DetNet B. Varga, Ed.
Internet-Draft J. Farkas
Intended status: Standards Track Ericsson
Expires: November 6, 2019 A. Malis
S. Bryant
Huawei Technologies
J. Korhonen
May 5, 2019

DetNet Data Plane: IEEE 802.1 Time Sensitive Networking over MPLS
draft-ietf-detnet-tsn-vpn-over-mpls-00

Abstract

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

Status of This Memo

Copyright Notice

Table of Contents

1. Introduction 2
2. Terminology 2
2.1. Terms Used in This Document 2
2.2. Abbreviations 3
3. Requirements Language 4
4. IEEE 802.1 TSN Over DetNet MPLS Data Plane Scenario 4
5. DetNet MPLS Data Plane Considerations 6
5.1. End-System Specific Considerations 7
6. MPLS-Based DetNet Data Plane Solution 8
6.1. DetNet Over MPLS Encapsulation Components 8
6.2. TSN over MPLS Data Plane Encapsulation 9
6.2.1. Edge Node Processing 9
6.2.2. Layer 2 Addressing and QoS Considerations 10
7. Controller Plane (Management and Control) Considerations 11
8. Security Considerations 11
9. IANA Considerations 11
10. Acknowledgements 11
11. References 11
11.1. Normative References 11
11.2. Informative References 13
Appendix A. Example of TSN over DetNet Data Plane Operation . . 17
Authors' Addresses 17

1. Introduction

[Editor's note: Introduction to be made specific to TSN over DetNet scenario. Do we intend to cover both TSN over DetNet IP and TSN over DetNet MPLS? Or this document is limited to MPLS scenarios?].

2. Terminology

[Editor's note: text to be review what is really needed here.].

2.1. Terms Used in This Document

This document uses the terminology established in the DetNet architecture [I-D.ietf-detnet-architecture], and the reader is assumed to be familiar with that document and its terminology.

The following terminology is introduced in this document:

F-Label A Detnet "forwarding" label that identifies the LSP used to forward a DetNet flow across an MPLS PSN, e.g., a hop-by-hop label used between label switching routers (LSR).

S-Label A DetNet "service" label that is used between DetNet nodes that implement also the DetNet service sub-layer functions. An S-Label is also used to identify a DetNet flow at DetNet service sub-layer.

d-CW A DetNet Control Word (d-CW) is used for sequencing and identifying duplicate packets of a DetNet flow at the DetNet service sub-layer.

2.2. Abbreviations

[Editor's note: text to be cleaned up].

The following abbreviations are used in this document:

AC Attachment Circuit.

CE Customer Edge equipment.

CoS Class of Service.

CW Control Word.

DetNet Deterministic Networking.

DF DetNet Flow.

DN-IWF DetNet Inter-Working Function.

L2 Layer 2.

L2VPN Layer 2 Virtual Private Network.

L3 Layer 3.

LSR Label Switching Router.

MPLS Multiprotocol Label Switching.

MPLS-TE Multiprotocol Label Switching - Traffic Engineering.

MPLS-TP Multiprotocol Label Switching - Transport Profile.

MS-PW	Multi-Segment PseudoWire (MS-PW).
NSP	Native Service Processing.
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.
PSN	Packet Switched Network.
PW	PseudoWire.
QoS	Quality of Service.
S-PE	Switching Provider Edge.
T-PE	Terminating Provider Edge.
TSN	Time-Sensitive Network.

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 DetNet MPLS Data Plane Scenario

[Author's note: review required on his part.]

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

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

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

Figure 1: A TSN over DetNet MPLS Enabled Network

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 pseudowire (PW) Terminating Provider Edge (T-PE) nodes which use MPLS-TE LSPs. In this example they understand and support IEEE 802.1 TSN and are able to map TSN flows into DetNet flows. The specific of this operation are discussed later in this document.

Native TSN flow and DetNet MPLS flow differ not only by the additional MPLS specific encapsulation, but DetNet MPLS 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 DN Flow is properly served at the Edge node (and inside the domain).

Figure 2 illustrates how DetNet can provide services for IEEE 802.1TSN end systems, CE1 and CE2, over a DetNet enabled MPLS network. Edge nodes, E1 and E2, insert and remove 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 ->|
    |                                                          |
    |<--- Emulated Time Sensitive Networking (TSN) Service --->|

    X   = Service protection
    DFx = DetNet member flow x over a TE LSP
```

Figure 2: IEEE 802.1TSN Over DetNet

5. DetNet MPLS Data Plane Considerations

[Editor's note: Needs clean up, what is relevant for TSN over DetNet scenarios.].

This section provides informative considerations related to providing DetNet service to flows which are identified based on their header information. At a high level, the following are provided on a per flow basis:

Eliminating contention loss and jitter reduction:

Use of allocated resources (queuing, policing, shaping) to ensure that the congestion-related loss and latency/jitter requirements of a DetNet flow are met.

Explicit routes:

Use of a specific path for a flow. This limits misordering and bounds latency.

Service protection:

Which in the case of this document primarily relates to replication and elimination. Changing the explicit path after a failure is detected in order to restore delivery of the required DetNet service characteristics is also possible. Path changes, even in the case of failure recovery, can lead to the out of order delivery of data.

Load sharing:

Generally, distributing packets of the same DetNet flow over multiple paths is not recommended. Such load sharing, e.g., via ECMP or UCMP, impacts ordering and possibly jitter.

Troubleshooting:

For example, to support identification of misbehaving flows.

Recognize flow(s) for analytics:

For example, increase counters.

Correlate events with flows:

For example, unexpected loss.

The DetNet data plane also allows for the aggregation of DetNet flows, e.g., via MPLS hierarchical LSPs, to improved scaling. When DetNet flows are aggregated, transit nodes provide service to the aggregate and not on a per-DetNet flow basis. In this case, nodes performing aggregation will ensure that per-flow service requirements are achieved.

5.1. End-System Specific Considerations

Data-flows requiring DetNet service are generated and terminated on end-systems. Encapsulation depends on application and its preferences. In a DetNet MPLS domain the DN functions use the d-CWs, S-Labels and F-Labels to provide DetNet services. However, an application may exchange further flow related parameters (e.g., time-stamp), which are not provided by DN functions.

Specifics related to non-MPLS DetNet end station behavior are out side the scope of this document. For example, details on support for DetNet IP data flows can be found in [I-D.ietf-detnet-dp-sol-ip]. This document is also useful for end stations that map IP flows to DetNet flows.

As a general rule, DetNet MPLS domains are capable of forwarding any DetNet MPLS flows and the DetNet domain does not mandate the end-system or edge system encapsulation format. Unless there is a proxy of some form present, end-systems peer with similar end-systems using the same application encapsulation format. For example, as shown in Figure 3, IP applications peer with IP applications and Ethernet L2VPN applications peer with Ethernet L2VPN applications.

```
             +-----+
             |  X  |                               +-----+
             +-----+                               |  X  |
             | Eth |               ________        +-----+
             +-----+     _____    /        \       | Eth |
                    \   /     \__/          \___   +-----+
                     \ /                        \ /
                      0======== tunnel-1 ========0_
                      |                             \
                       \                             |
                       0========= tunnel-2 =========0
                      / \                        __/ \
               +-----+   \__ DetNet MPLS domain /     \
               |  X  |      \         __       /       +-----+
               +-----+       \_______/  \_____/        |  X  |
               |  IP |                                 +-----+
               +-----+                                 |  IP |
                                                       +-----+
```

Figure 3: End-Systems and The DetNet MPLS Domain

6. MPLS-Based DetNet Data Plane Solution

[Editor's note: Needs clean up. Text should focus on Edge node related topics.].

6.1. DetNet Over MPLS Encapsulation Components

To carry DetNet over MPLS the following is required:

1. A method of identifying the MPLS payload type.

2. A method of identifying the DetNet flow group to the processing element.

3. A method of distinguishing DetNet OAM packets from DetNet data packets.

4. A method of carrying the DetNet sequence number.

5. A suitable LSP to deliver the packet to the egress PE.

6. A method of carrying queuing and forwarding indication.

In this design an MPLS service label (the S-Label), similar to a pseudowire (PW) label [RFC3985], is used to identify both the DetNet flow identity and the payload MPLS payload type satisfying (1) and (2) in the list above. OAM traffic discrimination happens through the use of the Associated Channel method described in [RFC4385]. The DetNet sequence number is carried in the DetNet Control word which carries the Data/OAM discriminator. To simplify implementation and to maximize interoperability two sequence number sizes are supported: a 16 bit sequence number and a 28 bit sequence number. The 16 bit sequence number is needed to support some types of legacy clients. The 28 bit sequence number is used in situations where it is necessary ensure that in high speed networks the sequence number space does not wrap whilst packets are in flight.

The LSP used to forward the DetNet packet may be of any type (MPLS-LDP, MPLS-TE, MPLS-TP [RFC5921], or MPLS-SR [I-D.ietf-spring-segment-routing-mpls]). The LSP (F-Label) label and/or the S-Label may be used to indicate the queue processing as well as the forwarding parameters. Note that the possible use of Penultimate Hop Popping (PHP) means that the only label in a received label stack may be the S-Label.

6.2. TSN over MPLS Data Plane Encapsulation

6.2.1. Edge Node Processing

An edge node is resposable for matching ingress packets to the service they require and encapsulating them accordingly.An edge node may participate in the packet replication and duplication elimination.

The DetNet-aware forwarder selects the egress DetNet member flow segment based on the flow identification. The mapping of ingress DetNet member flow segment to egress DetNet member flow segment may be statically or dynamically configured. Additionally the DetNet-aware forwarder 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.

The internal design of a relay node is out of scope of this document. However the reader's attention is drawn to the need to make any PREOF

state available to the packet processor(s) dealing with packets to which the PREOF functions must be applied, and to maintain that state is such as way that it is available to the packet processor operation on the next packet in the DetNet flow (which may be a duplicate, a late packet, or the next packet in sequence.

[Editor's note: I think the rest of this section belongs in a new "802.1 TSN (island Interconnect) over DetNet MPLS" section.]

This may be done in the DetNet layer, or where the native service processing (NSP) [RFC3985] is IEEE 802.1CB [IEEE8021CB] capable, the packet replication and duplicate elimination MAY entirely be done in the NSP, bypassing the DetNet flow encapsulation and logic entirely. This enables operating over unmodified implementations and deployments. The NSP approach works only between edge nodes and cannot make use of relay nodes.

The NSP approach is useful end to end tunnel and for for "island interconnect" scenarios. However, when there is a need to do PREOF in a middle of the network, such plain edge to edge operation is not sufficient.

The extended forwarder MAY copy the sequencing information from the native DetNet packet into the DetNet sequence number field and vice versa. If there is no existing sequencing information available in the native packet or the forwarder chose not to copy it from the native packet, then the extended forwarder MUST maintain a sequence number counter for each DetNet flow (indexed by the DetNet flow identification).

6.2.2. Layer 2 Addressing and QoS Considerations

[Editor's NOTE: review and simplify this section if possible.]

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 provide zero congestion loss and bounded latency in bridged networks. IEEE 802.1CB [IEEE8021CB] defines packet replication and elimination functions that should prove both compatible with and useful to, DetNet networks.

As is the case for DetNet, a Layer 2 network node such as a bridge may need to identify the specific DetNet flow to which a packet belongs in order to provide the TSN/DetNet QoS for that packet. It also will likely need a CoS marking, such as the priority field of an IEEE Std 802.1Q VLAN tag, to give the packet proper service.

Although the flow identification methods described in IEEE 802.1CB [IEEE8021CB] are flexible, and in fact, include IP 5-tuple identification methods, the baseline TSN standards assume that every Ethernet frame belonging to a TSN stream (i.e. DetNet flow) carries a multicast destination MAC address that is unique to that flow within the bridged network over which it is carried. Furthermore, IEEE 802.1CB [IEEE8021CB] describes three methods by which a packet sequence number can be encoded in an Ethernet frame.

Ensuring that the proper Ethernet VLAN tag priority and destination MAC address are used on a DetNet/TSN packet may require further clarification of the customary L2/L3 transformations carried out by routers and edge label switches. Edge nodes may also have to move sequence number fields among Layer 2, PW, and IP encapsulations.

7. Controller Plane (Management and Control) Considerations

[Editor's note: requires considerations related to TSN over DetNet.].

8. Security Considerations

The security considerations of DetNet in general are discussed in [I-D.ietf-detnet-architecture] and [I-D.sdt-detnet-security]. Other security considerations will be added in a future version of this draft.

9. IANA Considerations

This document makes no IANA requests.

10. Acknowledgements

Thanks for Norman Finn and Lou Berger for their comments and contributions.

11. References

11.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC2211] Wroclawski, J., "Specification of the Controlled-Load Network Element Service", RFC 2211, DOI 10.17487/RFC2211, September 1997, <https://www.rfc-editor.org/info/rfc2211>.

[RFC2212] Shenker, S., Partridge, C., and R. Guerin, "Specification of Guaranteed Quality of Service", RFC 2212, DOI 10.17487/RFC2212, September 1997, <https://www.rfc-editor.org/info/rfc2212>.

[RFC3031] Rosen, E., Viswanathan, A., and R. Callon, "Multiprotocol Label Switching Architecture", RFC 3031, DOI 10.17487/RFC3031, January 2001, <https://www.rfc-editor.org/info/rfc3031>.

[RFC3032] Rosen, E., Tappan, D., Fedorkow, G., Rekhter, Y., Farinacci, D., Li, T., and A. Conta, "MPLS Label Stack Encoding", RFC 3032, DOI 10.17487/RFC3032, January 2001, <https://www.rfc-editor.org/info/rfc3032>.

[RFC3209] Awduche, D., Berger, L., Gan, D., Li, T., Srinivasan, V., and G. Swallow, "RSVP-TE: Extensions to RSVP for LSP Tunnels", RFC 3209, DOI 10.17487/RFC3209, December 2001, <https://www.rfc-editor.org/info/rfc3209>.

[RFC3270] Le Faucheur, F., Wu, L., Davie, B., Davari, S., Vaananen, P., Krishnan, R., Cheval, P., and J. Heinanen, "Multi-Protocol Label Switching (MPLS) Support of Differentiated Services", RFC 3270, DOI 10.17487/RFC3270, May 2002, <https://www.rfc-editor.org/info/rfc3270>.

[RFC3443] Agarwal, P. and B. Akyol, "Time To Live (TTL) Processing in Multi-Protocol Label Switching (MPLS) Networks", RFC 3443, DOI 10.17487/RFC3443, January 2003, <https://www.rfc-editor.org/info/rfc3443>.

[RFC3473] Berger, L., Ed., "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Resource ReserVation Protocol-Traffic Engineering (RSVP-TE) Extensions", RFC 3473, DOI 10.17487/RFC3473, January 2003, <https://www.rfc-editor.org/info/rfc3473>.

[RFC4206] Kompella, K. and Y. Rekhter, "Label Switched Paths (LSP) Hierarchy with Generalized Multi-Protocol Label Switching (GMPLS) Traffic Engineering (TE)", RFC 4206, DOI 10.17487/RFC4206, October 2005, <https://www.rfc-editor.org/info/rfc4206>.

[RFC4385] Bryant, S., Swallow, G., Martini, L., and D. McPherson, "Pseudowire Emulation Edge-to-Edge (PWE3) Control Word for Use over an MPLS PSN", RFC 4385, DOI 10.17487/RFC4385, February 2006, <https://www.rfc-editor.org/info/rfc4385>.

[RFC5085] Nadeau, T., Ed. and C. Pignataro, Ed., "Pseudowire Virtual Circuit Connectivity Verification (VCCV): A Control Channel for Pseudowires", RFC 5085, DOI 10.17487/RFC5085, December 2007, <https://www.rfc-editor.org/info/rfc5085>.

[RFC5129] Davie, B., Briscoe, B., and J. Tay, "Explicit Congestion Marking in MPLS", RFC 5129, DOI 10.17487/RFC5129, January 2008, <https://www.rfc-editor.org/info/rfc5129>.

[RFC5462] Andersson, L. and R. Asati, "Multiprotocol Label Switching (MPLS) Label Stack Entry: "EXP" Field Renamed to "Traffic Class" Field", RFC 5462, DOI 10.17487/RFC5462, February 2009, <https://www.rfc-editor.org/info/rfc5462>.

[RFC7510] Xu, X., Sheth, N., Yong, L., Callon, R., and D. Black, "Encapsulating MPLS in UDP", RFC 7510, DOI 10.17487/RFC7510, April 2015, <https://www.rfc-editor.org/info/rfc7510>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

11.2. Informative References

[G.8275.1] International Telecommunication Union, "Precision time protocol telecom profile for phase/time synchronization with full timing support from the network", ITU-T G.8275.1/Y.1369.1 G.8275.1, June 2016, <https://www.itu.int/rec/T-REC-G.8275.1/en>.

[G.8275.2] International Telecommunication Union, "Precision time protocol telecom profile for phase/time synchronization with partial timing support from the network", ITU-T G.8275.2/Y.1369.2 G.8275.2, June 2016, <https://www.itu.int/rec/T-REC-G.8275.2/en>.

[I-D.ietf-detnet-architecture] Finn, N., Thubert, P., Varga, B., and J. Farkas, "Deterministic Networking Architecture", draft-ietf-detnet-architecture-12 (work in progress), March 2019.

[I-D.ietf-detnet-dp-sol-ip] Korhonen, J., Varga, B., "DetNet IP Data Plane Encapsulation", 2018.

[I-D.ietf-detnet-flow-information-model]
Farkas, J., Varga, B., Cummings, R., and Y. Jiang, "DetNet Flow Information Model", draft-ietf-detnet-flow-information-model-03 (work in progress), March 2019.

[I-D.ietf-pce-pcep-extension-for-pce-controller]
Zhao, Q., Li, Z., Negi, M., and C. Zhou, "PCEP Procedures and Protocol Extensions for Using PCE as a Central Controller (PCECC) of LSPs", draft-ietf-pce-pcep-extension-for-pce-controller-01 (work in progress), February 2019.

[I-D.ietf-spring-segment-routing-mpls]
Bashandy, A., Filsfils, C., Previdi, S., Decraene, B., Litkowski, S., and R. Shakir, "Segment Routing with MPLS data plane", draft-ietf-spring-segment-routing-mpls-22 (work in progress), May 2019.

[I-D.sdt-detnet-security]
Mizrahi, T., Grossman, E., Hacker, A., Das, S., "Deterministic Networking (DetNet) Security Considerations, draft-sdt-detnet-security, work in progress", 2017.

[IEEE1588]
IEEE, "IEEE 1588 Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems Version 2", 2008.

[IEEE8021CB]
Finn, N., "Draft Standard for Local and metropolitan area networks - Seamless Redundancy", IEEE P802.1CB /D2.1 P802.1CB, December 2015, <http://www.ieee802.org/1/files/private/cb-drafts/d2/802-1CB-d2-1.pdf>.

[IEEE8021Q]
IEEE 802.1, "Standard for Local and metropolitan area networks--Bridges and Bridged Networks (IEEE Std 802.1Q-2014)", 2014, <http://standards.ieee.org/about/get/>.

[RFC2205] Braden, R., Ed., Zhang, L., Berson, S., Herzog, S., and S. Jamin, "Resource ReSerVation Protocol (RSVP) -- Version 1 Functional Specification", RFC 2205, DOI 10.17487/RFC2205, September 1997, <https://www.rfc-editor.org/info/rfc2205>.

[RFC2474] Nichols, K., Blake, S., Baker, F., and D. Black, "Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers", RFC 2474, DOI 10.17487/RFC2474, December 1998, <https://www.rfc-editor.org/info/rfc2474>.

[RFC3272] Awduche, D., Chiu, A., Elwalid, A., Widjaja, I., and X. Xiao, "Overview and Principles of Internet Traffic Engineering", RFC 3272, DOI 10.17487/RFC3272, May 2002, <https://www.rfc-editor.org/info/rfc3272>.

[RFC3985] Bryant, S., Ed. and P. Pate, Ed., "Pseudo Wire Emulation Edge-to-Edge (PWE3) Architecture", RFC 3985, DOI 10.17487/RFC3985, March 2005, <https://www.rfc-editor.org/info/rfc3985>.

[RFC4448] Martini, L., Ed., Rosen, E., El-Aawar, N., and G. Heron, "Encapsulation Methods for Transport of Ethernet over MPLS Networks", RFC 4448, DOI 10.17487/RFC4448, April 2006, <https://www.rfc-editor.org/info/rfc4448>.

[RFC4872] Lang, J., Ed., Rekhter, Y., Ed., and D. Papadimitriou, Ed., "RSVP-TE Extensions in Support of End-to-End Generalized Multi-Protocol Label Switching (GMPLS) Recovery", RFC 4872, DOI 10.17487/RFC4872, May 2007, <https://www.rfc-editor.org/info/rfc4872>.

[RFC4873] Berger, L., Bryskin, I., Papadimitriou, D., and A. Farrel, "GMPLS Segment Recovery", RFC 4873, DOI 10.17487/RFC4873, May 2007, <https://www.rfc-editor.org/info/rfc4873>.

[RFC4875] Aggarwal, R., Ed., Papadimitriou, D., Ed., and S. Yasukawa, Ed., "Extensions to Resource Reservation Protocol - Traffic Engineering (RSVP-TE) for Point-to-Multipoint TE Label Switched Paths (LSPs)", RFC 4875, DOI 10.17487/RFC4875, May 2007, <https://www.rfc-editor.org/info/rfc4875>.

[RFC5440] Vasseur, JP., Ed. and JL. Le Roux, Ed., "Path Computation Element (PCE) Communication Protocol (PCEP)", RFC 5440, DOI 10.17487/RFC5440, March 2009, <https://www.rfc-editor.org/info/rfc5440>.

[RFC5586] Bocci, M., Ed., Vigoureux, M., Ed., and S. Bryant, Ed., "MPLS Generic Associated Channel", RFC 5586, DOI 10.17487/RFC5586, June 2009, <https://www.rfc-editor.org/info/rfc5586>.

[RFC5654] Niven-Jenkins, B., Ed., Brungard, D., Ed., Betts, M., Ed., Sprecher, N., and S. Ueno, "Requirements of an MPLS Transport Profile", RFC 5654, DOI 10.17487/RFC5654, September 2009, <https://www.rfc-editor.org/info/rfc5654>.

[RFC5921] Bocci, M., Ed., Bryant, S., Ed., Frost, D., Ed., Levrau, L., and L. Berger, "A Framework for MPLS in Transport Networks", RFC 5921, DOI 10.17487/RFC5921, July 2010, <https://www.rfc-editor.org/info/rfc5921>.

[RFC6003] Papadimitriou, D., "Ethernet Traffic Parameters", RFC 6003, DOI 10.17487/RFC6003, October 2010, <https://www.rfc-editor.org/info/rfc6003>.

[RFC6006] Zhao, Q., Ed., King, D., Ed., Verhaeghe, F., Takeda, T., Ali, Z., and J. Meuric, "Extensions to the Path Computation Element Communication Protocol (PCEP) for Point-to-Multipoint Traffic Engineering Label Switched Paths", RFC 6006, DOI 10.17487/RFC6006, September 2010, <https://www.rfc-editor.org/info/rfc6006>.

[RFC6073] Martini, L., Metz, C., Nadeau, T., Bocci, M., and M. Aissaoui, "Segmented Pseudowire", RFC 6073, DOI 10.17487/RFC6073, January 2011, <https://www.rfc-editor.org/info/rfc6073>.

[RFC6387] Takacs, A., Berger, L., Caviglia, D., Fedyk, D., and J. Meuric, "GMPLS Asymmetric Bandwidth Bidirectional Label Switched Paths (LSPs)", RFC 6387, DOI 10.17487/RFC6387, September 2011, <https://www.rfc-editor.org/info/rfc6387>.

[RFC6790] Kompella, K., Drake, J., Amante, S., Henderickx, W., and L. Yong, "The Use of Entropy Labels in MPLS Forwarding", RFC 6790, DOI 10.17487/RFC6790, November 2012, <https://www.rfc-editor.org/info/rfc6790>.

[RFC7551] Zhang, F., Ed., Jing, R., and R. Gandhi, Ed., "RSVP-TE Extensions for Associated Bidirectional Label Switched Paths (LSPs)", RFC 7551, DOI 10.17487/RFC7551, May 2015, <https://www.rfc-editor.org/info/rfc7551>.

[RFC7950] Bjorklund, M., Ed., "The YANG 1.1 Data Modeling Language", RFC 7950, DOI 10.17487/RFC7950, August 2016, <https://www.rfc-editor.org/info/rfc7950>.

[RFC8040] Bierman, A., Bjorklund, M., and K. Watsen, "RESTCONF Protocol", RFC 8040, DOI 10.17487/RFC8040, January 2017, <https://www.rfc-editor.org/info/rfc8040>.

[RFC8169] Mirsky, G., Ruffini, S., Gray, E., Drake, J., Bryant, S., and A. Vainshtein, "Residence Time Measurement in MPLS Networks", RFC 8169, DOI 10.17487/RFC8169, May 2017, <https://www.rfc-editor.org/info/rfc8169>.

Appendix A. Example of TSN over DetNet Data Plane Operation

[Editor's note: Add a simplified example of DetNet data plane and how labels etc work in the case of TSN over DetNet MPLS and utilizing e.g., PREOF.]

Authors' Addresses

Balazs Varga (editor)
Ericsson
Magyar Tudosok krt. 11.
Budapest 1117
Hungary

Email: balazs.a.varga@ericsson.com

Janos Farkas
Ericsson
Magyar Tudosok krt. 11.
Budapest 1117
Hungary

Email: janos.farkas@ericsson.com

Andrew G. Malis
Huawei Technologies

Email: agmalis@gmail.com

Stewart Bryant
Huawei Technologies

Email: stewart.bryant@gmail.com

Jouni Korhonen

Email: jouni.nospam@gmail.com