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DetNet Data Plane Encapsulation  
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Abstract

This document specifies Deterministic Networking data plane encapsulation solutions. The described data plane solutions can be applied over either IP or MPLS Packet Switched Networks.

Comment #1: SB> An overarching comment is that the early part of the document is really fundamental architecture and perhaps belongs in the arch draft, leaving this draft to be more specific about solutions. Indeed if we cannot find a single solution that maps to both IP and MPLS underlays I wonder if we should publish two specialist RFCs?

Discussion: One document at the beginning, split into two if/when needed. Would be post adoption in any case.

Comment #2: SB> Whilst I think we should look for a common solution to IP and MPLS I do not think that this is where the DT ended up.

Discussion: Agree.

Status of This Memo

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## 1. Introduction

Deterministic Networking (DetNet) is a service that can be offered by a network to DetNet flows. DetNet provides these flows extremely low packet loss rates and assured maximum end-to-end delivery latency. General background and concepts of DetNet can be found in [I-D.ietf-detnet-architecture].

This document specifies the DetNet data plane. It defines how DetNet traffic is encapsulated at the network layer, and how DetNet-aware nodes can identify DetNet flows. Two data plane definitions are given.

- o PW-based: One solution is based on PseudoWires (PW) [RFC3985] and [RFC5036] and makes use of multi-segment pseudowires (MS-PW) [RFC6073] to map DetNet Relay and Edge Nodes [I-D.ietf-detnet-architecture] [I-D.ietf-detnet-dp-alt] to PW architecture. The PW-based data plane can be run over an MPLS [RFC4448] [RFC6658] Packet Switched Network (PSN).

Comment #3: SB> This is really an MPLS one. The world of IP PWs is a bit scruffy with some work in PWE3 and some in L2TPext which

really went their own ways. There is for example no MS-PW IP design. The MS-PW approach needs to be examined more closely by the WG and thus at this stage be marked as provisional.

Discussion: Agree. "can be" -> "is".

Comment #3.1 LB> EVPN-based encapsulation is also a potential candidate. In general DetNet should look more closely to the development around EVPN.

Discussion Agree. EVPN could be a potential solution and the on-wire encapsulations are likely to be the same as PW-based encapsulation would be. EVPN even recommends using Control Word [RFC8214] (in the absence of entropy labels).

- o Native-IP: The other solution is based on IP header fields, namely on the IPv6 Flow Label and a new DetNet Control Word extension header option. It is targeted for native IPv6 networks.

Comment #4: SB> The IP solution has not been properly examined by the WG and needs to be marked as provisional.

Discussion: IP vs. MPLS is a deployment choice.

It is worth noting that while PWs are designed to work over IP PSNs this document describes a native-IP solution that operates without PWs. The primary reason for this is the benefit gained by enabling the use of a normal application stack, where transport protocols such as TCP or UDP are directly encapsulated in IP.

Comment #5: SB> We clearly need to look at the implications of running this with a new IP header extension. Firstly we need input from 6man, but we also need to understand what happens in middle boxes, other components of the host stack etc.

Discussion: A WG can develop their own extensions and then get approval from 6man. Sometimes that ends up redoing extensions in 6man but not always.

This document specifies the encapsulation for DetNet flows, including a DetNet Control Word (CW). Furthermore, it describes how DetNet flows are identified, how DetNet Relay and Edge nodes work, and how the Packet Replication and Elimination function (PREF) is implemented with these two data plane solutions. This document does not define the associated control plane functions, or Operations, Administration, and Maintenance (OAM). It also does not specify traffic handling capabilities required to deliver congestion

protection and latency control to DetNet flows as this is defined to be provided by the underlying MPLS or IP network.

Comment #6: SB> OK, although I think that this may be a mistake. There may well be some coupling needed between the Detnet DP and the substrate/transport/underlay needed to make this work. If this is a genuine technical layering we should talk about it. If this is an artificial constraint imposed by the IESG we need to talk to them.

Discussion: The only interaction needed is that the flow identification is possible. That needs to be available for lower layers.

Comment #6.1: LA> Even though this document does not specify any OAM functions, we will need to verify that the GACH (Generalized Associate Channel) works correctly in a network that has replication and elimination.

Discussion: --

## 2. Terminology

### 2.1. Terms used in this document

This document uses the terminology established in the DetNet architecture [I-D.ietf-detnet-architecture] and the DetNet Data Plane Solution Alternatives [I-D.ietf-detnet-dp-alt].

The following terms are also used in this document:

DA-T-PE	MPLS based DetNet edge node: a DetNet-aware PseudoWire Terminating Provider Edge (T-PE).
DA-S-PE	MPLS based DetNet relay node: a DetNet-aware PseudoWire Switching Provider Edge (S-PE).

Comment #7 SB> We need to look at whether the S-PE concept is the best fit, or whether we should use introduce a Detnet relay to do this. An S-PE just swaps the PW label, but Detnet needs it to do more and a better model might be a new construct. However we could also discard the relay concept and run 1+n end to end, in which case the S-PEs would retain their original function.

Discussion: Disagree of the dropping comment. However, the issues are most likely terminology related. The relay concept is part of the DetNet architecture A DA-S-PE was intended to be a DetNet relay, which may do more than just swapping labels (PREF

functionality). Current text is quite biased to MS-PW, which was the starting point for the DetNet relay in a MPLS PW network.

T-Label        A label used to identify the LSP used to transport a DetNet flow across an MPLS PSN, e.g., a hop-by-hop label used between label switching routers (LSR).

S-Label        A DetNet node to DetNet node "service" label that is used between DA-\*-PE devices.

PW Label       A PseudoWire label that is used to identify DetNet flow related PW Instances within a PE node.

Flow Label     IPv6 header field that is used to identify a DetNet flow (together with the source IP address field).

Comment #8    SB> If this is the IPv6 Flow label I think caution is needed as I don't think the handling of this is well defined or consistently implemented in networking equipment.

Discussion:   DetNet specifies the use and discusses possible interaction with RFC6347 in this I-D.

local-ID       An edge and relay node internal construct that uniquely identifies a DetNet flow. It may be used to select proper forwarding and/or DetNet specific service function.

Comment #9    SB> Is this really an internal construct, or is it an on the wire construct? If it is needed end to end, I don't think it is correct to describe it as an internal construct. When you say "select" presumably you mean by potentially any DN aware node on the path?

Discussion:   It is an internal construct, so yes.

PREF           A Packet Replication and Elimination Function (PREF) does the replication and elimination processing of DetNet flow packets in edge or relay nodes. The replication function is essentially the existing 1+1 protection mechanism. The elimination function reuses and extends the existing duplicate detection mechanism to operate over multiple (separate) DetNet member flows of a DetNet compound flow.

Comment #10   SB> I wonder if 1+1 is the right way to go, or whether 1+n is better. A bunch of new techniques have emerged over the years and we really ought to look at creating paths with MRT.

With 1+2 on main + the two MRT paths you have a two failure resiliency as far as it is possible to construct such paths in the underlying topology.

Discussion: As observed above, actually 1+n would be closer to what is needed. 1+1 was meant to be more an example showing there is existing work that can be leveraged.

## 2.2. Abbreviations

The following abbreviations used in this document:

AC	Attachment Circuit.
CE	Customer Edge equipment.
CoS	Class of Service.
CW	Control Word.
d-CW	DetNet Control Word.
DetNet	Deterministic Networking.
DF	DetNet Flow.
L2VPN	Layer 2 Virtual Private Network.
LSR	Label Switching Router.
MPLS	Multiprotocol Label Switching.
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.
PREF	Packet Replication and Elimination Function.
PSN	Packet Switched Network.
PW	PseudoWire.

QoS                      Quality of Service.

TSN Time-Sensitive Network.

### 3. Requirements language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

#### 4. DetNet data plane overview

Comment #11 I am not sure whether this is a DP overview, or an architecture overview and hence whether this needs to be here or in the architecture draft.

Discussion: Overview is more of an editorial matter and its final location can be discussed later on. Currently it is "no harm" to have it here but there are no binding reasons to keep the text in either.

This document describes how to use IP and/or MPLS to support a data plane method of flow identification and packet forwarding over layer-3. Two different cases are covered: (i) the inter-connect scenario, in which IEEE802.1 TSN is routed over a layer-3 network (i.e., to enlarge the layer-2 domain), and (ii) native connectivity between DetNet-aware end systems. Figure 1 illustrates an exemplary scenario.

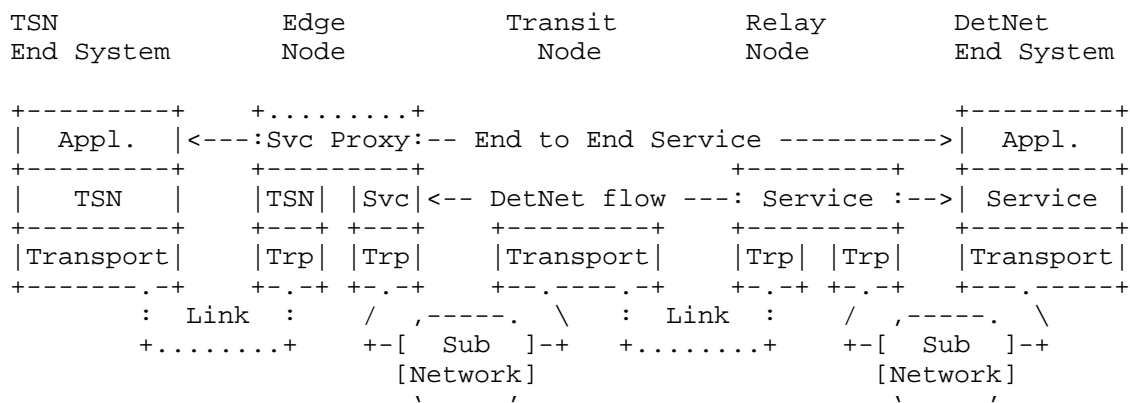


Figure 1: A simple DetNet enabled network architecture

Figure 2 illustrates how DetNet can provide services for IEEE 802.1TSN end systems over a DetNet enabled network. The edge nodes



insert and remove required DetNet data plane encapsulation. The 'X' in the edge and relay nodes represents a potential DetNet flow packet replication and elimination point. This conceptually parallels L2VPN services, and could leverage existing related solutions as discussed below.

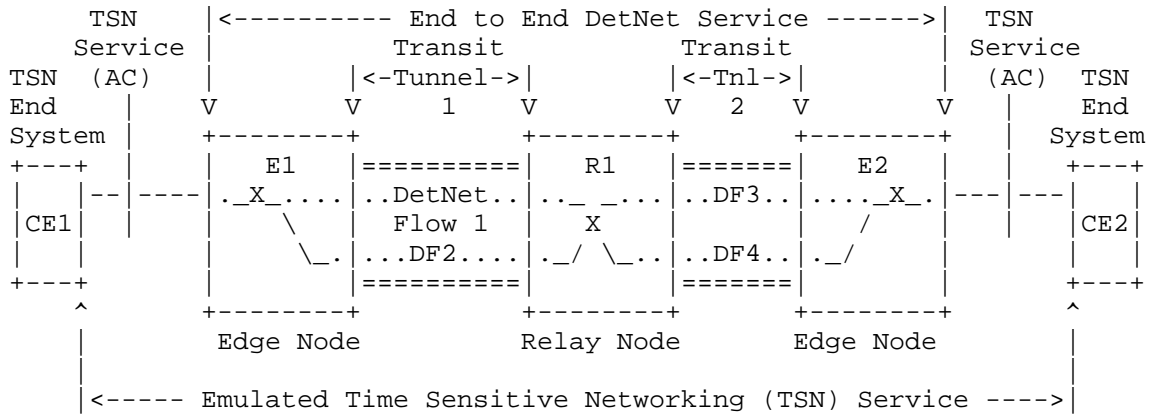


Figure 2: IEEE 802.1TSN over DetNet

Figure 3 illustrates how end to end PW-based DetNet service can be provided. In this case, the end systems are able to send and receive DetNet flows. For example, an end system sends data encapsulated in PseudoWire (PW) and in MPLS. Like earlier the 'X' in the end systems, edge and relay nodes represents potential DetNet flow packet replication and elimination points. Here the relay nodes may change the underlying transport, for example tunneling IP over MPLS, or simply interconnect network segments.

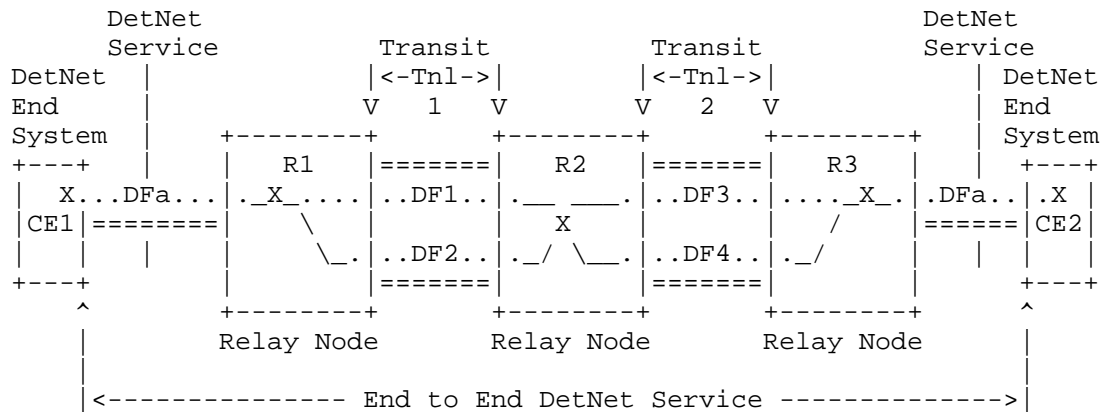


Figure 3: PW-Based Native DetNet

Figure 4 illustrates how end to end IP-based DetNet service can be provided. In this case, the end systems are able to send and receive DetNet flows. [Editor's note: TBD]

NOTE: This figures is TBD

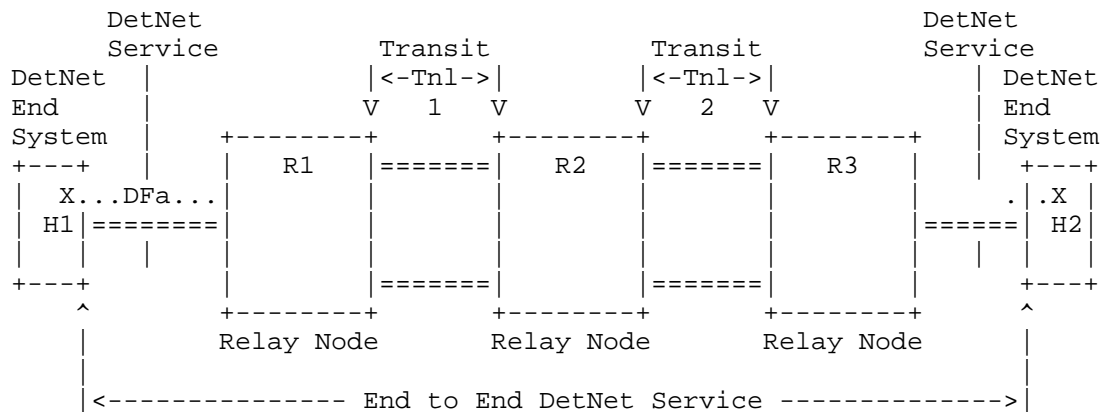


Figure 4: IP-Based Native DetNet

#### 4.1. DetNet data plane encapsulation requirements

Two major groups of scenarios can be distinguished which require flow identification during transport:

1. DetNet function related scenarios:

- \* Congestion protection and latency control: usage of allocated resources (queuing, policing, shaping).
- \* Explicit routes: select/apply the flow specific path.
- \* Service protection: recognize DetNet compound and member flows for replication and elimination.

Comment #12 I am not sure whether the correct architectural construct is flow or flow group. Flow suggests that sharing/aggregation is not allowed but whether this is allowed or not is an application specific issue.

Discussion: Agree that a flow group would be a better characterization.

Comment #13 I think that there needs to be some clarification as to whether FG is understood by the DN system exclusively or whether there is an expectation that it is understood by the underlay.

Discussion: Agree that more detail is needed here. DetNet aware nodes need to understand flow groups. Underlay needs to be aware of flow groups at the resource allocation level.

## 2. OAM function related scenarios:

- \* troubleshooting (e.g., identify misbehaving flows, etc.)
- \* recognize flow(s) for analytics (e.g., increase counters, etc.)
- \* correlate events with flows (e.g., volume above threshold, etc.)
- \* etc.

Each node (edge, relay and transit) use a local-ID of the DetNet-(compound)-flow in order to accomplish its role during transport. Recognizing the DetNet flow is more relaxed for edge and relay nodes, as they are fully aware of both the DetNet service and transport layers. The primary DetNet role of intermediate transport nodes is limited to ensuring congestion protection and latency control for the above listed DetNet functions.

The DetNet data plane allows for the aggregation of DetNet flows, e.g., via MPLS hierarchical LSPs, to improved scaling. When DetNet flows are aggregated, transit nodes may have limited ability to

provide service on per-flow DetNet identifiers. Therefore, identifying each individual DetNet flow on a transit node may not be achieved in some network scenarios, but DetNet service can still be assured in these scenarios through resource allocation and control.

Comment #14 You could introduce the concept of a flow group identified into the packet. You may also include a flow id at a lower layer.

Discussion: Agree on the identification properties. Adding a specific id into actual on-wire formats is not necessarily needed.

On each node dealing with DetNet flows, a local-ID is assumed to determine what local operation a packet goes through. Therefore, local-IDs MUST be unique on each edge and relay nodes. Local-ID MUST be unambiguously bound to the DetNet flow.

Comment #15 I am confused as to what you mean by local ID. Is this an internal construct which packet parameters map to, in which case why is it being called up? IETF practise is to specify on the wire behaviour but not internal behaviour of equipments.

Discussion: Local-id is an internal construct, which was intended to clarify the discussion in the I-D. Obviously it did not work as intended.

## 5. DetNet data plane solution

### 5.1. DetNet specific packet fields

The DetNet data plane encapsulation should include two DetNet specific information element in each packet of a DetNet flow: (1) flow identification and (2) sequence number.

Comment #16 should, SHOULD, must or MUST?

Discussion: SHOULD or MUST is ok. MUST is probably more appropriate.

The DetNet data plane encapsulation may consists further elements used for overlay tunneling, to distinguish between DetNet member flows of the same DetNet compound flow or to support OAM functions.

### 5.2. DetNet encapsulation

This document specifies two encapsulations for the DetNet data plane: (1) PseudoWire (PW) for MPLS PSN and (2) native IPv6 based encapsulation for IP PSN.

### 5.2.1. PseudoWire-based data plane encapsulation

Figure 5 illustrates a DetNet PW encapsulation over an MPLS PSN. The PW-based encapsulation of the DetNet flows fits perfectly for the Layer-2 interconnect deployment cases (see Figure 2). Furthermore, end to end DetNet service i.e., native DetNet deployment (see Figure 3) is also possible if DetNet-aware end systems are capable of initiating and termination MPLS encapsulated PWs. It is also possible use the same encapsulation format with a Packet PW over MPLS [RFC6658]. Transport of IP encapsulated DetNet flows, see Section 5.2.2, over DetNet PWs is also possible. Interworking between PW- and IPv6-based encapsulations is discussed further in Section 7.6.

The PW-based DetNet data plane encapsulation consists of:

- o DetNet control word (d-CW) containing sequencing information for packet replication and duplicate elimination purposes. There is a separate sequence number space for each DetNet flow.
- o PseudoWire Label (PW Label) that is a standard PW label identifying a DetNet flow and a PW Instance within a (DA-)T-PE or (DA-)S-PE device.
- o An optional S-Label that represents DetNet Service LSP used between (DA-)T-PE or (DA-)S-PE nodes. One possible use of an S-Label is to identify the different DetNet member flows used to provide protection to a DetNet composite flow, perhaps even when both LSPs appear on the same link for some reason.

Comment #17 This needs some discussion by the WG.

Discussion: Agree, specifically if the I-D becomes WG document.

- o MPLS transport LSP label(s) (T-label) which may be a hop-by-hop label used between LSRs.

Comment #18 Ordinarily this will of course be PHPed before arrival at an x-PE.

Discussion: In most cases yes - depends on the network configuration. PHP is not mandatory and TP does not even have PHP.

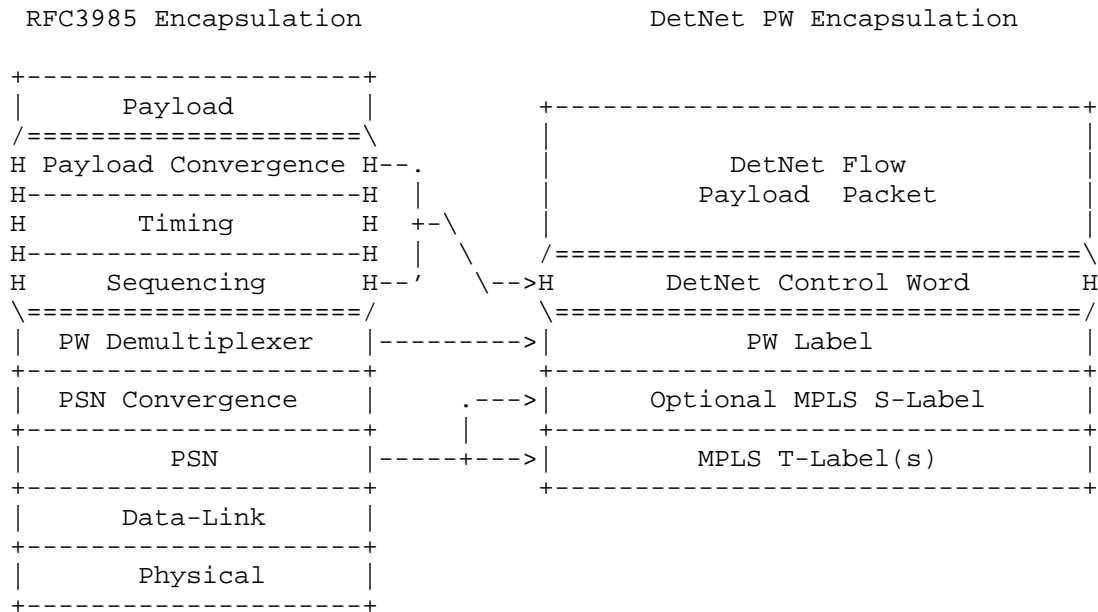


Figure 5: Encapsulation of a DetNet flow in a PW with MPLS(-TP) PSN

The DetNet control word (d-CW) is identical to the control word defined for Ethernet over MPLS networks in [RFC4448]. The DetNet control word is illustrated in Figure 6.

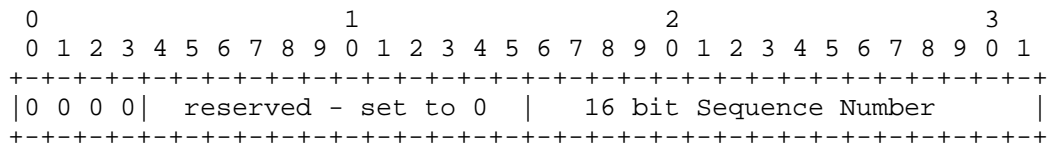


Figure 6: DetNet Control Word

Comment #19 We need to think about whether "identical is the correct term. The Ethernet S/N skips zero (it uses zero to mean no S/N in use). is that the behaviour that we want?

Discussion: Good point. Identical is a wrong statement. The format is the same the behaviour of SN is slightly different as 0 is assumed to be a valid SN.

### 5.2.2. Native IPv6-based data plane encapsulation

Comment #20 SB> This part of the design needs to be marked as provisional until it has a more thorough WG review.

Discussion: Ok, however, this is still an individual I-D.

Figure 7 illustrates a DetNet native IPv6 encapsulation. The native IPv6 encapsulation is meant for end to end Detnet service use cases, where the end stations are DetNet-aware (see Figure 4). Technically it is possible to use the IPv6 encapsulation to tunnel any traffic over a DetNet enabled network, which would make native IPv6 encapsulation also a valid data plane choice for an interconnect use case (see Figure 2).

The native IPv6-based DetNet data plane encapsulation consists of:

- o IPv6 header as the transport protocol.
- o IPv6 header Flow Label that is used to help to identify a DetNet flow (i.e., roughly an equivalent to the PW Label). A Flow Label together with the IPv6 source address uniquely identifies a DetNet flow.

Comment #21 SB> Have we validated that it is unconditionally safe to make this assumption about the use of the FL?

Discussion: RFC6437 does not restrict such use and DetNet DP solution can always define their own use of flow label. It should be noted that a DetNet aware node will always contain new code and is not a load balancer.

- o DetNet Control Word IPv6 Destination Option containing sequencing information for packet replication and duplicate elimination function (PREF) purposes. The DetNet Destination Option is equivalent to the DetNet Control Word.

A DetNet-aware end station (a host) or an intermediate node initiating an IPv6 packet is responsible for setting the Flow Label, adding the required DetNet Destination Option, and possibly adding a routing header such as the segment routing option (for pre-defined paths [I-D.ietf-6man-segment-routing-header]). The payload of the native IPv6 encapsulation is any payload protocol that can be identified using the Next Header field either in the IPv6 packet header or in the last IPv6 extension header.

Comment #22 SB> We will probably need to agree an option ordering, and need to note that the 6man IPv6 solution already operates on the edge of the ability of h/w to see that far into the packet.

Discussion: RFC8200 describes extension header ordering - there is not much to agree there. Agree on the hardware lookup challenges. However, the issues of SR header are not this I-D to fix.

Comment #23 SB> I am not sure the above is needed since it is by definition correct.

Discussion: (next header) agree.

A DetNet-aware end station (a host) or an intermediate node receiving an IPv6 packet destined to it and containing a DetNet Destination Option does the appropriate processing of the packet. This may involve packet duplication and elimination (PREF processing), terminating a tunnel or delivering the packet to the upper layers/Applications.

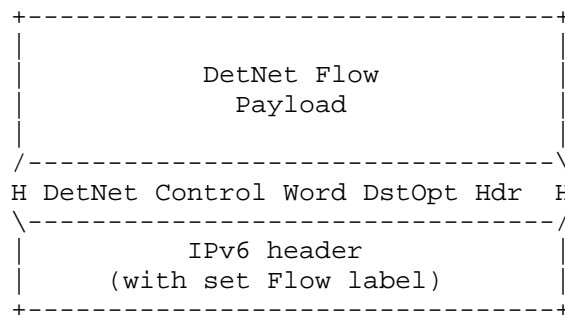


Figure 7: Encapsulation of a native IPv6 DetNet flow

A DetNet flow must carry sequencing information for packet replication and elimination function (PREF) purposes. This document specifies a new IPv6 Destination Option: the DetNet Destination Option for that purpose. The format of the option is illustrated in Figure 8.

Comment #24 SB> Can an SR node look at a DO?

Discussion: Yes.



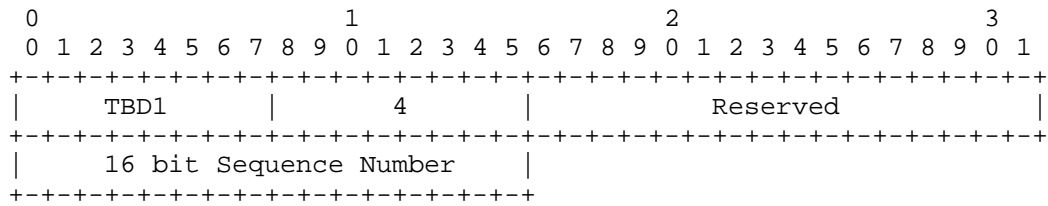


Figure 8: DetNet Destination Option

The Option Type for the DetNet Destination Option is set to TBD1.  
 [To be removed from the final version of the document: The Option Type MUST have the two most significant bits set to 10b]

### 5.3. DetNet flow identification for duplicate detection

Duplicate elimination depends on flow identification. Mapping between packet fields and Local-ID may impact the implementation of duplicate elimination.

Comment #25 SB> So I wonder if the right place to put the FI is in the IPv6 FI, or in the IPv6 address itself?

Discussion: Each flow having different address is challenging if we want to terminate multiple flows into the same node with one address or originate multiple flows from a node with one address (note, we are aware of the one /64 per node discussion but cannot assume it here, at least not yet).

#### 5.3.1. PseudoWire encapsulation

RFC3985 Section 5.2.1. describes PW sequencing provides a duplicate detection service among other things. This specification clarifies this definition as follows:

DetNet flows that need to undergo PREF processing MUST have the same PW Label when they arrive at the DA-\*-PE node.

From the label stack processing point of view receiving the same label from multiple sources is analogous to Fast Reroute backup tunnel behavior [RFC4090]. The PW Label for a DetNet flow can be different on each PW segment.

Comment #26 SB> I am not sure of the utility of this reference. In FRR you should not receive packets concurrently on two paths. It seems fine to state the requirement that a single label is used for both paths.

Discussion: OK with the same label comment. OK to remove the FRR reference here.

#### 5.3.2. Native IPv6 encapsulation

The DetNet flow identification is based on the IPv6 Flow Label and the source address combination. The two fields uniquely identify the end to end native IPv6 encapsulated DetNet flow. Obviously, the identification fails if any intermediate node modifies either the source address or the Flow Label.

Comment #27 SB> See earlier. If there are enough IPv6 addresses to address video fragments, why not DN flows? Then this problem goes away.

Discussion: See the earlier comment #25 discussion. If nodes get their addresses via DHCPv6 basically ruins this mechanism. Also the assumption for this to work is that the node has a full /64 to use, which is not always the case. Otherwise the idea is just fine.

### 6. PREF specific considerations

This section applies equally to DetNet flows transported via IPv6 and MPLS. While flow identification and some header related processing will differ between the two, the considerations covered in this section are common to both.

#### 6.1. PseudoWire-based data plane

##### 6.1.1. Forwarder clarifications

The DetNet specific new functionality in an edge or relay node processing is the packet replication and duplication elimination function (PREF). This function is a part of the DetNet-aware "extended" forwarder. The PREF processing is triggered by the received packet of a DetNet flow.

Comment #28 SB> I am not sure what you mean by triggered here. Hopefully we are not thinking of dataplane triggered configuration?

Discussion: "Initiated" is probably more appropriate wording.

Basically the forwarding entry has to be extended with a "PREF enabled" boolean configuration switch that is associated with the normal forwarding actions (e.g., in case of MPLS a swap, push, pop, ..). The output of the PREF elimination function is always a single

packet. The output of the PREF replication function is always one or more packets (i.e., 1:M replication). The replicated packets MUST share the same DetNet control word sequence number.

The complex part of the DetNet PREF processing is tracking the history of received packets for multiple DetNet member flows. These ingress DetNet member flows (to a node) MUST have the same local-ID if they belong to the same DetNet-(compound)-flow and share the same sequence number counter and the history information.

The edge and relay node internal procedures of the PREF are implementation specific. The order of a packet elimination or replication is out of scope in this specification. However, care should be taken that the replication function does not actually loopback packets as "replicas". Looped back packets include artificial delay when the node that originally initiated the packet receives it again. Also, looped back packets may make the network condition to look healthier than it actually is (in some cases link failures are not reflected properly because looped back packets make the situation appear better than it actually is).

Comment #29: SB> There needs to be some text about preventing a node ever receiving its own replicated packets. Indeed that would suggest that the flow id should be changed and replication should only take place on configured flow IDs. I have a feeling that this would all be a lot safer if replication only happened at ingress and we managed the diversity of the paths.

Discussion: Agree on hardening the loopback text considerations.

#### 6.1.2. Edge node processing clarifications

The DetNet data plane solution overloads the edge node with DetNet Edge Node functions. Edge nodes are also aware of DetNet flows and may need to operate upon those. Figure 9 illustrates the overall edge device functions. The figure shows both physical attachment circuit (AC) (e.g., Ethernet [RFC4448]) connecting to the edge node, and a packet service connecting to the edge node via an embedded router function (similarly as described e.g., in [RFC6658]). Whether traffic flow from a client AC and PSN tunnel receives DetNet specific treatment is up to a local configuration and policy.

Comment #30: SB> Shouldn't the behaviour simply be a property of a given PW?

Discussion: Agree in principle.

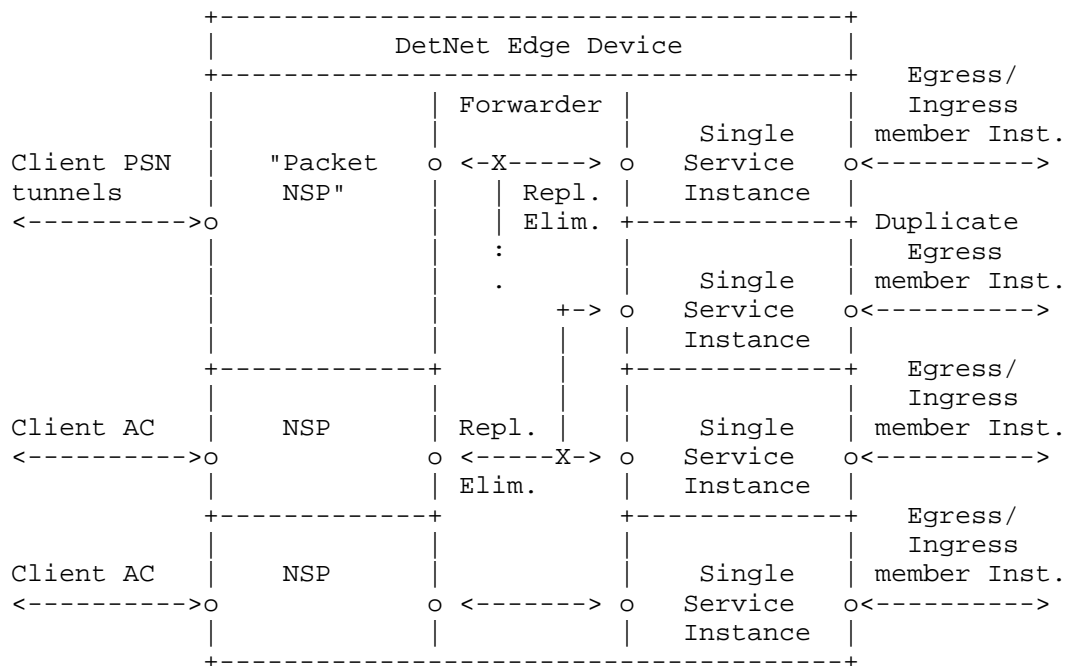


Figure 9: DetNet Edge Node processing

An edge node participates to the packet replication and duplication elimination. Required processing is done within an extended forwarder function. In the case the native service processing (NSP) is IEEE 802.1CB [IEEE8021CB] capable, the packet replication and duplicate elimination MAY entirely be done in the NSP and bypassing the DetNet flow encapsulation and logic entirely, and thus is able to operate over unmodified implementation and deployment. The NSP approach works only between edge nodes and cannot make use of relay nodes (see Section 6.1.3).

Comment #31 SB> This would be a fine way to operate the PW system - edge to edge.

Discussion: When it comes to use of NSPs, agree. Also for "island interconnect" this is a fine. However, when there is a need to do PREF in a middle, plain edge to edge is not enough.

The DetNet-aware extended forwarder selects the egress DetNet member flow based on the DetNet forwarding rules. In both "normal AC" and "Packet AC" cases there may be no DetNet encapsulation header available yet as it is the case with relay nodes (see Section 6.1.3).

It is the responsibility of the extended forwarder within the edge node to push the DetNet specific encapsulation (if not already present) to the packet before forwarding it to the appropriate egress DetNet member flow instance(s).

Comment #32 SB> I am not convinced of the wisdom of having a mid-point node convert a flow into a DN flow, which is what you are implying here. This seems like an ingress function.

Discussion: OK. The text here has issues and seems to mix relay and edge.

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).

#### 6.1.3. Relay node processing clarifications

The DetNet data plane solution overloads a relay node with DetNet Relay node functions. Relay node is aware of DetNet flows and may operate upon those. Figure 10 illustrates the overall DetNet relay device functions.

Comment #33 SB> I don't think that a relay node is not a normal construct so I am not sure "overload" is the right term here.

Discussion: Agree. There is a terminology issue here.

A DetNet Relay node participates to the packet replication and duplication elimination. This processing is done within an extended forwarder function. Whether an ingress DetNet member flow receives DetNet specific processing depends on how the forwarding is programmed. For some DetNet member flows the relay node can act as a normal relay node and for some apply the DetNet specific processing (i.e., PREF).

Comment #34 SB> Again relay node is not a normal term, so am not sure what it does in the absence of a PREF function.

Discussion: Relay node was a DetNet aware S-PE originally, which is not explicitly stated here anymore, thus slightly confusing text here. The text here needs to clarify the roles of PREF and switching functions. A DetNet relay is described in the

architecture document. However, there is definitely room for terminology and text improvements.

It is also possible to treat the relay node as a transit node, see Section 7.3. Again, this is entirely up to how the forwarding has been programmed.

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.

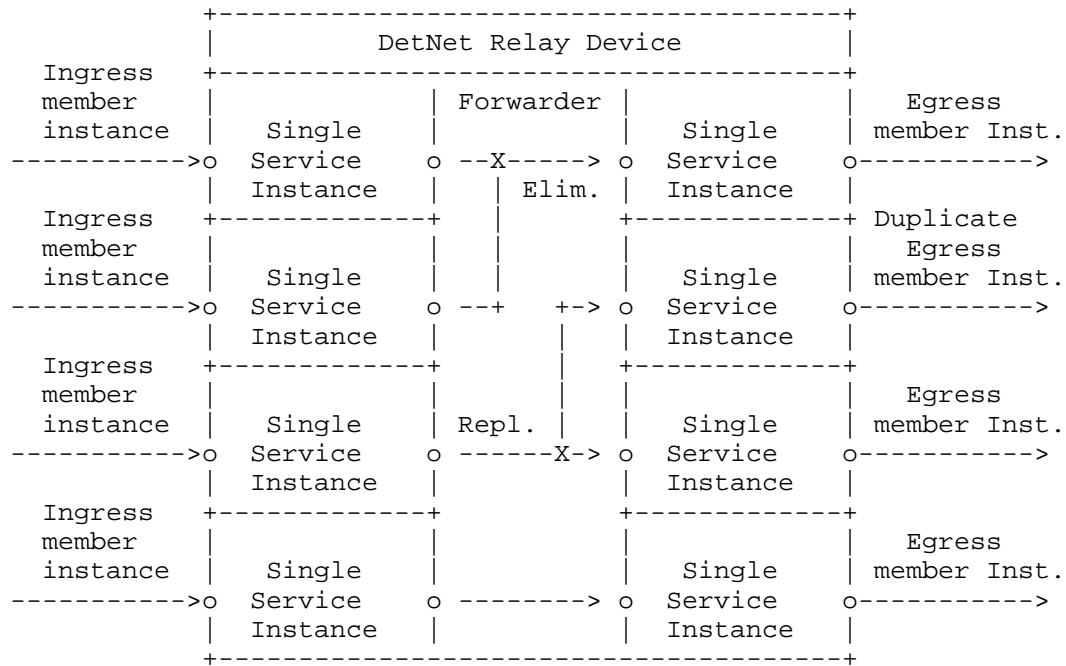


Figure 10: DetNet Relay Node processing

Comment #35 SB> Somewhere in the dp document there needs to be a note of the requirement for interfaces to do fast exchange of counter state, and a note to those planning the network and

designing the control plane that they need to provide support for this.

Discussion: We kind of agree but also think the above exchange or synchronization of counter states is not in our scope to solve.

## 6.2. Native IPv6-based data plane

[Editor's note: this section is TBD.]

## 7. Other DetNet data plane considerations

### 7.1. Class of Service

Class and quality of service, i.e., CoS and QoS, are terms that are often used interchangeably and confused. In the context of DetNet, CoS is used to refer to mechanisms that provide traffic forwarding treatment based on aggregate group basis and QoS is used to refer to mechanisms that provide traffic forwarding treatment based on a specific DetNet flow basis. Examples of existing network level CoS mechanisms include DiffServ which is enabled by IP header differentiated services code point (DSCP) field [RFC2474] and MPLS label traffic class field [RFC5462], and at Layer-2, by IEEE 802.1p priority code point (PCP).

CoS for DetNet flows carried in PWs and MPLS is provided using the existing MPLS Differentiated Services (DiffServ) architecture [RFC3270]. Both E-LSP and L-LSP MPLS DiffServ modes MAY be used to support DetNet flows. The Traffic Class field (formerly the EXP field) of an MPLS label follows the definition of [RFC5462] and [RFC3270]. The Uniform, Pipe, and Short Pipe DiffServ tunneling and TTL processing models are described in [RFC3270] and [RFC3443] and MAY be used for MPLS LSPs supporting DetNet flows. MPLS ECN MAY also be used as defined in ECN [RFC5129] and updated by [RFC5462].

CoS for DetNet flows carried in IPv6 is provided using the standard differentiated services code point (DSCP) field [RFC2474] and related mechanisms. The 2-bit explicit congestion notification (ECN) [RFC3168] field MAY also be used.

One additional consideration for DetNet nodes which support CoS services is that they MUST ensure that the CoS service classes do not impact the congestion protection and latency control mechanisms used to provide DetNet QoS. This requirement is similar to requirement for MPLS LSRs to that CoS LSPs do not impact the resources allocated to TE LSPs via [RFC3473].

## 7.2. Quality of Service

Quality of Service (QoS) mechanisms for flow specific traffic treatment typically includes a guarantee/agreement for the service, and allocation of resources to support the service. Example QoS mechanisms include discrete resource allocation, admission control, flow identification and isolation, and sometimes path control, traffic protection, shaping, policing and remarking. Example protocols that support QoS control include Resource ReSerVation Protocol (RSVP) [RFC2205] (RSVP) and RSVP-TE [RFC3209] and [RFC3473]. The existing MPLS mechanisms defined to support CoS [RFC3270] can also be used to reserve resources for specific traffic classes.

In addition to path pinning and packet replication and elimination, described in Section 5 above, DetNet provides zero congestion loss and bounded latency and jitter.

Comment #36 SB> I just searched from the beginning of the document and this was the the first reference I found to pinning.

Discussion: Terminology isssue. Should use, for example, explicit paths which is used in the architecture I-D.

As described in [I-D.ietf-detnet-architecture], there are different mechanisms that maybe used separately or in combination to deliver a zero congestion loss service. These mechanisms are provided by the either the MPLS or IP layers, and may be combined with the mechanisms defined by the underlying network layer such as 802.1TSN.

A baseline set of QoS capabilities for DetNet flows carried in PWS and MPLS can provided by MPLS with Traffic Engineering (MPLS-TE) [RFC3209] and [RFC3473]. TE LSPs can also support explicit routes (path pinning). Current service definitions for packet TE LSPs can be found in "Specification of the Controlled Load Quality of Service", [RFC2211], "Specification of Guaranteed Quality of Service", [RFC2212], and "Ethernet Traffic Parameters", [RFC6003]. Additional service definitions are expected in future documents to support the full range of DetNet services. In all cases, the existing label-based marking mechanisms defined for TE-LSPs and even E-LSPs are use to support the identification of flows requiring DetNet QoS.

QoS for DetNet flows carried in IPv6 MUST be provided locally by the DetNet-aware hosts and routers supporting DetNet flows. Such support will leverage the underlying network layer such as 802.1TSN. The traffic control mechanisms used to deliver QoS for IP encapsulated DetNet flows are expected to be defined in a future document. From an encapsulation perspective, and as defined in Section 5.2.2, the



combination of the Flow Label together with the IP source address uniquely identifies a DetNet flow.

Packets that are marked with a DetNet Class of Service value, but that have not been the subject of a completed reservation, can disrupt the QoS offered to properly reserved DetNet flows by using resources allocated to the reserved flows. Therefore, the network nodes of a DetNet network SHOULD:

Comment #37 SB> Why not MUST?

Discussion: OK with MUST.

- o Defend the DetNet QoS by discarding or remarking (to a non-DetNet CoS) packets received that are not the subject of a completed reservation.
- o Not use a DetNet reserved resource, e.g. a queue or shaper reserved for DetNet flows, for any packet that does not carry a DetNet Class of Service marker.

### 7.3. Cross-DetNet flow resource aggregation

The ability to aggregate individual flows, and their associated resource control, into a larger aggregate is an important technique for improving scaling of control in the data, management and control planes. This document identifies the traffic identification related aspects of aggregation of DetNet flows. The resource control and management aspects of aggregation (including the queuing/shaping/policing implications) will be covered in other documents. The data plane implications of aggregation are independent for PW/MPLS and IP encapsulated DetNet flows.

DetNet flows transported via MPLS can leverage MPLS-TE's existing support for hierarchical LSPs (H-LSPs), see [RFC4206]. H-LSPs are typically used to aggregate control and resources, they may also be used to provide OAM or protection for the aggregated LSPs. Arbitrary levels of aggregation naturally falls out of the definition for hierarchy and the MPLS label stack [RFC3032]. DetNet nodes which support aggregation (LSP hierarchy) map one or more LSPs (labels) into and from an H-LSP. Both carried LSPs and H-LSPs may or may not use the TC field, i.e., L-LSPs or E-LSPs. Such nodes will need to ensure that traffic from aggregated LSPs are placed (shaped/policed/enqueued) onto the H-LSPs in a fashion that ensures the required DetNet service is preserved.

DetNet flows transported via IP have more limited aggregation options, due to the available traffic flow identification fields of

the IP solution. One available approach is to manage the resources associated with a DSCP identified traffic class and to map (remark) individually controlled DetNet flows onto that traffic class. This approach also requires that nodes support aggregation ensure that traffic from aggregated LSPs are placed (shaped/policed/enqueued) in a fashion that ensures the required DetNet service is preserved.

Comment #38 SB> I am sure we can do better than this with SR, or the use of routing techniques that map certain addresses to certain paths.

Discussion: --

In both the MPLS and IP cases, additional details of the traffic control capabilities needed at a DetNet-aware node may be covered in the new service descriptions mentioned above or in separate future documents. Management and control plane mechanisms will also need to ensure that the service required on the aggregate flow (H-LSP or DSCP) are provided, which may include the discarding or remarking mentioned in the previous sections.

#### 7.4. Bidirectional traffic

Some DetNet applications generate bidirectional traffic. Using MPLS definitions [RFC5654] there are associated bidirectional flows, and co-routed bidirectional flows. MPLS defines a point-to-point associated bidirectional LSP as consisting of two unidirectional point-to-point LSPs, one from A to B and the other from B to A, which are regarded as providing a single logical bidirectional transport path. This would be analogous of standard IP routing, or PWs running over two reciprocal unidirection LSPs. MPLS defines a point-to-point co-routed bidirectional LSP as an associated bidirectional LSP which satisfies the additional constraint that its two unidirectional component LSPs follow the same path (in terms of both nodes and links) in both directions. An important property of co-routed bidirectional LSPs is that their unidirectional component LSPs share fate. In both types of bidirectional LSPs, resource allocations may differ in each direction. The concepts of associated bidirectional flows and co-routed bidirectional flows can be applied to DetNet flows as well whether IPv6 or MPLS is used.

While the IPv6 and MPLS data planes must support bidirectional DetNet flows, there are no special bidirectional features with respect to the data plane other than need for the two directions take the same paths. Fate sharing and associated vs co-routed bidirectional flows can be managed at the control level. Note, that there is no stated requirement for bidirectional DetNet flows to be supported using the same IPv6 Flow Labels or MPLS Labels in each direction. Control

mechanisms will need to support such bidirectional flows for both IPv6 and MPLS, but such mechanisms are out of scope of this document. An example control plane solution for MPLS can be found in [RFC7551].

#### 7.5. Layer 2 addressing and QoS Considerations

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 IPv6 encapsulations.

#### 7.6. Interworking between PW- and IPv6-based encapsulations

[Editor's note: add considerations for interworking between PW-based and native IPv6-based DetNet encapsuations.]

#### 8. Time synchronization

Comment #39 SB> This section should point the reader to RFC8169 (residence time in MPLS n/w. We need to consider if we need to introduce the same concept in IP.

Discussion: agree.

[Editor's note: describe a bit of issues and deployment considerations related to time-synchronization within DetNet. Refer to DT discussion and the slides that summarize different approaches and rough synchronization performance numbers. Finally, scope time-synchronization solution outside data plane.]

When DetNet is used, there is an underlying assumption that the application(s) require clock synchronization such as the Precision Time Protocol (PTP) [IEEE1588]. The relay nodes may or may not utilize clock synchronization in order to provide zero congestion loss and controlled latency delivery. In either case, there are a few possible approaches of how synchronization protocol packets are forwarded and handled by the network:

- o PTP packets can be sent either as DetNet flows or as high-priority best effort packets. Using DetNet for PTP packets requires careful consideration to prevent unwanted interactions between clock-synchronized network nodes and the packets that synchronize the clocks.
- o PTP packets are sent as a normal DetNet flow through network nodes that are not time-synchronized: in this approach PTP traffic is forwarded as a DetNet flow, and as such it is forwarded in a way that allows a low delay variation. However, since intermediate nodes do not take part in the synchronization protocol, this approach provides a relatively low degree of accuracy.
- o PTP with on-path support: in this approach PTP packets are sent as ordinary or as DetNet flows, and intermediate nodes take part in the protocol as Transparent Clocks or Boundary Clocks [IEEE1588]. The on-path PTP support by intermediate nodes provides a higher degree of accuracy than the previous approach. The actual accuracy depends on whether all intermediate nodes are PTP-capable, or only a subset of them.
- o Time-as-a-service: in this approach accurate time is provided as-a-service to the DetNet source and destination, as well as the intermediate nodes. Since traffic between the source and destination is sent over a provider network, if the provider supports time-as-a-service, then accurate time can be provided to both the source and the destination of DetNet traffic. This approach can potentially provide the highest degree of accuracy.

It is expected that the latter approach will be the most common one, as it provides the highest degree of accuracy, and creates a layer separation between the DetNet data and the synchronization service.

It should be noted that in all four approaches it is not recommended to use replication and elimination for synchronization packets; the replication/elimination approach may in some cases reduce the synchronization accuracy, since the observed path delay will be bivalent.

Comment #40 SB> I am not sure why we should not use PREP. We should explain to the reader.

Discussion: Agree that a this can be opened a bit more in detail. The issue is explained briefly in the last sentence but it could be more clear.

## 9. Management and control considerations

While management plane and control planes are traditionally considered separately, from the Data Plane perspective there is no practical difference based on the origin of flow provisioning information. This document therefore does not distinguish between information provided by a control plane protocol, e.g., RSVP-TE [RFC3209] and [RFC3473], or by a network management mechanisms, e.g., RestConf [RFC8040] and YANG [RFC7950].

[Editor's note: This section is a work in progress. discuss here what kind of enhancements are needed for DetNet and specifically for PREP and DetNet zero congest loss and latency control. Need to cover both traffic control (queuing) and connection control (control plane).]

### 9.1. PW Label and IPv6 Flow Label assignment and distribution

The PW label distribution follows the same mechanisms specified for MS-PW [RFC6073]. The details of the control plane protocol solution required for the label distribution and the management of the label number space are out of scope of this document.

The IPv6 Flow Label distribution and the label number space are out of scope of this document. However, it should be noted that the combination of the IPv6 source address and the IPv6 Flow Label is assumed to be unique within the DetNet-enabled network. Therefore, as long as each node is able to assign unique Flow Labels for the source address(es) it is using the DetNet-enabled network wide flow identification uniqueness is guaranteed.

## 9.2. Packet replication and elimination

The control plane protocol solution required for managing the PREF processing is outside the scope of this document.

## 9.3. Explicit paths

[TBD: based on MPLS TE and SR.]

## 9.4. Congestion protection and latency control

[TBD]

## 9.5. Flow aggregation control

[TBD]

## 10. 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.

## 11. IANA considerations

TBD.

## 12. Acknowledgements

The author(s) ACK and NACK.

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#### Appendix A. Example of DetNet data plane operation

[Editor's note: Add a simplified example of DetNet data plane and how labels etc work in the case of MPLS-based PSN and utilizing PREF. The figure is subject to change depending on the further DT decisions on the label handling..]

Appendix B. Example of pinned paths using IPv6

TBD.

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