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**DetNet Data Plane: IEEE 802.1 Time Sensitive Networking over SRv6
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Abstract

This document specifies the Deterministic Networking data plane when TSN networks interconnected over an Segment Routing IPv6 Packet Switched Networks.

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Table of Contents

1.	Introduction	2
2.	Terminology	3
2.1.	Terms Used in This Document	3
2.2.	Abbreviations	3
3.	Requirements Language	4
4.	IEEE 802.1 TSN Over SRv6 Data Plane Scenario	4
5.	IEEE 802.1 TSN Operation Over SRv6 Sub-Networks.	5
5.1.	Mapping of TSN Stream ID and Sequence Number	5
5.2.	SRv6 Network Programming new Functions	8
5.2.1.	End. B.Replication DetNet SID: Packet Replication Function	8
5.2.2.	End. B. Elimination: Packet Elimination Function.	9
6.	SRv6 Data Plane Considerations	9
6.1.	DetNet PREOF	9
6.2.	Edge Node Processing	10
6.3.	MTU and Fragmentation	10
7.	Management and Control Information Summary.	11
8.	Security Considerations	12
9.	IANA Considerations	12
10.	Acknowledgements	12
11.	Normative References.	12
	Authors' Addresses	13

[1.](#) Introduction

Deterministic Networking (DetNet) is a service that can be offered as DetNet flows in network. DetNet provides these flows extremely low packet loss rates and assured bounded end-to-end delivery latency. General background and concepts of DetNet can be found in the DetNet Architecture [[RFC8655](#)].

Segment Routing(SR) leverages the source routing paradigm. An ingress node steers a packet through an ordered list of instructions, called "segments". SR can be applied over IPv6 data plane using Routing Extension Header [[RFC8754](#)]. A segment in Segment Routing is not limited to a routing/forwarding function. A SRv6 Segment can indicate functions that are executed locally in the node where they are defined. [RDC8986] describes some well-known functions and segments associated to them. SRH TLVs ([[RFC8754](#)]) also provides meta-data for segment processing. All these features make SRv6 suitable to carry DetNet flows by defining new segments associated with DetNet functions and Meta data for DetNet.

The Time-Sensitive Networking (TSN) is to provide deterministic services through IEEE 802 networks, i.e., guaranteed packet transport with bounded latency, low packet delay variation, and low packet loss.

The TSN is a unified industrial Ethernet standard, and supports production control and information application.

TSN over DetNet needs to focus on the real-time interconnection of multi-subnet network layer. Based on the existing mechanism of TSN, interface scheduling is carried out for routers, firewalls, servers and other devices, in order to ensure the deterministic network services between cross-domain subnets. The remote control requirements across networks of TSN need deterministic transmission of network services through DetNet technology. TSN needs to be deployed with DetNet technology in larger areas such as networking of plant equipment, automatic building control of plant and office buildings.

This document defines how to carry DetNet IEEE 802.1 TSN flows over SRv6 networks.

2. Terminology

2.1. Terms Used in This Document

This document uses the terminology and concepts established in the DetNet architecture [[RFC8655](#)] and [[RFC8938](#)]. The reader is assumed to be familiar with these documents and their terminology.

2.2. Abbreviations

Terminologies for DetNet go along with the definition in [[RFC8655](#)]. The following abbreviations are used in this document:

CE: Customer Edge equipment.

CoS: Class of Service.

DetNet: Deterministic Networking.

DF: DetNet Flow.

L2: Layer 2.

L3: Layer 3.

OAM: Operations, Administration, and Maintenance.

PE: Provider Edge.

PEF: Packet Elimination Function.

PRF: Packet Replication Function.

PREOF: Packet Replication, Elimination and Ordering Functions.

POF: Packet Ordering Function.

QoS: Quality of Service.

TSN: IEEE 802.1 Time-Sensitive Network.

SR: Segment Routing.

SRv6: Segment Routing IPv6.

SL: Segment Left.

NH: The IPv6 next-header field.

SID: A Segment Identifier ([RFC8402]).

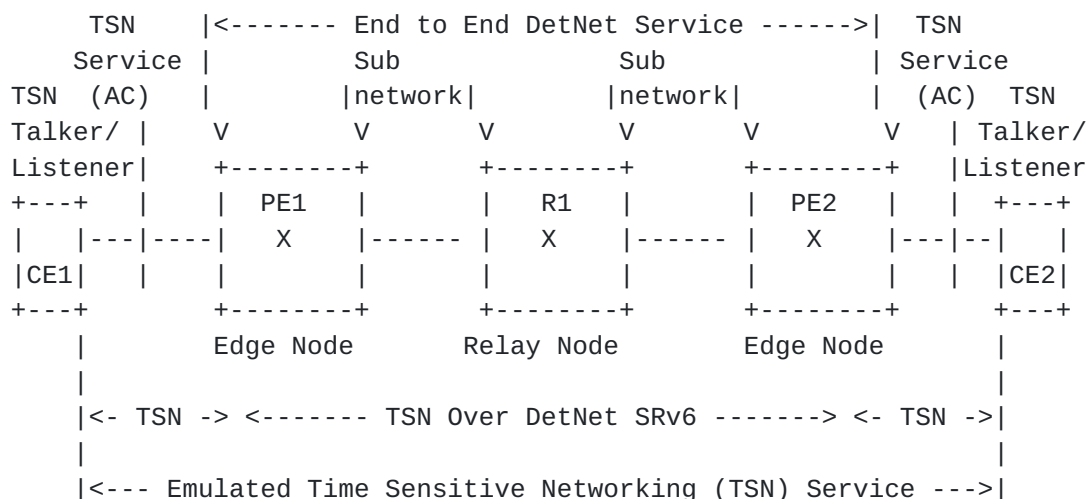
SRH: The Segment Routing Header ([RFC8754]).

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.

4. IEEE 802.1 TSN over SRv6 Data Plane Scenario

Realize the DetNet network in the Internet and connect with the time sensitive network in the factory. Figure 1 illustrates how DetNet can provide services for IEEE 802.1 TSN end systems, CE1 and CE2, over a DetNet enabled SRv6 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. They understand and support IEEE 802.1 TSN and are able to map TSN flows into DetNet flows. Edge nodes, PE1 and PE2, insert and remove required DetNet SRv6 data plane encapsulation. The 'X' in the edge nodes and relay node, R1, represent a potential DetNet compound flow packet replication and elimination point.



X = Service protection

Figure 1: IEEE 802.1TSN Over DetNet SRv6

Native TSN flow and DetNet SRv6 flow differ not only by the additional SRH specific encapsulation, but DetNet SRv6 flows have on

each DetNet node an associated DetNet specific data structure, what defines flow related characteristics and required forwarding functions. In this example, edge Nodes provide a service proxy function that "associates" the DetNet flows and native flows at the edge of the DetNet domain. This ensures that the DetNet SRv6 Flow is properly served at the Edge node (and inside the domain).

5. IEEE 802.1 TSN Operation Over SRv6 Sub-Networks

A classical SRv6 data plane solution is showed in the picture below:

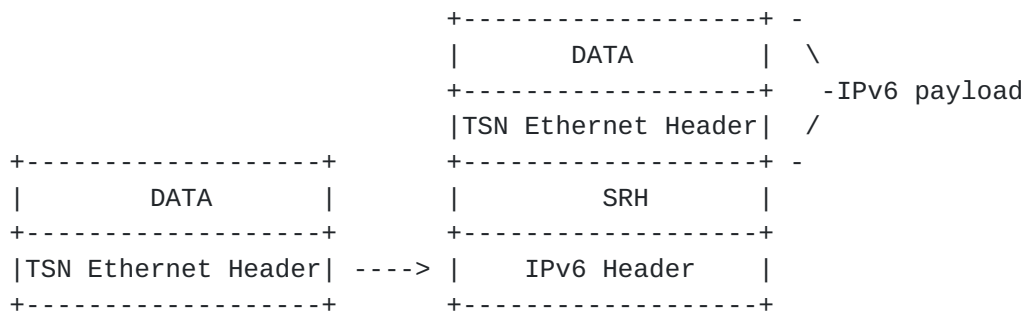


Figure 2: SRv6 DetNet data plane solution

In SRv6 for DetNet, the DATA with the SRH is used for carrying DetNet flows. Traffic Engineering is instantiated in the segment list of SRH, and other functions and arguments for service protection (packet replication, elimination and ordering) and congestion control (packet queuing and forwarding) are also defined in the SRH.

The Time-Sensitive Networking (TSN) Task Group of the IEEE 802.1 Working Group have defined (and are defining) a number of amendments to IEEE 802.1Q [[IEEE8021Q](#)] that provides zero congestion loss and bounded latency in bridged networks. Furthermore IEEE 802.1CB [[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 those require TSN treatment.

The challenge for SRv6 flows is that the protocol interworking function defined in IEEE 802.1CB [[IEEE8021CB](#)] does not work for segment list of SRH flows. The aim of the protocol interworking function is to convert a TSN ingress flow (for examples, identified by a specific destination MAC address and VLAN) to segment list of SRH. A similar interworking pair at the other end of the SRv6 sub-network would restore the packet to its original TSN packet.

The TSN layer 2 header and application payload carried by the TSN network are encapsulated in IPv6 payload field as figure 2.

5.1. IPv6 Header

The Edge Node encapsulates the Ipv6 Header when a TSN packet goes into DetNet SRv6 network, the Ipv6 header field values are as follows:

Version: 6, represented as Ipv6 packets;

Traffic Class: the level of the DetNet stream from Control Plane, if not, the same as the vlan priority in the TSN packet;

Flow label: as default incremental value by the edge node or same as the Sequence Number in the TSN packet;

Payload Length: according to the Ipv6 packet length, it is equal to the TSN packet length normally;

Next Header: 43, represents the Ipv6 routing extension head;

Hop Limit: set as default value;

Source Address: the sender Ipv6 address. when the packets from CE1 to CE2 as shown in figure 1, the PE1 node encapsulate Ipv6 Header source address as its own Ipv6 address;

Destination Address: the receiver Ipv6 address. when the packets from CE1 to CE2 as shown in figure 1, the PE1 node encapsulate Ipv6 Header destination address as the PE2 Ipv6 address.

5.2. DetNet SID Mapping from TSN Stream

The SRv6 network edge node uses BGP protocol to announce SRv6 service Sid. SRv6 edge node encapsulates the data payload in the outer IPv6 header and sets the outer destination address as the service Sid. The underlying network between the edge nodes needs to support IPv6 according to [RFC8200], and can transform TSN data flow into srsv6 service.

The Edge node MUST provide the SRv6 sub-network specific segment list of SRH encapsulation over the link(s) towards the sub-network. A SRv6-aware edge node MUST support the following TSN components:

1. For recognizing flows:
 - * Stream Identification (SRv6-flow-aware).
2. For FRER used inside the TSN domain, additionally:
 - * Sequencing function (SRv6-flow-aware);
 - * Sequence encode/decode function.
3. For FRER when the node is a TSN replication or elimination point.

additionally:

- * Stream splitting function;
- * Individual recovery function.

The Time-Sensitive Networking (TSN) Task Group of the IEEE 802.1

Working Group has defined Stream identification in [section 6.1](#) of IEEE 802.1CB [[IEEE8021CB](#)]. Four specific Stream identification functions are described: Null Stream identification, Source MAC and VLAN Stream identification, Active Destination MAC and VLAN Stream identification, and IP Stream identification. These Stream identification functions are summarized as follow:

- o Null Stream identification: destination MAC address, vlan identifier.
- o Source MAC and VLAN Stream identification: source MAC address, vlan identifier.
- o Active Destination MAC and VLAN Stream identification: destination MAC address, vlan identifier.
- o IP Stream identification: destination MAC address, vlan identifier, IP source address, IP destination address, DSCP, IP next protocol, source port, destination port.

The SRH for DetNet in the IPv6 header is showed as follows, according to [[RFC8754](#)], [[draft-geng-detnet-dp-sol-srv6-02](#)] and [[RFC8986](#)]:

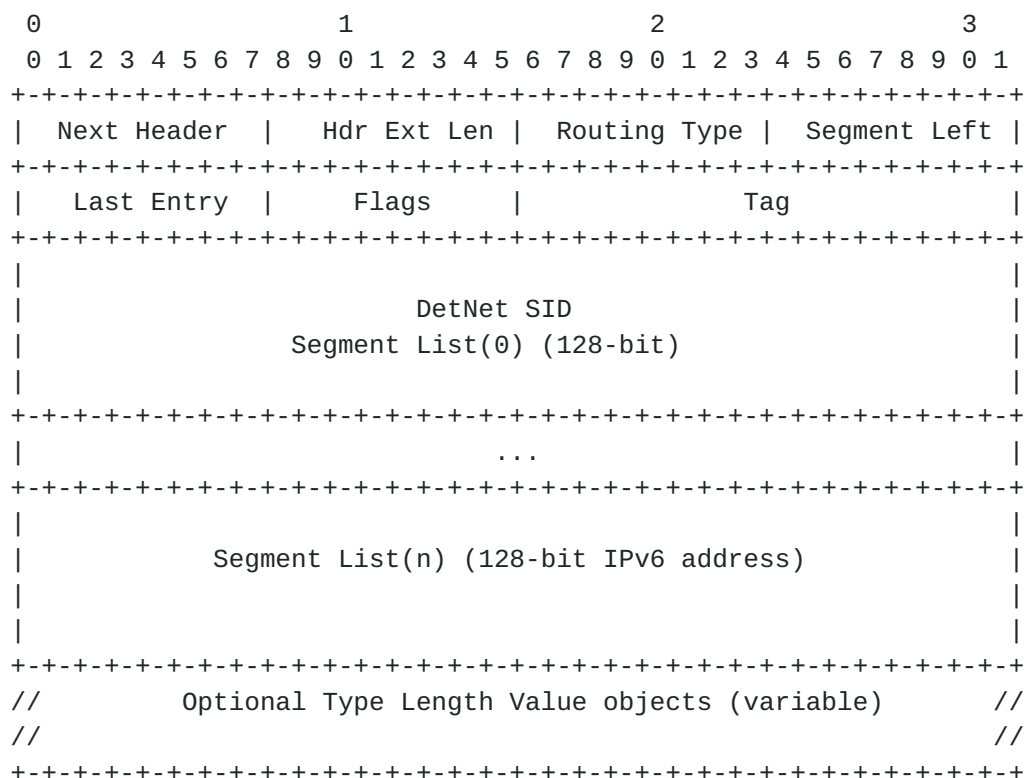


Figure 3: SRH for DetNet

The DetNet SRv6 flow is identified by DetNet SID in SRH. DetNet SID is defined as a 128-bit value.

A new DetNet SID is defined to support DetNet service protection for TSN stream. It is used to uniquely identify a DetNet flow in a SRv6 DetNet node and to discriminate packets in the same DetNet flow by sequence number. DetNet SID is defined as follows:

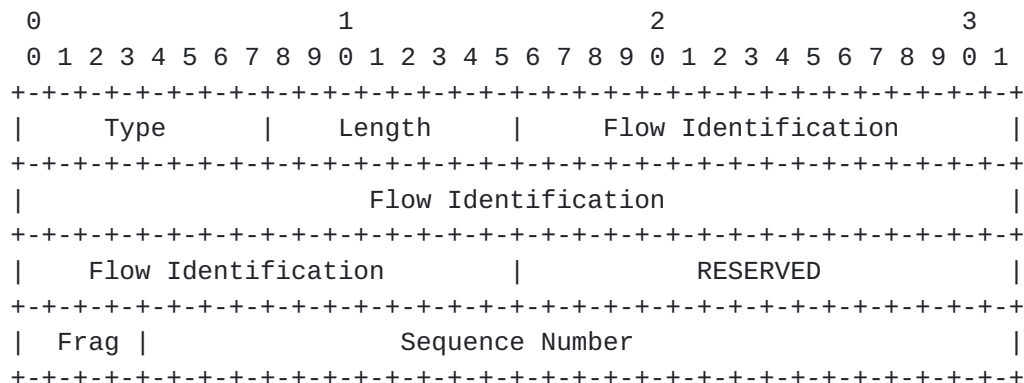


Figure 4: DetNet SID for Flow Identification

Where:

- o Type: 8bits, to be assigned by IANA.
- o Length: 8 bits.
- o Flow Identification: 64 bits, which is used for identifying DetNet flow.
- o RESERVED: 20 bits, MUST be 0 on transmission and ignored on receipt.
- o Sequence Number: 28 bits, which is used for indicating sequence number of a DetNet flow.
- o Frag: 4 bits, if a packet must be divided into multiple packages for transmission, record the fragmentation number.

When TSN stream is transmitted over a SRv6 network, TSN Stream Identification MUST pair SRv6 flows and TSN Streams and encode that in data plane formats as well. When the new DetNet SID is used to identify DetNet flow and the mapping for TSN stream is as follows:

- o Type: 8bits, to be assigned by IANA, used to identify sources from the TSN stream.
- o Length: 8 bits, the value is 16 octets.
- o Flow Identification: 64 bits, which is used for identifying DetNet flow. The former 48 bit corresponds to the MAC address identified by the TSN stream, and the post 16 bit comes from the VLAN-ID and priority parameters in TSN packet.
- o RESERVED: 20 bits, MUST be 0 on transmission and ignored on receipt.
- o Sequence Number: 28 bits, which is used for indicating sequence number of a DetNet flow. The value comes from the Redundancy tag (R-TAG) in TSN packet as defined in Clause 7.8 of IEEE 802.1CB [IEEE8021CB].

Flow Identification in SRH can identify Null Stream, Source MAC and VLAN Stream, Active Destination MAC and VLAN Stream in TSN stream. For TSN IP Stream, destination MAC address and vlan is still indicated by flow Identification, other IP-based fields correspond to IP fields in SRv6 one by one, such as IP source address, IP destination address, DSCP, IP next protocol, source port, destination port etc.

5.3. SRv6 Network Programming new Functions

New SRv6 Network Programming functions are defined as follows:

5.3.1. End. B.Replication DetNet SID: Packet Replication Function

When N receives a packet whose IPv6 DA is S and S is a local End.B. SL is Segment Left(SL), Replication DetNet SID, does:

```
S01. IF NH=SRH & SL>0 THEN {
S02. Extract the DetNet SID values from the SRH or TSN Stream
    identification and TSN Rtag.
S03. Create two new outer IPv6+SRH headers: IPv6-SRH-1 and
    IPv6-SRH-2 Insert the policy-instructed segment lists in each
    newly created SRH (SRH-1 and SRH-2). Also, add the extracted
    DetNet SID into SRH-1 and SRH-2.
S04. Remove the incoming outer IPv6+SRH header, restore DATA as the
    original packet.
S05. Create a duplication of the restore DATA as the duplicate
    packet.
S06. Encapsulate the original packet into the first outer IPv6+SRH
    header: (IPv6-SRH-1) (original packet)
S07. Encapsulate the duplicate packet into the second outer IPv6+SRH
    header: (IPv6-SRH-2) (duplicate packet)
S08. Set the IPv6 SA as the local address of this node.
S09. Set the IPv6 DA of IPv6-SRH-1 to the first segment of the SRv6
    Policy in of SRH-1 segment list.
S10. Set the IPv6 DA of IPv6-SRH-2 to the first segment of the SRv6
    Policy in of SRH-2 segment list.
S11. }
```

5.3.2. End. B. Elimination: Packet Elimination Function

When N receives a packet whose IPv6 DA is S and S is a local End.B. SL is Segment Left(SL), Elimination DetNet SID, does:

```
S01. IF NH=SRH & SL>0 & "the packet is not a redundant packet" THEN {
S02.   Do not decrement SL nor update the IPv6 DA with SRH(SL)
S03.   Extract the value of DetNet SID from the SRH
S04.   Extract Flow Identification and Sequence Number from DetNet
```



```

    SID.
S05.  IF NOT receive the packet with the same Flow Identification
      and Sequence Number {
S06.    Create a new outer IPv6+SRH header
S07.    Insert the policy-instructed segment lists in the newly
      created SRH and add the retrieved DetNet SID in the newly
      created SRH
S08.    Remove the incoming outer IPv6+SRH header.
S09.    Set the IPv6 DA to the first segment of the SRv6 Policy in
      the newly created SRH
S10.  } Else {
S11.    Drop the packet
S12.  }
S13. }
```

6. SRv6 Data Plane Considerations

6.1. DetNet PREOF

Flow Identification and sequence number are necessary in the encapsulation of SRv6 for DetNet in order to support service protection. Replication nodes decide which DetNet flows are supposed to be replicated by the flow identification. Elimination nodes decide whether a packet should be dropped because of redundancy by the flow identification and sequence number.

FRER function and the provided service recovery is available in that the Stream-ID and the TSN sequence number are paired with the SRv6 flow parameters they can be combined with PREOF functions.

SRv6 supporting DetNet flows may use Packet Replication, Elimination and Ordering Functions (PREOF) based on the DetNet SID in SRH, which is derived from TSN Stream. The specific operation of Frame Replication and Elimination for Redundancy (FRER) [802.1CB] is not modified by the use of DetNet and follows IEEE 802.1CB [[IEEE8021CB](#)].

6.2. Edge Node Processing

An edge node is responsible for matching ingress packets to the service they require and encapsulating them accordingly. An edge node is a SRv6 DetNet-aware forwarder, and may participate in the packet replication and duplication elimination.

The Controller sends Detnet SRv6 policies to the edge node. These policies include mapping of ingress TSN stream to DetNet SRv6 flow. The detnet SID is associated with an SR Policy, and its value comes from a TSN packet. When the edge node forwards a TSN packet to SRv6 network, inserting an SRH with the policy and adds an outer IPv6

header. The TSN flow identification and sequence number is copied to DetNet SID in SRv6 SRH.

Additionally the DetNet-aware edge node does duplicate frame elimination based on the flow identification and the sequence number combination. The packet replication is also done within the DetNet-aware forwarder. During elimination and the replication process the sequence number of the DetNet member flow MUST be preserved and copied to the egress DetNet member flow.

6.3. MTU and Fragmentation

Because the SRH field is added during transmission in the srV6 network, the data packet may exceed the MTU of the device interface, so it is necessary to divide the packet. The serial number of the fragment packet is recorded in the frag field of DetNet Sid for flow identification. At the SRv6 network edge node, reorganize these received fragment packets as one packet and send it to the TSN network.

In the process of fragment, the Flow Identification number and Sequence Number of the packet are consistent with the original packet. Based on the Flow Identification number of each stream, the transmission node sends the fragment alarm information to the controller.

7. Management and Control Information Summary

The following summarizes the set of information that is needed to support TSN over SRv6 at the ingress edge node:

- o TSN Stream identification and TSN R-tag information to be mapped to SRv6 SRH SID. Note that a single TSN Stream identification can map to one SRH DetNet SID, and it can be used for PREOF.
- o IPv6 source address.
- o IPv6 destination address.
- o IPv6 Traffic Class.

This information MUST be provisioned per DetNet flow via configuration, e.g., via the controller or management plane.

It is the responsibility of the DetNet controller plane to properly provision both flow identification information and the flow specific resources needed to be provided the traffic treatment needed to meet each flow's service requirements. This applies for aggregated and individual flows.

DetNet SRv6 flow and TSN Stream mapping related information are

required only for DetNet SRv6 edge nodes; the edge node is TSN-aware and DetNet SRv6-aware node. These DetNet SRv6 edge nodes are member of both the DetNet SRv6 domain and the TSN sub-network. Within the TSN sub-network the DetNet SRv6 node may have a TSM-aware 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 behaves differently. Therefore management and control plane design is an important aspect of scenarios, where mapping between DetNet SRv6 and TSN is required.

In order to use a DetNet SRv6 sub-network between TSN nodes, TSN stream specific information must be converted to SRv6 DetNet SRH. TSN Stream ID and stream related parameters/requirements must be converted to a SRv6 DetNet flow ID and flow related parameters/requirements. Note that, as the DetNet SRv6 sub-network is just a portion of the end2end TSN path (i.e., single hop from IP perspective), some parameters (e.g., delay) may differ significantly. Other TSN stream parameters (like bandwidth) also may have to be tuned due to the SRv6 encapsulation used in the DetNet sub-network.

In some case it may be challenging to determine some TSN Stream related information. For example which DetNet SRv6 paths are multi-Listener of the mapped TSN stream to one TSN stream Talker? 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 SRv6 and TSN domains.

Mapping between DetNet SRv6 flow identifiers and TSN Stream identifiers, if not provided explicitly, can be done by a DetNet SRv6 node locally based on the configuration of SRv6 Behaviors associated with a SID.

8. Security Considerations

This document will not introduce new security problems.

9. IANA Considerations

This document requests assigning new DetNet SID TLV code-points as described in [section 5](#).

10. Acknowledgements

Thanks for Guanghua Lan and Ximing Dong for their comments and contributions.

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