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RFC 9024
Deterministic Networking (DetNet) Data Plane: IEEE 802.1 Time-Sensitive Networking over MPLS

Abstract

This document specifies the Deterministic Networking data plane when Time-Sensitive Networking (TSN) networks are interconnected over a DetNet MPLS network.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at https://www.rfc-editor.org/info/rfc9024.

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1. Introduction

The Time-Sensitive Networking Task Group (TSN TG) within the IEEE 802.1 Working Group deals with deterministic services through IEEE 802 networks. Deterministic Networking (DetNet) defined by the IETF is a service that can be offered by an L3 network to DetNet flows. General background and concepts of DetNet can be found in [RFC8655].

This document specifies the use of a DetNet MPLS network to interconnect TSN nodes/network segments. The DetNet MPLS data plane is defined in [RFC8964].

2. Terminology

2.1. Terms Used in This Document

This document uses the terminology and concepts established in the DetNet architecture [RFC8655] [RFC8938] [RFC8964]. TSN-specific terms are defined in the TSN TG of the IEEE 802.1 Working Group. The reader is assumed to be familiar with these documents and their terminology.

2.2. Abbreviations

The following abbreviations are used in this document:

AC	Attachment Circuit
CE	Customer Edge equipment
d-CW	DetNet Control Word
DetNet	Deterministic Networking
DF	DetNet Flow
FRER	Frame Replication and Elimination for Redundancy (TSN function)
L2	Layer 2
L2VPN	Layer 2 Virtual Private Network
L3	Layer 3
LSP	Label Switched Path
LSR	Label Switching Router
MPLS	Multiprotocol Label Switching
MPLS-TE	Multiprotocol Label Switching - Traffic Engineering
NSP	Native Service Processing
OAM	Operations, Administration, and Maintenance
PE	Provider Edge
PREOF	Packet Replication, Elimination and Ordering Functions
PW	Pseudowire
S-PE	Switching Provider Edge

T-PE   Terminating Provider Edge

TSN   Time-Sensitive Network

2.3. Requirements Language

The key words "**MUST**", "**MUST NOT**", "**REQUIRED**", "**SHALL**", "**SHALL NOT**", "**SHOULD**", "**SHOULD
NOT**", "**RECOMMENDED**", "**NOT RECOMMENDED**", "**MAY**", and "**OPTIONAL**" in this document are to
be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in
all capitals, as shown here.

3. IEEE 802.1 TSN over DetNet MPLS Data Plane Scenario

Figure 1 shows IEEE 802.1 TSN end stations operating over a TSN-aware DetNet service running
over an MPLS network. DetNet edge nodes sit at the boundary of a DetNet domain. They are
responsible for mapping non-DetNet-aware L2 traffic to DetNet services. They also support the
imposition and disposition of the required DetNet encapsulation. These are functionally similar
to PW T-PE nodes, which use MPLS-TE LSPs. In this example, TSN Streams are simple
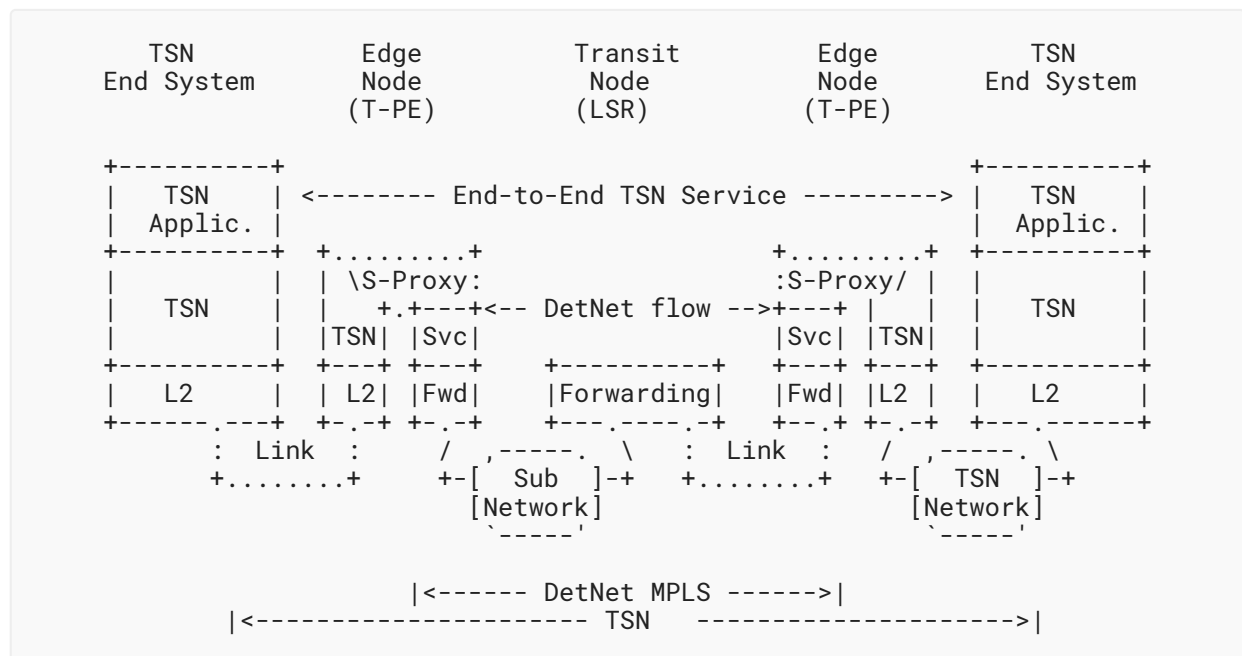applications over DetNet flows. The specifics of this operation are discussed later in this
document.

```
      TSN             Edge           Transit         Edge            TSN
  End System          Node            Node           Node        End System
                     (T-PE)          (LSR)          (T-PE)

  +----------+                                               +----------+
  |   TSN    | <-------- End-to-End TSN Service --------> |   TSN    |
  | Applic.  |                                               | Applic.  |
  +----------+  +.........+                   +.........+  +----------+
  |          |  | \S-Proxy:                   :S-Proxy/ |  |          |
  |   TSN    |  |   +.+---+<-- DetNet flow -->+---+ |  |   TSN    |
  |          |  |TSN| |Svc|                   |Svc| |TSN| |          |
  +----------+  +---+ +---+   +----------+   +---+ +---+  +----------+
  |   L2     |  | L2| |Fwd|   |Forwarding|   |Fwd| |L2 |  |   L2     |
  +------.---+  +-.-+ +-.-+   +---.----.-+   +--.+ +-.-+  +---.------+
      : Link  :   / ,-----. \   : Link  :   / ,-----. \
      +........+   +-[  Sub  ]-+   +........+   +-[  TSN  ]-+
                  [Network]                     [Network]
                   `-----'                       `-----'

                   |<------ DetNet MPLS ------>|
           |<--------------------- TSN   --------------------->|
```

Figure 1: A TSN over DetNet MPLS-Enabled Network

In this example, edge nodes provide a service proxy function that "associates" the DetNet flows
and native flows (i.e., TSN Streams) at the edge of the DetNet domain. TSN Streams are treated as
App-flows for DetNet. The whole DetNet domain behaves as a TSN relay node for the TSN
Streams. The service proxy behaves as a port of that TSN relay node.

Figure 2 illustrates how DetNet can provide services for IEEE 802.1 TSN end systems, CE1 and CE2, over a DetNet-enabled MPLS network. Edge nodes E1 and E2 insert and remove the required DetNet data plane encapsulation. The 'X' in the edge nodes and relay node, R1, represent a potential DetNet compound flow packet replication and elimination point. This conceptually parallels L2VPN services and could leverage existing related solutions as discussed below.
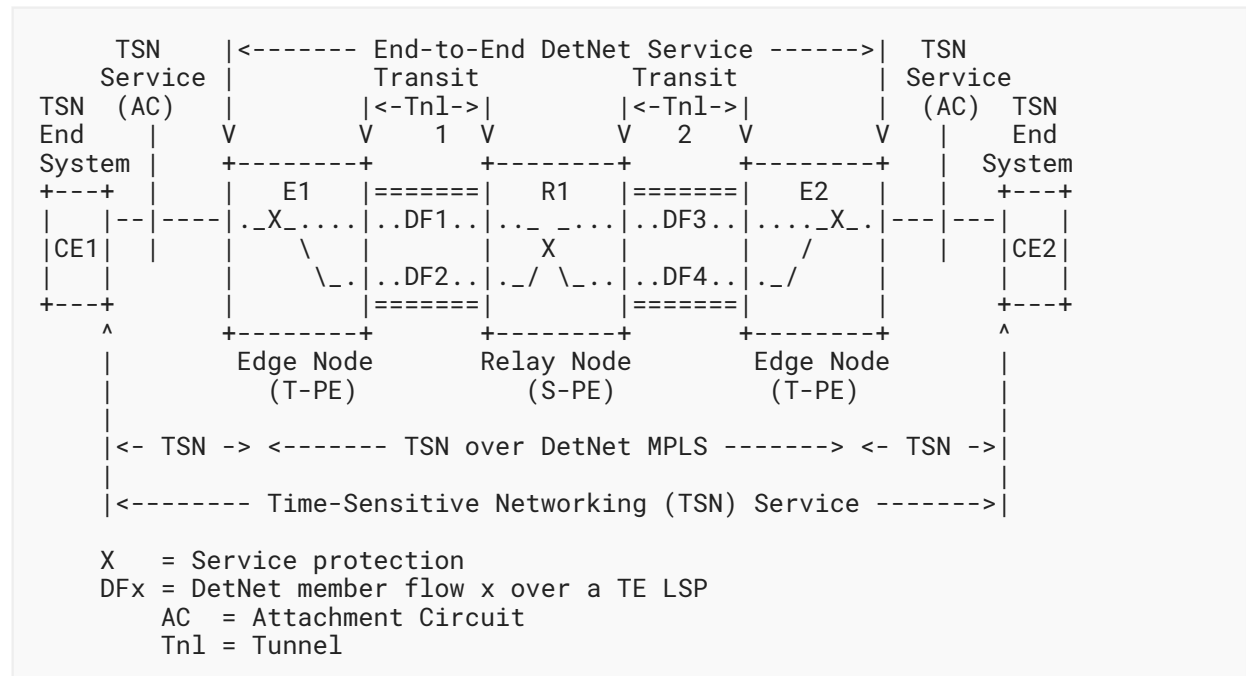
```
      TSN      |<------- End-to-End DetNet Service ------>|  TSN
     Service   |         Transit            Transit       | Service
 TSN  (AC)     |         |<-Tnl->|          |<-Tnl->|      |  (AC)  TSN
 End     |     V         V   1   V          V   2   V      V   |    End
 System  |   +--------+      +--------+      +--------+    |  System
 +---+   |   |   E1   |======|   R1   |======|   E2   |    |   +---+
 |   |--|----|._X_....|..DF1..|.._ _....|..DF3..|....._X_.|---|---|   |
 |CE1|   |   |   \    |       |   X    |       |   /    |    |   |CE2|
 |   |   |   |    \_..|..DF2..|._/ \...|..DF4..|._/     |    |   |   |
 +---+   |   |        |======|        |======|        |    |   +---+
    ^        +--------+      +--------+      +--------+         ^
    |          Edge Node      Relay Node      Edge Node         |
    |           (T-PE)          (S-PE)          (T-PE)          |
    |                                                           |
    |<- TSN -> <------- TSN over DetNet MPLS -------> <- TSN ->|
    |                                                           |
    |<-------- Time-Sensitive Networking (TSN) Service ------->|

    X   = Service protection
    DFx = DetNet member flow x over a TE LSP
       AC  = Attachment Circuit
       Tnl = Tunnel
```

Figure 2: IEEE 802.1TSN over DetNet

4. DetNet MPLS Data Plane

4.1. Overview

The basic approach defined in [RFC8964] supports the DetNet service sub-layer based on existing PW encapsulations and mechanisms and supports the DetNet forwarding sub-layer based on existing MPLS Traffic Engineering encapsulations and mechanisms.

A node operating on a DetNet flow in the DetNet service sub-layer, i.e., a node processing a DetNet packet that has the S-Label as top of stack, uses the local context associated with that S-Label. For example, a received F-Label can be used to determine what local DetNet operation(s) is applied to that packet. An S-Label may be unique when taken from the platform label space [RFC3031], which would enable correct DetNet flow identification regardless of which input interface or LSP the packet arrives on. The service sub-layer functions (i.e., PREOF) use a DetNet control word (d-CW).

The DetNet MPLS data plane builds on MPLS Traffic Engineering encapsulations and mechanisms to provide a forwarding sub-layer that is responsible for providing resource allocation and explicit routes. The forwarding sub-layer is supported by one or more forwarding labels (F-Labels).

DetNet edge/relay nodes are DetNet service sub-layer aware, understand the particular needs of DetNet flows, and provide both DetNet service and forwarding sub-layer functions. They add, remove, and process d-CWs, S-Labels, and F-Labels as needed. MPLS DetNet nodes and transit nodes include DetNet forwarding sub-layer functions -- notably, support for explicit routes and resource allocation to eliminate (or reduce) congestion loss and jitter. Unlike other DetNet node types, transit nodes provide no service sub-layer processing.

4.2. TSN over DetNet MPLS Encapsulation

The basic encapsulation approach is to treat a TSN Stream as an App-flow from the DetNet MPLS perspective. The corresponding example is shown in Figure 3. Note that three example flows are shown in the figure.
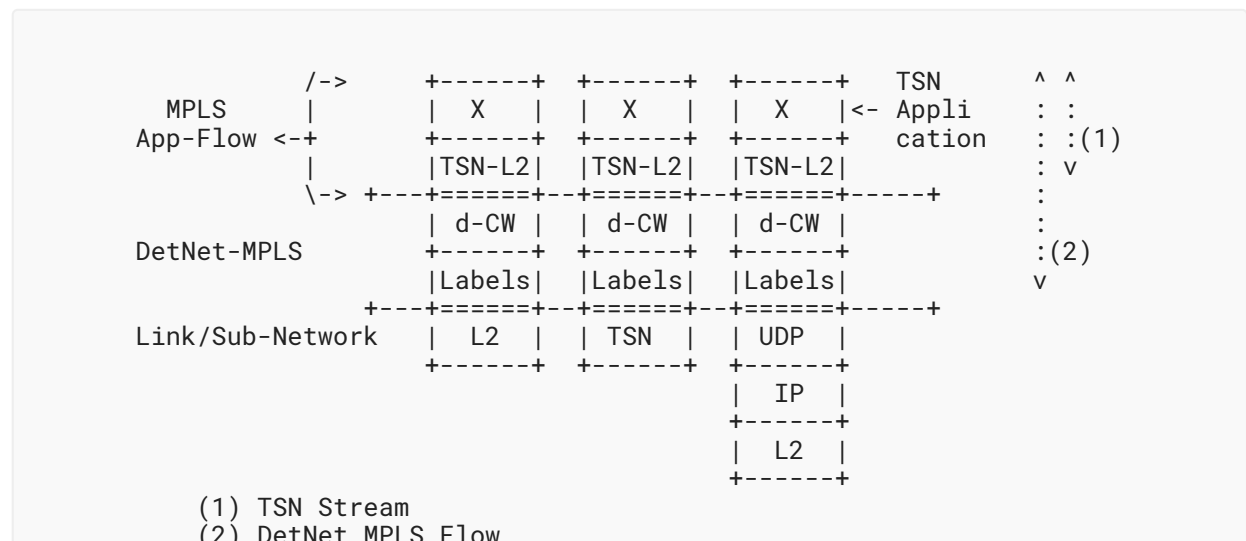
```
                   /->      +------+  +------+  +------+   TSN      ^ ^
         MPLS      |        |  X   |  |  X   |  |  X   |<- Appli    : :
         App-Flow <-+       +------+  +------+  +------+   cation   : :(1)
                   |        |TSN-L2|  |TSN-L2|  |TSN-L2|            : v
                   \-> +---+======+--+======+--+======+-----+      :
                       | d-CW |  | d-CW |  | d-CW |                 :
         DetNet-MPLS      +------+  +------+  +------+           :(2)
                       |Labels|  |Labels|  |Labels|              v
                   +---+======+--+======+--+======+-----+
         Link/Sub-Network  | L2   |  | TSN  |  | UDP  |
                       +------+  +------+  +------+
                                           | IP   |
                                           +------+
                                           | L2   |
                                           +------+
         (1) TSN Stream
         (2) DetNet MPLS Flow
```

Figure 3: Examples of TSN over MPLS Encapsulation Formats

In the figure, "Application" indicates the application payload carried by the TSN network. "MPLS App-Flow" indicates that the TSN Stream is the payload from the perspective of the DetNet MPLS data plane defined in [RFC8964]. A single DetNet MPLS flow can aggregate multiple TSN Streams.

> Note: Network fragmentation for DetNet is not supported and MUST be avoided. The reason for this is that network fragmentation is not consistent with the packet delivery times needed for DetNet. Therefore, when IP is used as the sub-network, IPv6 fragmentation MUST NOT be used, and IPv4 packets MUST be sent with the DF bit set. This means that the network operator MUST ensure that all the DetNet encapsulation overhead plus the maximum TSN App-flow frame size does not exceed the DetNet network's MTU.

5. TSN over MPLS Data Plane Procedures

The description of edge node procedures and functions for TSN over DetNet MPLS scenarios follows the concepts from [RFC3985] and covers the edge node components shown in Figure 1. In this section, the following procedures of DetNet edge nodes are described:

- TSN related (Section 5.1)
- DetNet Service Proxy (Section 5.2)
- DetNet service and forwarding sub-layer (Section 5.3)

The subsections describe procedures for forwarding packets by DetNet edge nodes, where such packets are received from either directly connected CEs (TSN nodes) or some other DetNet edge nodes.

5.1. Edge Node TSN Procedures

The TSN TG of the IEEE 802.1 Working Group has defined (and is defining) a number of amendments to [IEEE8021Q] that provide zero congestion loss and bounded latency in bridged networks. [IEEE8021CB] defines packet replication and elimination functions for a TSN network.

The implementation of a TSN entity (i.e., TSN packet processing functions) must be compliant with the relevant IEEE 802.1 standards.

TSN-specific functions are executed on the data received by the DetNet edge node from the connected CE before being forwarded to connected CE(s) or presented to the DetNet service proxy function for transmission across the DetNet domain. TSN-specific functions are also executed on the data received from a DetNet PW by a PE before the data is output on the AC(s).

The TSN packet processing function(s) of edge nodes (T-PE) belongs to the NSP [RFC3985] block. This is similar to other functionalities being defined by standards bodies other than the IETF (for example, in the case of Ethernet, stripping, overwriting, or adding VLAN tags, etc.). Depending on the TSN role of the edge node in the end-to-end TSN service, selected TSN functions are supported.

When a PE receives a packet from a CE on a given AC with DetNet service, it first checks via Stream identification (see Clause 6 of [IEEE8021CB] and [IEEEP8021CBdb]) whether the packet belongs to a configured TSN Stream (i.e., App-flow from the DetNet perspective). If no Stream ID is matched and no other (VPN) service is configured for the AC, then the packet **MUST** be dropped. If there is a matching TSN Stream, then the Stream-ID-specific TSN functions are executed (e.g., ingress policing, header field manipulation in the case of active Stream identification, FRER, etc.). Source Media Access Control (MAC) lookup may also be used for local MAC address learning.

If the PE decides to forward the packet, the packet **MUST** be forwarded according to the TSN-Stream-specific configuration to connected CE(s) (in case of local bridging) and/or to the DetNet service proxy (in case of forwarding to remote CE(s)). If there are no TSN-Stream-specific

forwarding configurations, the PE **MUST** flood the packet to other locally attached CE(s) and to the DetNet service proxy. If the administrative policy on the PE does not allow flooding, the PE **MUST** drop the packet.

When a TSN entity of the PE receives a packet from the DetNet service proxy, it first checks via Stream identification (see Clause 6 of [IEEE8021CB] and [IEEEP8021CBdb]) whether the packet belongs to a configured TSN Stream. If no Stream ID is matched, then the packet is dropped. If there is a matching TSN Stream, then the Stream-ID-specific TSN functions are executed (e.g., header field manipulation in case of active Stream identification, FRER, etc.). Source MAC lookup may also be used for local MAC address learning.

If the PE decides to forward the packet, the packet is forwarded according to the TSN-Stream-specific configuration to connected CE(s). If there are no TSN-Stream-specific forwarding configurations, the PE floods the packet to locally attached CE(s). If the administrative policy on the PE does not allow flooding, the PE drops the packet.

Implementations of this document **SHALL** use management and control information to ensure TSN-specific functions of the edge node according to the expectations of the connected TSN network.

5.2. Edge Node DetNet Service Proxy Procedures

The service proxy function maps between App-flows and DetNet flows. The DetNet edge node TSN entity **MUST** support the TSN Stream identification functions (as defined in Clause 6 of [IEEE8021CB] and [IEEEP8021CBdb]) and the related managed objects (as defined in Clause 9 of [IEEE8021CB] and [IEEEP8021CBdb]) to recognize the packets related to App-flow. The service proxy presents TSN Streams as an App-flow to a DetNet flow.

When a DetNet service proxy receives a packet from the TSN entity, it **MUST** check whether such an App-flow is present in its mapping table. If present, it associates the internal DetNet flow ID to the packet and **MUST** forward it to the DetNet service and forwarding sub-layers. If no match is found, it **MUST** drop the packet.

When a DetNet service proxy receives a packet from the DetNet service and forwarding sub-layers, it **MUST** be forwarded to the edge node TSN entity.

Implementations of this document **SHALL** use management and control information to map a TSN Stream to a DetNet flow. N:1 mapping (aggregating multiple TSN Streams in a single DetNet flow) **SHALL** be supported. The management or control function that provisions flow mapping **SHALL** ensure that adequate resources are allocated and configured to fulfill the service requirements of the mapped flows.

Due to the (intentional) similarities of the DetNet PREOF and TSN FRER functions, service protection function interworking is possible between the TSN and the DetNet domains. Such service protection interworking scenarios might require copying of sequence number fields from TSN (L2) to PW (MPLS) encapsulation. However, such interworking is out of scope in this document and is left for further study.

5.3. Edge Node DetNet Service and Forwarding Sub-Layer Procedures

In the design presented in [RFC8964], an MPLS service label (the S-Label), similar to a PW label [RFC3985], is used to identify both the DetNet flow identity and the MPLS payload type. The DetNet sequence number is carried in the d-CW, which carries the Data/OAM discriminator as well. In [RFC8964], two sequence number sizes are supported: a 16-bit sequence number and a 28-bit sequence number.

PREOF functions and the provided service recovery are available only within the DetNet domain as the DetNet flow ID and the DetNet sequence number are not valid outside the DetNet network. MPLS (DetNet) edge nodes terminate all related information elements encoded in the MPLS labels.

When a PE receives a packet from the service proxy function, it **MUST** handle the packet as defined in [RFC8964].

When a PE receives an MPLS packet from a remote PE, then, after processing the MPLS label stack, if the top MPLS label ends up being a DetNet S-Label that was advertised by this node, then the PE **MUST** forward the packet according to the configured DetNet service and forwarding sub-layer rules to other PE nodes or via the DetNet service proxy function towards locally connected CE(s).

For further details on DetNet service and forwarding sub-layers, see [RFC8964].

6. Controller Plane (Management and Control) Considerations

Information related to TSN Stream(s) to DetNet flow mapping is required only for the service proxy function of MPLS (DetNet) edge nodes. From the data plane perspective, there is no practical difference based on the origin of flow-mapping-related information (management plane or control plane).

The following summarizes the set of information that is needed to configure TSN over DetNet MPLS:

- TSN-related configuration information according to the TSN role of the DetNet MPLS node, as per [IEEE8021Q], [IEEE8021CB], and [IEEEP8021CBdb].
- DetNet MPLS-related configuration information according to the DetNet role of the DetNet MPLS node, as per [RFC8964].
- App-flow identification information to map received TSN Stream(s) to the DetNet flow. Parameters of TSN Stream identification are defined in [IEEE8021CB] and [IEEEP8021CBdb].

This information **MUST** be provisioned per DetNet flow.

Mappings between DetNet and TSN management and control planes are out of scope of the document. Some of the challenges are highlighted below.

MPLS DetNet edge nodes are a member of both the DetNet domain and the connected TSN network. From the TSN network perspective, the MPLS (DetNet) edge node has a "TSN relay node" role, so TSN-specific management and control plane functionalities must be implemented. There are many similarities in the management plane techniques used in DetNet and TSN, but that is not the case for the control plane protocols. For example, RSVP-TE and MSRP behave differently. Therefore, management and control plane design is an important aspect of scenarios where mapping between DetNet and TSN is required.

Note that as the DetNet network is just a portion of the end-to-end TSN path (i.e., single hop from the Ethernet perspective), some parameters (e.g., delay) may differ significantly. Since there is no interworking function, the bandwidth of the DetNet network is assumed to be set large enough to handle all TSN flows it will support. At the egress of the DetNet domain, the MPLS headers are stripped, and the TSN flow continues on as a normal TSN flow.

In order to use a DetNet network to interconnect TSN segments, TSN-specific information must be converted to DetNet-domain-specific information. TSN Stream ID(s) and stream-related parameters/requirements must be converted to a DetNet flow ID and flow-related parameters/requirements.

In some cases, it may be challenging to determine some information related to the egress-node. For example, it may be not trivial to locate the egress point/interface of a TSN Stream with a multicast destination MAC address. Such scenarios may require interaction between control and management plane functions and between DetNet and TSN domains.

Mapping between DetNet flow identifiers and TSN Stream identifiers, if not provided explicitly, can be done by the service proxy function of an MPLS (DetNet) edge node locally based on information provided for the configuration of the TSN Stream identification functions (e.g., Mask-and-Match Stream identification).

Triggering the setup/modification of a DetNet flow in the DetNet network is an example where management and/or control plane interactions are required between the DetNet and the TSN network.

Configuration of TSN-specific functions (e.g., FRER) inside the TSN network is a TSN-domain-specific decision and may not be visible in the DetNet domain. Service protection interworking scenarios are left for further study.

7. Security Considerations

Security considerations for DetNet are described in detail in [DETNET-SEC]. General security considerations are described in [RFC8655].

Considerations specific to the DetNet MPLS data plane are summarized and described in [RFC8964], including any application flow types. This document focuses on a scenario where TSN Streams are the application flows for DetNet, which is already covered by those DetNet MPLS data plane security considerations.

8. IANA Considerations

This document has no IANA actions.

9. References

9.1. Normative References

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