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Framework of Operations, Administration and Maintenance (OAM) for

Deterministic Networking (DetNet)

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Abstract

Deterministic Networking (DetNet), as defined in RFC 8655, is aimed

to provide a bounded end-to-end latency on top of the network

infrastructure, comprising both Layer 2 bridged and Layer 3 routed

segments. This document's primary purpose is to detail the specific

requirements of the Operation, Administration, and Maintenance (OAM)

recommended to maintain a deterministic network. With the

implementation of the OAM framework in DetNet, an operator will have

a real-time view of the network infrastructure regarding the

network's ability to respect the Service Level Objective, such as

packet delay, delay variation, and packet loss ratio, assigned to

each DetNet flow.

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Mirsky, et al. Expires 13 February 2022 [Page 1]

Internet-Draft Framework of OAM for DetNet August 2021

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Table of Contents

1. Introduction . . . . . . . . . . . . . . . . . . . . . . . . 3

1.1. Terminology . . . . . . . . . . . . . . . . . . . . . . . 3

1.2. Acronyms . . . . . . . . . . . . . . . . . . . . . . . . 4

1.3. Requirements Language . . . . . . . . . . . . . . . . . . 5

2. Role of OAM in DetNet . . . . . . . . . . . . . . . . . . . . 5

3. Operation . . . . . . . . . . . . . . . . . . . . . . . . . . 6

3.1. Information Collection . . . . . . . . . . . . . . . . . 7

3.2. Continuity Check . . . . . . . . . . . . . . . . . . . . 7

3.3. Connectivity Verification . . . . . . . . . . . . . . . . 7

3.4. Route Tracing . . . . . . . . . . . . . . . . . . . . . . 8

3.5. Fault Verification/detection . . . . . . . . . . . . . . 8

3.6. Fault Localization and Characterization . . . . . . . . . 8

3.7. Use of Hybrid OAM in DetNet . . . . . . . . . . . . . . . 9

4. Administration . . . . . . . . . . . . . . . . . . . . . . . 9

4.1. Collection of metrics . . . . . . . . . . . . . . . . . . 10

4.2. Worst-case metrics . . . . . . . . . . . . . . . . . . . 10

5. Maintenance . . . . . . . . . . . . . . . . . . . . . . . . . 10

5.1. Replication / Elimination . . . . . . . . . . . . . . . . 10

5.2. Resource Reservation . . . . . . . . . . . . . . . . . . 11

5.3. Soft transition after reconfiguration . . . . . . . . . . 11

6. Requirements . . . . . . . . . . . . . . . . . . . . . . . . 11

6.1. Requirements on OAM for DetNet Service Sub-layer . . . . 13

7. IANA Considerations . . . . . . . . . . . . . . . . . . . . . 13

8. Security Considerations . . . . . . . . . . . . . . . . . . . 13

9. Acknowledgments . . . . . . . . . . . . . . . . . . . . . . . 13

10. References . . . . . . . . . . . . . . . . . . . . . . . . . 13

10.1. Normative References . . . . . . . . . . . . . . . . . . 14

10.2. Informative References . . . . . . . . . . . . . . . . . 14

Authors' Addresses . . . . . . . . . . . . . . . . . . . . . . . 15

Mirsky, et al. Expires 13 February 2022 [Page 2]

Internet-Draft Framework of OAM for DetNet August 2021

1. Introduction

Deterministic Networking (DetNet) [RFC8655] has proposed to provide a

bounded end-to-end latency on top of the network infrastructure,

comprising both Layer 2 bridged and Layer 3 routed segments. That

work encompasses the data plane, OAM, time synchronization,

management, control, and security aspects.

Operations, Administration, and Maintenance (OAM) Tools are of

primary importance for IP networks [RFC7276]. DetNet OAM should

provide a toolset for fault detection, localization, and performance

measurement.

This document's primary purpose is to detail the specific

requirements of the OAM features recommended to maintain a

deterministic/reliable network. Specifically, it investigates the

requirements for a deterministic network, supporting critical flows.

In this document, the term OAM will be used according to its

definition specified in [RFC6291]. DetNet expects to implement an

OAM framework to maintain a real-time view of the network

infrastructure, and its ability to respect the Service Level

Objectives (SLO), such as in-order packet delivery, packet delay,

delay variation, and packet loss ratio, assigned to each DetNet flow.

This document lists the functional requirements toward OAM for DetNet

domain. The list can further be used for gap analysis of available

OAM tools to identify possible enhancements of existing or whether

new OAM tools are required to support proactive and on-demand path

monitoring and service validation.

1.1. Terminology

This document uses definitions, particularly of a DetNet flow,

provided in Section 2.1 [RFC8655]. The following terms are used

throughout this document as defined below:

\* DetNet OAM domain: a DetNet network used by the monitored DetNet

flow. A DetNet OAM domain (also referred to in this document as

"OAM domain") may have MEPs on its edge and MIPs within.

\* DetNet OAM instance: a function that monitors a DetNet flow for

defects and/or measures its performance metrics. Within this

document, a shorter version, OAM instance, is used

interchangeably.

Mirsky, et al. Expires 13 February 2022 [Page 3]

Internet-Draft Framework of OAM for DetNet August 2021

\* Maintenance End Point (MEP): an OAM instance that is capable of

generating OAM test packets in the particular sub-layer of the

DetNet OAM domain.

\* Maintenance Intermediate endPoint (MIP): an OAM instance along the

DetNet flow in the particular sub-layer of the DetNet OAM domain.

A MIP MAY respond to an OAM message generated by the MEP at its

sub-layer of the same DetNet OAM domain.

\* Control and management plane: the control and management planes

are used to configure and control the network (long-term).

Relative to a DetNet flow, the control and/or management plane can

be out-of-band.

\* Active measurement methods (as defined in [RFC7799]) modify a

DetNet flow by inserting novel fields, injecting specially

constructed test packets [RFC2544]).

\* Passive measurement methods [RFC7799] infer information by

observing unmodified existing flows.

\* Hybrid measurement methods [RFC7799] is the combination of

elements of both active and passive measurement methods.

\* In-band OAM is an active OAM is considered in-band in the

monitored DetNet OAM domain when it traverses the same set of

links and interfaces receiving the same QoS and Packet

Replication, Elimination, and Ordering Functions (PREOF) treatment

as the monitored DetNet flow.

\* Out-of-band OAM is an active OAM whose path through the DetNet

domain is not topologically identical to the path of the monitored

DetNet flow, or its test packets receive different QoS and/or

PREOF treatment, or both.

\* On-path telemetry can be realized as a hybrid OAM method. The

origination of the telemetry information is inherently in-band as

packets in a DetNet flow are used as triggers. Collection of the

on-path telemetry information can be performed using in-band or

out-of-band OAM methods.

1.2. Acronyms

OAM: Operations, Administration, and Maintenance

DetNet: Deterministic Networking

PREOF: Packet Replication, Elimination and Ordering Functions

Mirsky, et al. Expires 13 February 2022 [Page 4]

Internet-Draft Framework of OAM for DetNet August 2021

SLO: Service Level Objective

1.3. 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.

2. Role of OAM in DetNet

DetNet networks expect to provide communications with predictable low

packet delay and packet loss. Most critical applications will define

an SLO to be required for the DetNet flows it generates.

To respect strict guarantees, DetNet can use an orchestrator able to

monitor and maintain the network. Typically, a Software-Defined

Network (SDN) controller places DetNet flows in the deployed network

based on their SLO. Thus, resources have to be provisioned a priori

for the regular operation of the network. OAM represents the

essential elements of the network operation and necessary for OAM

resources that need to be accounted for to maintain the network

operational.

Many legacy OAM tools can be used in DetNet networks, but they are

not able to cover all the aspects of deterministic networking.

Fulfilling strict guarantees is essential for DetNet flows, resulting

in new DetNet specific functionalities that must be covered with OAM.

Filling these gaps is inevitable and needs accurate consideration of

DetNet specifics. Similar to DetNet flows itself, their OAM needs

careful end-to-end engineering as well.

For example, appropriate placing of MEPs along the path of a DetNet

flow is not always a trivial task and may require proper design

together with the design of the service component of a given DetNet

flow.

There are several DetNet specific challenges for OAM. Bounded

network characteristics (e.g., delay, loss) are inseparable service

parameters; therefore, PM is a key topic for DetNet. OAM tools are

needed to prove the SLO without impacting the DetNet flow

characteristics. A further challenge is the strict resource

allocation. Resources used by OAM must be considered and allocated

to avoid disturbing DetNet flow(s).

The DetNet Working Group has defined two sub-layers:

Mirsky, et al. Expires 13 February 2022 [Page 5]

Internet-Draft Framework of OAM for DetNet August 2021

DetNet service sub-layer, at which a DetNet service (e.g., service

protection) is provided.

DetNet forwarding sub-layer, which optionally provides resource

allocation for DetNet flows over paths provided by the underlying

network.

OAM mechanisms exist for the DetNet forwarding sub-layer,

nonetheless, OAM for the service sub-layer requires new OAM

procedures. These new OAM functions must allow, for example, to

recognize/discover DetNet relay nodes, to get information about their

configuration, and to check their operation or status.

DetNet service sub-layer functions using a sequence number. That

creates a challenge for inserting OAM packets in the DetNet flow.

Fault tolerance also assumes that multiple paths could be provisioned

to maintain an end-to-end circuit by adapting to the existing

conditions. The central controller/orchestrator typically controls

the PREOF on a node. OAM is expected to support monitoring and

troubleshooting PREOF on a particular node and within the domain.

Note that distributed controllers can also control PREOF in those

scenarios where DetNet solutions involve more than one single central

controller.

DetNet forwarding sub-layer is based on legacy technologies and has a

much better coverage regarding OAM. However, the forwarding sub-

layer is terminated at DetNet relay nodes, so the end-to-end OAM

state of forwarding may be created only based on the status of

multiple forwarding sub-layer segments serving a given DetNet flow

(e.g., in case of DetNet MPLS, there may be no end-to-end LSP below

the DetNet PW).

3. Operation

OAM features will enable DetNet with robust operation both for

forwarding and routing purposes.

It is worth noting that the test and data packets MUST follow the

same path, i.e., the connectivity verification has to be conducted

in-band without impacting the data traffic. Test packets MUST share

fate with the monitored data traffic without introducing congestion

in normal network conditions.

Mirsky, et al. Expires 13 February 2022 [Page 6]

Internet-Draft Framework of OAM for DetNet August 2021

3.1. Information Collection

Information about the state of the network can be collected using

several mechanisms. Some protocols, e.g., Simple Network Management

Protocol, send queries. Others, e.g., YANG-based data models,

generate notifications based on the publish-subscribe method. In

either way, information is collected and sent to the controller.

Also, we can characterize methods of transporting OAM information

relative to the path of data. For instance, OAM information may be

transported in-band or out-of-band relative to the DetNet flow. In

case of the former, the telemetry information uses resources

allocated for the monitored DetNet flow. If an in-band method of

transporting telemetry is used, the amount of generated information

needs to be carefully analyzed, and additional resources must be

reserved. [I-D.ietf-ippm-ioam-data] defines the in-band transport

mechanism where telemetry information is collected in the data packet

on which information is generated. Two tracing methods are described

- end-to-end, i.e., from the ingress and egress nodes, and hop-by-

hop, i.e., like end-to-end with additional information from transit

nodes. [I-D.ietf-ippm-ioam-direct-export] and

[I-D.mirsky-ippm-hybrid-two-step] are examples of out-of-band

telemetry transport. In the former case, information is transported

by each node traversed by the data packet of the monitored DetNet

flow in a specially constructed packet. In the latter, information

is collected in a sequence of follow-up packets that traverse the

same path as the data packet of the monitored DetNet flow. In both

methods, transport of the telemetry can avoid using resources

allocated for the DetNet domain.

3.2. Continuity Check

Continuity check is used to monitor the continuity of a path, i.e.,

that there exists a way to deliver the packets between two MEP A and

MEP B. The continuity check detects a network failure in one

direction, from the MEP transmitting test packets to the remote

egress MEP.

3.3. Connectivity Verification

In addition to the Continuity Check, DetNet solutions have to verify

the connectivity. This verification considers additional

constraints, i.e., the absence of misconnection. The misconnection

error state is entered after several consecutive test packets from

other DetNet flows are received. The definition of the conditions of

entry and exit for misconnection error state is outside the scope of

this document.

Mirsky, et al. Expires 13 February 2022 [Page 7]

Internet-Draft Framework of OAM for DetNet August 2021

3.4. Route Tracing

Ping and traceroute are two ubiquitous tools that help localize and

characterize a failure in the network. They help to identify a

subset of the list of routers in the route. However, to be

predictable, resources are reserved per flow in DetNet. Thus, DetNet

needs to define route tracing tools able to track the route for a

specific flow. Also, tracing can be used for the discovery of the

Path Maximum Transmission Unit or location of elements of PREOF for

the particular route in the DetNet domain.

DetNet is NOT RECOMMENDED to use multiple paths or links, i.e.,

Equal-Cost Multipath (ECMP) [RFC8939]. As the result, OAM in ECMP

environment is outside the scope of this document.

3.5. Fault Verification/detection

DetNet expects to operate fault-tolerant networks. Thus, mechanisms

able to detect faults before they impact the network performance are

needed.

The network has to detect when a fault occurred, i.e., the network

has deviated from its expected behavior. While the network must

report an alarm, the cause may not be identified precisely. For

instance, the end-to-end reliability has decreased significantly, or

a buffer overflow occurs.

DetNet OAM mechanisms SHOULD allow a fault detection in real time.

They MAY, when possible, predict faults based on current network

conditions. They MAY also identify and report the cause of the

actual/predicted network failure.

3.6. Fault Localization and Characterization

An ability to localize the network defect and provide its

characterization are necessary elements of network operation.

Fault localization, a process of deducing the location of a

network failure from a set of observed failure indications, might

be achieved, for example, by tracing the route of the DetNet flow

in which the network failure was detected. Another method of

fault localization can correlate reports of failures from a set of

interleaving sessions monitoring path continuity.

Fault characterization is a process of identifying the root cause

of the problem. For instance, misconfiguration or malfunction of

PREOF elements can be the cause of erroneous packet replication or

extra packets being flooded in the DetNet domain.

Mirsky, et al. Expires 13 February 2022 [Page 8]

Internet-Draft Framework of OAM for DetNet August 2021

3.7. Use of Hybrid OAM in DetNet

Hybrid OAM methods are used in performance monitoring and defined in

[RFC7799] as:

Hybrid Methods are Methods of Measurement that use a combination

of Active Methods and Passive Methods.

A hybrid measurement method may produce metrics as close to passive,

but it still alters something in a data packet even if that is the

value of a designated field in the packet encapsulation. One example

of such a hybrid measurement method is the Alternate Marking method

(AMM) described in [RFC8321]. As with all on-path telemetry methods,

AMM in a DetNet domain with the IP data plane is natively in-band in

respect to the monitored DetNet flow. Because the marking is applied

to a data flow, measured metrics are directly applicable to the

DetNet flow. AMM minimizes the additional load on the DetNet domain

by using nodal collection and computation of performance metrics in

combination with optionally using out-of-band telemetry collection

for further network analysis.

4. Administration

The network SHOULD expose a collection of metrics to support an

operator making proper decisions, including:

\* Queuing Delay: the time elapsed between a packet enqueued and its

transmission to the next hop.

\* Buffer occupancy: the number of packets present in the buffer, for

each of the existing flows.

The following metrics SHOULD be collected:

\* per a DetNet flow to measure the end-to-end performance for a

given flow. Each of the paths has to be isolated in multipath

routing strategies.

\* per path to detect misbehaving path when multiple paths are

applied.

\* per device to detect misbehaving device, when it relays the

packets of several flows.

Mirsky, et al. Expires 13 February 2022 [Page 9]

Internet-Draft Framework of OAM for DetNet August 2021

4.1. Collection of metrics

DetNet OAM SHOULD optimize the number of statistics / measurements to

collected, frequency of collecting. Distributed and centralized

mechanisms MAY be used in combination. Periodic and event-triggered

collection information characterizing the state of a network MAY be

used.

4.2. Worst-case metrics

DetNet aims to enable real-time communications on top of a

heterogeneous multi-hop architecture. To make correct decisions, the

controller needs to know the distribution of packet losses/delays for

each flow, and each hop of the paths. In other words, the average

end-to-end statistics are not enough. The collected information must

be sufficient to allow the controller to predict the worst-case.

5. Maintenance

In the face of events that impact the network operation (e.g., link

up/down, device crash/reboot, flows starting and ending), the DetNet

Controller need to perform repair and re-optimization actions in

order to permanently ensure the SLO of all active flows with minimal

waste of resources The controller MUST be able to continuously

retrieve the state of the network, to evaluate conditions and trends

about the relevance of a reconfiguration, quantifying:

the cost of the sub-optimality: resources may not be used

optimally (e.g., a better path exists).

the reconfiguration cost: the controller needs to trigger some

reconfigurations. For this transient period, resources may be

twice reserved, and control packets have to be transmitted.

Thus, reconfiguration may only be triggered if the gain is

significant.

5.1. Replication / Elimination

When multiple paths are reserved between two MEPs, packet replication

may be used to introduce redundancy and alleviate transmission errors

and collisions. For instance, in Figure 1, the source device S is

transmitting the packet to both parents, devices A and B. Each MEP

will decide to trigger the packet replication, elimination or the

ordering process when a set of metrics passes a threshold value.

Mirsky, et al. Expires 13 February 2022 [Page 10]

Internet-Draft Framework of OAM for DetNet August 2021

===> (A) => (C) => (E) ===

// \\// \\// \\

source (S) //\\ //\\ (R) (root)

\\ // \\ // \\ //

===> (B) => (D) => (F) ===

Figure 1: Packet Replication: S transmits twice the same data

packet, to DP(A) and AP (B).

5.2. Resource Reservation

Because the quality of service criteria associated with a path may

degrade, the network has to provision additional resources along the

path. We need to provide mechanisms to patch the network

configuration.

5.3. Soft transition after reconfiguration

Since DetNet expects to support real-time flows, DetNet OAM MUST

support soft-reconfiguration, where the the additional resources are

reserved before the those previously reserved but not in use are

released. Some mechanisms have to be proposed so that packets are

forwarded through the novel track only when the resources are ready

to be used, while maintaining the global state consistent (no packet

reordering, duplication, etc.)

6. Requirements

This section lists requirements for OAM in a DetNet domain:

1. It MUST be possible to initiate a DetNet OAM session from a MEP

located at a DetNet node towards downstream MEP(s) within the

given domain at a particular DetNet sub-layer. [Ed.note: FT: A

MEP may be inside the detnet domain: for instance, for PREOF, an

OAM session may be maintained between any pair of replicator /

eliminator / egress / ingress.]

2. It MUST be possible to initialize a DetNet OAM session from a

centralized controller.

3. DetNet OAM MUST support proactive and on-demand OAM monitoring

and measurement methods.

4. DetNet OAM MUST support unidirectional OAM methods, continuity

check, connectivity verification, and performance measurement.

Mirsky, et al. Expires 13 February 2022 [Page 11]

Internet-Draft Framework of OAM for DetNet August 2021

5. OAM methods MAY combine in-band monitoring or measurement in the

forward direction and out-of-bound notification in the reverse

direction, i.e., towards the ingress MEP.

6. DetNet OAM MUST support bi-directional DetNet flows.

7. DetNet OAM MAY support bi-directional OAM methods for

bidirectional DetNet flows. OAM test packets used for

monitoring and measurements MUST be in-band in both directions.

8. DetNet OAM MUST support proactive monitoring of a DetNet device

reachability for a given DetNet flow.

9. DetNet OAM MUST support Path Maximum Transmission Unit

discovery.

10. DetNet OAM MUST support the discovery of PREOF along a route in

the given DetNet domain.

11. DetNet OAM MUST support Remote Defect Indication (RDI)

notification to the DetNet OAM instance performing continuity

checking.

12. DetNet OAM MAY support hybrid performance measurement methods.

13. DetNet OAM MUST support unidirectional performance measurement

methods. Calculated performance metrics MUST include but are

not limited to throughput, packet loss, out of order, delay and

delay variation metrics. [RFC6374] provides detailed

information on performance measurement and performance metrics.

14. DetNet OAM MUST be able to measure metrics (e.g. delay) inside a

collection of OAM sessions, specially for complex DetNet flows,

with PREOF features.

15. DetNet OAM MUST support defect notification mechanism, like

Alarm Indication Signal. Any DetNet device within the given

DetNet flow MAY originate a defect notification addressed to any

subset of DetNet devices within that flow.

16. DetNet OAM MUST support methods to enable availability of the

DetNet domain. These recovery methods MAY use protection

switching and restoration.

17. DetNet OAM MUST support the discovery of Packet Replication,

Elimination, and Order preservation sub-functions locations in

the domain.

Mirsky, et al. Expires 13 February 2022 [Page 12]

Internet-Draft Framework of OAM for DetNet August 2021

18. DetNet OAM MUST support testing of Packet Replication,

Elimination, and Order preservation sub-functions in the domain.

19. DetNet OAM MUST support monitoring levels of resources allocated

for the particular DetNet flow. Such resources include but not

limited to buffer utilization, scheduler transmission calendar.

20. DetNet OAM MUST support monitoring any sub-set of paths

traversed through the DetNet domain by the DetNet flow.

6.1. Requirements on OAM for DetNet Service Sub-layer

The OAM functions for the DetNet service sub-layer allow, for

example, to recognize/discover DetNet relay nodes, to get information

about their configuration, and to check their operation or status.

The requirements on OAM for a DetNet relay node are:

1. DetNet OAM MUST provide OAM functions for the DetNet service sub-

layer.

2. DetNet OAM MUST support the discovery of DetNet relay nodes in a

DetNet network.

3. DetNet OAM MUST support the collection of the DetNet service sub-

layer specific (e.g., configuration/operation/status) information

from DetNet relay nodes.

4. DetNet OAM MUST work for DetNet data planes - MPLS and IP.

7. IANA Considerations

This document has no actionable requirements for IANA. This section

can be removed before the publication.

8. Security Considerations

This document lists the OAM requirements for a DetNet domain and does

not raise any security concerns or issues in addition to ones common

to networking and those specific to a DetNet discussed in [RFC9055].

9. Acknowledgments

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Mirsky, et al. Expires 13 February 2022 [Page 13]

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Mirsky, et al. Expires 13 February 2022 [Page 14]

Internet-Draft Framework of OAM for DetNet August 2021

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Mirsky, et al. Expires 13 February 2022 [Page 15]

Internet-Draft Framework of OAM for DetNet August 2021

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Mirsky, et al. Expires 13 February 2022 [Page 16]