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Deterministic Networking (DetNet) Data Plane: IP over IEEE 802.1 Time-Sensitive Networking (TSN)

Abstract

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

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Table of Contents

1. Introduction

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

[RFC8939] specifies the DetNet data plane operation for IP hosts and routers that provide DetNet service to IP-encapsulated data. This document focuses on the scenario where DetNet IP nodes are interconnected by a Time-Sensitive Networking (TSN) sub-network.

The DetNet Architecture decomposes the DetNet-related data plane functions into two sub-layers: a service sub-layer and a forwarding sub-layer. The service sub-layer is used to provide DetNet service protection and reordering. The forwarding sub-layer is used to provide congestion protection (low loss, assured latency, and limited reordering). As described in [RFC8939], no DetNet-specific headers are added to support DetNet IP flows. So, only the forwarding sub-layer functions can be supported inside the DetNet IP domain. Service protection can be provided on a per-sub-network basis as shown here for the IEEE 802.1 TSN sub-network scenario.

2. Terminology

2.1. Terms Used in This Document

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

2.2. Abbreviations

The following abbreviations are used in this document:

DetNet Deterministic Networking

FRER Frame Replication and Elimination for Redundancy (TSN function)

L2 Layer 2

L3 Layer 3

TSN Time-Sensitive Networking; TSN is a Task Group of the IEEE 802.1 Working Group.

3. DetNet IP Data Plane Overview

[RFC8939] describes how IP is used by DetNet nodes, i.e., hosts and routers, to identify DetNet flows and provide a DetNet service. From a data plane perspective, an end-to-end IP model is followed. DetNet uses flow identification based on a "6-tuple", where "6-tuple" refers to information carried in IP- and higher-layer protocol headers as defined in [RFC8939].

DetNet flow aggregation may be enabled via the use of wildcards, masks, prefixes, and ranges. IP tunnels may also be used to support flow aggregation. In these cases, it is expected that DetNet-aware intermediate nodes will provide DetNet service assurance on the aggregate through resource allocation and congestion control mechanisms.

Congestion protection, latency control, and the resource allocation (queuing, policing, and shaping) are supported using the underlying link / sub-net-specific mechanisms. Service protections (packet-replication and packet-elimination functions) are not provided at the IP DetNet layer end to end due to the lack of unified end-to-end sequencing information that would be available for intermediate nodes. However, such service protection can be provided per underlying L2 link and per sub-network.

DetNet routers ensure that DetNet service requirements are met per hop by allocating local resources, by both receiving and transmitting, and by mapping the service requirements of each flow to appropriate sub-network mechanisms. Such mappings are sub-network technology specific. DetNet nodes interconnected by a TSN sub-network are the primary focus of this document. The mapping of DetNet IP flows to TSN Streams and TSN protection mechanisms are covered in Section 4.

4. DetNet IP Flows over an IEEE 802.1 TSN Sub-network

This section covers how DetNet IP flows operate over an IEEE 802.1 TSN sub-network. Figure 1 illustrates such a scenario where two IP (DetNet) nodes are interconnected by a TSN sub-network. Dotted lines around the Service components of the IP (DetNet) nodes indicate that they are DetNet service aware but do not perform any DetNet service sub-layer function. Node-1 is single homed and Node-2 is dual homed to the TSN sub-network, and they are treated as Talker or Listener inside the TSN sub-network. Note that from the TSN perspective, dual-homed characteristics of Talker or Listener nodes are transparent to the IP Layer.

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

   ............                  ............
<--: Service  :-- DetNet flow ---: Service  :-->
   +----------+                  +----------+
   |Forwarding|                  |Forwarding|
   +--------.-+    <-TSN Str->   +-.-----.--+
             \      ,-------.     /     /
              +----[ TSN Sub-]---+     /
                   [ Network ]--------+
                    `-------'
<----------------- DetNet IP ----------------->
```

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

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

TSN capabilities of the TSN sub-network are made available for IP (DetNet) flows via the protocol interworking function described in Annex C.5 of [IEEE8021CB]. For example, applied on the TSN edge port it can convert an ingress unicast IP (DetNet) flow to use a specific L2 multicast destination Media Access Control (MAC) address and a VLAN in order to forward the packet through a specific path inside the bridged network. A similar interworking function pair at the other end of the TSN sub-network would restore the packet to its original L2 destination MAC address and VLAN.

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

4.1. Functions for DetNet Flow to TSN Stream Mapping

Mapping of a DetNet IP flow to a TSN Stream is provided via the combination of a passive and an active Stream identification function that operate at the frame level (Layer 2). The passive Stream identification function is used to catch the 6-tuple of a DetNet IP flow, and the active Stream identification function is used to modify the Ethernet header according to the ID of the mapped TSN Stream.

Clause 6.7 of [IEEE8021CB] defines an IP Stream identification function that can be used as a passive function for IP DetNet flows using UDP or TCP. Clause 6.8 of [IEEEP8021CBdb] defines a Mask-and-Match Stream identification function that can be used as a passive function for any IP DetNet flows.

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

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

4.2. TSN Requirements of IP DetNet Nodes

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

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

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

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

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

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

Figure 2: IP (DetNet) Node with TSN Functions

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

A Stream identification component must be able to instantiate the following: (1) Active Destination MAC and VLAN Stream identification, (2) IP Stream identification, (3) Mask-and-Match Stream identification, and (4) the related managed objects in Clause 9 of [IEEE8021CB] and [IEEEP8021CBdb].

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

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

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

4.3. Service Protection within the TSN Sub-network

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

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

4.4. Aggregation during DetNet Flow to TSN Stream Mapping

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

5. Management and Control Implications

DetNet flows and TSN Stream-mapping-related information are required only for TSN-aware IP (DetNet) nodes. From the data plane perspective, there is no practical difference based on the origin of flow-mapping-related information (management plane or control plane).

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

- DetNet-IP-related configuration information according to the DetNet role of the DetNet IP node, as per [RFC8939].
- TSN-related configuration information according to the TSN role of the DetNet IP node, as per [IEEE8021Q], [IEEE8021CB], and [IEEEP8021CBdb].
- Mapping between DetNet IP flow(s) and TSN Stream(s). DetNet IP flow identification is summarized in Section 5.1 of [RFC8939] and includes all wildcards, port ranges, and the ability to ignore specific IP fields. Information on TSN Stream identification information is defined in [IEEE8021CB] and [IEEEP8021CBdb]. Note that managed objects for TSN Stream identification can be found in [IEEEP8021CBcv].

This information must be provisioned per DetNet flow.

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

TSN-aware IP DetNet nodes are members of both the DetNet domain and the TSN sub-network. Within the TSN sub-network, the TSN-aware IP (DetNet) node has a TSN-aware Talker/Listener role, so TSN-specific management and control plane functionalities must be implemented. There are many similarities in the management plane techniques used in DetNet and TSN, but that is not the case for the control plane protocols. For example, RSVP-TE and the Multiple Stream Registration Protocol (MSRP) of IEEE 802.1 behave differently. Therefore, management and control plane design is an important aspect of scenarios where mapping between DetNet and TSN is required.

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

In some cases, it may be challenging to determine some TSN Stream-related information. For example, on a TSN-aware IP (DetNet) node that acts as a Talker, it is quite obvious which DetNet node is the Listener of the mapped TSN Stream (i.e., the IP next-hop). However, it may not be trivial to locate the point/interface where that Listener is connected to the TSN sub-network. Such attributes may require interaction between control and management plane functions and between DetNet and TSN domains.

Mapping between DetNet flow identifiers and TSN Stream identifiers, if not provided explicitly, can be done by a TSN-aware IP (DetNet) node locally based on information provided for configuration of the TSN Stream identification functions (IP Stream identification, Mask-and-Match Stream identification, and the active Stream identification function).

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

Configuration of TSN-specific functions (e.g., FRER) inside the TSN sub-network is a TSN-domain-specific decision and may not be visible in the DetNet domain.

6. Security Considerations

Security considerations for DetNet are described in detail in [DETNET-SECURITY]. General security considerations are described in [RFC8655]. Considerations specific to the DetNet IP data plane are summarized in [RFC8939]. This section discusses security considerations that are specific to the DetNet IP-over-TSN sub-network scenario.

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

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

7. IANA Considerations

This document has no IANA actions.

8. References

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