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**Title:** **KI #2, evaluation: Ethernet bridging principles**

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*Abstract of the contribution: We give an overview of the Ethernet bridging principles that apply also to 3GPP TSN networks and list a number of observations to progress the conclusion of Key Issue #2 on UE to UE communication.*

# Introduction

This paper progresses the conclusion of KI#2 on UE to UE communication by making a number of observations about the Ethernet bridging principles, and on how 3GPP supports those Ethernet principles. It is key for the success of 3GPP Ethernet specifications to be compatible with the IEEE 802 standards so that the 3GPP Ethernet solution can be brought into Ethernet deployments, e.g., TSN deployments for industrial automation. The general IEEE 802.1 Ethernet bridging principles equally apply to non-TSN and TSN traffic, hence the TSN solution must also be based on the general Ethernet bridging behavior.

An example illustration of an Ethernet bridged network including 3GPP components is shown in the figure below. The Ethernet end stations can all communicate with each other. In this example there are four Ethernet bridges, out of which two are realized by 3GPP 5GS bridges. The 5GS bridge also realizes bridging functionality that takes place within the UPF. Note that the granularity of a 5GS Ethernet bridge is per UPF. The example illustrates a tree Ethernet topology of the active links; there may be other physical links besides the links in the tree which are inactive. Additional Ethernet bridges may be present on both the UE side and on the N6 side of the 3GPP network. In general, 3GPP should support arbitrary Ethernet topologies. The forwarding in an Ethernet network may be realized by the general Ethernet flooding mechanism in combination with MAC learning. Alternatively, the forwarding may also be set by a central network controller such as the CNC, in which case the CNC populates the Filtering Database (FDB) with the entries that are used for frame forwarding.



# Flooding as the default Ethernet forwarding mechanism

The default forwarding mechanism in Ethernet is flooding which makes sure that frames are delivered to all other end stations in the network. The figure below illustrates the flooding, whereby an end station sends a frame which is forwarded on all other active links of the bridges that constitute the spanning tree except where the frame was received. In this way, the flooding mechanism guarantees that the frame reaches its destination in the Ethernet network. Flooding applies to broadcast frames, and to unicast and multicast frames when the location of the destination is unknown, i.e., there is no entry in the Filtering Database corresponding to the destination MAC address. Flooding and the Ethernet bridging model is described in IEEE 802.1Q in detail. Flooding is also described in 23.501 section 5.8.2.5.3 on a high level.



Flooding is the default Ethernet behavior which guarantees the simple plug&play nature of Ethernet networks and it is significantly different from how IP networks behave. The key differences between Ethernet and IP regarding the default behavior are highlighted in the table below.

|  |  |
| --- | --- |
| Ethernet  | IP |
| Default: FLOOD | Default: DROP |
| Broadcast: floodMulticast: floodUnknown unicast: flood | Broadcast: (not really used)Multicast: drop (default)Unknown unicast: drop (default) |
| Send out frame on all active ports except incoming | Drop unknown traffic |
| Ethernet supports broadcast/multicast by default. | Multicast traffic dropped by default. |
| Ethernet is plug&play.  | IP requires configuration.  |

The flooding mechanism makes sure that all end stations are always reachable as Ethernet destinations, and in this way Ethernet networks are plug&play – no preconfiguration is needed for the network to operate. The MAC learning mechanism can help to limit flooding, i.e., for known unicast and multicast destination addresses it is possible to send out the frame only on the interface(s) where the destination end station is reachable. It is also possible to use central configuration to establish forwarding, i.e., to populate the Filtering Database. tThe very basic plug&play nature of Ethernet must be maintained, as it is commonly used e.g., to enable bootstrapping and to support management traffic.

**Observation 1: All Ethernet stations can always communicate with each other on the same Ethernet network; no pre-configuration is needed for basic connectivity.**

# The possibility of UE to UE communication

In a TSN network, the 5GS acts as an Ethernet bridge on a per UPF granularity, as illustrated in the figure below. End stations may connect via the DS-TTs directly, or via one or more Ethernet bridges.



As described for observation 1, in an Ethernet network all end stations can always communicate with each other. It follows that end station 1 and 2 can always communicate; in other words UE to UE communication is always possible. For the 5GS bridge, this corresponds to communication between two bridge ports which is always possible; there is no such thing as an Ethernet bridge which cannot forward between two ports. So in an Ethernet network it is neither necessary nor possible to restrict communication between UEs; such restriction is not compliant with Ethernet bridging principles.

**Observation 2: UE-UE communication is always possible between UEs connected to the same Ethernet network.**

In situations where an operator would want to restrict communication, the following possibilities are available, which are already supported by the specifications.

* It is possible for an operator to control which UEs are allowed to connect to a given Ethernet network. Such control can be based on the DNN, possibly also using the group management mechanism defined for 5G VN. It is also possible to use session based DN authorization of the connectivity.
* It is possible to partition the network into VLANs. End stations in different VLANs cannot communicate with each other.

In TSN networks, the bridges report the bridge delay on a per port pair basis to the CNC in order to let the CNC know whether the application requirements for a TSN stream can be met along the TSN stream’s path. Note that the reporting of the bridge delay in itself does not influence the possibility of UE to UE communication as such, especially that UE to UE communication is not TSN specific. Irrespective of what delays the 5GS bridge reports to the CNC, UE to UE communication is always possible, as dictated by the general Ethernet principles. Note also that the reporting of the delay for a port pair is triggered by the CNC; i.e., the CNC can always ask for the delay between two DS-TT ports (or for any other port pair) whenever the CNC needs that information for the setup of TSN streams.

**Observation 3: Bridge delay reporting between the CNC and the TSN AF does not influence the possibility of UE to UE communication; it only influences whether and how application requirements for a TSN stream can be met.**

# 3GPP rel-16 bridge forwarding

In 3GPP release-16, Ethernet bridge forwarding is described in 23.501 section 5.8.2.5.3. That section applies to Ethernet in general irrespective of whether the traffic is non-TSN or TSN. The description gives rules for unicast forwarding to known destinations as well as flooding for broadcast and for unknown unicast and multicast destination addresses. The description gives high-level rules without any implementation requirement. Using of PDR/FAR rules as components in an implementation is possible but not required; a vendor is free to implement the Ethernet forwarding rules in any way. Keeping implementation flexibility is helpful for efficient vendor implementations.

**Observation 4: Realization of 3GPP Ethernet bridge forwarding is implementation specific. Use of PDR/FAR rules for bridge forwarding is not excluded, but not required.**

Hence, the release 16 bridge forwarding mechanism can be represented as a “black box” within the UPF without any assumptions about the implementation. However, the externally observable forwarding behavior should be exactly as specified by IEEE 802.1Q because, the 5GS overall acts as an IEEE 802.1Q VLAN bridge from external perspective. VLAN bringing is on the data plane of an IEEE 802.1Q bridge, which corresponds to the 5G user plane. The UPF is the entity in the 5GS that is providing the VLAN bridging on the user plane, in line with the per-UPF 5G bridge concept. This is shown in the figure below. The bridging functionality is shown within the UPF as a box that realizes flooding and MAC learning functionality in release 16. In the downlink direction, it is the bridging functionality that determines which PDU Session a given Ethernet frame is to be sent on. For unicast Ethernet frames to known destinations, the Ethernet frame would be sent on a single PDU Session only, whereas for broadcast, and unknown unicast and multicast frames, it would be sent on all active PDU sessions (except the incoming). This means that there is a binding between the bridge ports and the PDU sessions; it is not needed to set PDR filtering rules for the selection of the PDU session, because the PDU Session is selected based on the binding between the PDU Sessions and the bridge ports. It is not specified how this binding is achieved within the UPF.



The release 16 specification also clarifies this as follows: “the SMF may, for each PDU Session corresponding to a Network Instance, set an Ethernet PDU Session Information in a DL PDR that identifies all (DL) Ethernet packets matching the PDU session.” This is possible, since the PDU Session is selected not based on the DL PDR, but based on the binding between the bridge port and the PDU Session. Hence, a one-to-one binding between the UPF bridge ports and the PDU Sessions can make it unnecessary to set PDR explicit filtering rules for the selection of PDU Session.

**Observation 5: The release 16 implementation specific bridging can determine the PDU Session in the DL using an implementation specific binding mechanism between the bridge ports and the PDU Sessions, and then there is no need to explicitly set PDRs for selecting the PDU Session in the DL direction.**

In the context of 5G VN, there are two options for user plane forwarding for Ethernet. The first option refers to the general Ethernet forwarding mechanism as described above (section 5.8.2.5.3 of 23.501) whose realization is implementation specific and does not require explicit DL PDRs to be set by the SMF. There is also a second option using PDRs explicitly set by the SMF. The PFCP specification 29.244 also includes the two options: “For Ethernet unicast traffic on 5G VN Group Communication, the SMF may either explicitly configure DL PDR with the MAC addresses detected by the UPF on PDU Sessions supporting a 5G VN group, or rely on MAC address learning in UPF related with a 5G VN group by setting the Ethernet PDU Session Information indication in the DL PDR of the "5G VN internal" interface as specified in clause 5.8.2.13.0 of 3GPP TS 23.501 [28].”

Packet replication using PDRs is one option, which is supported in release-16 5G VN with the so-called carry on indication that is described in 23.501 section 5.8.2.13.3.2. However, we must note that the carry on indication can only be applied under a very restrictive set of conditions which are documented in the same section. We list those conditions and their applicability for the TSN use case.

|  |  |
| --- | --- |
| Limitation of the carry on indication mechanism | Applicability to 5G TSN use case |
| When N19 is used, there is a full mesh of N19 tunnels between UPFs serving the 5G VN group. | Not aligned with Ethernet which would use a spanning tree active topology by default. |
| There is no support of forwarding packets with destination MAC address not known by SMF/UPF (i.e. no support for new UE MAC addresses from the UE during the PDU Session lifetime). | Not applicable for Ethernet which requires flooding for unknown addresses. |
| There is no support for forwarding a broadcast/multicast packet with source address not known to SMF/UPF. | Not applicable for Ethernet which requires broadcast/multicast to be supported irrespective of the source address. |
| Each UPF supports one N6 interface instance towards the data network, or only supports N19-based forwarding without N6. | Not applicable for TSN networks which could have multiple N6 interfaces. |
| Multicast group formation of selected members of a 5G VN is not described in this release of the specification. | Not applicable with TSN networks which often use multicast destination addresses for TSN streams but flooding needs to be avoided. |

We see that the assumptions listed for the carry on indication mechanism make it extremely restrictive, and not applicable for general use in Ethernet networks. Hence we cannot base the Ethernet forwarding mechanisms on the carry on indication.

**Observation 6: The currently specified carry on indication (23.501 section 5.8.2.13.3.2) has very limiting restrictions, and therefore it is not applicable for general use in Ethernet networks. The realization of packet replication in Ethernet networks is implementation specific in the general case.**

# The unity of the IEEE 802.1Q bridge forwarding process

The figure below is Figure 8-2 from subclause 8.6 of IEEE Std 802.1Q-2018, which is the illustration of the general IEEE 802.1Q bridge forwarding process. The core part of the actual forwarding is in the frame filtering step. As the figure illustrates, the filtering database is an input to the whole process, where the filtering database is set using a number of possible mechanisms, including MAC learning and CNC provided static filtering entries.



The logical view of the forwarding process assumes a single filtering database and a single unified forwarding process. The unity of the forwarding process is important as the filtering database may be also populated by an entity that is external to the bridge (e.g., by CNC provided static filtering entries). Besides, for the correct implementation of flooding, the bridge needs to know when a destination address is known or unknown, for which the bridge also needs a single unified filtering database. Note also that VLAN processing is also part of the forwarding process and uses the same filtering database.

Due to the fact that the forwarding process relies on a single process and a single database, we suggest that the 3GPP Ethernet forwarding model should also keep the forwarding process and the associated database unified in order to achieve the externally observable behavior of an IEEE 802.1Q bridge. This means that we should not split up the Ethernet forwarding into two parts, one based on PDR/FAR rules and another one based on UPF internal mechanisms. It could be extremely difficult to run the Ethernet forwarding like that, one running in the UPF and one running based on SMF controlled PDR/FAR rules, since the data for these two parts would reside at different entities (SMF vs. UPF). It could be extremely complex to harmonize the data and the processes for the two parts, whereas for correct IEEE 802 compliant Ethernet behavior we need a single unified database and unified process.

The UPF implementations are of course always free to realize Ethernet frame forwarding based on the vendor’s decisions which should not be restricted. The 3GPP standard should not limit the implementations by imposing special ways of splitting up the unified IEEE 802.1Q forwarding process. The use of PDR/FAR rules as components in the forwarding are not excluded depending on how a UPF vendor realizes the bridge forwarding. But the standard must not force a specific way for splitting up the bridge forwarding in the implementations.

**Observation 7: Ethernet bridge forwarding process, including VLAN handling, must be a single component in the UPF in the specifications with implementation specific realization. The specification must not require the bridge forwarding to be split it up to multiple parts, such as a UPF internal part and a part with SMF controlled PDR/FAR rules.**

# Proposal

It is proposed to add the observations to 23.700-20 as part of the conclusions for Key Issue #2.

**\* \* \* \* Start change \* \* \* \***

## 8.2 Key Issue #2: UE-UE TSC communication

Editor's note: This clause will capture conclusions for Key Issue #2.

The following is taken as the basis for the way forward:

* All Ethernet stations can always communicate with each other on the same Ethernet network; no pre-configuration is needed for basic connectivity.
* UE-UE communication is always possible between UEs connected to the same Ethernet network.
* Bridge delay reporting between the CNC and the TSN AF does not influence the possibility of UE to UE communication; it only influences whether and how application requirements for a TSN stream can be met.
* Realization of 3GPP Ethernet bridge forwarding is implementation specific. Use of PDR/FAR rules for bridge forwarding is not excluded, but not required.
* The release 16 implementation specific bridging can determine the PDU Session in the DL using an implementation specific binding mechanism between the bridge ports and the PDU Sessions, and then there is no need to explicitly set PDRs for selecting the PDU Session in the DL direction.
* The currently specified carry on indication (23.501 section 5.8.2.13.3.2) has very limiting restrictions, and therefore it is not applicable for general use in Ethernet networks. The realization of packet replication in Ethernet networks is implementation specific in the general case.
* Ethernet bridge forwarding process, including VLAN handling, must be a single component in the UPF in the specifications with implementation specific realization. The specification must not require the bridge forwarding to be split it up to multiple parts, such as a UPF internal part and a part with SMF controlled PDR/FAR rules.

- TSN AF or any AF provides information (e.g. QoS requirements such as delay, burst size, periodicity, burst arrival time) about a UE-UE TSC stream.

- TSN AF or any AF sends the request separately for talker (uplink traffic) and listeners (downlink traffic).

**\* \* \* \* End change \* \* \* \***