Stream: Internet Engineering Task Force (IETF)
RFC: 9037
Category: Informational
Published: June 2021
ISSN: 2070-1721
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RFC 9037
Deterministic Networking (DetNet) Data Plane: MPLS over IEEE 802.1 Time-Sensitive Networking (TSN)

Abstract

This document specifies the Deterministic Networking (DetNet) MPLS data plane when operating over an IEEE 802.1 Time-Sensitive Networking (TSN) sub-network. This document does not define new procedures or processes. Whenever this document makes statements or recommendations, they are taken from normative text in the referenced RFCs.

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Table of Contents

1. Introduction

Deterministic Networking (DetNet) is a service that can be offered by a network to DetNet flows. DetNet provides these flows with low packet loss rate and assured maximum end-to-end delivery latency. General background and concepts of DetNet can be found in [RFC8655].

The DetNet architecture decomposes DetNet-related data plane functions into two sub-layers: a service sub-layer and a forwarding sub-layer. The service sub-layer is used to provide DetNet service protection and reordering. The forwarding sub-layer is used to provide congestion protection (low loss, assured latency, and limited reordering) leveraging MPLS Traffic Engineering mechanisms.

[RFC8964] specifies the DetNet data plane operation for an MPLS-based PSN. MPLS-encapsulated DetNet flows can be carried over network technologies that can provide the DetNet-required level of service. This document focuses on the scenario where MPLS (DetNet) nodes are interconnected by an IEEE 802.1 TSN sub-network. There is close cooperation between the IETF DetNet Working Group and the IEEE 802.1 Time-Sensitive Networking Task Group (TSN TG).

2. Terminology

2.1. Terms Used in This Document

This document uses the terminology established in the DetNet architecture [RFC8655] [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:

A-Label	Aggregation label; a special case of an S-Label.
d-CW	DetNet Control Word
DetNet	Deterministic Networking
F-Label	Forwarding label that identifies the LSP used by a DetNet flow.
FRER	Frame Replication and Elimination for Redundancy (TSN function)
L2	Layer 2
L3	Layer 3
LSP	Label Switched Path
MPLS	Multiprotocol Label Switching
PREOF	Packet Replication, Elimination, and Ordering Functions
PSN	Packet Switched Network
PW	Pseudowire
RSVP-TE	Resource Reservation Protocol - Traffic Engineering
S-Label	Service label

TSN Time-Sensitive Networking

3. DetNet MPLS Data Plane 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 operates on a DetNet flow in the DetNet service sub-layer, i.e., a node processing a DetNet packet that has the service label (S-Label) as the top of stack uses the local context associated with that S-Label, for example, a received forwarding label (F-Label), 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 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 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, notable 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.

MPLS (DetNet) nodes and transit nodes interconnected by a TSN sub-network are the primary focus of this document. The mapping of DetNet MPLS flows to TSN Streams and TSN protection mechanisms are covered in Section 4.

4. DetNet MPLS Operation over IEEE 802.1 TSN Sub-networks

The DetNet WG collaborates with IEEE 802.1 TSN in order to define a common architecture for both Layer 2 and Layer 3 that maintains consistency across diverse networks. Both DetNet MPLS and TSN use the same techniques to provide their deterministic service:

- Service protection
- Resource allocation
- Explicit routes

As described in the DetNet architecture [RFC8655], from the MPLS perspective, a sub-network provides a single-hop connection between MPLS (DetNet) nodes. Functions used for resource allocation and explicit routes are treated as domain internal functions and do not require function interworking across the DetNet MPLS network and the TSN sub-network.

In the case of the service protection function, due to the similarities of the DetNet PREOF and TSN FRER functions, some level of interworking is possible. However, such interworking is out of scope of this document and left for further study.

Figure 1 illustrates a scenario where two MPLS (DetNet) nodes are interconnected by a TSN sub-network. Node-1 is single-homed, and Node-2 is dual-homed to the TSN sub-network.

```
   MPLS (DetNet)                 MPLS (DetNet)
      Node-1                        Node-2

   +----------+                  +----------+
<--| Service* |-- DetNet flow ---| Service* |-->
   +----------+                  +----------+
   |Forwarding|                  |Forwarding|
   +--------.-+    <-TSN Str->   +-.-----.--+
             \      ,-------.     /     /
              +----[ TSN Sub-]---+     /
                   [ network ]--------+
                    `-------'
<---------------- DetNet MPLS --------------->

Note: * no service sub-layer required for transit nodes
```

Figure 1: DetNet-Enabled MPLS Network over a TSN Sub-network

At the time of this writing, the TSN TG of the IEEE 802.1 Working Group have defined (and are defining) a number of amendments to [IEEE8021Q] that provide zero congestion loss and bounded latency in bridged networks. Furthermore, [IEEE8021CB] defines frame replication and elimination functions for reliability that should prove both compatible with and useful to DetNet networks. All these functions have to identify flows that require TSN treatment (i.e., applying TSN functions during forwarding).

TSN capabilities of the TSN sub-network are made available for MPLS (DetNet) flows via the protocol interworking function defined in Annex C.5 of [IEEE8021CB]. For example, when applied on the TSN edge port, it can convert an ingress unicast MPLS (DetNet) flow to use a specific Layer 2 multicast destination Media Access Control (MAC) address and a VLAN, in order to direct the packet through a specific path inside the bridged network. A similar interworking function pair at the other end of the TSN sub-network would restore the packet to its original Layer 2 destination MAC address and VLAN.

The placement of TSN functions depends on the TSN capabilities of the nodes along the path. MPLS (DetNet) nodes may or may not support TSN functions. For a given TSN Stream (i.e., DetNet flow), an MPLS (DetNet) node is treated as a Talker or a Listener inside the TSN sub-network.

4.1. Functions for DetNet Flow to TSN Stream Mapping

Mapping of a DetNet MPLS flow to a TSN Stream is provided via the combination of a passive and an active Stream identification function that operate at the frame level. The passive Stream identification function is used to catch the MPLS label(s) of a DetNet MPLS flow, and the active Stream identification function is used to modify the Ethernet header according to the ID of the mapped TSN Stream.

Clause 6.8 of [IEEEP8021CBdb] defines a Mask-and-Match Stream identification function that can be used as a passive function for MPLS DetNet flows.

Clause 6.6 of [IEEE8021CB] defines an Active Destination MAC and a VLAN Stream identification function that can replace some Ethernet header fields, namely (1) the destination MAC address, (2) the VLAN-ID, and (3) priority parameters with alternate values. Replacement is provided for the frame that is passed either down the stack from the upper layers or up the stack from the lower layers.

Active Destination MAC and VLAN Stream identification can be used within a Talker to set flow identity or a Listener to recover the original addressing information. It can also be used in a TSN bridge that is providing translation as a proxy service for an end system.

4.2. TSN Requirements of MPLS DetNet Nodes

This section covers required behavior of a TSN-aware MPLS (DetNet) node using a TSN sub-network. The implementation of TSN packet-processing functions must be compliant with the relevant IEEE 802.1 standards.

From the TSN sub-network perspective, MPLS (DetNet) nodes are treated as a Talker or Listener, which may be (1) TSN-unaware or (2) TSN-aware.

In cases of TSN-unaware MPLS DetNet nodes, the TSN relay nodes within the TSN sub-network must modify the Ethernet encapsulation of the DetNet MPLS flow (e.g., MAC translation, VLAN-ID setting, sequence number addition, etc.) to allow proper TSN-specific handling inside the sub-network. There are no requirements defined for TSN-unaware MPLS DetNet nodes in this document.

MPLS (DetNet) nodes that are TSN-aware can be treated as a combination of a TSN-unaware Talker/Listener and a TSN-Relay, as shown in Figure 2. In such cases, the MPLS (DetNet) node must provide the TSN sub-network-specific Ethernet encapsulation over the link(s) towards the sub-network.

```
              MPLS (DetNet)
                  Node
   <----------------------------------->

   +----------+
<--| Service* |-- DetNet flow ------------------
   +----------+
   |Forwarding|
   +----------+    +---------------+
   |    L2    |    | L2 Relay with |<--- TSN ---
   |          |    | TSN function  |    Stream
   +-----.----+    +--.------.---.-+
          \__________/        \   \______
                               \_________
    TSN-unaware
     Talker /         TSN-Bridge
     Listener            Relay
                                       <----- TSN Sub-network -----
   <------- TSN-aware Tlk/Lstn ------->

Note: * no service sub-layer required for transit nodes
```

Figure 2: MPLS (DetNet) Node with TSN Functions

A TSN-aware MPLS (DetNet) node implementation must support the Stream identification TSN component for recognizing flows.

A Stream identification component must be able to instantiate the following functions: (1) Active Destination MAC and VLAN Stream identification function, (2) Mask-and-Match Stream identification function, and (3) the related managed objects in Clause 9 of [IEEE8021CB] and [IEEEP8021CBdb].

A TSN-aware MPLS (DetNet) node implementation must support the Sequencing function and the Sequence encode/decode function as defined in Clauses 7.4 and 7.6 of [IEEE8021CB] in order for FRER to be used inside the TSN sub-network.

The Sequence encode/decode function must support the Redundancy tag (R-TAG) format as per Clause 7.8 of [IEEE8021CB].

A TSN-aware MPLS (DetNet) node implementation must support the Stream splitting function and the Individual recovery function as defined in Clauses 7.5 and 7.7 of [IEEE8021CB] in order for that node to be a replication or elimination point for FRER.

4.3. Service Protection within the TSN Sub-network

TSN Streams supporting DetNet flows may use FRER as defined in Clause 8 of [IEEE8021CB] based on the loss service requirements of the TSN Stream, which is derived from the DetNet service requirements of the DetNet mapped flow. The specific operation of FRER is not modified by the use of DetNet and follows [IEEE8021CB].

FRER function and the provided service recovery is available only within the TSN sub-network as the TSN Stream-ID and the TSN sequence number are not valid outside the sub-network. An MPLS (DetNet) node represents an L3 border, and as such, it terminates all related information elements encoded in the L2 frames.

As the Stream-ID and the TSN sequence number are paired with similar MPLS flow parameters, FRER can be combined with PREOF functions. Such service protection interworking scenarios may require moving sequence number fields among TSN (L2) and PW (MPLS) encapsulations, and they are left for further study.

4.4. Aggregation during DetNet Flow to TSN Stream Mapping

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

5. Management and Control Implications

Information related to DetNet flow and TSN Stream mapping is required only for TSN-aware MPLS (DetNet) 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 DetNet MPLS over TSN:

- DetNet MPLS-related configuration information according to the DetNet role of the DetNet MPLS node, as per [RFC8964].
- TSN-related configuration information according to the TSN role of the DetNet MPLS node, as per [IEEE8021Q], [IEEE8021CB], and [IEEEP8021CBdb].
- Mapping between a DetNet MPLS flow(s) (label information: A-Labels, S-Labels, and F-Labels as defined in [RFC8964]) and a TSN Stream(s) (as Stream identification information defined in [IEEEP8021CBdb]). Note that managed objects for TSN Stream identification can be found in [IEEEP8021CBcv].

This information must be provisioned per DetNet flow.

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

TSN-aware MPLS DetNet nodes are members of both the DetNet domain and the TSN sub-network. Within the TSN sub-network, the TSN-aware MPLS (DetNet) node has a TSN-aware Talker/Listener 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 the

Multiple Stream Registration Protocol (MSRP) behave differently. Therefore, management and control plane design are important aspects of scenarios where mapping between DetNet and TSN is required.

In order to use a TSN sub-network between DetNet nodes, DetNet-specific information must be converted to information specific to the TSN sub-network. DetNet flow ID and flow-related parameters/requirements must be converted to a TSN Stream ID and stream-related parameters/requirements. Note that, as the TSN sub-network is just a portion of the end-to-end DetNet path (i.e., a single hop from the MPLS perspective), some parameters (e.g., delay) may differ significantly. Other parameters (like bandwidth) also may have to be tuned due to the L2 encapsulation used within the TSN sub-network.

In some cases, it may be challenging to determine some TSN-Stream-related information. For example, on a TSN-aware MPLS (DetNet) node that acts as a Talker, it is quite obvious which DetNet node is the Listener of the mapped TSN Stream (i.e., the MPLS next hop). However, it may be not trivial to locate the point/interface where that Listener is connected to the TSN sub-network. Such attributes 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 a TSN-aware MPLS (DetNet) node locally based on information provided for configuration of the TSN Stream identification functions (Mask-and-Match Stream identification and active Stream identification).

Triggering the setup/modification of a TSN Stream in the TSN sub-network is an example where management and/or control plane interactions are required between the DetNet and TSN sub-network. TSN-unaware MPLS (DetNet) nodes make such a triggering even more complicated as they are fully unaware of the sub-network and run independently.

Configuration of TSN-specific functions (e.g., FRER) inside the TSN sub-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.

6. Security Considerations

Security considerations for DetNet are described in detail in [DETNET-SECURITY]. General security considerations are described in [RFC8655]. Considerations specific to the DetNet MPLS data plane are summarized in [RFC8964]. This section considers exclusively security considerations that are specific to the DetNet MPLS over TSN sub-network scenario.

The sub-network between DetNet nodes needs to be subject to appropriate confidentiality. Additionally, knowledge of what DetNet/TSN services are provided by a sub-network may supply information that can be used in a variety of security attacks. The ability to modify information exchanges between connected DetNet nodes may result in bogus operations. Therefore, it is important that the interface between DetNet nodes and the TSN sub-network are subject to authorization, authentication, and encryption.

The TSN sub-network operates at Layer 2, so various security mechanisms defined by IEEE can be used to secure the connection between the DetNet nodes (e.g., encryption may be provided using MACsec [IEEE802.1AE-2018]).

7. IANA Considerations

This document has no IANA actions.

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Acknowledgements

The authors wish to thank Norman Finn, Lou Berger, Craig Gunther, Christophe Mangin, and Jouni Korhonen for their various contributions to this work.

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