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MPLS Network Action for Deterministic Latency
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Abstract

This document specifies formats and principles for the MPLS Network Action for Deterministic Latency to provide guaranteed latency services. They are used to make scheduling decisions for time-sensitive services running on Deterministic Network (DetNet) nodes that operate within a single or multiple domains.

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1. Introduction

[RFC8655] defines Deterministic Network (DetNet) architecture. The overall framework for DetNet data plane is introduced in [RFC8938]. Deterministic Networking (DetNet) operates at the IP layer and delivers services with low data loss rates and bounded latency guarantee within a network domain.

[RFC8964] introduces the DetNet MPLS data plane technology, providing a foundation of building blocks to enable PREOF (Packet Replication, Elimination and Ordering Functions (PREOF)) functions to the DetNet service sub-layer and forwarding sub-layer. The DetNet service sub-layer includes a DetNet Control Word (d-CW), service label (S-Label), and aggregation label (A-Label) in special case of S-Label used for aggregation. The DetNet forwarding sub-layer supports one or more forwarding labels (F-Labels) to forward a DetNet flow over MPLS domains. The DetNet forwarding sub-layer provides corresponding forwarding assurance with resource allocations and explicit routes.

To support time-sensitive services with ultra-low loss rates and deterministic latency, feasible scheduling mechanisms must be applied to specific applications for deterministic networking. As described in [RFC9320], the end-to-end bounded latency is the sum of non-queuing and queuing delay bounds along with the queuing mechanisms.

The queuing mechanisms, as mentioned in [RFC9320] and [RFC8655], which include Time Aware Shaping IEEE802.1Qbv, Asynchronous Traffic Shaping IEEE802.1Qcr, cyclic-scheduling queuing mechanism proposed in IEEE802.1Qch. In terms of delay guarantee for different applications, selecting the right scheduling/queuing mechanism applied to a specific application is required. Based on the existing DetNet MPLS encapsulations and mechanisms [RFC8964], the document defines the encoding format for the Deterministic Latency Network Action (DLNA) option in the MPLS data plane.

But with DetNet network scaling up or flows number increased in the same work, some enhanced data plane requirements for DetNet network are brought, which are described at the [I-D.ietf-detnet-scaling-requirements]. This document follows the enhanced data plane requirements and introduces the MPLS Network Actions (MNA) solution to address the requirements specified in section 4.2 of [I-D.ietf-detnet-scaling-requirements]. The deterministic network should support synchronized or asynchronized queuing mechanisms. Different queuing mechanisms require different information to be defined as the DetNet-specific metadata to help ensure deterministic latency, including regulation, queue management, etc.

The use case Delay Budgets for Time Bound Applications are under discussion in the MPLS MNA [I-D.ietf-mpls-mna-usecases] document. MPLS Network Actions (MNA) indicate actions for LSPs and/or MPLS packets and transfer data needed for these actions. [I-D.ietf-mpls-mna-hdr] defined the MNA solution for carrying Network Actions with Sub-Stack Data and associated Ancillary Data (AD) (i.e., in the MPLS label stack).

This document presents one MPLS MNA solution for Deterministic Latency. It follows the MPLS MNA requirements specified at [I-D.ietf-mpls-mna-requirements] and MPLS MNA header specifid at [I-D.ietf-mpls-mna-hdr] to support basic DetNet service and DetNet service with enhanced DetNet data plane requirements specified at [I-D.ietf-detnet-scaling-requirements] .

2. Conventions

2.1. 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.

2.2. Terminology

Refer to [RFC8655], [RFC8964], [I-D.ietf-mpls-mna-hdr], [I-D.ietf-mpls-mna-fwk], [I-D.ietf-mpls-mna-requirements] and [RFC9320] for the key terms used in this document.

Deterministic Latency (DL): The ability to precisely determine the delay in the network from source to destination(s). The delay is variable and depends on the queuing mechanisms used for network flows and the operations of the network nodes. The delay variation is acceptable but should be bounded and measurable.

Deterministic Latency Network Action (DLNA): Used to indicate deterministic latency network action for MPLS data plane.

3. Enhanced Deterministic Network Requirements

3.1. Queuing Delay

[RFC8655] provides the architecture for deterministic networking (DetNet), which enables the service delivery of DetNet flows with extremely low packet loss rates and deterministic latency. The forwarding sub-layer provides corresponding forwarding assurance but can not provide the deterministic latency (including bounded latency, low packet loss and in-order delivery). As described at [RFC9320], the end-to-end bounded latency for one DetNet flow is the sum of the delay bound of non-queuing and queuing processing latency. The delay bound for non-queuing processing may include output delay, link delay, frame preemption delay, and processing delay, the delay bound for queuing processing may include regulator delay, queuing delay. It is assumed that the delay of non-queuing processing is fixed or be ignorable, the delay of queuing processing is variable. To realize the guarantee of bounded latency service, it is important to select the right queuing methodology applied to specific applications and carry necessary queuing delay information for the computation of end-to-end latency.

The existing switches and routers have the ability to classify traffic and provide independent queuing mechanisms based on Class of Service (CoS) that CoS is used in the Priority Code Point (PCP) field of the 802.1Q, DSCP field in IPv4 header and Traffic Class field in IPv6 field. CoS defines the priority levels of traffic and QoS uses these CoS values to handle traffic to optimize traffic transmission. To achieve deterministic/bounded latency service requirements, the queuing mechanisms, as mentioned in [RFC9320] and [RFC8655], Time Aware Shaping IEEE802.1Qbv, Asynchronous Traffic Shaping IEEE802.1Qcr, cyclic-scheduling queuing mechanism proposed in IEEE802.1Qc are used in single or multiple domains network.

3.2. Deterministic Latency

The DetNet data plane encapsulation in the transport network using the MPLS data plane is specified in [RFC8964]. A deterministic latency option is required to address the DetNet scaling question and support the enhanced data plane requirements described at [I-D.ietf-detnet-scaling-requirements]. The option should include end-to-end and hop-by-hop processing of packets to be adaptive to different queuing mechanisms in DetNet networks.

The DetNet routers in the data plane perform MPLS forwarding functions using a feasible way with sufficient network resources for the incoming packets and make the right selection on the queuing or scheduling mechanisms applied for specific DetNet flows to satisfy strict deterministic service criteria in the forwarding output port. The queuing or scheduling mechanism information is carried in the MPLS header. Refer to [I-D.stein-srtsn], considering the time latency information is processed per hop so that the time latency information (such as deadline time, cycle identify, etc.) of each DetNet node for DetNet flows is expected to be carried as a set of lists of LSEs in MPLS data plane.

4. MPLS Extensions for Deterministic Latency

This document provides an optional MNA header to address enhanced DetNet data plane requirements described at [I-D.ietf-detnet-scaling-requirements] to support different deterministic service categories such as bandwidth guarantee, bounded latency, loss ratio guarantee, etc.

4.1. Enhanced DetNet MPLS Header for Deterministic Latency

To support deterministic bounded latency service, this document introduces an MNA option for Deterministic Latency Network Action (DLNA). As shown in Figure 1, the MNA label is inserted to indicate the presence of MPLS Network Actions. The format for DLNA follows the DetNet data plane MPLS encapsulation specified at [RFC8964] and MNA encapsulation specified in [I-D.ietf-mpls-mna-hdr] and [I-D.ietf-mpls-mna-fwk], which is comprised of a set of Label Stack

Entries (LSEs) that carry the DLNA Indicator and Ancillary Data to perform DLNA actions for MPLS packets.

```
        +----------------------------+
        |          Physical          |
        +----------------------------+
        |          Data-Link         |
        +----------------------------+<-\-- Top of Stack
        |         F-Label(s)         |  |
        +----------------------------+  | DetNet
        |          MNA Label         |  | Data Plane
        +----------------------------+  | MPLS Encapsulation
        |            DLNA            |  |
        +----------------------------+  |
        |           S-Label          |  |
        +----------------------------+  |
        |     DetNet Control Word    |  |
        +----------------------------+<-/-- Bottom of Stack
        |       DetNet App-Flow      |
        |          Payload           |
        +----------------------------+
```

Figure 1: Enhanced DetNet MPLS Header for Deterministic Latency

As defined in [RFC8964], the DetNet functionality PREOF (Packet Replication, Elimination and Ordering Functions) is supported through d-CW,S-label and F-label. The queue mechanism for DetNet networks is expected to use the existing COS mechanism, such as PCP for VLAN, DSCP for IPv4, Traffic Class for IPv6. The S-lable is at the bottom of MPLS label stack and is normally followed by d-CW (DetNet Control-Word, i.e., sequence number). The S-label is used to identify DetNet service-type. F-lable(s) identify explicit route and allocated resources for DetNet nodes, the route schedule and resource reservation are achieved via provision by the controller. D-CW (i.e., sequence number) is used for the ordering function of DetNet packets. To support backward compatibility, the aspects (DetNet d-CW, S-label, F-label and A-label) are kept shown in MPLS sub-stack but outside of MPLS MNA sub-stack. The base DetNet data plane MPLS encapsulation follows specification at [RFC8964]. For base DetNet services, it’s assumed that the requirements can be satisfied via deploying CoS mechanisms (i.e., PCP for VLAN, DSCP for IPv4 and Traffic Class for IPv6) to DetNet network nodes.

For enhanced DetNet services, enhanced queuing mechanisms are expected to be deployed, and the queueing information may be carried in data packets. The enhanced DetNet data plane requirements are specified in [I-D.ietf-detnet-scaling-requirements]. To support enhanced deterministic services, strict queuing technologies may be required for DetNet devices. Its related latency requirements may involve different categories: (1) Industrial, tight jitter, strict latency limit; (2) Industrial, strict latency limit; (3) Non-periodic, relatively loose latency requirements; (4) Best effort. And different network implementations require different SLA requirements with different queueing mechanisms implemented in single or multiple network domains.

4.2. Deterministic Latency Network Action

The Deterministic Latency Network Action Sub-Stack format for MNA is shown in Figure 2. The network action follows LSE format C to carry DLNA Opcode and LSE format D for Additional Data as specified in [I-D.ietf-mpls-mna-hdr].

```
 0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             |                         |R|IHS|S|U|  NASL | NAL |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| DLNA Opcode1|       A-Latency Data        |S|U|  Data | NAL |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| DLNA Opcode2|        Latency Data         |S|U|  Data | NAL |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1|               Latency Data              |S|    Data       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: DLNA Sub-Stack

As specified in [I-D.ietf-mpls-mna-hdr], The header for MPLS Sub-Stack Network Action encodes:

R (1 bit) : Reserved bit. This MUST be transmitted as zero and ignored upon receipt.

IHS (2 bits) : The processing scope of the sub-stack. The IHS scope values refer to [I-D.ietf-mpls-mna-hdr]. The filed is set as 00 for End-to-End processing and 01 for Hop-By-Hop processing.

S (1 bit) : The Bottom of Stack [RFC3032].

U (1 bit): Unknown Action Handling. This field MUST be transmited as zero and ignore upon receipt.

NASL (4 bits) : The Network Action Sub-Stack Length (NASL). The number of additional LSEs in the sub-stack, not including the leading Format A LSE and the Format B LSE.

DLNA Opcode1 (7 bits): This is the first 7-bit value in the Label Field. The value is used to indicate DLNA network action with aggregated service and to be assigned by IANA as value TBA1. The field is only set when an A-Label exits.

DLNA Opcode2 (7 bits): This is the second 7-bit value in the Label Field. The value is used to indicate DLNA network action with individual service and to be assigned by IANA as value TBA2.

A-Latency Data (20 bits): A-latency data is used for time recording corresponding to DetNet A-Label services, which helps with the selection of underlying queues and network resources associated with DetNet aggregated flows.

Latency Data: It is used for time recording corresponding to DetNet S-Label for individual flows.

The ancillary data carried in Format D LSE is not mandatory. In common DetNet scenario (i.e., not network topo at scale or network flows at scale), the traditional mechanisms such as DSCP and Traffic Class are used for queue processing. The basic DetNet functionality PREOF (Packet Replication, Elimination and Ordering Functions) is supported through sequence number and S-label and the aggregated flow function is supported via MPLS A-label. In this case, the DLNA is assumed to be the only MNA data carried in LSE format B. The value for Opcode in Format B LSE will be set as 2 and not perform the DLNA network action.

The Deterministic Latency Data speicification refers to [RFC9320] and [I-D.ietf-detnet-dataplane-taxonomy], which introduces DetNet Bounded Latency Model. To support deterministic latency services the latency variation across the DetNet-aware or DetNet-unaware islands should be bounded and computable. The Deterministic Latency Bound of End-to-End and each nodes along with the DetNet flows should be included. It is important to select the right queuing method applied to specific applications and carry necessary queuing delay information in data plane. And network delay is related to network topology scale and network flows scale, hop counts for delay assessment is an important factor. The possible parameters for latency data carried in Format C and D LSE is showed as Figure 3.

```
 0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1|              Timestamp                   |S|   Timestamp   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: Ancillary Data Format

Packet-by-packet load-sharing e.g., via ECMP is not utilized in DETNET [RFC8938], Section 3.5.1.5, hence timestamp can be added in In-Stack Data as label stack will not be used for hashing.

Timestamps are used to record key time points such as when a packet is generated and when it enters the network. This enables network nodes to calculate the transmission duration based on these timestamps, and then determine whether the delay requirements are met. According to the urgency of the service, combined with queue mechanisms (such as CQF, TAS, etc.), the network nodes will prioritize the processing of packets in the high-priority queues.

5. IANA Considerations

This document requests one new IANA-managed code-point for Deterministic Latency processing. IANA maintains the "Network Action Opcodes" registry when created from IANA request in [I-D.ietf-mpls-mna-hdr]. IANA is requested to allocate a value for MPLS Network Action Opcode for Deterministic Latency Network Action from this registry:

Value	Description	Reference
TBA1	DLNA Opcode1	This document
TBA2	DLNA Opcode2	This document

Table 1: MPLS Network Action Opcode for Deterministic Latency

6. Security Considerations

Security considerations for DetNet are covered in the DetNet Architecture [RFC8655], DetNet Data Plane Framework [RFC8938] and DetNet Security Considerations [RFC9055]. MPLS security considerations are covered in [RFC8964], [RFC3031], [RFC3032]. These security considerations also apply to this document. The MNA security considerations speicified at [I-D.ietf-mpls-mna-hdr] and [I-D.ietf-mpls-mna-fwk] are also applicable to the procedures defined in this document.

7. Acknowledgements

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