

# Control Two-Way Monitoring Process Using Metro Ethernet Forum

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**Abstract:** Metro Ethernet Forum (MEF) protocol is described as a bridged-Ethernet per-VLAN (Virtual Local Area Network) implementation and with the help of Ping and Hello packets estimates service assurance (SA) metrics and specific connectivity tests.

MEF protocol is an Operations, Administration, and Maintenance (OAM) feature. MEF is a powerful tool for network engineers to test real-time connectivity, latency, jitter, and frame-loss parameters on the bridged network, without higher-layer implementations.

In this paper, new commands were developed for monitoring two-way connectivity, jitter, frame-loss, and latency. Also, there is an example on how to use these commands.

*Keywords:* domain, jitter, frame delay, frame-loss, latency, command, example

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## 1. INTRODUCTION

Metro Ethernet Forum (MEF) protocol provides mechanisms to perform Ethernet network-wide service assurance (SA) for providers and end-to-end service assurance for Ethernet customers.

Operations, Administration, and Maintenance (OAM) feature [8] describes the tools and utilities for installing, monitoring, and troubleshooting the network. This feature is a family of standards providing reliable remotely managed service assurance mechanisms for both the provider and customer networks. With OAM, users can perform automatic periodic network-wide service assurance and quality verifications.

Bridges, implementing MEF-OAM standard [11], are added to the MEF-OAM domains on the 802.1q bridged network and participate in service-level assurance (SLA) and fault isolation. By enabling MEF, users can monitor the activity of a single link or the entire bridged-Ethernet network.

MEF-OAM supports the following basic functions:

- Network discovery (802.1q bridged network-discovery per VLAN – Virtual Local Area Network);
- Connectivity verification;
- Latency and loss measurement;
- Delay variation measurement;
- Traceroute functions.

The direct effect of OAM service assurance is the discovery of the equipment on each VLAN and the maintenance of connectivity tables regarding this equipment.

### 1.1 MEF-OAM Domains

A MEF-OAM domain [12] is defined by a connected topology of bridges in which OAM operates unobstructed. At the edges of a domain, there are filters that prevent Ethernet service OAM frames from exiting the domain. On each bridge, each port is classified as interior or exterior for that domain. Up to seven domains can exist on a device at a time.

MEF-OAM PDU (Protocol Data Unit) exchange is the key element of the MEF-OAM implementation. Forwarding decisions reflect connectivity discovery and security requirements of the implementation.

MEF-OAM PDUs can be added as tagged for a specific VLAN. Untagged PDUs are assumed to belong to the default VLAN assigned to the port that received the PDU.

Each bridge defines a MEF-OAM domain on specific ports and VLANs.

The MEF-OAM domain on each bridge is specified by:

- The VLANs the PDUs are forwarded to;
- The ports of a specific VLAN participating in the PDU exchange;
- The maximum allowed PDU exchange rate between all MAC addresses in this MEF-OAM domain.

### 1.2 Generating MEF-OAM PDUs

When a bridge generates a multicast MEF-OAM PDU on a specific MEF-OAM domain, it must conform to the following:

- Send this PDU to all the allowed VLANs on all allowed ports for that MEF-OAM domain;
- Receive PDUs up to the maximum specified rate from the ports on the same VLANs;
- If the generated packet is an OAM multicast response, the bridge sends the PDU to the port on which the destination MAC address, for a specific VLAN, is learned (using its FDB – Forwarding Database).

### 1.3 Unicast OAMPDU

When a bridge generates a unicast MEF-OAM PDU on a specific MEF-OAM domain, it must conform to the following:

- In case a VLAN is specified, send the PDU to the port that has connectivity to the destination MAC address on that VLAN (using its FDB). If no adequate entry exists in the FDB, send this PDU to all the allowed ports on that VLAN.
- If no VLAN is specified, repeat the same steps for all VLANs.

### 1.4 Forwarding OAMPDU

When receiving a MEF-OAM PDU, the bridge must conform to the forwarding:

- If the device is not part of the MEF-OAM domain specified in the PDU, it forwards this packet as a normal Ethernet packet.
- If the device is a part of the MEF-OAM domain specified in the PDU, it follows the below rules:
  - If this is a unicast packet, it checks if the VLAN specified in the PDU and the target port determined by the FDB are members of the MEF-OAM domain. If they are, it forwards this packet as a normal Ethernet packet. Otherwise, it broadcasts this packet (unknown unicast).
  - If the received packet is an OAM multicast response, it forwards the PDU to the port on which the destination MAC address for the specific VLAN is learned (using its FDB).
  - If this is an OAM multicast packet but not a Connectivity response, it extracts the VLAN number (ID – Identifier) from the PDU and forwards it to all the ports defined by the OAM process in that device in that specific VLAN.

### 1.5 Network Discovery

At the Discovery stage, each device initiates periodic Hello multicasts. Each device in the MEF-OAM domain receiving these multicasts, builds a connectivity table and a jitter table of the reachable bridges within the MEF-OAM domain. A device can send a multicast Ping (Packet Internet Groper) request to another device from the network and expects it to respond. Ping and Hello packets sent to the same network can be used to measure the delay, latency, jitter, and frame-loss.

Hello packets are transmitted from a device to another to make it aware of the connection between them. This packet is sent in a specified interval, if not transmitted, the connection is considered broken.

Ping packets are sent "to see" if the device where packets were sent is a part of the network.

### 1.6 Connectivity Verification

The connectivity verification process sends a connectivity test request to the specified bridge and waits for a connectivity test reply message.

The alternative mechanism is to use periodic Hello frames between the devices on the MEF-OAM domain. Each Hello frame between two MEF-OAM domain members indicates the direct connectivity from the source bridge to the target bridge.

To measure specific service assurance aspects, the system administrator can initiate a connectivity verification test, in which one device sends a connectivity test request to a remote bridge. Each device in the network that supports MEF-OAM replies to the connectivity test request with a connectivity test response. Based on this response, the device originating the test calculates the two-way packet loss, two-way packet jitter, and two-way delay.

### 1.7 MAC Traceroute

MAC traceroute implements a functionality (similar to the Layer 3 traceroute functionality) on Layer 2 (the MAC sub-layer).

MAC traceroute communicates by using both unicast and multicast PDUs, obligating users to specify a destination MAC address. The source device transmits MEF-OAM PDUs with a proprietary flag.

If a MEF-OAM domain is enabled on the device receiving this packet, the device:

- Responds to the sender;
- Forwards the packet to the destination device.

If no MEF-OAM domain is enabled to receive the packet, the device only forwards the PDU to the destination device without responding to the sender.

## 2. MEF-OAM STRUCTURE

The following are the MEF-OAM configuration guidelines:

- When configuring an OAM bridge, users have to always specify the VLAN ID on which he wants to gather information. Users cannot configure more than 5 VLAN IDs at the same time.
- When data collection is finished, user should remove the OAM configuration.
- MEF-OAM supports

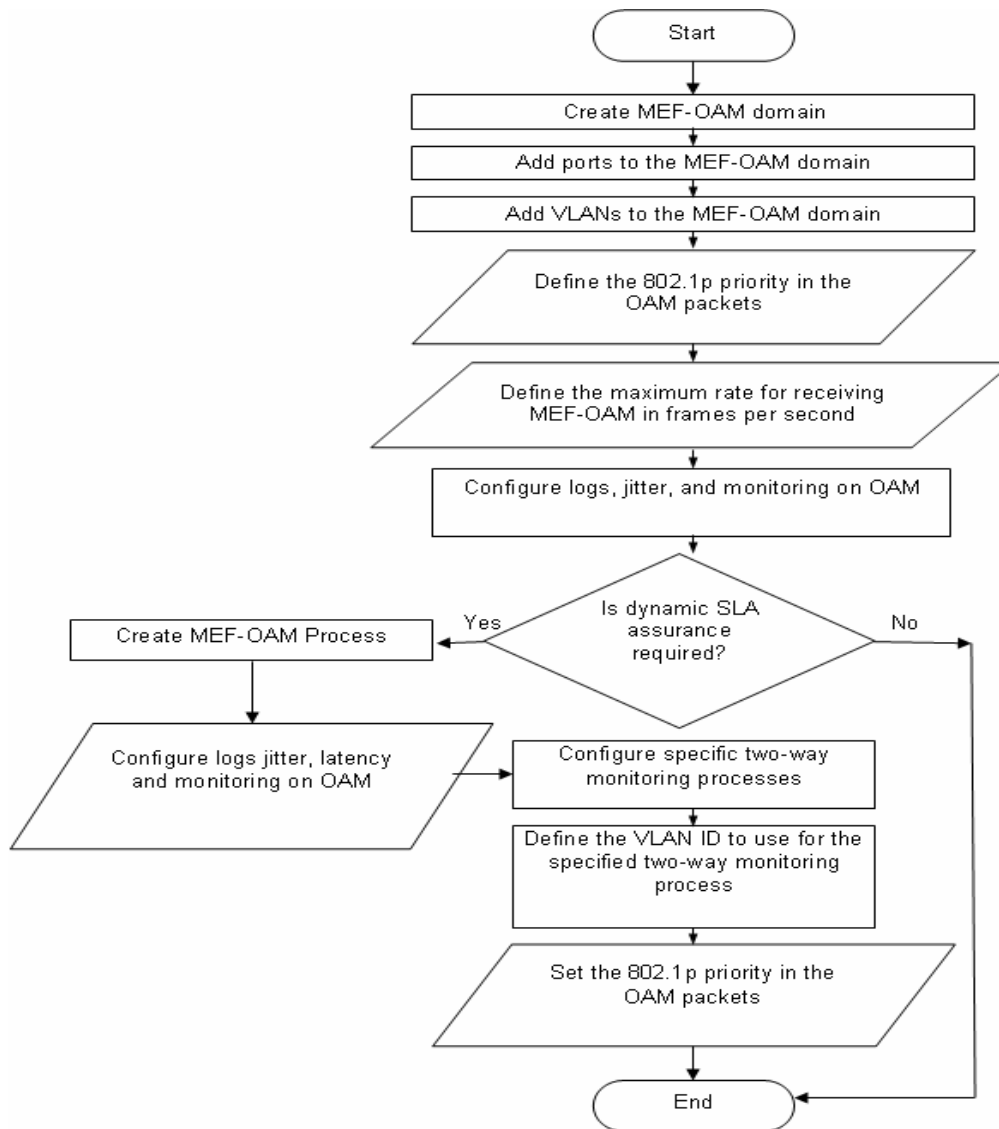


Fig. 1. MEF-OAM Structure

### 3. MONITORING PARAMETERS

Service-assurance metrics are calculated per VLAN (Virtual Local Area Network). In cases where several VLANs exist, the service-assurance metrics between them are calculated several times: once for each entity on the same MEF-OAM domain that shares the same VLANs.

To ensure service assurance, administrators can define threshold metrics values [5] for different conditions (such as one-way connectivity and jitter, two-way connectivity, jitter, frame-loss, and latency) and the allowed number of consecutive samples that exceed them. The results are then compared to the pre-defined thresholds generating warning or error message log entries.

The administrator can also define the creation of log lines in case the conditions of thresholds *are* met, indicating that specific alarms are not triggered.

#### 3.1. One-Way Connectivity and Jitter

Each MEF-OAM domain defined on the device multicasts periodic Hello packets (the multicast period, the packet size, and their quantity configured).

All the devices that belong to the same domain and receive these PDUs:

- Forward them as a multicast;
- Add the PDU record to the cyclic queue (a bucket with a pre-defined size) of received MEF-OAM PDUs per MAC address per VLAN;
- Periodically update the connectivity matrix, specifying the local timestamp of the last Hello packet received for the specific device on the specific VLAN, creating the connectivity test result.

### 3.2. Two-way Connectivity, Jitter, Frame-Loss, and Latency

Using the two-way connectivity test, users can test and monitor the connectivity parameters between a device and a specific MAC address or all members of a MEF-OAM domain on a specific VLAN.

This test is not issued by default and has to be triggered by configuring the following test parameters:

- The MEF-OAM domain to which this process belongs;
- The destination MAC address or multicast (all MEF-OAM domain members of a specific VLAN);
- The test period (for example, every 60 seconds);
- The size and number of packets sent per each test.

When sending a connectivity test request, the source device stores a copy of this request in the response bucket. This copy exists for timeout validation in case no response arrives.

All the devices on this VLAN receiving a connectivity test request perform the following:

- Forward the PDU if it is a multicast;
- Stop processing the PDU if it is not directed to the current device;
- If the PDU is directed to the current device, a unicast connectivity test response PDU is sent to the source device;
- Update the PDU's timestamp for this device on this specific VLAN.

When the source device receives a connectivity test response, the device:

- Updates the timestamp of this device;
- Adds a record of this PDU, for the specific MAC address in the specific VLAN, to the connectivity cyclic queue of the received PDUs;
- Calculates the jitter for this MAC address for the specific VLAN (contained in this PDU), comparing its timestamp to the local receipt timestamps of previous connectivity test responses (the variance between the packet's sending timestamp and receiving timestamp);
- Calculates the latency per bucket (the differences between sent connectivity-tests' timestamp and connectivity-tests' local receipts timestamps);
- Calculates the frame-loss per bucket (the difference between connectivity tests sent and connectivity test responses received, in percents).

In case of insufficient network performance, SA metrics can trigger the generation of log entries on a bridge or transfer them to a Syslog server.

## 4. CALCULATE TWO-WAY PARAMETERS

### 4.1. Jitter

Jitter [6] is the deviation or displacement of pulses in a high-frequency digital signal. The deviation can be in terms of amplitude, phase timing, or the width of the signal pulse.

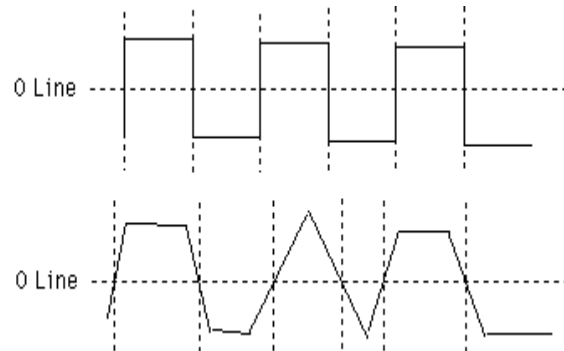


Fig. 2. Jitter Example

The waveform from Fig. 2 represents a theoretically perfect digital signal. The value 101010, which appears at equal periods of time, is represented by dotted vertical lines at equal distances. When first waveform passes through long cables with incorrect impedance, or when a source impedance load is incorrect, the signal can become rounded, the fast rise time becomes slow, and the reflection in the cable can cause a misinterpretation of zero crossing point of the wave. Triangle, trapezoid or simply rounded edge signals can be observed. New transitions (measured at zero line) for the second waveform occur at varying time periods. Even so, numerical interpretation of that wave is still 101010.

Random Jitter [2, 6], also called Gaussian jitter, is the unpredictable electronic timing noise. Random jitter typically follows a Gaussian distribution or Normal distribution. It follows this pattern because most noises or jitters in an electrical circuit are caused by thermal noises, which have a Gaussian distribution. Another reason for random jitter to have a distribution like this is due to the central limit theorem. The central limit theorem states that composite effect of many uncorrelated noise sources, regardless of the distributions, approaches a Gaussian distribution. One of the main differences between random and deterministic jitter is that deterministic jitter is bounded and random jitter is unbounded.

Deterministic jitter [2, 6] is a type of clock timing jitter or data signal jitter, which is predictable and reproducible. The peak-to-peak value of this jitter is bounded, and the bounds can easily be observed and predicted. Periodic jitter, data-dependent jitter, and duty-cycle dependent jitter are all types of deterministic jitter.

Total jitter (T) is the combination of random jitter (R) and deterministic jitter (D):

$$T = D_{peak-to-peak} + 2 \times n \times R \quad (1)$$

The value of  $n$  is based on the bit error rate (BER). A common bit error rate used in communication standards such as Ethernet is  $10^{-12}$ .

#### 4.2. Frame Delay

Frame delay [3] is defined as the time elapsed from reception of the first bit of the frame until the transmission of the last bit of frame. Frame delay performance for a particular service class (Class of Service - COS), in a specified interval ( $T$ ), is defined as the "P-percentile" method ( $P$ ) of the delay for all service frames with a green bandwidth profile compliance. COS is a set of service frames that receive from the service provider a particular level of performance.

$S_T$  is a set of frame delay values for successfully delivered service frames declared green whose first bit arrived in the interval  $T$ .

$S_T$  [11] can be expressed as  $S_T = \{d_1, d_2, \dots, d_n\}$ , where  $d_i$  is the frame delay for service frame  $i$ .

Performance  $\bar{d}_T$  can be expressed as:

$$\bar{d}_T = \min \left\{ d \mid P \leq \frac{100}{n} \sum_{j=1}^n I(d, d_j) \right\} \quad (2)$$

where

$$I(d, d_j) = \begin{cases} 1, & \text{if } d > d_j \\ 0, & \text{if } d \leq d_j \end{cases}$$

Frame delay [10] can be broken into three parts, as Fig. 3 shows, represented by A, B, and C. For example, A and B introduce 1.2 ms of transmission delay for a standard service frame size of 1518 bytes. C is the delay introduced by Metro Ethernet Network. Frame delay is represented by  $A+B+C$ .

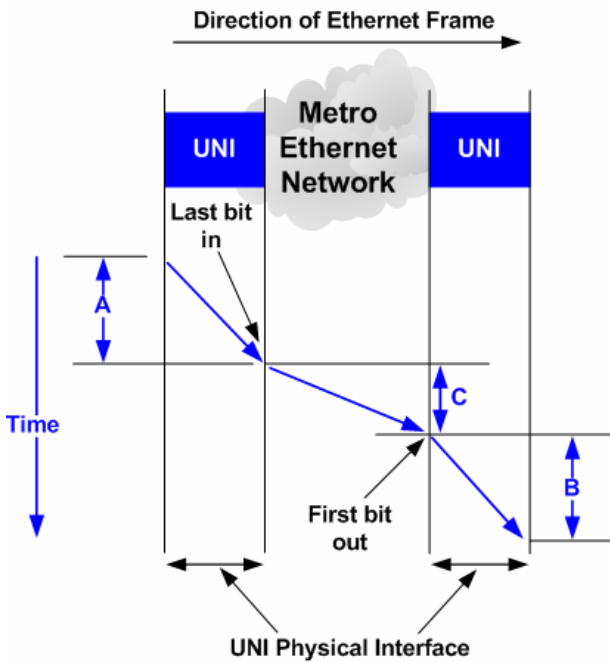


Fig. 3. Network Frame Delay

The delay is measured between two 10 Mbps UNIs (User Network Interface) using a 5 minutes measurement interval and a percentile of 95%. During the measurement interval, 1000 service frames were successfully transmitted. The maximum delay was measured to be 15 ms (C).

$$\text{Frame delay} = 1.2 + 1.2 + 15 = 17.4 \text{ ms} \quad (3)$$

$$\text{Frame jitter} = \text{Frame delay} - C = 17.4 - 15 = 2.4 \text{ ms} \quad (4)$$

#### 4.3. Latency

Latency [1] in a packet-switched network is measured either *one-way* (the time from the source sending a packet to the destination receiving it), or *round-trip* (the one-way latency from source to destination plus the one-way latency from the destination back to the source). The latency is usually relatively small, and has only a few milliseconds [10].

$$\text{latency} \cdot (\text{ms}) = \frac{\text{buffer} \cdot \text{size} \cdot (\text{samples})}{\text{sample} \cdot \text{rate} \cdot (\text{Hz})} \quad (5)$$

#### 4.4. Frame-loss

Frame-loss [7] is the percentage of service frames that were not delivered between UNIs (see Fig. 3).

$$\text{Frame-loss} = \left( 1 - \frac{\text{service} \cdot \text{frames} \cdot \text{delivered}}{\text{total} \cdot \text{service} \cdot \text{frames} \cdot \text{sent}} \right) \times 100 \quad (6)$$

For example, if 1000 service frames were delivered from source to destination during a 5 minutes measurement interval, but only 990 service frames were delivered successfully, frame-loss is 1%.

$$\text{Frame-loss} = \left( 1 - \frac{990 \cdot (\text{frames} \cdot \text{delivered})}{1000 \cdot (\text{total} \cdot \text{frames} \cdot \text{sent})} \right) \times 100 \quad (7)$$

$$\text{Frame-loss} = 1\%$$

A 1% packet loss for a Voice over IP (VoIP) application may be acceptable, but a 5% packet loss will make an unacceptable voice quality [10].

## 5. MEF-OAM LOG MESSAGES

In order to maintain and monitor the network, MEF-OAM generates various log entries notifying of communication failure, exceeded thresholds, and MEF-OAM PDU process errors.

The following informational log is sent when untriggered two-way frame-loss, latency or jitter threshold is triggered for a specific MEF-OAM monitoring process: Informational: **Untriggered <number> alarms for MAC HH:HH:HH:HH:HH:HH on OAM Domain <domain> on VLAN <vlan-id> on process <process-name>.**

The following warning is sent when a threshold error is triggered for a specific two-way monitoring process threshold: jitter, frame-loss or latency two-way monitoring: **Warning: <test-name> exceeded limit of <threshold> for MAC HH:HH:HH:HH:HH:HH on OAM Domain <domain> on VLAN <vlan-id> on process <process-name>.**

The following notification is sent when a threshold warning is triggered for a specific two-way monitoring process threshold: jitter, frame-loss or latency two-way monitoring: **Notification: <test-name> exceeded limit of <threshold> for MAC HH:HH:HH:HH:HH:HH on OAM Domain <domain> on VLAN <vlan-id> on process <process-name>.**

The following notification is sent when an untriggered two-way threshold error is triggered for a specific MEF-OAM process, but a threshold warning is triggered for a specific two-way monitoring process: jitter, frame-loss or latency two-way monitoring: **Notification: <test-name> threshold drop to warning level, <current-value> exceeded limit of <threshold> for MAC HH:HH:HH:HH:HH:HH on OAM Domain <domain> on VLAN <vlan-id> on process <process-name>.**

The following warning is sent when untriggered two-way threshold error and warning triggers for a specific MEF-OAM process: jitter, frame-loss or latency two-way monitoring: **Informational: Untriggered <test-name> alarm. Alarm was disabled for MAC HH:HH:HH:HH:HH:HH on OAM Domain <domain> on VLAN <vlan-id> on process <process-name>.**

The following error message is sent when MEF-OAM PDU is received from un-allowed port or VLAN and is not processed: **Error: Unallowed PDU received for domain <domain> on port UU/SS/PP on VLAN <vlan-id>.**

The following error message is sent when an invalid MEF-OAM PDU is received. Check the MEF-OAM versions: **Error: Invalid MEF-OAM packet received: <pdu-type>.**

The following error message is sent when more PDUs are received per second than a limit defined on the device. Check the PDU limitation settings for the MEF-OAM domain: **Error: PDU Overflow for domain <domain>. Cause: Low PDU limit or Security attack.**

## 6. NEW MEF-OAM COMMANDS

To apply and configure MEF-OAM two-way monitoring process the following commands were implemented:

- **mef jitter-error** [*<error>* *<error-time>*] command enables the two-way jitter error monitoring, defines the jitter error threshold, and the time period for monitoring jitter errors. The jitter is calculated using the last connectivity test request results throughout the specified period. By default, jitter error monitoring is enabled with a threshold value of 700 milliseconds, and a calculation period of 90 seconds.
  - The two-way jitter error threshold value is in the range of <1–10000> milliseconds.
  - The period for monitoring the jitter errors is in the range of <1–3600> seconds.

- **mef jitter-warning** [*<warning>* *<warning-time>*] command enables two-way jitter warning monitoring, defines the jitter warning threshold, and the time period for monitoring jitter warning. The jitter is calculated using the last connectivity test request results throughout the specified period. By default, jitter warning monitoring is enabled with a threshold value of 600 milliseconds, and a calculation period of 180 seconds.
  - The two-way jitter warning threshold value is in the range of <1–10000> milliseconds.
  - The period for monitoring the jitter warnings is in the range of <1–3600> seconds.
- **mef frame-loss-error** [*<error-percent>* *<error-tenth-percent>*] command enables the frame-loss error monitoring and defines the two-way frame-loss error threshold value. By default, the frame-loss error is enabled with a threshold value of 10 percents.
  - The two-way frame-loss error threshold is in the range of <1–99> %.
  - The two-way frame-loss error threshold is in the range of <0–9> in 1/10 percents.
- **mef frame-loss-warning** [*<warning-percent>* *<warning-tenth-percent>*] command enables the frame-loss warning monitoring and defines the two-way frame-loss warning threshold value. By default, the frame-loss warning is enabled with a threshold value of 8 percents.
  - The two-way frame-loss warning threshold is in the range of <1–99> %.
  - The two-way frame-loss warning threshold is in the range of <0–9> in 1/10 percents.
- **mef latency-error** [*<error>* *<error-time>*] command enables the average two-way latency error monitoring, defines the two-way latency error threshold value, and the time period for monitoring two-way latency errors. By default, average two-way latency error monitoring is enabled with a threshold of 2000 milliseconds and average calculation period of 90 seconds.
  - The two-way latency error threshold value is in the range of <1–10000> milliseconds.
  - The period for calculating the average latency error value is in the range of <1–3600> seconds.
- **mef latency-warning** [*<warning>* *<warning-time>*] enables the average two way latency warning monitoring, defines the two way latency warning threshold value, and the time period for monitoring two way latency warnings. By default, average two-way latency warning monitoring is enabled with a threshold of 1600 milliseconds and average calculation period of 180 seconds.
  - The two-way latency warning threshold value is in the range of <1–10000> milliseconds.
  - The period for calculating the average latency warning value is in the range of <1–3600> seconds.

## 7. TESTING RESULTS

The following configuration example is based on the new two-way monitoring implemented commands and shows the results after configuring the commands listed in the section above:

- Define thresholds for two-way frame-loss error and warning:  
(config-oam 3)#mef frame-loss-error 5 0  
(config-oam 3)#mef frame-loss-warning 4 0
- Define thresholds for two-way jitter error and warning:  
(config-oam 3)#mef jitter-error 800 120  
(config-oam 3)#mef jitter-warning 100
- Define thresholds for two-way latency error and warning:  
(config-oam 3)#mef latency-error 900 10  
(config-oam 3)#mef jitter-warning 800 120

After applying the above configuration example, the following results are obtained:

- Frame-loss error monitoring value is 5% and the warning value is 0%;
- Jitter error monitoring value is 800 ms and the warning value is 120 ms;
- Latency error monitoring is 900 ms and the warning value is 120 ms.

## 8. CONCLUSIONS

Tracking and monitoring data in a network means collecting, recording, organizing, and retrieving details of the data transmitted across the network, with accuracy and promptitude.

Metro Networks [9] are a component of the broadband era. High bandwidth capabilities and effective solutions, in terms of costs, are engines that make Ethernet a natural choice for these services. In addition, critical business applications, voice, and video conferencing require specified levels of service quality to guarantee application performance.

With a suite of carrier-class Ethernet services, more benefits are obtained. Ethernet services enable carriers to capitalize on some opportunities of the market immediately.

The operation of OAM on an Ethernet interface does not adversely affect data traffic as OAM is a slow protocol with very limited bandwidth potential, and it is not required for normal link operation.

This slow protocol can be implemented in hardware or software, ensuring media independence. By using the slow protocol MAC address, OAM frames are intercepted by the MAC sublayer and cannot propagate across multiple hops in an Ethernet network.

In this paper, new commands were added for configuring the MEF-OAM two-way monitoring process, new commands can be selected for two-way jitter, frame-loss and latency.

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