INVITED PAPER *Special Section on the Next Generation Ethernet Technologies*

Standardization Status on Carrier Class Ethernet OAM

Hiroshi OHTA[†a)], ***Member***

SUMMARY This paper shows the recent standardization activities on Ethernet OAM functions. First, it briefly introduces recent carrier class Ethernet services indicating their characteristics and operational issues. Then, it explains current standardization status on Ethernet OAM functions. Finally it shows the requirements for Ethernet OAM functions and details of the OAM mechanisms currently being standardized by ITU-T SG13, SG15 and IEEE 802.1 WG.

key words: *Ethernet, OAM, ITU-T, IEEE 802*

1. Introduction

Ethernet was invented initially as a technology for local area networks (LANs). However, recent evolution changed the characteristics of Ethernet drastically. For example, Ethernet can now support high bit rate (up to 10 Gbit/s) and long distance (up to 40 km) transmission [1]. Ethernet capabilities as access networks have been enhanced by IEEE (Institute of Electrical and Electronics Engineers) 802.3 WG (Working Group) (IEEE 802.3ah [2]). This includes point-to-point and point-to-multipoint (passive optical network (PON)) optical transmission methods as well as link level Ethernet operation and maintenance (OAM) functions. Another standardization activity is enhancing the scalability of the Ethernet. IEEE 802.1 WG is developing the “Provider Bridges” [3] and “Provider Backbone Bridges” [4] drafts. The former provides independent virtual LAN (VLAN) spaces both for users and carriers by using two VLAN tags. As such, each user can define up to 4094 customer VLANs within a service VLAN, which is provided by the carrier. The carrier can define up to 4094 service VLANs. The latter is being standardized to realize further scalable networks. It is standardizing a method which uses B-tag (Backbone tunnel tag), I-tag (Service instance tag) and C-tag (Customer VLAN tag). B-tag and C-tag include 12 bit VLAN IDs. I-tag includes the 20 bit service ID (note that the size of the service ID is under study). One VLAN ID identifies a customer VLAN. Service ID identifies a service in a carrier network. Another VLAN ID identifies a backbone VLAN. This method allows the carrier to use 12 bit VLAN ID space and 20 bit service ID space while letting each user use 12 bit VLAN ID space. Ethernet is expected to become more scalable by these new standards. In addition, Ethernet equipments are relatively less expensive. As a result, Ethernet became to be used widely in carrier networks.

One of the typical Ethernet services is transparent LAN service (TLS). This service provides each user with a dedicated closed network. Each user can interconnect their sites through this dedicated closed network. It is used mainly by corporate users. It is also called as layer 2 virtual private network (L2 VPN) because layer 2 (Ethernet) transport capability is provided. TLS allows transporting any layer 3 protocol over Ethernet while an IP VPN only transports IP protocol. This is one of the reasons that TLS became popular.

Since Ethernet was originally developed for LANs, its OAM functions are not enough for carrier use. As such, it is difficult to detect a defect quickly, to localize it and to take necessary actions for large scale carrier networks. In addition, it is also difficult to guarantee network performance and provide high quality services since its performance management function is not enough for providing carrier class services, either. On the other hand, TLS is provided mainly for corporate users, who expect high reliability and high performance. Since they use TLS in lieu of leased line services in many cases, they tend to expect the same or similar level of reliability and performance.

In order to overcome this situation, industry demand for standardization of Ethernet OAM functions has been increasing. ITU-T (International Telecommunication Union - Telecommunication Standardization Sector) SG13 (Study Group 13) initiated the standardization of Ethernet OAM functions in early 2002. Since then, other standardization bodies joined this activity as the need for Ethernet OAM functions have been identified. Currently, ITU-SG15, IEEE 802.1 WG are actively working on this issue in addition to ITU-T SG13.

The remainder of this paper is organized as follows. Ethernet services are briefly introduced in Sect. 2. Section 3 shows standardization status concerning Ethernet OAM. Sections 4 and 5 show requirements and mechanisms for Ethernet OAM functions, respectively. Conclusion is given in Sect. 6.

2. Ethernet Services

2.1 Overview of Transparent LAN Services (TLS)

One of the popular Ethernet services is TLS. It provides a

Manuscript received July 11, 2005.
Manuscript revised September 30, 2005.

[†]The author is with NTT Network Service Systems Laboratories, NTT Corporation, Musashino-shi, 180-8585 Japan.
a) E-mail: ohta.hiroshi@lab.ntt.co.jp

DOI: 10.1093/ietcom/e89–b.3.644

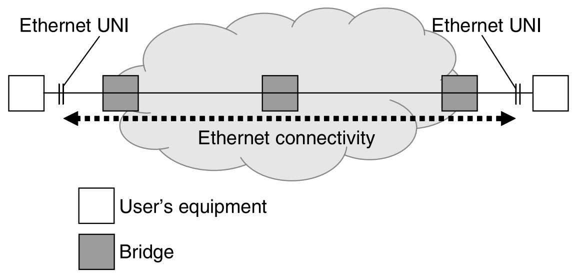


Fig. 1 Example of point-to-point TLS.

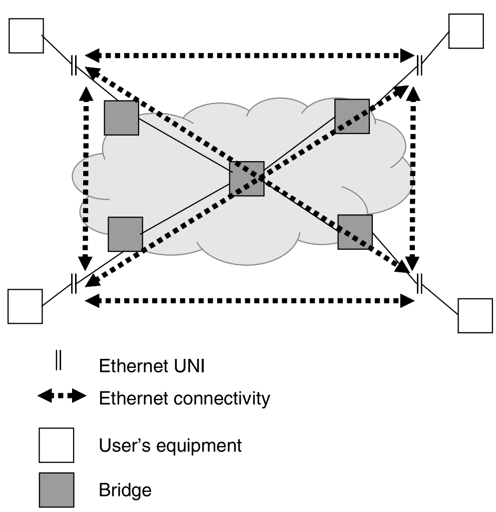


Fig. 2 Example of multipoint-to-multipoint TLS.

virtually dedicated network for each user. This dedicated network is called a closed user group (CUG). The user's local networks (sites) are connected to a CUG though Ethernet UNI (user network interface). A CUG provides full mesh connectivity among UNIs belonging to the same CUG. Each user's traffic is separated by VLANs. TLS can be point-to-point (see Fig. 1) and multipoint-to-multipoint (see Fig. 2). Point-to-point TLS connects two user sites while multipoint-to-multipoint TLS provides mesh connectivity among more than three user sites. From the OAM mechanism point of view, similar approach to the existing technologies (e.g., ATM (Asynchronous Transfer Mode) and MPLS (Multiprotocol Label Switching)) can be used for point-to-point case. However, a new approach is needed for multipoint-to-multipoint case.

2.2 Characteristics of Ethernet

Ethernet is a connectionless technology and it can provide multipoint-to-multipoint connectivity. These are the biggest differences from existing transport technologies such as PDH (Plesiochronous Digital Hierarchy), SDH (Synchronous Digital Hierarchy) and ATM, which are connection oriented point-to-point technologies. Transport routes are not set up beforehand in a connectionless network while they are set up beforehand in a connection oriented network. However, from the network operation viewpoint, it is important to grasp the route in which frames are transported. A bridge (a layer 2 switch) in a Ethernet copies received frames and transmits them from all of its output ports when it has not learned the location of the destination MAC address. In this case, all the frames are delivered to all the destinations (stations). Each destination takes frames which are directed to it and discards other frames. After a bridge has leaned the location of MAC addresses, the bridge transmits frames to the output ports connected to the target destination address only. These behaviours of bridges need to be taken into account when designing Ethernet OAM functions. In addition, since Ethernet provides full mesh connectivity, there are $n*(n-1)/2$ connectivity combinations which OAM functions need to manage when there are n sites.

2.3 Operational Issues of Ethernet

Since OAM functions are limited in current Ethernet, carriers are facing difficulties in operation. For example, carriers cannot identify the defects immediately when they receive a report of a defect from a customer because defect detection, localization and notification functions are not sufficient. This can lead dissatisfaction of the customer because users expect that carriers know about the network much better than the customer and can solve problems quickly. Or when an operator receives a complaint that the throughput of the service does not meet the service specifications, it is not possible to check the throughput remotely. Since performance management functions which allow remote maintenance are not sufficient, operators need to send engineers and test equipment to the field. This activity takes time and costs considerably.

Current Ethernet provides the rapid spanning tree protocol (RSTP) [5] and the link aggregation control protocol (LACP) [6]. They are effective methods to enhance the reliability of Ethernet. However, protection switching is more suitable in some cases in carrier networks because protection switching can recover services quicker and the bandwidth allocation is deterministic. In addition to survivability functions, OAM functions for network management are necessary to realize 'carrier class' Ethernet services. They should include quick defect detection, precise defect localization and performance management functions as indicated above. Ethernet OAM functions and protection switching function are being developed to meet these requirements and to enhance current Ethernet capabilities.

3. Standardization Status

Ethernet OAM functions are being standardized within ITU-T SG13, SG15 and IEEE 802.1 WG. These standard bodies are working with close cooperation. This section shows their current activities.

3.1 ITU-T SG13

ITU-T SG13, Question 5 (Q.5/13), which is responsible for standardization of OAM functions, published Recommendation on requirements for Ethernet OAM functions (Y.1730 [7]) in January 2004. This group is now progressing Draft Recommendation on Ethernet OAM mechanisms (Y.17ethoam [8]). This draft Recommendation is planned to be approved in early 2006.

3.2 ITU-T SG15

There are three groups (Questions) in ITU-T SG15 where standardizations related to Ethernet OAM are progressing. Q.9/15 is working on protection switching and network equipment. This group is progressing Draft Recommendation on Ethernet protection switching (G.8031 [9]) and functional modelling of Ethernet equipment (G.8021 [10]). Q.11/15 is working on Ethernet services. Q.12/15 is working on functional architecture modelling of Ethernet (G.8010 [11]). New Recommendation G.8031 and revised G.8021 are planned to be approved in early 2006. Revised G.8010 is planned to be approved in late 2006 or early 2007 timeframe.

3.3 IEEE 802.1WG

IEEE 802.1 WG set up a project on "Connectivity Fault Management (CFM)" for Ethernet (P802.1ag). This group is developing a draft standard for this project [12]. It should be noted that this group is focusing only on fault management functions while ITU-T is working on both fault and performance management functions. This is the reason why IEEE 802.1 WG is using the term CFM instead of OAM. P802.1ag is intended to be completed by July 2007. However, this WG is trying to complete this project earlier than this deadline.

4. Ethernet OAM Requirements

4.1 User Plane OAM

Telecommunication networks are controlled by operation support systems (OSS's). Figure 3 shows the relationships between an OSS and network elements (NEs). Each NE is connected to the OSS. It is controlled by the OSS and reports its status to the OSS. At the same time, NEs exchange OAM related information among them so that OAM functions can be executed between NEs. OAM functions which are executed on the same path as the user traffic is called "user plane OAM." This paper focuses on the user plane OAM functions.

User plane OAM functions have been standardized for ATM and MPLS as specified by I.610 [13] and Y.1711 [14], respectively. Ethernet OAM functions are being developed based on the same notion. However, Ethernet

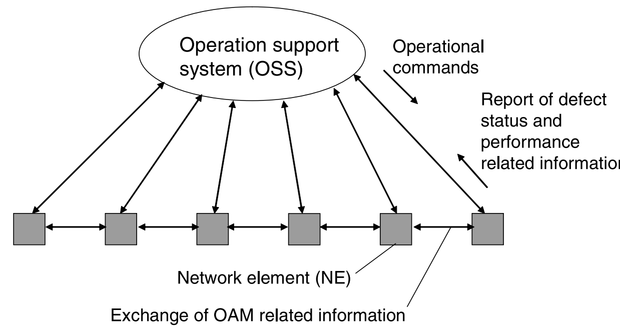


Fig. 3 Relationships between OSS and NEs.

provides multipoint-to-multipoint connectivities using connectionless technology while ATM and MPLS use point-to-point paths (i.e., VP (virtual path)/VC (virtual channel) and LSP (label switched path)) as basic components of connection-oriented technologies. It is a major challenge to develop Ethernet OAM functions which is applicable to multipoint-to-multipoint connectionless networks.

4.2 OAM Requirements Overview

The requirements for OAM functions are classified into the following areas:

- Defect and failure detection
- Defect information
- Fault localization
- System protection
- Performance monitoring

The following subsections describe the above required items in detail. Further detailed requirements are described in ITU-T Recommendation Y.1730 [7].

4.3 Defect Detection

Telecommunication networks are viewed as a layered network. User plane OAM functions can be defined for each layer networks (e.g., physical layer, data link layer, transport layer, etc.). If a defect occurs in the Ethernet layer, Ethernet OAM function should detect it immediately and reports to the OSS automatically. This function is activated continuously in general. Defects can be (a) simple loss of connection, (b) misconnection, (c) swapped connection, (d) mismerging and (e) loop/unintended replication. Figure 4 shows possible defect scenarios.

4.4 Defect Information

Once a defect is detected, the information about the detected defect should be given to the related OSS and network elements. This information can be used to take necessary actions (e.g., stop charging) by NEs in downstream and in upstream.

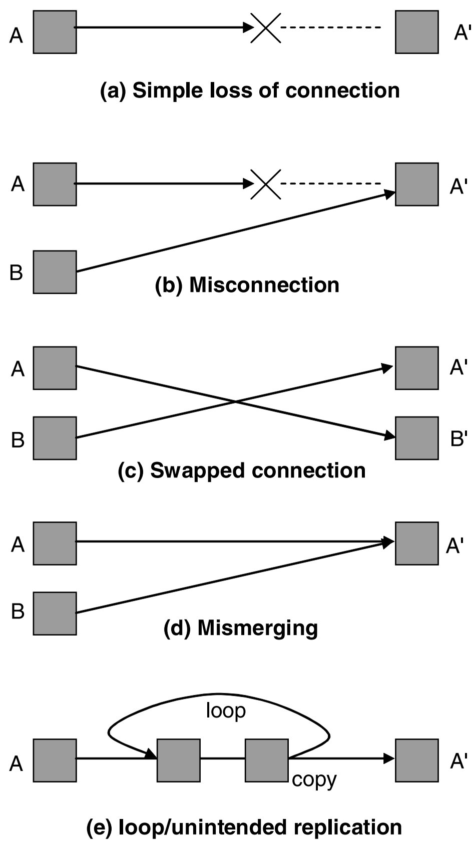


Fig. 4 Possible defect scenarios.

Table 1 Requirements and OAM functions.

Required functions	OAM function under standardization
Defect detection	Continuity check (CC) [8], [12]
Defect information	Alarm indication signal (AIS) [8], [12]
Defect localization	Loopback (LB) [8], [12] link trace (LT) [8], [12]
System protection	Rapid spanning tree protocol (RSTP) [5] link aggregation control protocol (LACP) [6] protection switching [9]
Performance monitoring	Test function [8] frame loss/delay and availability measurement [8]

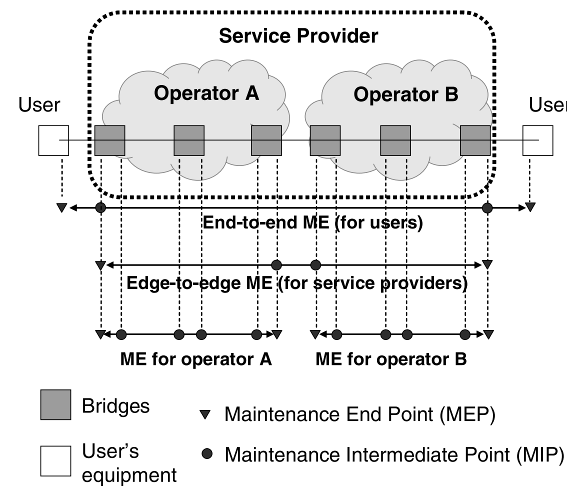


Fig. 5 Maintenance entity (ME).

4.5 Defect Localization

When a defect is detected, it is necessary to determine the location of a defect. This function is called "defect localization." It is important for network operators to take necessary action as soon as possible.

4.6 System Protection

When a service is interrupted by a defect, system protection function can restore the service by switching a impaired part to its backup. System protection can be conducted on a link, a network element or end-to-end connection.

4.7 Performance Monitoring

In order to guarantee the service performance, carriers need to grasp the service and network performance they are providing. Performance monitoring functions allow operators to monitor the service and network performance. Performance parameters include bit errors, frame losses, frame misinsertions, delay and delay variation.

5. Ethernet OAM Mechanisms

This section explains the OAM mechanisms which are under standardization by ITU-T and IEEE 802.1 WG. Although the scope of ITU-T and IEEE 802.1 WG are not exactly the same, these standard bodies are developing exactly the same specification when they standardize the same function (e.g., continuity check, loopback and link trace). It should be noted that the specifications may be changed in the future since it is an ongoing work within these standardization bodies. Table 1 summarizes the relationships between requirements shown in Sect. 4 and OAM functions under standardization.

The following sections explain the mechanisms of OAM functions.

5.1 Maintenance Entity (ME)

A maintenance entity (ME) is an object to which OAM functions are applied. In order to meet the requirements for OAM functions from users, service providers and network operators, maintenance entities can be defined over various portions of a network as well as end-to-end. Figure 5 shows an example of maintenance entities. An ME is terminated by maintenance end points (MEPs). OAM information is inserted and extracted at MEPs. In addition, an ME can have several maintenance intermediate points (MIPs). MIPs allow monitoring at an intermediate point of an ME. In this example, operator A and B are jointly providing a service under coordination by a service provider. An end-to-end ME (top in the figure) is defined for the user to manage end-to-end connectivity from user's perspective. An edge-to-edge ME (middle in the figure) is defined for the service provider so that they can monitor the service they are providing. MEs are also defined for network operators. These MEs enable each network operator to monitor the portion of a network for which each operator is responsible. MEs can be nested as shown in Fig. 5 so that a shorter portion (e.g., operator ME) and a longer portion (e.g., provider ME) can be monitored at the same time.

Since Ethernet provides multipoint-to-multipoint connectivity, OAM functions have to be applicable such connectivity. If there are n MEPs, $n(n-1)/2$ MEs are necessary to cover as shown in Fig. 6. This group of MEs is called a maintenance entity group (MEG).

5.2 Transport of OAM Information

Similar to ATM [13] and MPLS [14], OAM information is transported by dedicated OAM frames. Figure 7 shows the OAM frame format currently studied by ITU-T [8] and IEEE 802.1 [12]. EtherType (VLAN) and VLAN Tag fields are only present when a VLAN is used. It should be noted that it may be changed in the future since it is still under study now.

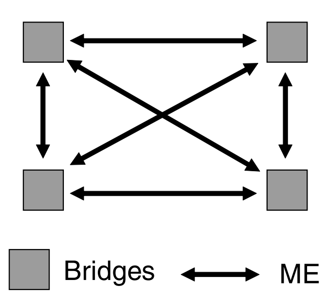
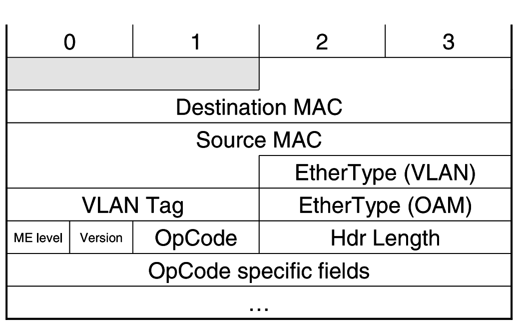


Fig. 6 Maintenance entity group (MEG).



Legends:
OpCode: Operation code
Hdr: Header

Fig. 7 OAM frame format.

5.3 Identification of OAM Frames

OAM frames are identified using EtherType (OAM). The OpCode field specifies the function for which the frame is used.

5.4 Continuity Check (CC)

This function is used for defect detection. Each MEP sends CC OAM frames periodically with a multicast address. A CC frame sent by an MEP is received by all other MEPs. An MEP is expected to receive CC frames from all other MEPs. Defects can be detected from received CC frames at each MEP.

When each MEP sends CC frames with an interval t, defects can be detected as follows.

(a) If a MEP (A) does not receive any CC frame from a MEP (B) for an interval of longer than $3.5t$, then loss of connectivity defect between A and B is declared. MEP (A) waits for $3.5t$ to prevent its generating a loss of connectivity alarm due to one or two CC frame losses caused by congestion or bit errors. In this case, this alarm should not be generated because connectivity is not lost.
(b) If a MEP (A) does not receive expected CC frames from a MEP (B) but receives unexpected CC frames from another MEP (X), then misconnection defect is declared. "Swapped connection" (see Fig. 4) also leads to a declaration of misconnection defect.
(c) If a MEP (A) receives both expected CC frames from a MEP (B) and unexpected CC frames from another MEP (X), then mismerging defect is declared.
(d) If a MEP (A) receives expected CC frames from a MEP (B) with a frequency of more than one CC frames within the period of t, then loop/unintended replication defect is declared.

5.5 Alarm Indication Signal (AIS)

This function is used for notification of the existence of a defect and for suppression of unnecessary alarms. When a transmission line that accommodates several numbers of flows fails, loss of connectivity defect is detected at each MEP. Since these defects are secondary defects that are caused by a defect of the transmission line, they should be suppressed if the root cause is properly handled.

For those purposes, AIS frames are generated and transmitted to downstream by a MIP when it detects a server (lower) layer defect.

Figure 8 shows how alarm suppression works. When the link between E and F breaks, connectivities A-H, B-J and C-K are interrupted. Then H, J and K detect loss of connectivity defect. F detects the link defect and reports it to the OSS. Then, F generates AIS frames towards H, J and K respectively. When H, J and K receive AIS frames, they

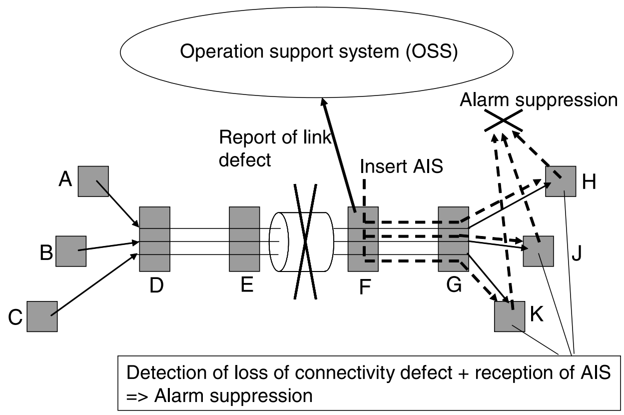


Fig. 8 Alarm suppression by AIS.

do not report loss of connectivity defect to the OSS even if they detect it because they understand that this defect is already detected and reported upstream. It should be noted that this example shows a point-to-point case. Further study is needed for multipoint-to-multipoint cases.

5.6 Loopback (LB)

This function is used as a defect localization function. When a MEP sends a LB frame with a target MEP indication, that MEP replies to the originator of the received LB frame. Thus, this function tests connectivity between these MEPs on the basis of operator's command. Alternatively, when a MEP sends a LB frame with a multicast address, all the MEPs reply to the originator of the received LB frames. This can be used to detect unintended connectivities.

5.7 Link Trace (LT)

This function is also used as a defect localization function. When a MEP sends a LT frame with a target MEP indication, the MEP and all the MIPs between these MEPs reply to the originator of the received LT frame. Network topology can be grasped by analyzing the replies.

There is one issue to be solved. Although bridges learn the location of reachable MAC addresses, they are aged out (removed) after predefined time has passed (typically, 5 minutes) without receiving frames from nodes with these MAC addresses. As such, MAC addresses can be aged out when a defect occurs. It is necessary to clarify how LT can be realized when MAC addresses are aged out.

5.8 Protection Switching

In addition to the RSTP [5] and the LACP [6], which were developed by IEEE 802 LAN/MAN Standards Committee, protection switching function is being studied by ITU-T SG15. One of the objectives is to realize a system protection method which is faster and easier to control. Currently, 1+1 and 1:1 architecture with bidirectional and unidirectional protection switching methods are being studied [9].

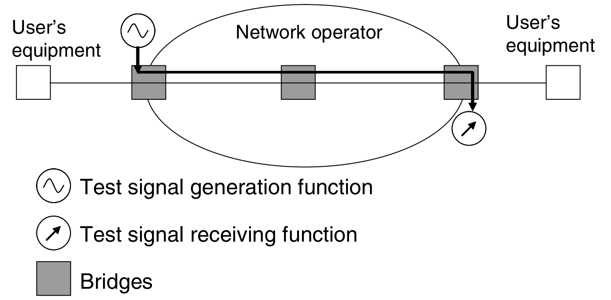


Fig. 9 Test function.

The 1+1 architecture transmits the traffic on both working and protection entities while 1:1 architecture transmits the traffic only on the selected one. The bidirectional protection switching always selects the same entity (either working or protection) in both directions while unidirectional protection switching makes selection independently in each direction.

5.9 Test Function

This function is used for performance management. It inserts test OAM frames at a MEP and extracts at another MEP. It tests throughput, frame losses and frame misinsertions between the insertion and extraction points. Figure 9 shows an example of a usage of this function. This function can be used for pre-service performance test as well as for trouble shooting when the operator receives a complaint from a user indicating poorer performance (e.g., throughput) than contracted. For these purposes, both out-of-service test and in-service test are possible.

5.10 Frame Loss Measurement

ITU-T SG13 (Q.5/13) is studying frame loss measurement methods. For the point-to-point case, the basic idea is to send a loss measurement (LM) request from a MEP to another MEP. When a MEP receives this request, it replies with an LM reply message with its performance data. Alternatively, unsolicited performance data collection is also possible. In this case, each MEP sends its performance data periodically.

Frame loss measurement methods for multipoint case are left for further study.

5.11 Frame Delay Measurement

Q.5/13 is studying a frame delay measurement method for point-to-point case. It uses a loopback (LB) with a timestamp field. A MEP sends an LB request with a timestamp indicating the transmission time. The receiving MEP replies with an LB reply message copying the content from the LB request message. When the originating MEP receives the LB reply message, it can measure the round-trip delay by comparing the timestamp value (transmission time) and the reception time.

Q.5/13 is studying a frame delay variation measurement method also. It uses CC frames with a transmission timestamp field. Each CC frame carries a timestamp which indicates the time when it is transmitted. By observing the variation of the difference between the transmission time stamp value and its local time, each MEP can measure the frame delay variation from each MEP to the receiving MEP.

5.12 Availability Measurement

Availability can be measured based on frame loss, frame delay and delay variation. If any one of these performance value exceeds a pre-defined thresholds during a measurement period (e.g., 1 minute), this period is considered as unavailable. Otherwise, this period is considered as available.

5.13 Relationships with Lower Layer OAM Functions

Several technologies are available as the lower layer for networks that provide Ethernet services. They include SDH, RPR (resilient packet ring) [15], ATM, etc. OAM functions for the lower layer and Ethernet OAM work independently in principle. However, when a defect is detected in the lower layer, Ethernet layer is notified of this defect so that it can grasp the defect and suppress unnecessary alarms. In addition, survivability functions such as protection switching and restoration for these layers (i.e., Ethernet layer and the lower layer) need to be coordinated. In general, survivability function for the lower layer needs to be executed first. If it is not successful, then survivability function for Ethernet should be executed. For this purpose, hold-off timer is used. If a defect occurs, Ethernet layer survivability function waits until the hold-off timer has been expired. If the lower layer survivability function is executed successfully during this period, Ethernet layer survivability function is not executed. Otherwise, Ethernet layer survivability function is executed.

6. Issues to Be Addressed

As indicated in 5.7, LT mechanism under fault condition, in particular, LT mechanism to be used after the learned MAC addresses have been aged out due to a defect, needs to be clarified. It is now under study within the development of Ethernet OAM standard.

7. Conclusion

This paper described the status of recent Ethernet services including service characteristics and operational issues. Then, it showed the standardization status of Ethernet OAM functions. Finally, the requirements for these functions and currently studied OAM functions are explained in detail. Since this issue is currently being studied actively within ITU-T SG13, SG15 and IEEE 802.1 WG, readers are encouraged to follow the ongoing work within these standardization bodies.

References

[1] IEEE 802.3ae, "Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications—Amendment: Media access control (MAC) parameters, physical layers, and management parameters for 10 Gb/s operation," June 2002.

[2] IEEE 802.3ah, "Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications—Amendment: Media access control parameters, physical layers, and management parameters for subscriber access networks," June 2004.

[3] IEEE P802.1ad/D6.0, "Virtual bridged local area networks—Amendment 4: Provider bridges," Aug. 2005.

[4] IEEE P802.1ah/D1.2, "Virtual bridged local area networks—Amendment 6: Provider backbone bridges," Aug. 2005.

[5] IEEE 802.1D, "Media access control (MAC) bridges," June 2004.

[6] IEEE 802.3, "Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications," March 2002.

[7] ITU-T Recommendation Y.1730, "Requirements for OAM functions in Ethernet-based networks and Ethernet services," Jan. 2004.

[8] ITU-T Draft Recommendation Y.17ethoam, "OAM functions and mechanisms for Ethernet based networks," ITU-T SG13, TD75(PLEN), May 2005.

[9] ITU-T Draft Recommendation G.ethps (G.8031), "Ethernet protection switching," ITU-T SG15, TD150(WP3/15), May 2005.

[10] ITU-T Recommendation G.8021, "Characteristics of Ethernet transport network equipment functional blocks," Aug. 2004.

[11] ITU-T Recommendation G.8010, "Architecture of Ethernet layer networks," Feb. 2004.

[12] IEEE 802.1ag/D4.1, "Virtual bridged local area networks amendment 5: Connectivity fault management," Aug. 2005.

[13] ITU-T Recommendation I.610, "B-ISDN operation and maintenance principles and functions," Feb. 1999.

[14] ITU-T Recommendation Y.1711, "Operation & maintenance mechanism for MPLS networks," Feb. 2004.

[15] IEEE 802.17, "Resilient packet ring (RPR) access method and physical layer specifications," Sept. 2004.

Hiroshi Ohta received his B.S. degree in Electrical Engineering and his M.S. and Dr. Eng. degrees in Electronics Engineering from Kyoto University, Kyoto, Japan in 1985, 1987 and 2000 respectively. He joined Electrical Communication Laboratories of Nippon Telegraph and Telephone Corporation (NTT), Kanagawa, Japan in 1987. Since 1987 to 1999 he was engaged in research and development of ATM based transport systems, in particular, optical subscriber loops, cell loss analysis/recovery, OAM functions and protection switching as well as development of an ATM cross-connect system. Since 2000, he has been engaged in development of services for corporate users such as IP-VPN and metro Ethernet services and development of services for consumers such as content delivery services (CDS). Since 1992, he actively participates in standardization meetings of ITU-T SG13, SG15, IEEE 802 LAN/MAN Standards Committee and IETF. He is a rapporteur for Question 3/15 (General characteristics of optical transport networks) of ITU-T SG15. He is currently a senior research engineer at NTT Network Service Systems Laboratories. He is a member of the IEEE Communications Society.