC-address-based multicast filtering mode with static MAC address registration[a]

Classifier rules	Modifier actions	Description
`IF (DA == MDA`$_1$`) THEN drop`	`N/A`	These rules are provisioned when the static MAC address registration is enabled and the status of the given `MDA`$_x$ value is set to `drop`. When the frame DA matches one of the provisioned DA values (`MDA`$_1$–`MDA`$_n$), the frame is discarded.
`...`		
`IF (DA == MDA`$_n$`) THEN drop`		

[a] `MDA`$_1$–`MDA`$_n$ are provisioned MAC addresses that represent the Destination Addresses to be blocked by a given ESP (when filtering based on MAC addresses is enabled). These are the addresses for which the status flag is `drop`.

7.4.2.4.2 Dynamic MAC address registration

In the dynamic MAC address based registration method, multicast addresses allowed at the ONU are provisioned by the OLT using the *DefaultFilter* eOAMPDU. A frame with the DA matching the provisioned MAC destination group address is forwarded to the output port. All frames whose DA is a MAC group address (except for the broadcast address) and does not match any of the provisioned allowed MAC group addresses are discarded. The target range of MAC address that is handled in this filtering mode is 0x01-00-5E-00-00-00 through 0x01-00-5E-7F-FF-FF for IPv4 multicast traffic and 0x33-33-00-01-00-00 through 0x33-33-FF-FF-FF-FF for IPv6 multicast traffic.

In the MAC-address-based multicast filtering mode with dynamic MAC address registration, in the downstream direction, the ONU shall apply rules and actions as illustrated in Table 7-35. The rules associated with the MAC-address-based multicast filtering mode may be combined with the rules for multicast filtering based on VLAN values (7.4.2.3).

Table 7-35—Classifier rules and Modifier actions for downstream ESP in the ONU MAC-address-based multicast filtering mode with dynamic MAC address registration[a, b, c]

Classifier rules	Modifier actions	Description
IF (DA >= MDA_{min} AND DA <= MDA_{max} AND DA != MDA_1 AND ... DA != MDA_n) THEN drop	N/A	All frames with Destination Addresses in the range from MDA_{min} to MDA_{max} and not matching one of the provisioned DA values (MDA_1–MDA_n) are dropped.

[a] MDA_{min} is the starting address of the range of allowed multicast addresses. In the case of IPv4 multicast traffic, MDA_{min} = 0x01-00-5E-00-00-00. In the case of IPv6 multicast traffic, MDA_{min} = 0x33-33-00-01-00-00.

[b] MDA_{max} is the ending address of the range of allowed multicast addresses. In the case of IPv4 multicast traffic, MDA_{max} = 0x01-00-5E-7F-FF-FF. In the case of IPv6 multicast traffic, MDA_{max} = 0x33-33-FF-FF-FF-FF.

[c] MDA_1–MDA_n are provisioned MAC addresses that represent the Destination Addresses to be forwarded by a given ESP (when filtering based on MAC addresses is enabled).

7.4.3 Multicast based on combined VLAN and group address with no authorization control

7.4.3.1 Operation outline

In the multicast method based on combined VLAN and group address with no authorization control, multicast frames for the given multicast group are uniquely identified by a combination of a multicast group address (MAC or IP) and a multicast VLAN tag. A multicast VLAN can be shared by a number of multicast groups. A multicast VLAN is typically assigned to a single Content Provider, while individual groups within this multicast VLAN are differentiated based on the multicast group address.

Multicast content distribution is Client-controlled using

— IP multicast control protocols, i.e., IGMPv2 (per IETF RFC 2236) for IPv4 multicast and MLD (per IETF RFC 2710) for IPv6 multicast, to exchange information about the current membership status in specific multicast groups between multicast client(s) and multicast server; and

— TLVs as defined in 7.4.3.2, 7.4.3.3, and 7.4.3.4.

7.4.3.1.1 OLT operation

Depending on its configuration, the OLT may use a unicast or multicast ESP to carry multicast traffic (see Figure 7-22 and Figure 7-23). These ESPs are referred to *multicast-bearing ESPs*.

The OLT shall be able to configure (instantiate) a multicast-bearing ESP for each multicast group. The multicast-bearing ESP shall be able to classify multicast traffic based on matching a combination of either VLAN and MAC destination group address or VLAN and IP destination group address. The OLT passes through all multicast traffic identified with selected multicast VLAN, as configured by the NMS.

7.4.3.1.2 ONU operation

The multicast VLAN is used by the ONU to identify the content for the given multicast group and is used together with the multicast group address to make forwarding decisions at the ONU. Prior to handing off multicast frames to multicast clients, the ONU strips the multicast VLAN tag, translates it, or forwards it

~~unmodified, as provisioned using the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42), as defined in 14.2.2.24.~~

~~The forwarding rules in the Classifier and Modifier blocks within the ONU MAC Client are modified dynamically by the IGMP/MLD agent operating on the ONU and based on the information retrieved from snooped IGMP/MLD control frames. In this mode of operation, the ONU locally makes decision on whether the given IGMP/MLD *JOIN* request can be served, depending on whether the given multicast group is already accessible to the ONU, as configured using the *Multicast VLAN Configuration* TLV (0xC7/0x00-41), as defined in 14.2.2.24.~~

~~An ONU may support a number of multicast groups, where each of the multicast groups is individually managed in terms of IGMP/MLD *JOIN* and *LEAVE* requests received from the connected multicast clients. Likewise, the OLT manages multicast groups in an individual manner, provisioning or disabling specific groups as requested by the NMS or as a result of IGMP *JOIN* requests received from CPE(s) and relayed by the ONU.~~

~~7.4.3.2 Multicast management and control~~

~~7.4.3.2.1 ONU requirements~~

~~In the multicast mode based on combined VLAN and group address with no authorization control, the ONU IGMP/MLD agent shall operate in the IGMP/MLD snooping mode, as defined in IETF RFC 4541. In the snooping mode, IGMP/MLD control messages are snooped and used to immediately update the local multicast membership table and forwarding rules. These frames are then forwarded unmodified toward the multicast server. The IGMP/MLD agent shall support IGMP operating modes with fast leave enabled and with fast leave disabled, as defined in IETF RFC 2236, and it shall support MLD operating modes with fast leave enabled and with fast leave disabled, as defined in IETF RFC 3810.~~

~~The ONU shall be able to configure the IGMP/MLD agent to enable or disable the fast leave mode, based on the received *Fast Leave Admin Control* TLV (0xC9/0x00-48), as defined in 14.2.5.3. The fast leave mode shall be disabled by default. The ONU shall be able to indicate the supported fast leave mode and current fast leave status by generating the *Fast Leave Capability* TLV (0xC7/0x00-46) and *Fast Leave Admin Status* TLV (0xC7/0x00-47), respectively, as defined in 14.2.2.28 and 14.2.2.29, in response to the OLT query.~~

~~Additionally, the ONU shall be able to receive *Multicast Group Number Max* TLV (0xC7/0x00-45) to establish the maximum allowed number of multicast groups for the given UNI port, as defined in 14.2.2.27, and *Multicast Control Mode* TLV (0xC7/0x00-43) to configure the multicast delivery mode (in this case, multicast mode with no authorization control), as defined in 14.2.2.25.~~

~~7.4.3.2.2 OLT requirements~~

~~In the multicast mode based on combined VLAN and group address with no authorization control, the OLT IGMP/MLD agent shall operate in the IGMP/MLD proxy mode, as defined in IETF RFC 4541.~~

~~The OLT shall be able to configure the ONU IGMP/MLD agent using the *Fast Leave Admin Control* TLV (0xC9/0x00-48), *Multicast Group Number Max* TLV (0xC7/0x00-45), and *Multicast Control Mode* TLV (0xC7/0x00-43). The OLT may assess what specific fast leave modes the given ONU supports using the *Fast Leave Capability* TLV (0xC7/0x00-46). The OLT may inquire about the current fast leave status on the ONU using the *Fast Leave Admin Status* TLV (0xC7/0x00-47).~~

~~Different ONU UNI ports may be configured to operate in different VLAN modes. If a UNI is configured to operate in a VLAN mode that strips or passes the multicast VLANs unaltered, the OLT shall first send the *Multicast VLAN Configuration* TLV (0xC7/0x00-41), as defined in 14.2.2.23, to configure multicast~~

VLANs allowed on the given UNI port and then the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42), as defined in 14.2.2.24, to configure the selected Modifier action (strip or pass).

If a UNI port is configured to operate in a VLAN mode that translates multicast VLANs, the OLT shall send the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42) to configure the selected Modifier action (translate), together with the list of source and target multicast VLAN values.

7.4.3.3 Multicast transport based on VLAN and MAC group address

In the multicast mode based on combined VLAN and MAC group address with no authorization control, each multicast group is uniquely identified by a VLAN tag carrying a multicast VLAN tag value, while each multicast subgroup within the given multicast group is identified by a MAC group address. MAC group addresses are not required to be unique across different multicast groups (i.e., different multicast VLANs); however, a combination of the multicast VLAN value and multicast group address uniquely identifies a multicast subgroup across the entire EPON.

7.4.3.3.1 OLT forwarding behavior

At the OLT, multicast frames arrive at the NNI tagged with VLAN tags, which together with the MAC group address identify the multicast group to which each frame belongs. The OLT forwards frames toward ONUs using the SCB MAC. Selection of the SCB MAC (1 Gb/s SCB MAC, 10 Gb/s SCB MAC, or both) is based on the combination of the multicast VLAN tag value and the MAC group address carried in the forwarded multicast frame, where the related classification and forwarding rules for the given multicast group are configured on the OLT by the operator via NMS.

The OLT shall configure the set of multicast VLANs allowed on individual UNI ports for the selected ONU using the *Multicast VLAN Configuration* TLV (0xC7/0x00-41). The OLT shall configure the selected operation on the multicast VLAN tag values for the specific UNI ports for the selected ONU using the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42).

In the multicast mode based on combined VLAN and MAC group address with no authorization control, in the downstream direction, the OLT shall apply rules and actions as illustrated in Table 7-36.

Table 7-36—Classifier rules and Modifier actions for downstream ESP in the OLT multicast filtering mode based on VLAN and MAC group address[a, b, c]

Classifier rules	Modifier actions	Description
IF (exists(VLAN0) AND VLAN0_VID == $MVID_1$ AND DA == $MACGA_m$) THEN <m_0, …, x_B>	[m_0]: none	The OLT forwards any frames with the outermost VID matching the provisioned multicast VID values ($MVID_1$–$MVID_k$) and with the DA matching the provisioned MAC group address (MACGA) to the CrossConnect entry (x_B) that forwards the frame further to an output port associated with the proper SCB MAC.
…		
IF (exists(VLAN0) AND VLAN0_VID == $MVID_k$ AND DA == $MACGA_n$) THEN <m_0, …, x_B>	[m_0]: none	

[a] $MVID_1$–$MVID_k$ are provisioned 12-bit values representing the set of allowed multicast VID values.

[b] $MACGA_m$–$MACGA_n$ are provisioned MAC group addresses. The same values of MAC group addresses may be combined with different values of multicast VIDs.

[e] x_B represents the CrossConnect entry that forwards the frame to an output port associated with the SCB MAC. When the OLT supports 1 Gb/s and 10 Gb/s downstream channels, the x_B entry is provisioned to duplicate frames to two output ports: one associated with 1 Gb/s SCB MAC and the other associated with 10 Gb/s SCB MAC.

7.4.3.3.2 ONU forwarding behavior

In the multicast mode based on combined VLAN and MAC group address with no authorization control, multicast frames arrive at the ONU_MDI tagged with VLAN tags carrying multicast VLAN tag values, which together with the MAC destination group address identify the multicast group to which each frame belongs. The ONU forwards individual multicast frames toward specific UNIs based on the combination of the multicast VLAN tag value and MAC destination address, carried in the forwarded multicast frame. The related classification and forwarding rules for the given multicast group shall be generated locally by the IGMP/MLD agent. The ONU shall configure the set of multicast VLANs allowed on individual UNI ports upon reception of the *Multicast VLAN Configuration* TLV (0xC7/0x00-41). The ONU shall configure the selected operation on the multicast VLAN tag values for the specific UNI port upon reception of the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42).

In the multicast mode based on combined VLAN and MAC group address with no authorization control, in the downstream direction, the ONU shall apply rules and actions as illustrated in Table 7-37.

Table 7-37—Classifier rules and Modifier actions for downstream ESP in the ONU multicast filtering mode based on VLAN and MAC group address[a–e]

Classifier rules	Modifier actions	Description

`IF (exists(VLAN0) AND VLAN0_VID == MVID`$_1$` AND DA == MACGA`$_1$`)`
`THEN <m`$_1$`, …, x`$_{11}$`>`
	Option 1:
	`[m`$_1$`]: none`
	
	Option 2:
	`[m`$_1$`]: REMOVE (VLAN0)`
	
	Option 3:
	`[m`$_1$`]: REPLACE (VLAN0_VID, UVID`$_1$`)`
		The ONU forwards each selected multicast frame to the specific CrossConnect entry associated with the unique combination of the multicast VLAN tag value (identified by the `MVID`) and MAC destination group address (`MACGA`) carried in the frame.
		These rules are generated locally by the IGMP/MLD agent based on the snooped IGMP/MLD control messages.

…		

`IF (exists(VLAN0) AND VLAN0_VID == MVID`$_k$` AND DA == MACGA`$_n$`)`
`THEN <m`$_j$`, …, x`$_{kn}$`>`
	Option 1:
	`[m`$_j$`]: none`
	
	Option 2:
	`[m`$_j$`]: REMOVE (VLAN0)`
	
	Option 3:
	`[m`$_j$`]: REPLACE (VLAN0_VID, UVID`$_k$`)`	

[a] `MVID`$_1$–`MVID`$_k$ are provisioned 12-bit values representing the set of VID values configured by the operator to designate multicast VLAN used to transfer content from specific multicast groups.

[b] `MACGDA`$_1$–`MACGDA`$_n$ are provisioned MAC destination group addresses. The same values of MAC destination group addresses may be combined with different values of the multicast VLANs. Different

combinations of MVID and MACGDA identify different multicast groups and, therefore, direct matching frames to different CrossConnect entries.

[c] $UVID_1$–$UVID_k$ are provisioned 12-bit values that represent the user-side VID values associated with the network-side VIDs ($MVID_1$–$MVID_k$). When the multicast VLAN translation option is enabled, each network-side VID $MVID_k$ representing a multicast group is translated into a user-side VID $UVID_k$. There is a one-to-one relationship between network-side and user-side VIDs.

[d] x_{ab} represents the CrossConnect entry that forwards the frame to an output port associated with the given unique combination of the multicast VLAN $MVID_a$ and the MAC destination group address $MACGDA_b$.

[e] Options 1, 2, and 3 represent alternative Modifier actions that may be provisioned independently per UNI. The OLT configures only one option at any time on each UNI. The selection between Options 1, 2, and 3 is done using the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42).

7.4.3.4 Multicast transport based on VLAN and IP multicast address

In the multicast mode based on combined VLAN and IP group address with no authorization control, each multicast group is uniquely identified by a VLAN tag carrying a multicast VLAN tag value, while each multicast subgroup within the given multicast group is identified by an IP group address. L3 group addresses are not required to be unique across different multicast groups (i.e., different multicast VLANs); however, a combination of the multicast VLAN value and multicast group address uniquely identifies a multicast subgroup across the entire EPON.

7.4.3.4.1 OLT forwarding behavior

In the multicast mode based on combined VLAN and IP group address with no authorization control, multicast frames arrive at the NNI tagged with VLAN tags, which together with the IP (either IPv4 or IPv6, as provisioned by the operator) destination group address identify the multicast group to which each frame belongs. The OLT forwards frames toward individual ONUs based on the combination of the multicast VLAN tag value and the IP destination group address carried in the forwarded multicast frame, where the related classification and forwarding rules for the given multicast group are configured on the OLT by the operator via NMS.

For requirements associated with SCB MAC and replication of multicast data into SCB MAC domains, see 7.4.1.1.2.

The OLT shall configure the set of multicast VLANs allowed on individual UNI ports for the selected ONU using the *Multicast VLAN Configuration* TLV (0xC7/0x00-41). The OLT shall configure the selected operation on the multicast VLAN tag values for the specific UNI ports for the selected ONU using the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42).

In the multicast mode based on combined VLAN and IP group address with no authorization control, in the downstream direction, the OLT shall apply rules and actions as illustrated in Table 7-38.

Table 7-38—Classifier rules and Modifier actions for downstream ESP in the OLT multicast filtering mode based on multicast VLAN and IP group address[a–d]

Classifier rules	Modifier actions	Description
`IF (exists(VLAN0) AND EXISTS(IPv4_HEADER) AND VLAN0_VID == MVID₁ AND IPv4_DA == IPGA4₁) THEN <m₀,…,x_B>`	$\{m_0\}$: none	These rules are provisioned when multicast filtering is performed based on multicast VLAN and IPv4 multicast destination address. If a frame matches both the provisioned multicast VID value MVID and the associated IPv4 multicast address IPGA4, the frame is forwarded to the CrossConnect entry (x_B) that forwards the frame further to an output port associated with the proper SCB MAC (broadcast LLID).
…		
`IF (exists(VLAN0) AND EXISTS(IPv4_HEADER) AND VLAN0_VID == MVIDₖ AND IPv4_DA == IPGA4ₙ) THEN <m₀,…,x_B>`		
`IF (exists(VLAN0) AND EXISTS(IPv6_HEADER) AND VLAN0_VID == MVID₁ AND IPv6_DA == IPGA6₁) THEN <m₀,…,x_B>`	$\{m_0\}$: none	These rules are provisioned when multicast filtering is performed based on multicast VLAN and IPv6 multicast destination address. If a frame matches both the provisioned multicast VID value MVID and the associated IPv6 multicast address IPGA6, the frame is forwarded to the CrossConnect entry (x_B) that forwards the frame further to an output port associated with the proper SCB MAC (broadcast LLID).
…		
`IF (exists(VLAN0) AND EXISTS(IPv6_HEADER) AND VLAN0_VID == MVIDₖ AND IPv6_DA == IPGA6ₘ) THEN <m₀,…,x_B>`		

[a] $MVID_1$–$MVID_k$ represent provisioned 12-bit values that define the set of allowed VID values for the multicast data frames.

[b] $IPGA4_1$–$IPGA4_n$ represent n provisioned IPv4 destination group addresses. The same values of IPv4 destination group addresses may be combined with different values of the multicast VLANs. Different combinations of MVID and IPGA4 identify different multicast groups.

[c] $IPGA6_1$–$IPGA6_m$ represent m provisioned IPv6 destination group addresses. The same values of IPv6 destination group addresses may be combined with different values of the multicast VLANs. Different combinations of MVID and IPGA6 identify different multicast groups.

[d] x_B represents the CrossConnect entry that forwards the frame to an output port associated with the SCB MAC. When the OLT supports 1 Gb/s and 10 Gb/s downstream channels, the x_B entry is provisioned to duplicate frames to two output ports: one associated with 1 Gb/s SCB MAC and the other associated with 10 Gb/s SCB MAC.

7.4.3.4.2 ONU forwarding behavior

In the multicast mode based on combined VLAN and IP group address with no authorization control, multicast frames arrive at the ONU_MDI tagged with VLAN tags carrying multicast VLAN tag values, which together with the IP group address (either IPv4 or IPv6, as provisioned by the operator) identify the multicast group to which each frame belongs. The ONU forwards individual multicast frames toward specific UNIs based on the combination of VLAN tag and IP destination address, carried in the forwarded multicast frame. The related classification and forwarding rules for the given multicast group shall be generated locally by the IGMP/MLD agent.

~~The ONU shall configure the set of multicast VLANs allowed on individual UNI ports upon reception of the *Multicast VLAN Configuration* TLV (0xC7/0x00-41). The ONU shall configure the selected operation on the multicast VLAN tag values for the specific UNI port upon reception of the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42).~~

~~In the multicast mode based on combined VLAN and IP group address with no authorization control, in the downstream direction, the ONU shall apply rules and actions as illustrated in Table 7-39.~~

~~Table 7-39—Classifier rules and Modifier actions for downstream ESP in the ONU multicast filtering mode based on multicast VLAN and IP group address~~[a–f]

~~Classifier rules~~	~~Modifier actions~~	~~Description~~
~~IF (exists(VLAN0) AND EXISTS(IPv4_HEADER) AND VLAN0_VID == MVID$_1$ AND IPv4_DA == IPGA4$_1$) THEN <m$_1$,…,x$_{11}$>~~	~~Option 1: [m$_1$]: none~~ ~~Option 2: [m$_1$]: REMOVE (VLAN0)~~ ~~Option 3: [m$_1$]: REPLACE (VLAN0_VID,UVID$_1$)~~	~~These rules are generated locally by the IGMP/MLD agent based on the snooped IGMP/MLD control messages when multicast filtering is performed based on multicast VLAN and IPv4 multicast destination address.~~ ~~The ONU forwards each selected multicast frame to the specific CrossConnect entry (x$_{ab}$) associated with the specific values of the multicast VLAN tag value (identified by the MVID$_a$) and IPv4 multicast address (IPGA4$_b$) carried in the frame.~~
~~…~~		
~~IF (exists(VLAN0) AND EXISTS(IPv4_HEADER) AND VLAN0_VID == MVID$_k$ AND IPv4_DA == IPGA4$_n$) THEN <m$_1$,…,x$_{kn}$>~~	~~Option 1: [m$_1$]: none~~ ~~Option 2: [m$_1$]: REMOVE (VLAN0)~~ ~~Option 3: [m$_1$]: REPLACE (VLAN0_VID,UVID$_k$)~~	
~~IF (exists(VLAN0) AND EXISTS(IPv6_HEADER) AND VLAN0_VID == MVID$_1$ AND IPv6_DA == IPGA6$_1$) THEN <m$_1$,…,x$_{11}$>~~	~~Option 1: [m$_1$]: none~~ ~~Option 2: [m$_1$]: REMOVE (VLAN0)~~ ~~Option 3: [m$_1$]: REPLACE (VLAN0_VID,UVID$_1$)~~	~~These rules are generated locally by the IGMP/MLD agent based on the snooped IGMP/MLD control messages when multicast filtering is performed based on multicast VLAN and IPv6 multicast destination address.~~ ~~The ONU forwards each selected multicast frame to the specific CrossConnect entry (x$_{ab}$) associated with the specific values of the multicast VLAN tag value (identified by the MVID$_a$) and IPv4 multicast address (IPGA6$_b$) carried in the frame.~~
~~…~~		
~~IF (exists(VLAN0) AND EXISTS(IPv6_HEADER) AND VLAN0_VID == MVID$_k$ AND IPv6_DA == IPGA6$_m$) THEN <m$_1$,…,x$_{km}$>~~	~~Option 1: [m$_1$]: none~~ ~~Option 2: [m$_1$]: REMOVE (VLAN0)~~ ~~Option 3: [m$_1$]: REPLACE (VLAN0_VID,UVID$_k$)~~	

~~[a] MVID$_1$–MVID$_k$ represent provisioned 12-bit values that define the set of allowed VID values for the multicast data frames.~~

[b] IPGA4$_1$–IPGA4$_n$ represent n provisioned IPv4 destination group addresses. The same values of IPv4 destination group addresses may be combined with different values of the multicast VLANs. Different combinations of MVID and IPGA4 identify different multicast groups.

[c] IPGA6$_1$–IPGA6$_m$ represent m provisioned IPv6 destination group addresses. The same values of IPv6 destination group addresses may be combined with different values of the multicast VLANs. Different combinations of MVID and IPGA6 identify different multicast groups.

[d] UVID$_1$–UVID$_k$ are provisioned 12-bit values that represent the user-side VID values associated with the network-side VIDs (MVID$_1$–MVID$_k$). When the multicast VLAN translation option is enabled, each network-side VID MVID$_p$ representing a multicast group is translated into a user-side VID UVID$_p$. There is a one-to-one relationship between network-side and user-side VIDs.

[e] x_{ab} represents the CrossConnect entry that forwards the frame to an output port associated with the given unique combination of the multicast VLAN MVID$_a$ and the IPv4 or IPv6 destination group address (MACGA4$_b$ or MACGA6$_b$).

[f] Options 1, 2, and 3 represent alternative Modifier actions that may be provisioned independently per UNI. The OLT configures only one option at any time on each UNI. The selection between Options 1, 2, and 3 is done using the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42).

7.4.4 Multicast based on combined VLAN and group address with authorization control

7.4.4.1 Operation outline

7.4.3.2 In the multicast mode based on combined VLAN and group address with authorization control, access to specific multicast content is and server-controlled through a centralized authorization system, whereby the OLT authorizes multicast clients to access specific multicast groups.multicast group membership

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Multicast content distribution is controlled using

- IP multicast control protocols, i.e., IGMPv2 (per IETF RFC 2236) for IPv4 multicast and MLD (per IETF RFC 2710) for IPv6 multicast, to exchange information about the current membership status in specific multicast groups between multicast client(s) and multicast server; and
- TLVs as defined in 7.4.4.2, 7.4.4.3, and 7.4.4.4.

7.4.4.1.1 OLT operation

In the multicast mode based on combined VLAN and group address with authorization control, upon reception of an IGMP/MLD *JOIN* request forwarded by the ONU, the multicast client authorization is verified using information stored in the authorization table maintained by the OLT and NMS. Depending on the outcome of the authorization verification process, the OLT may reconfigure its multicast authorization table and the forwarding table on the ONU using eOAM management.

In the multicast mode based on combined VLAN and group address with authorization control, the OLT manages individual multicast groups by establishing multicast membership for individual multicast clients and ONUs to which they are connected. Multicast frames belonging to a given multicast group are uniquely identified by a combination of a multicast group address (MAC and IP) and a multicast VLAN tag. A multicast VLAN can be shared by a number of multicast groups. A multicast VLAN is typically assigned to a single Content Provider, while individual groups within this multicast VLAN are differentiated based on the multicast group address.

7.4.4.1.2 ONU operation

In the multicast mode based on combined VLAN and group address with authorization control, a multicast client requests access to the given multicast group by sending an IGMP/MLD *JOIN* request, which is then forwarded, with appropriate VLAN tagging, to the OLT. The VLAN tag is associated with the ONU UNI port to which the given multicast client is connected. In this mode, the ONU forwards IGMP/MLD control frames and does not update its local forwarding table without an explicit provisioning from the OLT.

The multicast VLAN is used by the ONU to identify the content for the given multicast group and is used together with the multicast group address to make forwarding decisions. Prior to handing off multicast frames to multicast clients, the ONU removes the VLAN tag, translates it, or forwards it unmodified, as provisioned using the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42), as defined in 14.2.2.24, and *Multicast VLAN Configuration* TLV (0xC7/0x00-41), as defined in 14.2.2.23. Any multicast frame belonging to an unknown multicast group is discarded by the ONU.

An ONU may support a number of multicast groups, where each of the multicast groups is individually managed in terms of IGMP/MLD *JOIN* and *LEAVE* requests received from the connected multicast clients. Likewise, the OLT manages multicast groups in an individual manner, provisioning or disabling specific groups as requested by the NMS or as a result of IGMP *JOIN* requests received from CPE(s) and relayed by the ONU.

7.4.4.2 Multicast management and control

7.4.4.2.1 ONU requirements

The ONU IGMP/MLD agent shall be disabled. The ONU shall forward all IGMP/MLD control messages received at the UNI to the ONU_MDI without any processing. The ONU shall forward all IGMP/MLD control messages received at the ONU_MDI to all ONU UNIs subscribed to the given group. Such control messages may be carried in the multicast ESP or in unicast ESP provisioned for the given multicast group in the ONU.

7.4.4.2.2 OLT requirements

The OLT IGMP/MLD agent maintains the multicast authorization table, containing information on the authorization levels for individual multicast clients connected to EPON. The authorization table may be organized in different ways, e.g., information can be stored in the per-UNI-port or per-multicast-group fashion, depending on the target resolution of the multicast access control mechanism. Any multicast client recorded in this authorization table has one of the following statuses: ‘permitted’ if the given multicast content stream is accessible or ‘preview’ if only preview of the given multicast content is accessible. If the given multicast client identity is not present in the authorization table, the status of such a multicast client is said to be ‘prohibited’, and access to the given multicast content is not allowed.

The OLT parses the IGMP/MLD *JOIN* requests received from the unicast ESP and verifies the presence of the multicast client identity in the authorization table to determine whether this multicast client is authorized to obtain access to the given multicast stream. If the validation process is successful and the entry for the given multicast client is found with the status of ‘permitted’ or ‘preview’, the OLT IGMP/MLD authorization agent shall send the *Multicast Control Table* TLV (0xC7/0x00-44), as defined in 14.2.2.26, to the source ONU using a unicast ESP, instructing it to create the appropriate forwarding rule in the ONU Classifier. If the requested multicast stream is not yet forwarded to the EPON, the OLT undertakes all necessary steps to start forwarding the stream, using the data plane and control plane mechanisms defined in the following subclauses. Otherwise, no additional action needs to be undertaken by the OLT.

If the multicast client status retrieved from the authorization table is equal to ‘preview’, the OLT shall start a preview timer, which determines the duration of the preview of the given multicast stream allowed for the given multicast client. The value for this timer is set by the NMS and may be configured for each multicast group or each multicast client independently, depending on the implementation of the multicast authorization system. Once the preview timer expires, the OLT shall generate the *Multicast Control Table* TLV (0xC7/0x00-44) to reconfigure the ONU to which the given multicast client is connected to prevent the ONU from forwarding the multicast stream to this multicast client. The ONU receives the *Multicast Control Table* TLV (0xC7/0x00-44), and it removes or modifies the Classifier rules and Modifier actions as needed.

Additionally, the OLT shall implement the function of a preview blackout timer, which is started when the given multicast client status is changed from 'preview' to 'prohibited' or 'permitted' and supports the range of one second to one hour with one second resolution. The value for this timer is set by the NMS. The timer may be configured with the same value for all multicast clients or alternatively configured for each multicast group or each multicast client independently. The OLT shall ignore any further requests for preview from this multicast client when the multicast client status is equal to 'preview' or the preview blackout timer is running and has not yet expired. This effectively prevents a multicast client from accessing the 'preview' mode for the selected multicast channel in a continuous manner.

Moreover, the OLT shall implement the function of a resettable, nonrolling preview counter, which counts the total number of times the given multicast client enters the 'preview' mode a day and supports the range of zero to 1024 with the resolution of one. A multicast client is allowed to enter the 'preview' mode only up to a specific number of times per day. The maximum value for this counter is set by the NMS. The counter may be configured with the same value for all multicast clients or alternatively configured for each multicast group or each multicast client independently. Once the maximum number of times the given multicast client is allowed to enter the 'preview' mode is exceeded, the OLT shall ignore any further requests for preview from this multicast client. This counter is reset typically once a day at a selected time, e.g., at midnight.

The OLT also monitors the membership for individual multicast groups. The OLT shall stop forwarding multicast content to particular multicast groups that have no active multicast clients in the authorization table with the 'permitted' or 'preview' status. A multicast group is considered to not have active clients if the IGMP/MLD last member detection algorithm does not detect any members in the given multicast group.

An ONU may process multicast frames destined to distinct UNI ports differently.

If an ONU is expected to strip or pass the multicast VLANs unaltered for a UNI, the OLT shall send first the *Multicast VLAN Configuration* TLV (0xC7/0x00-41) to configure multicast VLANs allowed on the given UNI port and then the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42) to configure the selected Modifier action (strip or pass).

If an ONU is expected to translate multicast VLANs, the OLT shall send the *Multicast VLAN Operation Configuration* TLV (0xC7/0x00-42) to configure the selected Modifier action (translate), together with the list of source and target multicast VLAN values.

7.4.4.3 Multicast transport based on VLAN and MAC group address

7.4.4.3.1 OLT forwarding behavior

The OLT forwarding behavior shall be identical to the forwarding behavior specified in 7.4.3.3.1.

Additionally, the OLT shall configure, modify, and update (as needed) forwarding information on each UNI port on the selected ONU operating in the multicast mode with authorization control using the *Multicast Control Table* TLV (0xC7/0x00-44).

7.4.4.3.2 ONU forwarding behavior

The ONU forwarding behavior shall be identical to the forwarding behavior specified in Table 7-37. However, the Classifier rules and Modifier actions are provisioned by the OLT, rather than being generated locally by the IGMP/MLD agent. The ONU shall be able to parse and process the *Multicast Control Table* TLV (0xC7/0x00-44) to provision locally the necessary forwarding rules.

7.4.4.4 Multicast transport based on VLAN and IP multicast address

7.4.4.4.1 OLT forwarding behavior

The OLT forwarding behavior shall be identical to the forwarding behavior specified in 7.4.3.4.1.

Additionally, the OLT shall configure, modify, and update (as needed) forwarding information on each UNI port on the selected ONU operating in the multicast mode with authorization control using the *Multicast Control Table* TLV (0xC7/0x00-44).

7.4.4.4.2 ONU forwarding behavior

The ONU forwarding behavior shall be identical to the forwarding behavior specified in Table 7-39. However, the Classifier rules and Modifier actions are provisioned by the OLT, rather than being generated locally by the IGMP/MLD agent. The ONU shall be able to parse and process the *Multicast Control Table* TLV (0xC7/0x00-44) to provision locally the necessary forwarding rules.

7.4.4.5 Examples of multicast with authorization control

This subclause presents three examples of operation of the authorization control system in the multicast mode with authorization control, where the multicast user is prohibited from accessing (see Figure 7-26), permitted to access (see Figure 7-27), and permitted to temporarily access (see Figure 7-28) the requested multicast content. These examples assume that the requested multicast stream is not already present at the ONU and OLT.

7.4.4.5.1 Multicast client prohibited from accessing multicast content

Figure 7-26 presents the flow of information in the example when the multicast client entry is not found in the multicast authorization table. In such a case, the multicast client status is equal to ‘prohibited’.

When an untagged frame containing an IGMP/MLD *JOIN* (1) request (for multicast stream (1)) from the multicast client is received at the ONU, the ONU tags such a frame with the configured VLAN tag, identifying the given UNI port in an unequivocal manner (see point [1]). The VLAN-tagged frame containing the IGMP/MLD *JOIN* request is then forwarded to the OLT within a unicast ESP established between the OLT and the ONU. Once at the OLT, the OLT IGMP/MLD agent confirms whether the given multicast client is authorized to obtain access to the requested multicast group (see point [2]) – in this case, no entry in the multicast authorization table is found, and the multicast client status is equal to ‘prohibited’. The OLT does not send any follow-up messages, and the given multicast client does not obtain access to the requested multicast group.

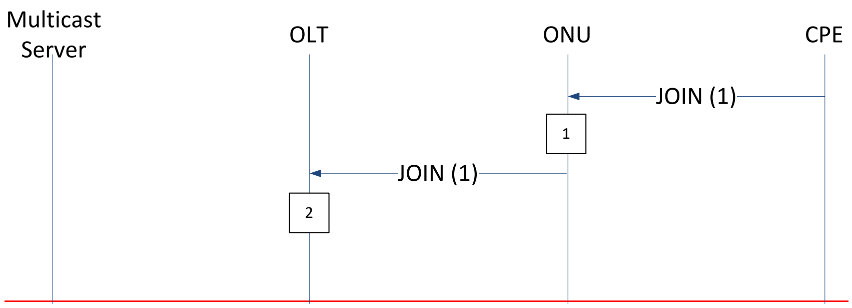

Figure 7-26—Information flow when multicast client status is 'prohibited'

7.4.4.5.2 Multicast client permitted to access multicast content

Figure 7-27 presents the flow of information in the example when the multicast client entry is found in the multicast authorization table. In such a case, the multicast client status is equal to 'permitted'.

When an untagged IGMP/MLD *JOIN* request from the CPE is received at the ONU (see point [0]), the ONU tags such a frame with the configured VLAN tag, identifying the given UNI port in an unequivocal manner (see point [1]). The VLAN-tagged frame containing the IGMP/MLD *JOIN* request is then forwarded to the OLT within a unicast ESP established between the OLT and the ONU. Once at the OLT, the OLT IGMP/MLD agent confirms whether the given multicast client is authorized to obtain access to the requested multicast group (see point [2]) – in this case, an entry in the multicast authorization table is found, and the multicast client status is evaluated to be equal to 'permitted'. The OLT then uses the *Multicast Control Table* TLV (0xC7/0x00-44) to configure the Classifier rules in the ONU (see point [3]).

Next, the OLT forwards the IGMP/MLD *JOIN* request toward the multicast server if required according to principles of the IGMP/MLD proxy operation per IETF RFC 4541. When received, this frame causes the multicast server to start forwarding multicast frames toward the OLT (see point [4]). Multicast frames are then forwarded by OLT at time indicated by point [5] into the EPON on the selected multicast ESP and then forwarded by the ONU to the specific output port associated with the UNI that initially received the request from the CPE for the multicast content at time indicated by point [0].

At some later time indicated by point [7], the given multicast client sends the IGMP/MLD *LEAVE* frame indicating that the given multicast content transfer may be discontinued. The control frame is tagged at the ONU at time indicated by point [8] and forwarded to the IGMP/MLD agent at the OLT as described before. When received, this frame causes the OLT IGMP/MLD agent to generate at time indicated by point [9] the *Multicast Control Table* TLV (0xC7/0x00-44) to reconfigure the Classifier rules in the ONU. The given multicast content is no longer forwarded to the specific output ports associated with the UNI user port(s) that initially requested the given multicast content at time indicated by point [0].

The OLT IGMP/MLD agent validates the status of the particular multicast group by issuing the IGMP/MLD Last Member Query frames per the requirements in IETF RFC 2236 (IGMPv2) or IETF RFC 2710 (MLD). These frames are forwarded to the specific output ports associated with the UNI user port(s) that initially requested the given multicast content at time indicated by point [0]. If within the configured IGMP/MLD Last Member Query response window no member is found active (with state 'permitted' or 'preview'), the given multicast group is disabled, and the OLT stops forwarding multicast content for this group at time indicated by point [10]. Simultaneously, the OLT issues the IGMP/MLD *LEAVE* frame toward the multicast server, requesting that the multicast server stop the delivery of multicast content for the specific multicast group. The server complies with this request at time indicated by point [11], when the delivery of the selected multicast content is terminated.

In addition to issuing Last Member Query frames in response to received client leave messages, the OLT IGMP/MLD agent periodically issues Last Member Query frames to all active groups and acts as described above when no replies are received from active members. This is to ensure that groups whose last clients did not exit gracefully (e.g., after a power loss) are nevertheless torn down gracefully by the OLT.

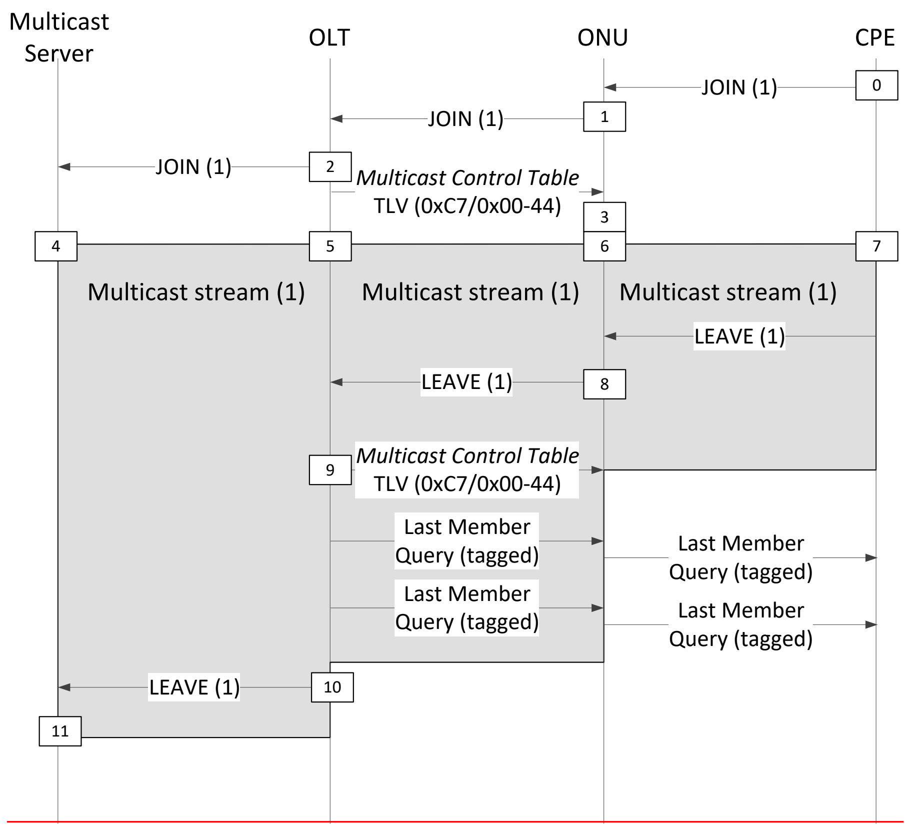

Figure 7-27—Information flow when multicast client status is 'permitted'

7.4.4.5.3 Multicast client permitted to temporarily access multicast content

Figure 7-28 presents the flow of information in the example when the multicast client entry is found in the multicast authorization table, allowing for temporary access to the requested multicast content. In such a case, the multicast client status is equal to 'preview'.

When an untagged frame containing an IGMP/MLD *JOIN* request from the multicast client is received at the ONU, the ONU tags such a frame with the configured VLAN tag, uniquely identifying the UNI port to which the frame arrived (see point [1]). The VLAN-tagged frame containing the IGMP/MLD *JOIN* request is then forwarded to the OLT within a unicast ESP established between the OLT and the ONU. Once at the OLT, the OLT IGMP/MLD agent confirms whether given multicast client is authorized to obtain access to the requested multicast group (see point [2]) – in this case, an entry in the multicast authorization table is found, and the multicast client status is evaluated to be equal to 'preview'. The OLT then uses the *Multicast Control Table* TLV (0xC7/0x00-44) to configure the Classifier rules in the ONU (see point [3]). Additionally, the OLT starts the preview timer, which later expires at time indicated by point [8].

Next, the OLT forwards the IGMP/MLD *JOIN* request toward the multicast server if required according to principles of the IGMP/MLD proxy operation per IETF RFC 4541. When received, this frame causes the multicast server to start forwarding multicast frames toward the OLT at time indicated by point [4]. Multicast frames are then forwarded by OLT at time indicated by point [5] into the EPON on the selected multicast ESP and then forwarded by the ONU to the specific output port associated with the UNI that initially received the request from the CPE for the multicast content at time indicated by point [0].

When the preview timer expires at time indicated by point [8], the OLT IGMP/MLD agent generates the *Multicast Control Table* TLV (0xC7/0x00-44) to reconfigure the Classifier rules in the ONU to cease forwarding multicast frames to the output ports. The given multicast content is no longer forwarded to the specific output ports associated with the UNI user port(s) that initially requested the given multicast content at time indicated by point [0]. Note that at this time, the preview blackout timer is still running and thereby preventing the OLT from receiving any further preview requests from this particular multicast client.

Next, the OLT IGMP/MLD agent validates the status of the particular multicast group as described in 7.4.4.1 and, if the given multicast group is empty, issues the IGMP/MLD *LEAVE* frame toward the multicast server at time indicated by point [9], requesting that the multicast server stop the delivery of multicast content for the specific multicast group. The server complies with this request at time indicated by point [10], when the delivery of the selected multicast content is terminated.

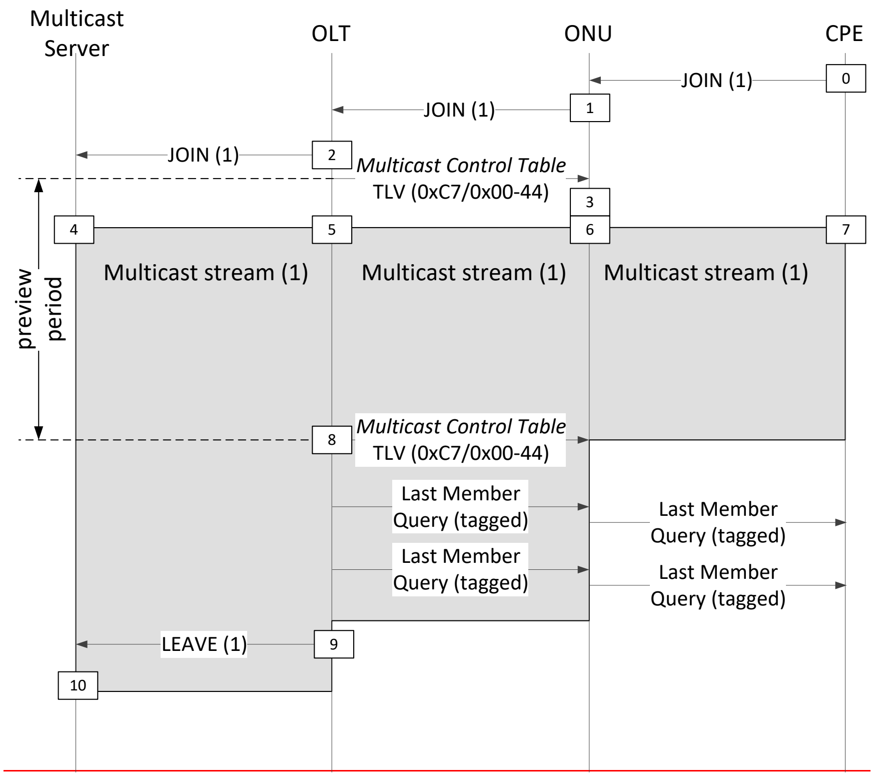

Figure 7-28—Information flow when multicast client status is 'preview'

7.4.5 Multicast based on multicast LLID

7.4.5.1 Operation outline

In the multicast mode based on multicast LLID (mLLID), the OLT forwards downstream multicast packets on the mLLID with active group membership.

A multicast group membership may be *client-controlled* or *server-controlled*. A client-controlled group membership (sometimes refered to as a *dynamic multicast session*) is initiated by multicast clients that independently issue requests to join or leave a multicast group. A server-controlled group membership (sometimes refered to as *static multicast session*) is initiated and configured by a multicast server or NMS without any explicit input from multicast clients. The OLT and ONUs shall support server-controlled multicast and should support client-controlled multicast.

From the OLT perspective, an mLLID represents a logical channel that delivers frames to a set of ONUs. The OLT configures the ONU with the mLLID (see 7.4.5.3.1). The OLT controls the intra-ONU forwarding of downstream multicast packets to specific UNI ports through provisioning of necessary classification and forwarding rules.

In some configurations, the logical channel formed by the mLLID is dedicated to a single multicast session. In such configurations, the mLLID value uniquely identifies an individual multicast session and the ONU classification rules may classify multicast frames solely by the mLLID value.

In other configurations, an mLLID logical channel is allocated for a set of multicast sessions. In such configurations, an individual multicast session is identified by a combination of mLLID value and values of some other fields, typically IP Group DA and/or IP SA. Correspondingly, the ONU classification rules may require multiple fields to classify frames belonging to individual multicast sessions.

To configure classification and forwarding rules for a specific multicast session, the OLT specifies a set of destination UNI ports for this sesssion. In scenarios where UNI ports belonging to a given multicast session are known to the OLT, the OLT performs the *port-based multicast control* (see 7.4.5.3.2). However, in some scenarios (e.g., when using the client-controlled multicast), the OLT is only aware of the MAC addresses of the multicast clients. In this case, the OLT uses the *MAC-based multicast control* method (see 7.4.5.3.3).

7.4.5.27.4.3.3 IGMP-based and MLD-based multicast group control

WhenIf the client-controlled multicast group membership method is utilized, it relies on either IGMP or MLD protocols. The ONU does not proxy or snoop IGMP/MLD messages to track IP multicast group membership and has no IP multicast control protocol awareness. In the upstream direction, the ONU forwards IGMP/MLD control messages received from the multicast clients to the OLT after adding appropriate encapsulation parameters as configured by the OLT. All processing of IGMP/MLD control messages and tracking of IP multicast group membership are centralized and performed by the OLTa multicast control agent, that may reside in the OLT or elsewhere.

7.4.5.2.17.4.3.3.1 ONU requirements

In the upstream direction, the ONU shall forward all IGMP/MLD control messages received at the UNIservice to the ONU_MDI using a provisioned unicast ESP. The Modifier block of the ESP may be configured to add a VLAN Tag to the multicast control frame prior to forwarding the multicast control frame to the ONU_MDI.

In the downstream direction, multicast-group-specific IGMP/MLD control frames are forwarded according to the forwarding rules configured on the ONU.

~~7.4.5.2.2~~7.4.3.3.2 OLT requirements

The following requirements apply to the OLT if the optional client-controlled multicast membership method is supported and the multicast control agent resides in the OLT.

When the OLT receives a *JOIN* request for a specific IP multicast session from a multicast client connected to a specific ~~UNI~~service port, it performs the following actions:

a) If OLT does not know the instance of the ~~UNI~~service port to which the multicast client is connected, it shall query the ONU to determine an instance of a ~~UNI~~service port on which the given client's MAC address has been learned.

b) If the ONU is not already configured to receive the mLLID carrying the requested IP multicast session, the OLT shall provision the mLLID (see 7.4.~~5.3~~4.1).

c) If the ONU is not already configured to receive the requested IP multicast session, the OLT shall add a new classification and forwarding rule to forward the requested multicast session to the specific ~~UNI~~service port (see 7.4.~~5.3~~4.2).

d) If the ONU is already receiving the requested multicast session, but the given ~~UNI~~service port is not configured to receive the multicast session, the OLT shall modify the existing classification and forwarding rule to include the additional ~~UNI~~service port into the existing multicast group. The rule modification involves provisioning of a new rule and then deleting the old rule (see 7.4.~~5.3~~4.2).

e) If the given ~~UNI~~service port is already configured to receive the requested IP multicast session, the OLT takes no action.

In some implementations, when the OLT receives the first *JOIN* request for a specific IP multicast session from a multicast client connected to a specific ~~UNI~~service port, the OLT verifies whether this ~~UNI~~service port is authorized to receive the requested IP multicast session. In such scenario, the OLT provisions the mLLID and the necessary classification and forwarding rules in the ONU only if the ~~UNI~~service port is authorized to receive the multicast session. The method used to authorize the ~~UNI~~service ports is outside of scope of this standard.

If the IP multicast session requested by a client does not exist in the OLT (i.e., the requested multicast stream is not being currently forwarded to any multicast clients on the given EPON), the OLT shall provision a local multicast-bearing ESP that forwards multicast traffic identified by the requested IP multicast address to the same mLLID that is provisioned on the ONUs to receive this multicast stream.

When the OLT determines that there are no multicast clients for an IP multicast session connected to an ONU ~~UNI~~service port, the OLT shall modify the associated classification and forwarding rules at the ONU to stop forwarding the indicated multicast session to the ~~UNI~~service port (see 7.4.~~5.3~~4.3).

When the OLT determines that there are no multicast clients for an IP multicast session connected to any of the ~~UNI~~service ports on an ONU, the OLT shall configure the ONU to delete the associated classification and forwarding rule (see 7.4.~~5.3~~4.3).

When the OLT determines that there are no multicast clients connected to any of the ~~UNI~~service ports on an ONU for any of IP multicast sessions being delivered on a specific mLLID, in addition to deleting the classification and forwarding rules associated with these IP multicast sessions, the OLT shall configure the ONU to delete the mLLID used to deliver these IP multicast sessions (see 7.4.~~5.3~~4.1).

~~7.4.5.3~~7.4.4 Provisioning of multicast ~~forwarding~~transport

The OLT provisions multicast forwarding either in response to multicast clients' requests to join a specific multicast group, in case of client-controlled multicast group membership, or in response to a NMS request, in case of server-controlled multicast group membership. In either case, provisioning of LLID-based multicast forwarding involves the following two steps:

— Configuring inter-ONU multicast ~~per~~(see 7.4.~~5.3~~4.1~~,~~), and

— Configuring intra-ONU multicast ~~per~~

— The OLT controls the intra-ONU forwarding through provisioning of classification/forwarding rules that forward the multicast frames to a set of destination service ports for the given multicast sesssion. In scenarios where service ports belonging to a given multicast session are known to the OLT, the OLT provisions the intra-ONU multicast using the method defined in 7.4.4.2. However, in some scenarios (e.g., when using the client-controlled multicast), the OLT is only aware of the MAC addresses of the multicast clients. ~~7.4.5.3.2 or~~In this case, the OLT provisions the intra-ONU multicast as specified in 7.4.~~5.3~~4.3.

~~7.4.5.3.1~~7.4.4.1 Provisioning of inter-ONU multicast based on mLLID

The inter-ONU multicast is provisioned using the ~~*acConfigMulticastLlid* (0xD9~~*acConfigLlid* (0xDD/0x01-~~07~~20) action (see ~~14.4.5.2.7~~14.6.2.8). Using this action, the OLT may add a new mLLID to an ONU, delete a specific mLLID from the ONU, or delete all mLLIDs from the ONU.

Deleting one or all mLLIDs from the ONU shall not modify or delete any of the rules provisioned into Classifier/Modifier using the *aRuleSetConfig* (~~0xD7~~0xDB/0x05-01) attribute.

The OLT may retrieve a list of all registered mLLIDs in the ONU using the attribute ~~*aOnuMulticastLlid* (0xD7~~*aLlidType* (0xDB/0x01-~~10~~20) (see 14.4.~~3.~~2.~~14~~16).

~~7.4.5.3.2~~7.4.4.2 Provisioning of intra-ONU multicast using ~~port-based multicast group control~~service ports

A multicast group at an ONU denotes a set of ~~UNI~~service ports configured to forward frames belonging to a given multicast session. A multicast group is created at an ONU when the first ~~UNI~~service port is configured to forward frames belonging to a given multicast session. A multicast group is considered deleted when the last port is configured to not forward frames belonging to a given multicast session.

To add a port to a specific multicast group, the OLT uses the attribute *aRuleSetConfig* (~~0xD7~~0xDB/0x05-01) (see 14.4.~~3.~~6.1). To replicate a multicast frame to multiple ~~UNI~~service ports, the *aRuleSetConfig* attribute includes multiple *sResult* sub-attributes with the *sFrameAction* set to *QUEUE* (see 14.4.~~3~~.6.1.2).

To add the *first* ~~UNI~~service port to a multicast group, the OLT shall generate the *aRuleSetConfig* attribute that includes:

— One or more *sClause*~~-~~ sub-attributes necessary to match frames belonging to specific multicast flow

— A single *sResult* sub-attribute with the action set to *QUEUE,* directing traffic to a specific queue associated with a specific ~~UNI~~service port instance.

To add an additional ~~UNI~~service port to a multicast group already existing in the ONU, the OLT shall generate a new *aRuleSetConfig* attribute~~,~~ that contains an additional *sResult* sub-attribute with the action set to *QUEUE*, but is otherwise identical to the existing rule for the given multicast group.

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The OLT shall not generate a rule with multiple *sResult* sub-attributes pointing to the same instance of a ~~UNI~~service port. The ONU shall reject a rule with multiple *sResult* sub-attributes pointing to the same instance of a ~~UNI~~service port.

To delete a ~~UNI~~service port from an existing multicast group in the given ONU, the OLT shall generate a new *aRuleSetConfig* attribute, that does not contain the *sResult* sub-attribute forwarding traffic to the port being deleted, but is otherwise identical to the existing rule for the given multicast group.

To ensure that the multicast sessions currently being forwarded to the existing multicast clients are not interrupted when the multicast group is modified (i.e., a new ~~UNI~~service port is added to the group or one of existing ~~UNI~~service ports is deleted from the group), the OLT shall generate the new *aRuleSetConfig* attribute before deleting the old *aRuleSetConfig* attribute. The OLT shall not configure the ONU to delete the old *aRuleSetConfig* attribute before it receives a confirmation from the ONU that the new attribute was configured successfully.

When a new rule is added at the ONU and the old rule is deleted after that, and if the new rule contains the same *sClause*~~-~~ sub-attributes and some of the *sResult* clauses forwarding traffic to the same queues as the old rule, the Classifier at the ONU shall not discard any frames destined to these queues, i.e., the multicast flows to the existing and remaining multicast clients are not interrupted when other clients are added or deleted.

To delete all ~~UNI~~service ports from an existing multicast group in the given ONU, the OLT shall delete the associated *aRuleSetConfig* attribute entirely. This effectively deletes the entire multicast group in the given ONU.

~~7.4.5.3.3~~7.4.4.3 Provisioning of intra-ONU multicast using MAC~~-based multicast group control~~ addresses

The MAC-based multicast group control is used in situations where only the MAC addresses of multicast clients are known to the OLT. The MAC-based multicast group control is a two-step process:

~~1)~~The OLT queries the ONU to find out an instance of a ~~UNI~~service port on which the given MAC address has been learned.

~~2)~~The OLT adds this instance of ~~UNI~~service port to the given multicast group using the method described in ~~7.4.5.3.2~~7.4.4.2.

To retrieve the instance of the ~~UNI~~service port on which the given MAC address has been learned, the OLT shall use the *acGetUniMacLearned* (~~0xD9~~0xDD/0x01-08) action (see 14.~~4.5~~6.2.~~8~~7). If the sub-attribute *sUniPort* contains the value 0xFF, indicating that the given MAC address has not been learned on any of ~~UNI~~service ports, the OLT shall not perform step 2).

To delete a multicast client from a given multicast group under the MAC-based multicast group control method, the OLT may query the ONU again to find out the instance of the ~~UNI~~service port of a given multicast client. Alternatively, the OLT may retain the association of MAC clients and ~~UNI~~service ports when each new multicast client is added, and the OLT may proceed to modify forwarding rules (i.e., add a new rule and/or delete an old rule) without additional querying of the ONU.

~~7.4.5.4~~7.4.4.4 ~~Multicast~~Provisioning examples of multicast forwarding based on ~~mLLID~~mULID and IP group address

This subclause ~~defines~~illustrates OLT and ONU multicast forwarding process based on ~~mLLID~~mULID and IP group address. Other configurations, while not explicitly described here, are also possible. For example, multicast forwarding can be based on ~~mLLID~~mULID only, on ~~mLLID~~mULID and L2 DA and/or SA, etc.

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~~7.4.5.4.1 OLT forwarding behavior~~

~~7.4.5.4.2~~7.4.4.4.1 OLT forwarding behavior

Multicast frames arriving to the NNI are classified using either IP destination address or a combination of IP destination address and IP source address and are then associated with an ~~mLLID~~mULID for forwarding across the PON. This is achieved by provisioning an ESP Classifier rule that includes minimally the destination IP multicast address, and may additionally include the source IP address, to determine the appropriate ~~mLLID~~mULID on which to transport the frames.

In the simplest case, there is a one-to-one association between an IP multicast group and an ~~mLLID~~mULID. A more complex case exists wherein an ~~mLLID~~mULID carries frames from more than one multicast group. The set of multicast groups that may be aggregated to use the same ~~mLLID~~mULID for transport across the PON is determined by operator provisioning.

In the multicast mode based on combined ~~LLID~~ULID and IP group address, in the downstream direction, the OLT ~~shall apply~~applies rules and actions as illustrated in Table 7-~~40~~32. Each rule (row) in the given table represents a separate multicast group.

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Table 7-32—Classifier rules and Modifier actions for downstream ESP in the OLT multicast filtering mode based on ~~mLLID~~mULID and IP group address[a–f]

Classifier rules	Modifier actions	Description
`IF (EXISTS(IPv4_HEADER) AND IPv4_DA == IP4GA`$_1$`) THEN <`m_0`,…,`x_1`>`	`[`m_0`]: none`	These rules are provisioned when multicast filtering is performed based on IPv4 multicast destination address. If a frame's `IPv4_DA` field matches the provisioned IPv4 group address `IP4GA`$_n$, the frame is forwarded to the CrossConnect entry (x_n) that forwards the frame further to an output port associated with the proper ~~mLLID~~mULID.
…		
`IF (EXISTS(IPv4_HEADER) AND IPv4_DA == IP4GA`$_n$`) THEN <`m_0`,…,`x_n`>`		

Classifier rules	Modifier actions	Description
IF (EXISTS(IPv4_HEADER) AND IPv4_DA == IP4GA$_1$ AND IPv4_SA == IP4SA$_1$) THEN <m$_0$,…,x$_1$>	[m$_0$]: none	These rules are provisioned when multicast filtering is performed based on IPv4 destination and source addresses. If a frame's IPv4_DA field matches the provisioned IPv4 group address IP4GA$_n$ and IPv4_SA field matches the provisioned IPv4 source address IP4SA$_n$, the frame is forwarded to the CrossConnect entry (x$_n$) that forwards the frame further to an output port associated with the proper ~~mLLID~~mULID.
…		
IF (EXISTS(IPv4_HEADER) AND IPv4_DA == IP4GA$_n$ AND IPv4_SA == IP4SA$_n$) THEN <m$_0$,…,x$_n$>		
IF (EXISTS(IPv6_HEADER) AND IPv6_DA == IP6GA$_1$) THEN <m$_0$,…,x$_1$>	[m$_0$]: none	These rules are provisioned when multicast filtering is performed based on IPv6 multicast destination address. If a frame's IPv6_DA field matches the provisioned IPv6 group address IP6GA$_n$, the frame is forwarded to the CrossConnect entry (x$_n$) that forwards the frame further to an output port associated with the proper ~~mLLID~~mULID.
…		
IF (EXISTS(IPv6_HEADER) AND IPv6_DA == IP6GA$_n$) THEN <m$_0$,…,x$_n$>		
IF (EXISTS(IPv6_HEADER) AND IPv6_DA == IP6GA$_1$ AND IPv6_SA == IP6SA$_1$) THEN <m$_0$,…,x$_1$>	[m$_0$]: none	These rules are provisioned when multicast filtering is performed based on IPv6 destination and source addresses. If a frame's IPv6_DA field matches the provisioned IPv6 group address IP6GA$_n$ and IPv6_SA field matches the provisioned IPv6 source address IP6SA$_n$, the frame is forwarded to the CrossConnect entry (x$_n$) that forwards the frame further to an output port associated with the proper ~~mLLID~~mULID.
…		
IF (EXISTS(IPv6_HEADER) AND IPv6_DA == IP6GA$_n$ AND IPv6_SA == IP6SA$_n$) THEN <m$_0$,…,x$_n$>		

[a] IP4GA$_1$–IP4GA$_n$ represent provisioned IPv4 destination group addresses.

[b] IP4SA$_1$–IP4SA$_n$ represent provisioned IPv4 source addresses.

[c] IP6GA$_1$–IP6GA$_n$ represent provisioned IPv6 destination group addresses.

[d] IP6SA$_1$–IP6SA$_n$ represent provisioned IPv6 source addresses.

[e] When both source and destination addresses are used for matching multicast frames, the same values of destination group addresses may be combined with different values of the source addresses, and the same value of the source address may be combined with different values of the destination addresses. A unique combination of source and destination addresses identifies a unique multicast group.

[f] x$_1$–x$_n$ represent the CrossConnect entry that forwards the frame to an output port associated with the proper ~~mLLID~~mULID. When the OLT supports ~~1~~10 Gb/s and ~~10~~25/50 Gb/s downstream channels, the x$_i$ entry is provisioned to duplicate frames to two ~~output ports~~downstream queues: one associated with

110 Gb/s mLLID and the other associated with 1025 Gb/s mLLIDmULID. Both mLLIDsmulticast LLIDs may have the same or different numerical values.

7.4.5.4.37.4.4.4.2 ONU forwarding behavior

At the ONU, multicast sessions may be identified by any of the following combinations of fields:

- IP DA
- IP DA and IP SA
- mLLIDmULID value and IP DA
- mLLIDmULID value, IP DA, and IP SA

In the multicast mode based on combined LLIDULID and IP group address, in the downstream direction, the ONU shall apply rules and actions as illustrated in Table 7-4133. Each rule (row) in the given table represents a separate multicast session.

Table 7-33—Classifier rules and Modifier actions for downstream ESP in the ONU multicast filtering mode based on mLLIDmULID and IP group address[a–g]

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Classifier rules	Modifier actions	Description
IF (EXISTS(IPv4_HEADER) AND IPv4_DA == $IP4GA_1$) THEN <m_0,…,x_1>	$[m_0]$: none	These rules are provisioned when multicast filtering is performed based on IPv4 multicast destination address. If a frame's IPv4_DA field matches the provisioned IPv4 group address $IP4GA_n$, the frame is forwarded to the CrossConnect entry (x_n) that forwards the frame further to a set of output ports associated with the given IP multicast session.
…		
IF (EXISTS(IPv4_HEADER) AND IPv4_DA == $IP4GA_n$) THEN <m_0,…,x_n>		

Classifier rules	Modifier actions	Description
IF (EXISTS(IPv4_HEADER) AND IPv4_DA == IP4GA$_1$ AND IPv4_SA == IP4SA$_1$) THEN <m$_0$,…,x$_1$>	[m$_0$]: none	These rules are provisioned when multicast filtering is performed based on IPv4 destination and source addresses. If a frame's IPv4_DA field matches the provisioned IPv4 group address IP4GA$_n$ and IPv4_SA field matches the provisioned IPv4 source address IP4SA$_n$, the frame is forwarded to the CrossConnect entry (x$_n$) that forwards the frame further to a set of output ports associated with the given IP multicast session.
…		
IF (EXISTS(IPv4_HEADER) AND IPv4_DA == IP4GA$_n$ AND IPv4_SA == IP4SA$_n$) THEN <m$_0$,…,x$_n$>		
IF (EXISTS(IPv6_HEADER) AND IPv6_DA == IP6GA$_1$) THEN <m$_0$,…,x$_1$>	[m$_0$]: none	These rules are provisioned when multicast filtering is performed based on IPv6 multicast destination address. If a frame's IPv6_DA field matches the provisioned IPv6 group address IP6GA$_n$, the frame is forwarded to the CrossConnect entry (x$_n$) that forwards the frame further to a set of output ports associated with the given IP multicast session.
…		
IF (EXISTS(IPv6_HEADER) AND IPv6_DA == IP6GA$_n$) THEN <m$_0$,…,x$_n$>		
IF (EXISTS(IPv6_HEADER) AND IPv6_DA == IP6GA$_1$ AND IPv6_SA == IP6SA$_1$) THEN <m$_0$,…,x$_1$>	[m$_0$]: none	These rules are provisioned when multicast filtering is performed based on IPv6 destination and source addresses. If a frame's IPv6_DA field matches the provisioned IPv6 group address IP6GA$_n$ and IPv6_SA field matches the provisioned IPv6 source address IP6SA$_n$, the frame is forwarded to the CrossConnect entry (x$_n$) that forwards the frame further to a set of output ports associated with the given IP multicast session.
…		
IF (EXISTS(IPv6_HEADER) AND IPv6_DA == IP6GA$_n$ AND IPv6_SA == IP6SA$_n$) THEN <m$_0$,…,x$_n$>		
IF (~~LLID~~ULID_VALUE == ~~MLLID~~MULID AND EXISTS(IPv4_HEADER) AND IPv4_DA == IP4GA$_1$) THEN <m$_0$,…,x$_1$>	[m$_0$]: none	These rules are provisioned when multicast filtering is performed based on ~~mLLID~~mULID value and IPv4 multicast destination address. If a frame's ~~LLID~~ULID_VALUE field matches the provisioned ~~MLLID~~MULID value and IPv4_DA
…		

Classifier rules	Modifier actions	Description
IF (~~LLID~~ULID_VALUE == ~~MLLID~~MULID AND EXISTS(IPv4_HEADER) AND IPv4_DA == $IP4GA_n$) THEN <m_0,…,x_n>		field matches the provisioned IPv4 group address $IP4GA_n$, the frame is forwarded to the CrossConnect entry (x_n) that forwards the frame further to a set of output ports associated with the given IP multicast session.
IF (~~LLID~~ULID_VALUE == ~~MLLID~~MULID AND EXISTS(IPv4_HEADER) AND IPv4_DA == $IP4GA_1$ AND IPv4_SA == $IP4SA_1$) THEN <m_0,…,x_1>	[m_0]: none	These rules are provisioned when multicast filtering is performed based on ~~mLLID~~mULID value and IPv4 destination and source addresses. If a frame's ~~LLID~~ULID_VALUE field matches the provisioned ~~MLLID~~MULID value and IPv4_DA field matches the provisioned IPv4 group address $IP4GA_n$ and IPv4_SA field matches the provisioned IPv4 source address $IP4SA_n$, the frame is forwarded to the CrossConnect entry (x_n) that forwards the frame further to a set of output ports associated with the given IP multicast session.
…		
IF (~~LLID~~ULID_VALUE == ~~MLLID~~MULID AND EXISTS(IPv4_HEADER) AND IPv4_DA == $IP4GA_n$ AND IPv4_SA == $IP4SA_n$) THEN <m_0,…,x_n>		
IF (~~LLID~~ULID_VALUE == ~~MLLID~~MULID AND EXISTS(IPv6_HEADER) AND IPv6_DA == $IP6GA_1$) THEN <m_0,…,x_1>	[m_0]: none	These rules are provisioned when multicast filtering is performed based on ~~mLLID~~mULID value and IPv6 multicast destination address. If a frame's ~~LLID~~ULID_VALUE field matches the provisioned ~~MLLID~~MULID value and IPv6_DA field matches the provisioned IPv6 group address $IP6GA_n$, the frame is forwarded to the CrossConnect entry (x_n) that forwards the frame further to a set of output ports associated with the given IP multicast session.
…		
IF (~~LLID~~ULID_VALUE == ~~MLLID~~MULID AND EXISTS(IPv6_HEADER) AND IPv6_DA == $IP6GA_n$) THEN <m_0,…,x_n>		
IF (~~LLID~~ULID_VALUE == ~~MLLID~~MULID AND EXISTS(IPv6_HEADER) AND IPv6_DA == $IP6GA_1$ AND IPv6_SA == $IP6SA_1$) THEN <m_0,…,x_1>	[m_0]: none	These rules are provisioned when multicast filtering is performed based on ~~mLLID~~mULID value and IPv6 destination and source addresses. If a frame's ~~LLID~~ULID_VALUE field matches the provisioned ~~MLLID~~MULID value and IPv6_DA
…		

Classifier rules	Modifier actions	Description
`IF (LLIDULID_VALUE == MLLIDMULID AND EXISTS(IPv6_HEADER) AND IPv6_DA == IP6GA`$_n$` AND IPv6_SA == IP6SA`$_n$`) THEN <m`$_0$`,…,x`$_n$`>`		field matches the provisioned IPv6 group address IP6GA$_n$ and IPv6_SA field matches the provisioned IPv6 source address IP6SA$_n$, the frame is forwarded to the CrossConnect entry (x$_n$) that forwards the frame further to a set of output ports associated with the given IP multicast session.

[a] IP4GA$_1$–IP4GA$_n$ represent provisioned IPv4 destination group addresses.

[b] IP4SA$_1$–IP4SA$_n$ represent provisioned IPv4 source addresses.

[c] IP6GA$_1$–IP6GA$_n$ represent provisioned IPv6 destination group addresses.

[d] IP6SA$_1$–IP6SA$_n$ represent provisioned IPv6 source addresses.

[e] MLLIDMULID represents provisioned mLLIDmULID value.

[f] When both source and destination addresses are used for matching multicast frames, the same values of destination group addresses may be combined with different values of the source addresses, and the same value of the source address may be combined with different values of the destination addresses. A unique combination of source and destination addresses identifies a unique multicast group.

[g] x$_1$–x$_n$ represent the CrossConnect entry that forwards the frame to a set of output portdownstream queues associated with the the given IP multicast session.