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                                                   April 15, 2014

                  Loss and Delay Measurement in
        Transparent Interconnection of Lots of Links (TRILL)
                 <draft-ietf-trill-loss-delay-03.txt>

Abstract

   Performance Monitoring (PM) is a key aspect of Operations,
   Administration and Maintenance (OAM). It allows network operators to
   verify the Service Level Agreement (SLA) provided to customers, and
   to detect network anomalies. This document specifies mechanisms for
   Loss Measurement and Delay Measurement in TRILL networks.

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1. **Introduction**

   TRILL [RFCTRILL] is a protocol for transparent least cost routing,
   where RBridges route traffic to their destination based on least
   cost, using a TRILL encapsulation header with a hop count.

   Operations, Administration and Maintenance (OAM) [OAM] is a set of
   tools for detecting, isolating and reporting connection failures and
   performance degradation. Performance Monitoring (PM) is a key aspect
   of OAM. PM allows network operators to detect and debug network
   anomalies and incorrect behavior. PM consists of two main building
   blocks - Loss Measurement and Delay Measurement. PM may also include
   other derived metrics such as Packet Delivery Rate, and Inter-Frame
   Delay Variation.

   The requirements of OAM in TRILL networks are defined in [OAM-REQ],
   and the TRILL OAM framework is described in [OAM-FRAMEWK]. These two
   documents also highlight the main requirements in terms of
   performance monitoring.

   This document defines protocols for loss measurement and for delay
   measurement in TRILL networks. These protocols generally conform to
   the performance monitoring functionality defined in ITU-T
   G.8013/Y.1731 [Y.1731].

   o Loss Measurement: the Loss Measurement protocol measures packet
     loss between two RBridges. The measurement is performed by sending
     a set of synthetic packets, and counting the number of packets
     transmitted and received during the test. The frame loss is
     calculated by comparing the numbers of transmitted and received
     packets. This provides a statistical estimate of the packet loss
     between the involved RBridges, with a margin of error that can be
     controlled by varying the number of transmitted synthetic packets.
     This document does not define procedures for packet loss
     computation based on counting user data. For further details see
     [OAM-FRAMEWK].

   o Delay Measurement: the Delay Measurement protocol measures the
     packet delay and packet delay variation between two RBridges. The
     measurement is performed using timestamped OAM messages.

2. Conventions Used in this Document

2.1. Keywords

   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 [KEYWORDS].

   The requirement level of PM in [OAM-REQ] is 'SHOULD'. Nevertheless,
   this memo uses the entire range of requirement levels, including
   'MUST'; the requirements in this memo are to be read as 'A MEP
   (Maintenance End Point) that implements TRILL PM
   MUST/SHOULD/MAY/...'.

2.2. Definitions

   o One-way packet delay - (based on [IPPM-1DM]) the time elapsed from
     the start of transmission of the first bit of a packet by an
     RBridge until the reception of the last bit of the packet by the
     remote RBridge.

   o Two-way packet delay - (based on [IPPM-2DM]) the time elapsed from
     the start of transmission of the first bit of a packet from the
     local RBridge, receipt of the packet at the remote RBridge, the
     remote RBridge sending a response packet back to the local RBridge
     and the local RBridge receiving the last bit of that response
     packet.

o Packet loss - (based on [IPPM-Loss]) the number of packets sent by
  a source RBridge and not received by the destination Rbridge.
  In the context of this document, packet loss is measured at a
  specific probe instance, and a specific observation period.
  As in [Y.1731], this document distinguishes between near-end and
  far-end packet loss. Note that this semantic distinction specifies
  the direction of packet loss, but does not affect the nature of
  the packet loss metric, which is defined in [IPPM-Loss].

o Far-end packet loss - the number of packets lost on the path from
  the local RBridge to the remote RBridge in a specific probe
  instance, and a specific observation period.

o Near-end packet loss - the number of packets lost on the path from
  the remote RBridge to the local RBridge in a specific probe
  instance, and a specific observation period.

2.3. Abbreviations

1DM   One-way Delay Measurement message

1SL   One-way Synthetic Loss Measurement message

DMM   Delay Measurement Message

DMR   Delay Measurement Reply

FGL   Fine Grained Label [RFC-FGL]

MD   Maintenance Domain

MD-L   Maintenance Domain Level

MEP   Maintenance End Point

MIP   Maintenance Intermediate Point

MP   Maintenance Point

OAM   Operations, Administration and Maintenance

PM   Performance Monitoring

SLM   Synthetic Loss Measurement Message

SLR   Synthetic Loss Measurement Reply

   TLV   Type, Length and Value

   TRILL   Transparent Interconnection of Lots of Links [RFCTRILL]

3. Loss and Delay Measurement in the TRILL Architecture

   As described in [OAM-FRAMEWK], OAM protocols in a TRILL campus
   operate over two types of Maintenance Points (MPs): Maintenance End
   Points (MEPs) and Maintenance Intermediate Points (MIPs).

```
        +-------+     +-------+     +-------+
        |       |     |       |     |       |
        |  RB1  |<===>|  RB3  |<===>|  RB2  |
        |       |     |       |     |       |
        +-------+     +-------+     +-------+
          MEP           MIP           MEP
```
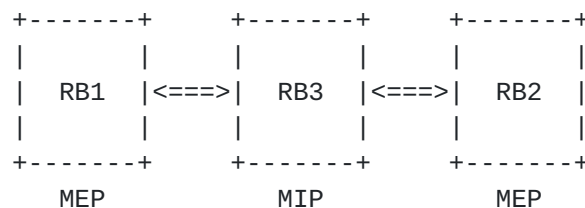
            Figure 1 Maintenance Points in a TRILL Campus

   Performance Monitoring (PM) allows a MEP to perform loss and delay
   measurements to any other MEP in the campus. Performance Monitoring
   is performed in the context of a specific Maintenance Domain (MD).

   The PM functionality defined in this document is not applicable to
   MIPs.

3.1. Performance Monitoring Granularity

   As defined in [OAM-FRAMEWK], PM can be applied at three levels of
   granularity: 'Network', 'Service' and 'Flow'.

   o Network-level PM: the PM protocol is run over a dedicated test
      VLAN or FGL [RFC-FGL].

   o Service-level PM: the PM protocol is used to perform measurements
      of actual user VLANs or FGL.

   o Flow-level PM: the PM protocol is used to perform measurements on
      a per-flow basis. A flow, as defined in [OAM-REQ], is a set of
      packets that share the same path and per-hop behavior (such as
      priority). As defined in [OAM-FRAMEWK], flow-based monitoring uses
      a Flow Entropy field that resides at the beginning of the OAM
      packet header (see Section 6.1.), and mimics the forwarding
      behavior of the monitored flow.

3.2. One-Way vs. Two-Way Performance Monitoring

Paths in a TRILL network are not necessarily symmetric, that is, a packet sent from RB1 to RB2 does not necessarily traverse the same set of RBridges or links as a packet sent from RB2 to RB1. Even within a given flow, packets from RB1 to RB2 do not necessarily traverse the same path as packets from RB2 to RB1.

3.2.1. One-Way Performance Monitoring

In one-way PM, RB1 sends PM messages to RB2, allowing RB2 to monitor the performance on the path from RB1 to RB2.

A MEP that implements TRILL PM SHOULD support one-way performance monitoring. A MEP that implements TRILL PM SHOULD support both the PM functionality of the sender, RB1, and the PM functionality of the receiver, RB2.

One-way PM can be applied either proactively or on-demand, although the more typical scenario is the proactive mode, where RB1 and RB2 periodically transmit PM messages to each other, allowing each of them to monitor the performance on the incoming path from the peer MEP.

3.2.2. Two-Way Performance Monitoring

In two-way PM, a sender, RB1, sends PM messages to a reflector, RB2, and RB2 responds to these messages, allowing RB1 to monitor the performance of:

o The path from RB1 to RB2.

o The path from RB2 to RB1.

o The two-way path from RB1 to RB2, and back to RB1.

Note that in some cases it may be interesting for RB1 to monitor only the path from RB1 to RB2. Two-way PM allows the sender, RB1, to monitor the path from RB1 to RB2, as opposed to one-way PM (Section 3.2.1.), which allows the receiver, RB2, to monitor this path.

A MEP that implements TRILL PM MUST support two-way PM. A MEP that implements TRILL PM MUST support both the sender and the reflector PM functionality.

As described in Section 3.1. , flow-based PM uses the Flow Entropy field as one of the parameters that identify a flow. In two-way PM,

the Flow Entropy of the path from RB1 to RB2 is typically different
from the Flow Entropy of the path from RB2 to RB1. This document uses
the Reflector Entropy TLV [TRILL-FM], which allows the sender to
specify the Flow Entropy value to be used in the response message.

Two-way PM can be applied either proactively or on-demand.

3.3. Point-to-point vs. Point-to-multipoint PM

PM can be applied either as a point-to-point measurement protocol, or
as a point-to-multi-point measurement protocol.

The point-to-point approach measures the performance between two
RBridges using unicast PM messages.

In the point-to-multipoint approach, an RBridge RB1 sends PM messages
to multiple RBridges using multicast messages. The reflectors (in
two-way PM) respond to RB1 using unicast messages. To protect against
reply storms, the reflectors MUST send the response messages after a
random delay in the range of 0 to 2 seconds. This ensures that the
responses are staggered in time, and that the initiating RBridge is
not overwhelmed with responses. Moreover, a scope TLV [TRILL-FM] can
be used to limit the set of RBridges from which a response is
expected, thus reducing the impact of potential response bursts.

4. Loss Measurement

The Loss Measurement protocol has two flavors, one-way Loss
Measurement, and two-way Loss Measurement.

Note: The terms 'one-way' and 'two-way' Loss Measurement should not
be confused with the terms 'single-ended' and 'dual-ended' Loss
Measurement used in [Y.1731]. As defined in Section 3.2. , the terms
'one-way' and 'two-way' specify whether the protocol monitors
performance on one direction, or on both directions. The terms
'single-ended' and 'dual-ended', on the other hand, describe whether
the protocol is asymmetric or symmetric, respectively.

4.1. One-Way Loss Measurement

One-way Loss Measurement measures the one-way packet loss from one
MEP to another. The loss ratio is measured using a set of One-way
Synthetic Loss Measurement (1SL) messages. The packet format of the
1SL message is specified in Section 6.2.2. Figure 2 illustrates a
one-way Loss Measurement message exchange.

```
                TXp                 TXc
        Sender  ----------------------------------------
                  \                  \
                   \ 1SL    . . .     \ 1SL
                    \                  \
                    \/                 \/
        Receiver ----------------------------------------
                  RXp                 RXc
```
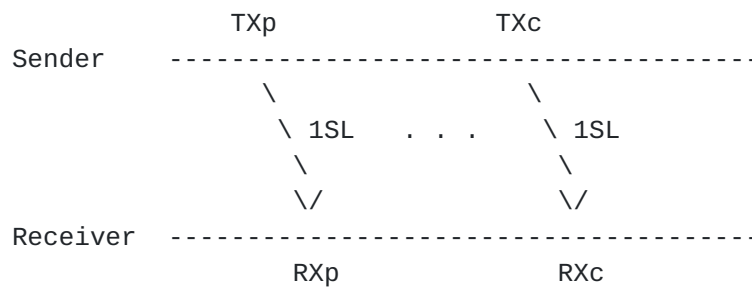
Figure 2 One-Way Loss Measurement

The one-way Loss Measurement procedure uses a set of 1SL messages to
measure the packet loss. The figure shows two non-consecutive
messages from the set.

The sender maintains a counter of transmitted 1SL messages, and
includes the value of this counter, TX, in each 1SL message it
transmits. The receiver maintains a counter of received 1SL messages,
RX, and can calculate the loss by comparing its counter values to the
counter values received in the 1SL messages.

In Figure 2, the subscript 'c' is an abbreviation for current, and
'p' is an abbreviation for previous.

4.1.1. 1SL Message Transmission

One-way Loss Measurement can be applied either proactively or on-
demand, although as mentioned in Section 3.2.1. , it is more likely
to be applied proactively.

The term 'on-demand' in the context of one-way Loss Measurement
implies that the sender transmits a fixed set of 1SL messages,
allowing the receiver to perform the measurement based on this set.

A MEP that supports one-way Loss Measurement MUST support unicast
transmission of 1SL messages.

A MEP that supports one-way Loss Measurement MAY support multicast
transmission of 1SL messages.

The sender MUST maintain a packet counter for each peer MEP and probe
instance (test ID). Every time the sender transmits a 1SL packet, it

   increments the corresponding counter, and then integrates the value
   of the counter into the <Counter TX> field of the 1SL packet.

   The 1SL message MAY be sent with a variable size Data TLV, allowing
   loss measurement for various packet sizes.

4.1.2. 1SL Message Reception

   The receiver MUST maintain a reception counter for each peer MEP and
   probe instance (test ID). Upon receiving a 1SL packet, the receiver
   MUST verify that:

   o The 1SL packet is destined to the current MEP.

   o The packet's MD level matches the MEP's MD level.

   If both conditions are satisfied, the receiver increments the
   corresponding receive packet counter, and records the new value of
   the counter, RX1.

   A MEP that supports one-way Loss Measurement MUST support reception
   of both unicast and multicast 1SL messages.

   The receiver computes the one-way packet loss with respect to a probe
   instance measurement interval. A probe instance measurement interval
   includes a sequence of 1SL messages with the same test ID. The one-
   way packet loss is computed by comparing the counter values TXp and
   RXp at the beginning of the measurement interval, and the counter
   values TXc and RXc at the end of the measurement interval (Figure 2):

        one-way packet loss = (TXc-TXp) - (RXc-RXp)   (1)

   The calculation in Equation (1) is based on counter value
   differences, implying that the sender's counter, TX, and the
   receiver's counter, RX, are not required to be synchronized with
   respect to a common initial value.

   It is noted that if the sender or receiver resets one of the
   counters, TX or RX, the calculation in Equation (1) produces a false
   measurement result. Hence the sender and receiver SHOULD NOT clear
   the TX and RX counters during a measurement interval.

   When the receiver calculates the packet loss per Equation (1) it MUST
   perform a wraparound check. If the receiver detects that one of the
   counters has wrapped around, the receiver adjusts the result of
   Equation (1) accordingly.

A 1SL receiver MUST support reception of 1SL messages with a Data
TLV.

Since synthetic one-way Loss Measurement is performed using 1SL
messages, obviously some 1SL messages may be dropped during a
measurement interval. Thus, when the receiver does not receive a 1SL,
the receiver cannot perform the calculations in Equation (1) for that
specific 1SL message.

4.2. Two-Way Loss Measurement

Two-way Loss Measurement allows a MEP to measure the packet loss on
the paths to and from a peer MEP. Two-way Loss Measurement uses a set
of Synthetic loss Measurement Messages (SLM) to compute the packet
loss. Each SLM is answered with a Synthetic loss Measurement Reply
(SLR). The packet formats of the SLM and SLR packets are specified in
Sections 6.2.3. and 6.2.4. , respectively. Figure 2 illustrates a
two-way Loss Measurement message exchange.

```
                 TXp        RXp              TXc        RXc
     Sender   ------------------------------------------------
                  \         /\              \         /\
                   \        /      . . .     \        /
                SLM \     / SLR              SLM \     / SLR
                    \/   /                       \/   /
     Reflector  ------------------------------------------------
                    TRXp                        TRXc
```
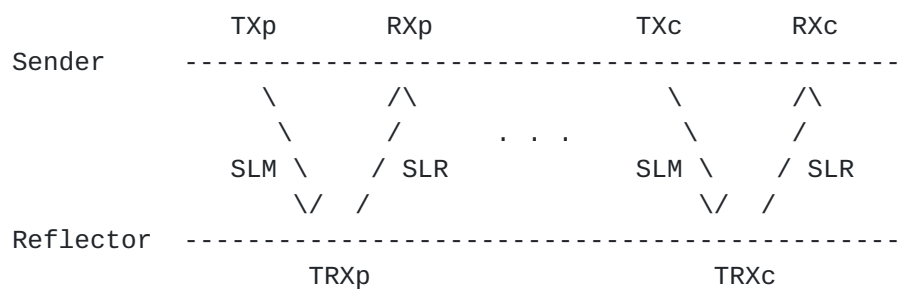
Figure 3 Two-Way Loss Measurement

The two-way Loss Measurement procedure uses a set of SLM-SLR
handshakes. The figure shows two non-consecutive handshakes from the
set.

The sender maintains a counter of transmitted SLM messages, and
includes the value of this counter, TX, in each transmitted SLM
message. The reflector maintains a counter of received SLM messages,
TRX. The reflector generates an SLR, and incorporates TRX into the
SLR packet. The sender maintains a counter of received SLR messages,

RX. Upon receiving an SLR message, the sender can calculate the loss by comparing the local counter values to the counter values received in the SLR messages.

The subscript 'c' is an abbreviation for current, and 'p' is an abbreviation for previous.

4.2.1. SLM Message Transmission

Two-way Loss Measurement can be applied either proactively or on-demand.

A MEP that supports two-way Loss Measurement MUST support unicast transmission of SLM messages.

A MEP that supports two-way Loss Measurement MAY support multicast transmission of SLM messages.

The sender MUST maintain a counter of transmitted SLM packets for each peer MEP and probe instance (test ID). Every time the sender transmits an SLM packet it increments the corresponding counter, and then integrates the value of the counter into the <Counter TX> field of the SLM packet.

A sender MAY include a Reflector Entropy TLV in an SLM message. The Reflector Entropy TLV format is specified in [TRILL-FM].

An SLM message MAY be sent with a Data TLV, allowing loss measurement for various packet sizes.

4.2.2. SLM Message Reception

The reflector MUST maintain a reception counter, TRX, for each peer MEP and probe instance (test ID).

Upon receiving an SLM packet, the reflector MUST verify that:

o The SLM packet is destined to the current MEP.

o The packet's MD level matches the MEP's MD level.

If both conditions are satisfied, the reflector increments the corresponding packet counter, and records the value of the new counter, TRX. The reflector then generates an SLR message that is identical to the received SLM, except for the following modifications:

o The reflector incorporates TRX into the <Counter TRX> field of the
   SLR.

o The <OpCode> field in the OAM header is set to the SLR OpCode.

o The reflector assigns its MEP ID in the <Reflector MEP ID> field.

o If the received SLM includes a Reflector Entropy TLV [TRILL-FM],
   the reflector copies the value of the Flow Entropy from the TLV
   into the <Flow Entropy> field of the SLR message. The outgoing SLR
   message does not include a Reflector Entropy TLV.

o The TRILL header and transport header are modified to reflect the
   source and destination of the SLR packet. The SLR is always a
   unicast message.

A MEP that supports two-way Loss Measurement MUST support reception
of both unicast and multicast SLM messages.

A reflector MUST support reception of SLM packets with a Data TLV.
When receiving an SLM with a Data TLV, the reflector includes the
unmodified TLV in the SLR.

4.2.3. SLR Message Reception

The sender MUST maintain a reception counter, RX, for each peer MEP
and probe instance (test ID).

Upon receiving an SLR message, the sender MUST verify that:

o The SLR packet is destined to the current MEP.

o The <Sender MEP ID> field in the SLR packet matches the current
   MEP.

o The packet's MD level matches the MEP's MD level.

If the conditions above are met, the sender increments the
corresponding reception counter, and records the new value, RX.

The sender computes the packet loss with respect to a probe instance
measurement interval. A probe instance measurement interval includes
a sequence of SLM messages, and their corresponding SLR messages, all
with the same test ID. The packet loss is computed by comparing the
counters at the beginning of the measurement interval, denoted with a
subscript 'p', and the counters at the end of the measurement
interval, denoted with a subscript 'c' (as illustrated in Figure 3).

far-end packet loss = (TXc-TXp) - (TRXc-TRXp)   (2)

near-end packet loss = (TRXc-TRXp) - (RXc-RXp)   (3)

Note: total two-way packet loss is the sum of the far and near end packet losses, that is (TXc-TXp) - (RXc-RXp).

The calculations in the two equations above are based on counter value differences, implying that the sender's counters, TX and RX, and the reflector's counter, TRX, are not required to be synchronized with respect to a common initial value.

It is noted that if the sender or reflector resets one of the counters, TX, TRX or RX, the calculation in Equations (2) and (3) produces a false measurement result. Hence the sender and reflector SHOULD NOT clear the TX, TRX and RX counters during a measurement interval.

When the sender calculates the packet loss per Equations (2) and (3) it MUST perform a wraparound check. If the reflector detects that one of the counters has wrapped around, the reflector adjusts the result of Equations (2) and (3) accordingly.

Since synthetic two-way Loss Measurement is performed using SLM and SLR messages, obviously some SLM and SLR messages may be dropped during a measurement interval. When an SLM or an SLR is dropped, the corresponding two-way handshake (Figure 3) is not completed successfully, and thus the reflector does not perform the calculations in Equations (2) and (3) for that specific message exchange.

A sender MAY choose to monitor only the far-end packet loss, that is, perform the computation in Equation (2), and ignore the computation in Equation (3). Note that, in this case, the sender can run flow-based PM of the path TO the peer MEP without using the Reflector Entropy TLV.

5. Delay Measurement

The Delay Measurement protocol has two flavors, One-Way Delay Measurement, and Two-Way Delay Measurement.

5.1. One-Way Delay Measurement

One-way Delay Measurement is used for computing the one-way packet delay from one MEP to another. The packet format used in one-way Delay Measurement is referred to as 1DM, and is specified in Section

6.3.2. The one-way Delay Measurement message exchange is illustrated
in Figure 4.

```
                              T1
                 Sender     ------------------        ----> time
                               \
                                \ 1DM
                                 \
                                 \/
                 Receiver   ------------------
                                T2
```
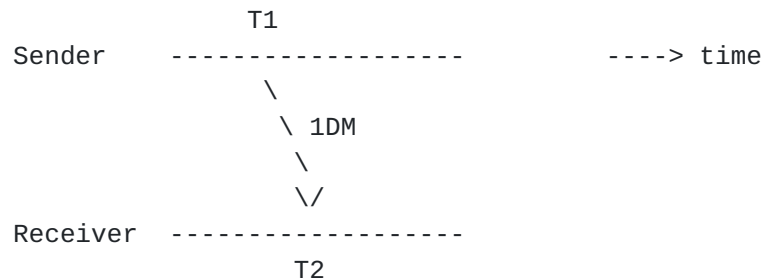
Figure 4 One-Way Delay Measurement

The sender transmits a 1DM message incorporating its time of
transmission, T1. The receiver then receives the message at time T2,
and calculates the one-way delay as:

$$\text{one-way delay} = T2-T1 \qquad (4)$$

Equation (4) implies that T2 and T1 are measured with respect to a
common reference time. Hence, two MEPs running an one-way Delay
Measurement protocol MUST be time-synchronized. The method used for
synchronizing the clocks associated with the two MEPs is outside the
scope of this document.

5.1.1. 1DM Message Transmission

1DM packets can be transmitted proactively or on-demand, although as
mentioned in Section 3.2.1. , they are typically transmitted
proactively.

A MEP that supports one-way Delay Measurement MUST support unicast
transmission of 1DM messages.

A MEP that supports one-way Delay Measurement MAY support multicast
transmission of 1DM messages.

A 1DM message MAY be sent with a variable size Data TLV, allowing
packet delay measurement for various packet sizes.

The sender incorporates the 1DM packet's time of transmission into
the <Timestamp T1> field.

[5.1.2](). 1DM Message Reception

Upon receiving a 1DM packet, the receiver records its time of
reception, T2. The receiver MUST verify two conditions:

o The 1DM packet is destined to the current MEP.

o The packet's MD level matches the MEP's MD level.

If both conditions are satisfied, the receiver terminates the packet
and calculates the one-way delay as specified in Equation (4).

A MEP that supports one-way Delay Measurement MUST support reception
of both unicast and multicast 1DM messages.

A 1DM receiver MUST support reception of 1DM messages with a Data
TLV.

When one-way Delay Measurement packets are received periodically, the
receiver MAY compute the packet delay variation based on multiple
measurements. Note that packet delay variation can be computed even
when the two peer MEPs are not time synchronized.

[5.2](). Two-Way Delay Measurement

Two-way Delay Measurement uses a two-way handshake for computing the
two-way packet delay between two MEPs. The handshake includes two
packets, a Delay Measurement Message (DMM) and a Delay Measurement
Reply (DMR). The DMM and DMR packet formats are specified in [Section
6.3.3](). and 6.3.4. , respectively.

The two-way Delay Measurement message exchange is illustrated in
Figure 5.

```
                          T1              T4
             Sender     -----------------------      ----> time
                          \            /\
                           \           /
                      DMM \         / DMR
                           \/     /
             Reflector   -----------------------
                          T2     T3
```
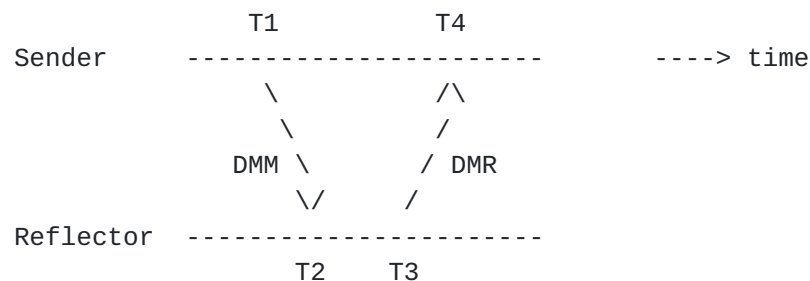
Figure 5 Two-Way Delay Measurement

The sender generates a DMM message incorporating its time of
transmission, T1. The reflector receives the DMM message and records
its time of reception, T2. The reflector then generates a DMR
message, incorporating T1, T2 and the DMR's transmission time, T3.
The sender receives the DMR message at T4, and using the 4 timestamps
it calculates the two-way packet delay.

5.2.1. DMM Message Transmission

DMM packets can be transmitted periodically or on-demand.

A MEP that supports two-way Delay Measurement MUST support unicast
transmission of DMM messages.

A MEP that supports two-way Delay Measurement MAY support multicast
transmission of DMM messages.

A sender MAY include a Reflector Entropy TLV in a DMM message. The
Reflector Entropy TLV format is specified in [TRILL-FM].

A DMM MAY be sent with a variable size Data TLV, allowing packet
delay measurement for various packet sizes.

The sender incorporates the DMM packet's time of transmission into
the <Timestamp T1> field.

5.2.2. DMM Message Reception

Upon receiving a DMM packet, the reflector records its time of
reception, T2. The reflector MUST verify two conditions:

o The DMM packet is destined to the current MEP.

o The packet's MD level matches the MEP's MD level.

If both conditions are satisfied, the reflector terminates the
packet, and generates a DMR packet. The DMR is identical to the
received DMM, except for the following modifications:

o The reflector incorporates T2 into the <Timestamp T2> field of the
   DMR.

o The reflector incorporates the DMR's transmission time, T3, into
   the <Timestamp T3> field of the DMR.

   o The <OpCode> field in the OAM header is set to the DMR OpCode.

   o If the received DMM includes a Reflector Entropy TLV [TRILL-FM],
      the reflector copies the value of the Flow Entropy from the TLV
      into the <Flow Entropy> field of the DMR message. The outgoing DMR
      message does not include a Reflector Entropy TLV.

   o The TRILL header and transport header are modified to reflect the
      source and destination of the DMR packet. The DMR is always a
      unicast message.

   A MEP that supports two-way Delay Measurement MUST support reception
   of both unicast and multicast DMM messages.

   A reflector MUST support reception of DMM packets with a Data TLV.
   When receiving a DMM with a Data TLV, the reflector includes the
   unmodified TLV in the DMR.

5.2.3. DMR Message Reception

   Upon receiving the DMR message, the sender records its time of
   reception, T4. The sender MUST verify:

   o The DMR packet is destined to the current MEP.

   o The packet's MD level matches the MEP's MD level.

   If both conditions above are met, the sender uses the 4 timestamps to
   compute the two-way delay:

$$\text{two-way delay} = (T4-T1) - (T3-T2) \qquad (5)$$

   Note that two-way delay can be computed even when the two peer MEPs
   are not time synchronized. One-way Delay Measurement, on the other
   hand, requires the two MEPs to be synchronized.

   Two MEPs running a two-way Delay Measurement protocol MAY be time-
   synchronized. If two-way Delay Measurement is run between two time-
   synchronized MEPs, the sender MAY compute the one-way delays:

$$\text{one-way delay } \{sender\text{->}reflector\} = T2 - T1 \qquad (6)$$

$$\text{one-way delay } \{reflector\text{->}sender\} = T4 - T3 \qquad (7)$$

   When two-way Delay Measurement is run periodically, the sender MAY
   also compute the delay variation based on multiple measurements.

A sender MAY choose to monitor only the sender->reflector delay, that
is, perform the computation in Equation (6), and ignore the
computations in (5) and (7). Note that in this case the sender can
run flow-based PM of the path to the peer MEP without using the
Reflector Entropy TLV.

6. Packet Formats

6.1. TRILL OAM Encapsulation

The TRILL OAM packet format is generally discussed in [OAM-FRAMEWK],
and specified in detail in [TRILL-FM]. It is quoted in this document
for convenience.

```
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                               |
    .     Link  Header              . (variable)
    |                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                               |
    +     TRILL Header              + 6 or more bytes
    |                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                               |
    .    Flow Entropy               . 96 bytes
    .                               .
    |                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |    OAM Ether Type             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                               |
    .    OAM Message Channel        . Variable
    .                               .
    |                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |      Link Trailer             | Variable
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 6 TRILL OAM Encapsulation

The OAM Message Channel used in this document is defined in [TRILL-
FM], and has the following structure:

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |MD-L | Version | OpCode       | Flags        |TLVOffset       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   .            OpCode-specific fields                             .
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   .            TLVs                                               .
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
                    Figure 7 OAM Packet Format

The first 4 octets of the OAM Message Channel are common to all
OpCodes, whereas the rest is OpCode-specific. Below is a brief
summary of the fields in the first 4 octets:

o MD-L : Maintenance Domain Level.

o Version: indicates the version of this protocol. Always zero in
   the context of this document.

o Flags: always zero in the context of this document.

o FirstTLVOffset: defines the location of the first TLV, in octets,
   starting from the end of the FirstTLVOffset field.

For further details about the OAM packet format, see [TRILL-FM].

6.2. Loss Measurement Packet Formats

6.2.1. Counter Format

Loss Measurement packets use a 32-bit packet counter field. When a
counter is incremented beyond its maximal value, 0xFFFFFFFF, it wraps
around back to 0.

6.2.2. **1SL Packet Format**

```
      0                   1                   2                   3
       0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |MD-L | Ver (0) | OpCode     | Flags (0)     |TLVOffset (16) |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |        Sender MEP ID       |            Reserved           |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                           Test ID                          |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                         Counter TX                         |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                         Reserved                           |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                                                            |
      .          TLVs                                              .
      |                                                            |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                     Figure 8 1SL Packet Format
```

   o Sender MEP ID: the MEP ID of the MEP that initiated the 1SL.

   o Reserved: always 0.

   o Test ID: a 32-bit unique test identifier.

   o Counter TX: the value of the sender's transmission counter,
      including this packet, at the time of transmission.

6.2.3. SLM Packet Format

```
      0                   1                   2                   3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |MD-L | Ver (0) | OpCode      |  Flags (0)     |TLVOffset (16) |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |        Sender MEP ID        | Reserved for Reflector MEP ID |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                            Test ID                           |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                          Counter TX                          |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |               Reserved for SLR: Counter TRX (0)              |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                                                              |
     .            TLVs                                              .
     |                                                              |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                       Figure 9 SLM Packet Format
```

   o Sender MEP ID: the MEP ID of the MEP that initiated this packet.

   o Reserved: this field is reserved for the reflector's MEP ID, to be
     added in the SLR.

   o Test ID: a 32-bit unique test identifier.

   o Counter TX: the value of the sender's transmission counter,
     including this packet, at the time of transmission.

   o Reserved: this field is reserved for the SLR corresponding to this
     packet. The reflector uses this field in the SLR for carrying TRX,
     the value of its reception counter.

6.2.4. **SLR Packet Format**

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |MD-L | Ver (0) | OpCode      |  Flags (0)    |TLVOffset (16) |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |        Sender MEP ID        |       Reflector MEP ID        |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                            Test ID                          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                          Counter TX                         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                         Counter TRX                         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                            |
   .          TLVs                                               .
   |                                                            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                   Figure 10 SLR Packet Format
```

   o Sender MEP ID: the MEP ID of the MEP that initiated the SLM that
     this SLR replies to.

   o Reflector MEP ID: the MEP ID of the MEP that transmits this SLR
     message.

   o Test ID: a 32-bit unique test identifier, copied from the
     corresponding SLM message.

   o Counter TX: the value of the sender's transmission counter at the
     time of the SLM transmission.

   o Counter TRX: the value of the reflector's reception counter,
     including this packet, at the time of reception of the
     corresponding SLM packet.

6.3. Delay Measurement Packet Formats

6.3.1. Timestamp Format

   The timestamps used in Delay Measurement packets are 64 bits long.
   These timestamps use the 64 least significant bits of the IEEE 1588-
   2008 (1588v2) Precision Time Protocol timestamp format [IEEE1588].

   This truncated format consists of a 32-bit seconds field followed by
   a 32-bit nanoseconds field. This truncated format is also used in
   IEEE 1588v1, in [Y.1731], and in [MPLS-LM-DM].

6.3.2. 1DM Packet Format

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |MD-L | Ver (1) | OpCode      | Reserved    |T|TLVOffset (16) |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       Timestamp T1                           |
   |                                                             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |           Reserved for 1DM receiving equipment (0)           |
   |                     (for Timestamp T2)                       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                             |
   .         TLVs                                                 .
   |                                                             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                    Figure 11 1DM Packet Format
```

   o T: Type flag. When this flag is set it indicates proactive
      operation, and when cleared it indicates on-demand mode.

   o Timestamp T1: specifies the time of transmission of this packet.

   o Reserved: this field is reserved for internal usage of the 1DM
      receiver. The receiver can use this field for carrying T2, the
      time of reception of this packet.

6.3.3. DMM Packet Format

```
       0                   1                   2                   3
       0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |MD-L | Ver (1) | OpCode      | Reserved    |T|TLVOffset (32) |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                         Timestamp T1                         |
      |                                                              |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |          Reserved for DMM receiving equipment (0)            |
      |                      (for Timestamp T2)                      |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                      Reserved for DMR (0)                    |
      |                      (for Timestamp T3)                      |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |           Reserved for DMR receiving equipment               |
      |                                                              |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                                                              |
      .            TLVs                                              .
      |                                                              |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
                    Figure 12 DMM Packet Format

   o T: Type flag. When this flag is set it indicates proactive
     operation, and when cleared it indicates on-demand mode.

   o Timestamp T1: specifies the time of transmission of this packet.

   o Reserved: this field is reserved for internal usage of the MEP
     that receives the DMM (the reflector). The reflector can use this
     field for carrying T2, the time of reception of this packet.

   o Reserved for DMR: two timestamp fields are reserved for the DMR
     message. One timestamp field is reserved for T3, the DMR
     transmission time, and the other field is reserved for internal
     usage of the MEP that receives the DMR.

6.3.4. **DMR Packet Format**

```
     0                   1                   2                   3
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |MD-L | Ver (1) | OpCode      |   Reserved   |T|TLVOffset (32) |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                         Timestamp T1                         |
    |                                                              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                         Timestamp T2                         |
    |                                                              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                         Timestamp T3                         |
    |                                                              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |           Reserved for DMR receiving equipment               |
    |                     (for Timestamp T4)                       |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                                                              |
    .            TLVs                                              .
    |                                                              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                      Figure 13 DMR Packet Format
```
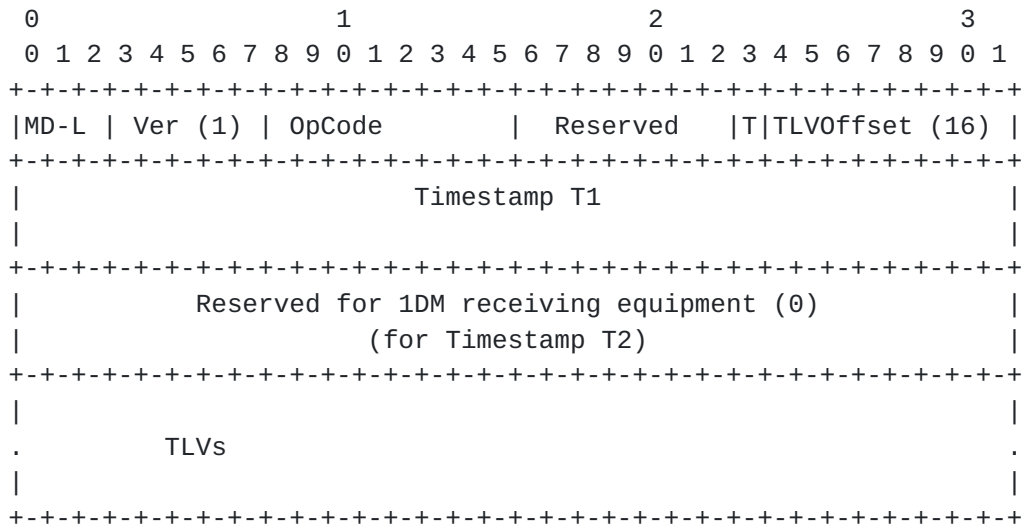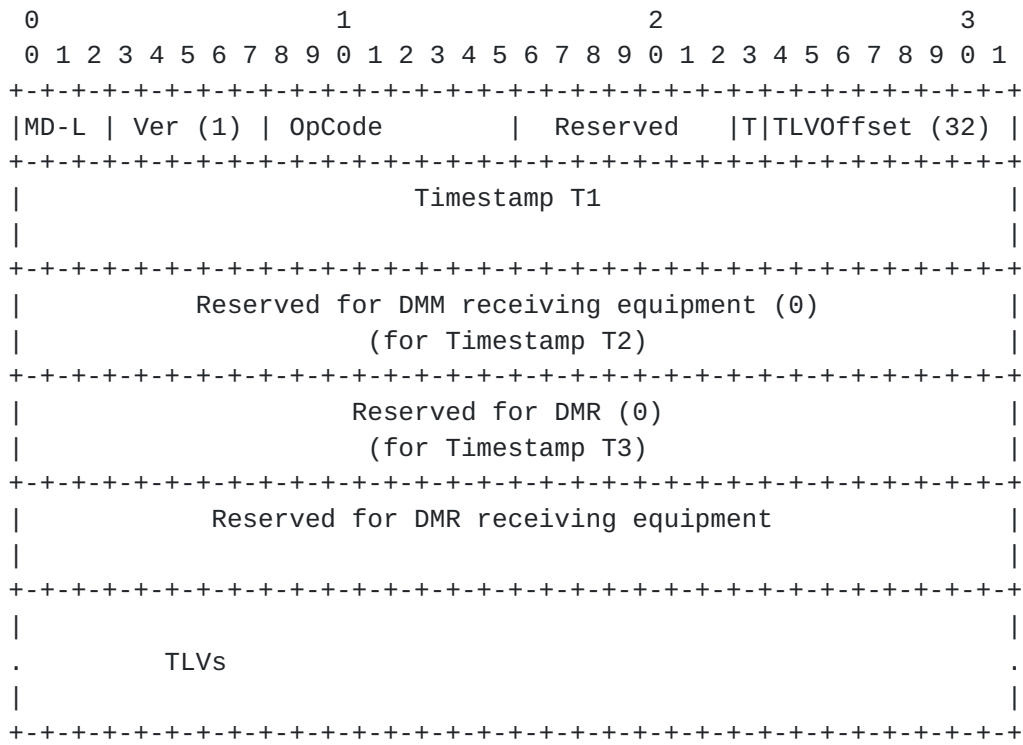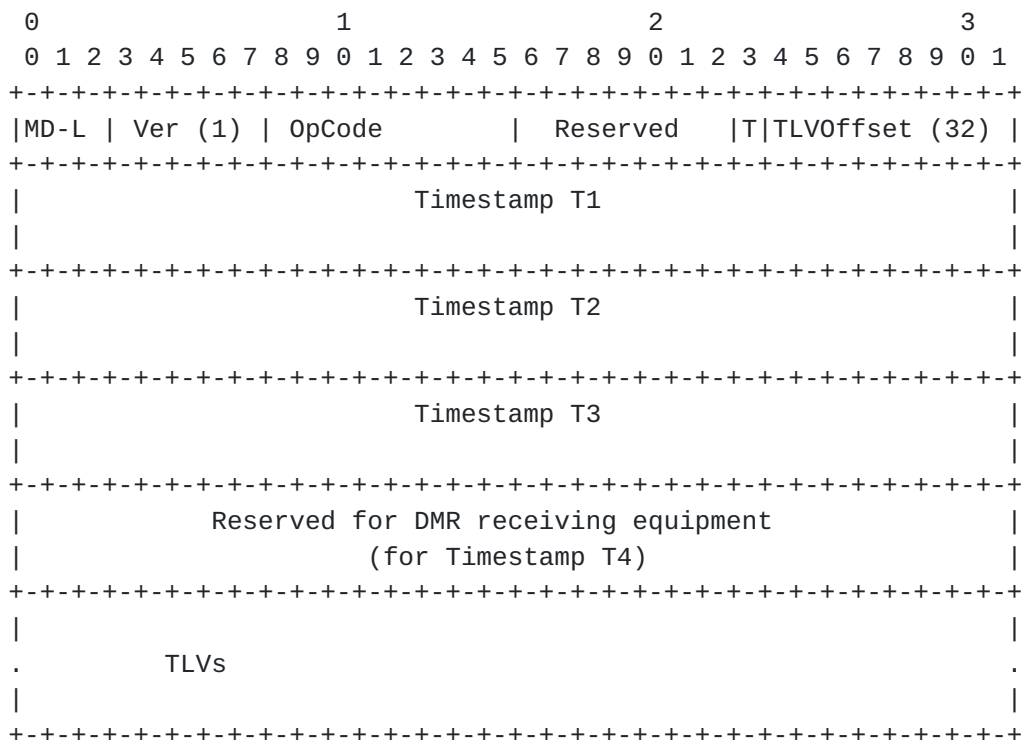
   o T: Type flag. When this flag is set it indicates proactive
     operation, and when cleared it indicates on-demand mode.

   o Timestamp T1: specifies the time of transmission of the DMM packet
     that this DMR replies to.

   o Timestamp T2: specifies the time of reception of the DMM packet
     that this DMR replies to.

   o Timestamp T3: specifies the time of transmission of this DMR
     packet.

   o Reserved: this field is reserved for internal usage of the MEP
     that receives the DMR (the sender). The sender can use this field
     for carrying T4, the time of reception of this packet.

6.4. OpCode Values

As the OAM packets specified herein generally conform to [Y.1731], the same OpCodes are used as follows:

```
OpCode    OAM packet
value     type
------    ----------

45        1DM

46        DMR

47        DMM

53        1SL

54        SLR

55        SLM
```

7. Performance Monitoring Process

The Performance Monitoring process is made up of a number of Performance Monitoring instances, known as PM Sessions. A PM session can be initiated between two MEPs on a specific flow and be defined as either a Loss Measurement session or Delay Measurement session.

The Loss Measurement session can be used to determine the performance metrics Frame Loss Ratio, availability, and resiliency. The Delay Measurement session can be used to determine the performance metrics Frame Delay, Inter-Frame Delay Variation, Frame Delay Range, and Mean Frame Delay.

The PM session is defined by the specific PM function (PM tool) being run, and also by the Start Time, Stop time, Message Period, Measurement Interval, and Repetition Time. These terms are defined as follows:

o The Start Time is the time that the PM session begins.

o The Stop Time is the time that the measurement ends.

o The Message Period is the message transmission frequency (the time between message transmissions).

   o The Measurement Interval is the time period over which
     measurements are gathered and then summarized. The Measurement
     Interval can align with the PM Session duration, but it doesn't
     need to. PM messages are only transmitted during a PM Session.

   o The Repetition Time is the time between start times of the
     Measurement Intervals.


```
        Measurement Interval     Measurement Interval
        (Completed, Historic)    (In Process, Current)
    |                        |
    |                        |
     0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    ^                     ^ ^                                   ^
    |                     | |                                   |
 Start time            Message                           Stop time
(service enabled)      Period                        (Service disabled)
```

           Figure 14 Relationship Between Different Timing Parameters

8. Security Considerations

   The security considerations of TRILL OAM are discussed in [OAM-REQ]
   and in [OAM-FRAMEWK] and in [TRILL-FM]. As in [TRILL-FM], TRILL PM
   OAM Messages MAY include the OAM Authentication TLV.

   General TRILL security considerations are discussed in [RFCTRILL].

9. IANA Considerations

   This document requires no IANA actions. RFC Editor: Please delete
   this section before publication.

10. Acknowledgments

   This document was prepared using 2-Word-v2.0.template.dot.

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