T-MPLS Technology and Application on Carrier Ethernet

Qu Hua[1], *Zhao Jihong*[2], *Mao Hongbao*[2]
(1. Xi'an Jiaotong University, Xi'an 710049, P. R. China;
2. Xi'an University of Posts and Telecommunications, Xi'an 710061, P. R. China)

Abstract:
As a connection-oriented packet transport technology, Transport Multi-Protocol Label Switching (T-MPLS) is an important bearer technology for Carrier Ethernet (CE). This article starts with the technological characteristics of T-MPLS, then goes on to the latest T-MPLS standardization progress and challenges, followed by the description of T-MPLS based CE architecture. Next, the article covers several key technologies related with T-MPLS, including the data forwarding plane, control plane, network survivability, and Operation, Administration and Maintenance (OAM). Finally, the article analyzes the applications of T-MPLS based CE.

Being a carrier-class transport technology, Transport Multi-Protocol Label Switching (T-MPLS)[1] eliminates the unnecessary connectionless IP-based processing capabilities of MPLS, and uses a unified data transport plane. Essentially, it enables connection-oriented packet transport, and can provide carrier-class services. It boasts almost the same end-to-end OAM, Quality of Service (QoS) and less than 50 ms protection switching capability as the traditional transport technologies, and has the hierarchical structure similar to Synchronous Digital Hierarchy (SDH) and Optical Transport Network (OTN) with matched network management and intelligent control capabilities. All the mentioned features guarantee its wide application.

Carrier Ethernet (CE)[2] does not refer to a specific network technology, but a general conception; generally speaking, all the standardized, scalable and highly-reliable networking technologies that provide Ethernet interface, QoS guarantee and service management capabilities, and that bear multiple services, can be called CE technologies. Defined by the Metro Ethernet Forum (MEF), CE involves five aspects: standardized services, scalability, reliability, QoS, and carrier-class network management. So far most potential CE technologies are T-MPLS, Virtual Private LAN Service (VPLS) and Provider Backbone Transport (PBT).

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1 Technological Characteristics and Standardization Progress of T-MPLS

1.1 Technological Characteristics of T-MPLS

T-MPLS, as defined by ITU-T SG15, is a MPLS-based connection-oriented packet transport technology. It is deemed as the natural extension of MPLS from the core network to the Metropolitan Area Network (MAN) and Access Network (AN); it can be simply described as the following equation: T-MPLS = MPLS-the complexity of L3 + Operation, Administration and Maintenance (OAM) + Traffic Engineering (TE). For carrier-class applications, T-MPLS has the following features:

(1) It discards the complicated control protocol stack defined by IETF for MPLS, simplifies the data plane, and deletes unnecessary forwarding actions (e.g., Penultimate Hop Popping (PHP), label combination of MPLS, and Equal Cost Multipath (ECMP) routing).

(2) It boasts perfect OAM mechanism.

(3) It allows for performance monitoring.

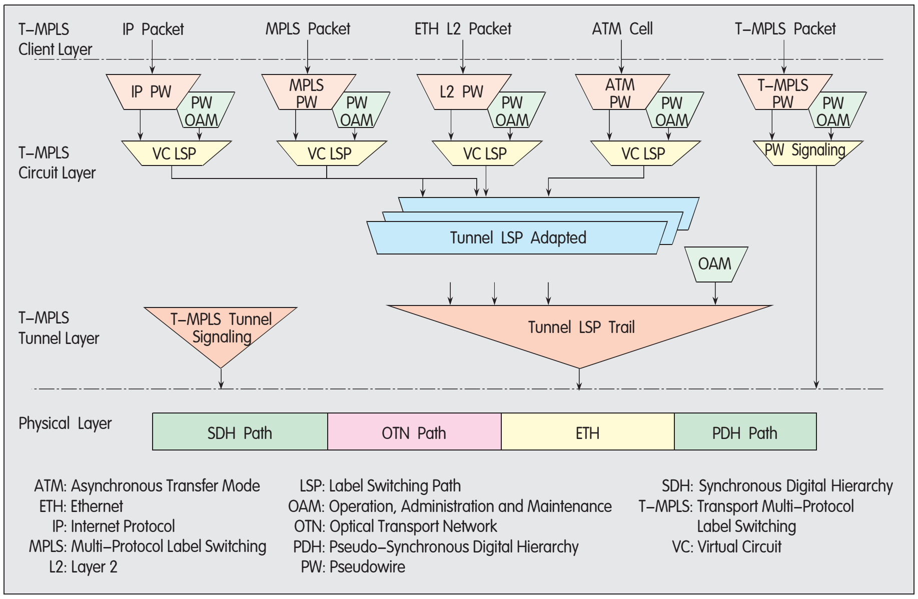
(4) It ensures the end-to-end less than 50 ms protection.

(5) For the sake of TE and end-to-end transport, it does not support the connectionless transport mode. Therefore, all connections are explicitly end-to-end, which makes T-MPLS a pure transport-oriented, operation-based transport network technology.

(6) It supports Differentiated Service (DiffServ) QoS, multicast, and global label space, and provides bi-directional Label Switching Path (LSP).

(7) The transport plane and control plane of T-MPLS are independent, which is different from MPLS that depends on the control plane. This feature better ensures expandability and flexibility.

These features make T-MPLS qualified as the CE bearer technology. Besides, T-MPLS supports the Ethernet



▲Figure 1. T-MPLS architecture.

Virtual Connection (EVC) service, and meets the abovementioned five requirements of CE.

1.2 T-MPLS Architecture and Networking Model

T-MPLS LSP has two sublayers: the path sublayer and tunnel sublayer, as shown in Figure 1. The client layer supported by T-MPLS can make any Layer 2 (L2) technologies adopt the mapping technology defined by IETF for the Pseudowire Emulation Edge-to-Edge (PWE3) PW model. The circuit sublayer corresponds to the Virtual Circuit (VC) LSP connection. Moreover, it adapts the client layer service to the data forwarding domain of T-MPLS, and in the adaptation process, it also adapts the OAM information used for VC LSP management. The tunnel sublayer corresponds to the tunnel LSP connection, supports aggregation of T-MPLS VC LSP, which can be either the nesting mode or the multiplexing of T-MPLS and VC LSP, and also adapts the OAM information for tunnel LSP management.

The CE architecture is set up within the framework of the hierarchical network. It requires that the operations of the hierarchical network are independent of the customer layer and control layer so that the user service can be transported in CE over T-MPLS in a more transparent, safe and intact way.

G.8110.1[3] (T-MPLS Architecture) defines the adaptation and processing of messages between the ETH/T-MPLS hierarchical networks. If T-MPLS supports CE, the Ethernet service can be carried over T-MPLS to form the structure of Ethernet over T-MPLS. In the CE over T-MPLS architecture, shown in Figure 2, the T-MPLS technology can be employed to support the MEF-defined EVC service, and the EVC service can in turn be used to transfer the Ethernet frame structure.

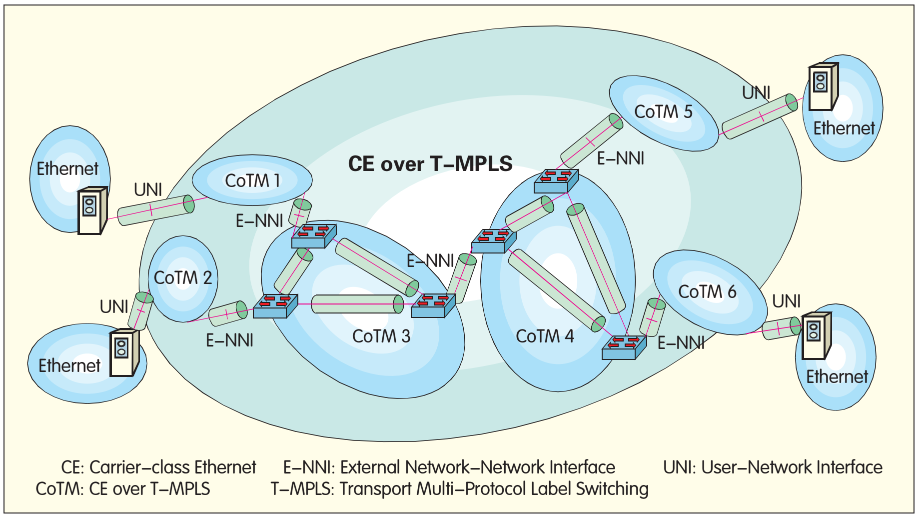
1.3 T-MPLS Standardization

In the progress of standardization, T-MPLS is the pioneer as compared to other CE technologies.

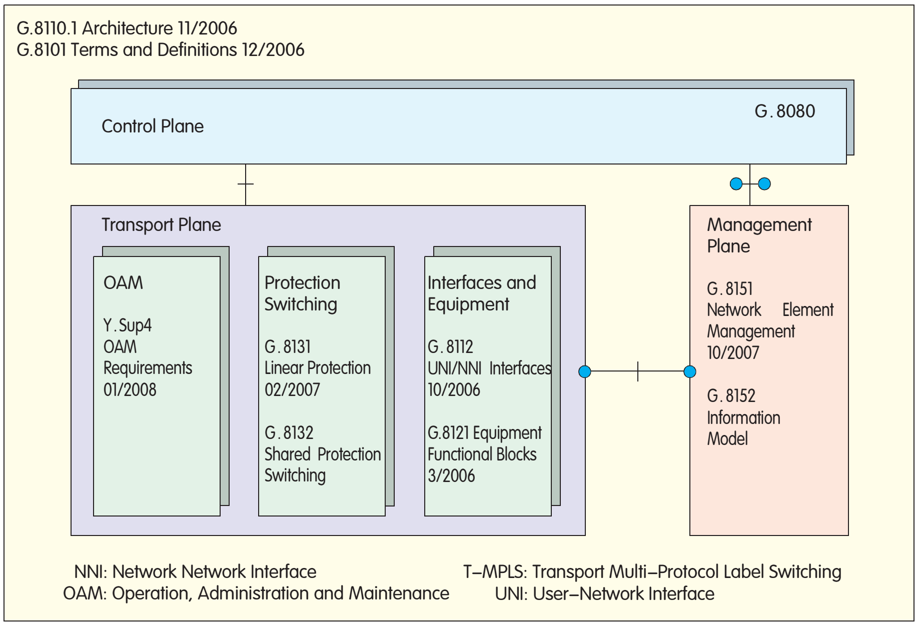
ITU-T SG15 embarked on preparing G.8110.1 in 2005 and since then, ITU-T has started formulating a series of G. 81XX recommendations related with T-MPLS, as shown in Figure 3. The primary purpose of ITU-T to start the T-MPLS-related tasks was to define some secondary functions of MPLS for the transport network, such as the connection-oriented attributes. However, to fully meet the requirements of the transport network, it is necessary to make some expansions for the MPLS functions defined by IETF, for example, OAM and protection switching. T-MPLS OAM was originally designed to be compatible with Ethernet OAM, however, IETF pointed out that these expansions were incompatible with IETF MPLS.

In July 2007, IETF submitted an official report to ITU-T on the compatibility issues between MPLS and T-MPLS, noting the possible network problems in the event of T-MPLS and MPLS interconnection. Moreover, it suggested a joint development of MPLS expansion, and assured that the MPLS and T-MPLS networks are independent of each other and there must be no denomination confusions.

In September 2007, ITU-T SG15 Q12 reached an agreement with IETF on the standards of T-MPLS structure. Moreover, the T-MPLS OAM standardization work of SG13 Q5 will be forwarded to SG15 in the study period 2009-2013. In April 2007, the recommendations about OAM (G.8113



▲Figure 2. Networking pattern of CE over T-MPLS.



▲Figure 3. The status of T-MPLS standardization.

and G.8114) were not approved because IETF pointed out 61 problems to be solved. G.8113 will be published as Y.Supple.4.

In February 2008, ITU-T and IETF set up the Joint Working Team (JWT) for the study of T-MPLS technology. The JWT will examine the approved or agreed ITU-T proposals. In March 2008, the IETF MPLS Interoperability Design Group discussed the requirements of ITU-T OAM and data forwarding. In the JWT work meeting held in March 2008, IETF MPLS was defined as Multi-Protocol Label Switching Transport Profile (MPLS-TP) to adapt to the expansion of transport requirements, and IETF would be responsible for the task; ITU-T would include MPLS-TP into its new recommendations. It was expected that the T-MPLS standard series would be completed after 2008. At present, the JWT is focusing on the data forwarding plane, control plane technology, network element management and interface/equipment, network survivability, and OAM mechanism.

In China, China Communications Standard Association (CCSA) has finished "MSTP Technical Requirements: Nesting MPLS". It is now working on the technical report named "T-MPLS Technical Requirements".

While supporting CE, T-MPLS also faces the following challenges:

(1) Resource management: The logic label has to be mapped to the proper bandwidth; the connected bandwidth tends to be dynamic; Connection Acceptance Control (CAC) is needed; more connections are needed as compared with that of a circuit-switched network; and the bandwidth management is complex.

(2) Bi-directional non-symmetric LSP: The bi-directional LSP is overlapping and non-symmetric; signaling has to be expanded; and resource allocation and management have difficulties.

(3) Nesting LSP: The nesting LSP improves expandability, but it has difficulties in protection and restoration.

(4) Link discovery and fault management: With the function of link discovery, the link connection between nodes can be discovered automatically, hence less manual configuration is needed and more unexpected configuration errors can be avoided.

(5) Link Management Protocol (LMP) is an option in T-MPLS link discovery and management. The discovery mechanism can also be implemented by OAM on the data transport plane.

(6) T-MPLS survivability: The protection technology includes 1:1, 1+1 and ring network protection; the restoration technology includes hard/soft routing, pre-computation/dynamic restoration. The problems to be solved in this aspect include the mode of starting the restoration action, segmental protection/restoration and end-to-end protection/restoration, and the survivability based on Grade of Service (GoS).

(7) Service supported: Point-to-Point (P2P) LSP (E-Line), Point-to-Multipoint (P2MP) LSP (E-Tree) and multiple P2P LSP (E-LAN).

(8) Multi-level interconnection: Signaling interoperability, flooding and extraction of TE link, Path Computation Element (PCE), multi-level survivability, and peer or overlay.

2 Data Forwarding Plane Technology of T-MPLS

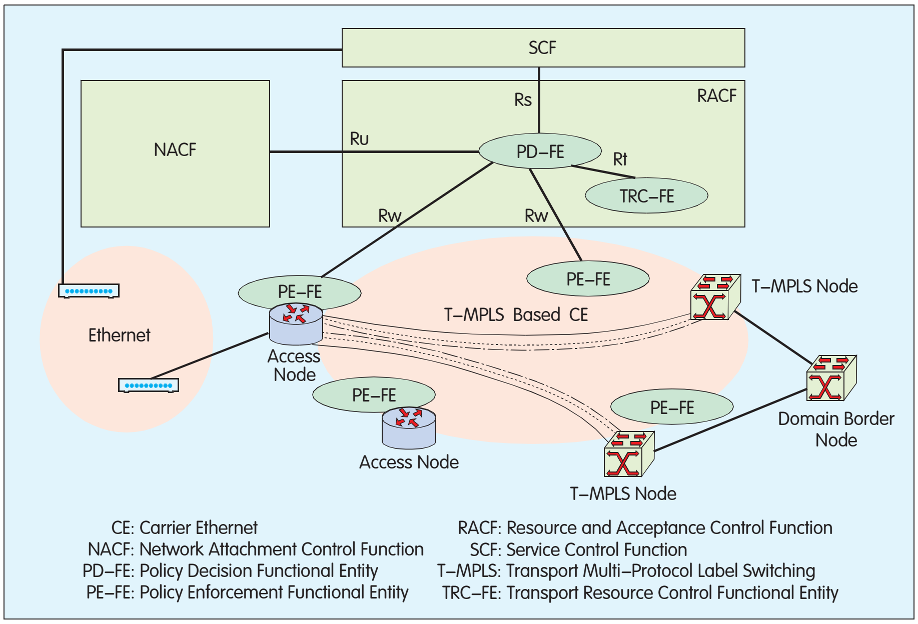
T-MPLS uses the dual-label switching and forwarding mode, that is, T-MPLS allocates two types of label to the client while it provides the client with packet transport. The two label types are the virtual channel/PW label, and the transport switching path/tunnel label. The channel label connects the clients at both ends together, and is used for the terminal equipment to differentiate client data. The tunnel label is used for data switching and forwarding in the T-MPLS packet path.

The T-MPLS data forwarding technology is based on the MPLS data forwarding, label operation and washer label formatting specified in IETF recommendation RFC3031/3032[4]. It has the following features:

(1) Uni-directional and bi-directional T-MPLS LSP: Two uni-directional LSPs on the data plane transported in the same physical path form a bi-directional LSP.

(2) Differentiated services: It supports expansion-based LSP or label LSP, and enables data forwarding of differentiated services, based on Pipe Model and Short Pipe Model specified in RFC3270[5]. The Uniform Model in RFC 3270 is not considered in T-MPLS because it does not suit the L2VPN data forwarding mode.

(3) It supports Time-to-Live (TTL) processing and coordinates with tunnel LSP, with considerations of Pipe-Model and Short-Pipe LSP data forwarding modes specified in RFC3443[6].



▲Figure 4. Delivering RACF in the architecture of CE over T-MPLS.

P2MP multicast is an important research direction of T-MPLS. It includes next-hop label forwarding access, packet copying, data plane (tree or point-to-point), and label allocation and layering. Since the JWT was set up not long ago, there are no other documents covering details of T-MPLS multicast except G8110.1 that mentions the support of T-MPLS for multicast. The MPLS and Frame Relay Alliance (MFA) conference, held in Chicago in March 2007, believed that the details of uni-directional P2MP multicast of T-MPLS in G.8110.1 can be improved based on the IETF RFC about MPLS P2MP multicast. The latest proposal G.8110.1 Amendment 1[7] about T-MPLS architecture has given the schematic diagram of T-MPLS uni-directional P2MP connection architecture.

3 Control Plane Technology of T-MPLS

CE's greatest strength is its separated and independent control function and transport function. The transport plane is responsible for data forwarding and transport only, while the control plane delivers all functions related with network resource control and management.

ITU-T, IETF and Optical Internetworking Forum (OIF) are responsible for the standardization of the T-MPLS control plane. ITU-T focuses on the requirements, architecture and functions of the plane. IETF mainly prepares the design and expansion of the control protocols, for example, signaling, routing and LMP protocol; IETF also clarifies and addresses specific issues related with the control plane. OIF puts its efforts mainly on User Network Interface (UNI) and External Network Network Interface (E-NNI).

T-MPLS deploys the General Multiple Protocol Switching/Automatic Switching Optical Network (GMPLS/ASON) as its unified control plane to perform label distribution and T-MPLS path establishment. This is a critical breakthrough and reform in the history of transport network technology. In the architecture of CE over T-MPLS, the control plane is described vividly as the network Resource and Acceptance Control Function (RACF)[8-9] and the Network Attachment Control Function (NACF). Figure 4 shows the RACF scheme in the architecture of CE over T-MPLS.

RACF is made up of Policy Decision Functional Entity (PD-FE) and Transport Resource Control Functional Entity (TRC-FE), responsible for technology-unrelated and technology-related resource acceptance and control functions respectively. TRC-FE is a functional entity customized especially for the T-MPLS-based transport network. To meet the specific requirements of CE, TRC-FE has to deliver such functions as real-time monitoring and information collection of transport network resource (topology and link capacity), CAC, and technology-related QoS requirements and attributes.

4 Survivability Technology of T-MPLS

One of the major characteristics of T-MPLS is its perfect survivability technology. The survivability of the T-MPLS network is very important to guarantee its network performances, including the transport plane-based protection switching and control plane-based restoration. The protection switching based on the transport plane includes linear protection switching and shared protection ring. The restoration based on the control plane means that, after a fault occurs and with the coordination of the control plane, the working path is computed again for the service or the protection path is pre-computed.

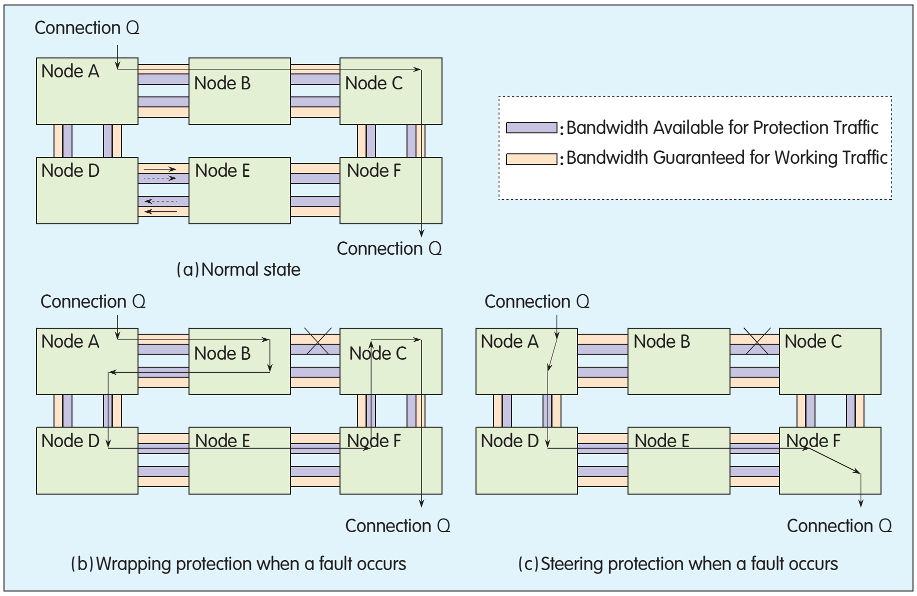
So far only the linear protection switching for T-MPLS survivability has been standardized. The T-MPLS shared ring protection has been drafted.

(1) Linear Protection Switching

The linear protection switching for T-MPLS survivability has been standardized in ITU-T G.8131/Y.1382[10], which specifies both the T-MPLS end-to-end path protection structure and T-MPLS subnet connection protection structure, as well as defines the uni-directional/bi-directional switching types and the return/non-return operation types. Based on APS coordination, T-MPLS can perform protection switching on the section layer, path layer and circuit layer. The protection switching can be initiated by the management plane or initiated by the fault indication signal after an equipment fault is detected.

(2) Shared Protection Ring

ITU-T G.8132[11] specified the T-MPLS Shared Protection Ring (TM-SPRing) standards, which has two protection mechanisms, wrapping and steering, to support P2P and P2MP



▲Figure 5. TM-SPRing working principle and signaling procedure.

T-MPLS connection.

TM-SPRing is a bi-directional dual-ring topology with each section of optical path along the ring working at the same rate. The transport direction of the outer loop is clockwise while that of the inner loop is anti-clockwise. The protection requires no dedicated bandwidth backup and two of the loops can be used to transport data. By broadcasting switching control messages on the ring, all nodes on the ring will be notified of a fault route or node. TM-SPRing provides reliable mechanism of less than 50 ms protection switching for all protected services.

Figure 5 depicts the TM-SPRing signaling procedure of T-MPLS wrapping and steering protection mechanisms. In Figure 5(a), the service traffic Q is in normal network status, and the outer loop is taken. After a link fault occurs, wrapping protection, as shown in Figure 5(b), is employed to perform protection switching operation on the upstream Node B of the neighboring faulty link, with a new path of A-B-A-D-E-F-C-F, while steering protection, as shown in Figure 5(c), is employed and the service traffic from Node A to Node D is rerouted to the inner loop to get to the destination node, with a new path of A-D-E-F.

(3) Restoration Technology

T-MPLS restoration is fulfilled on the control and management planes. The distributed control plane technology based on GMPLS/ASON is deployed to perform LSP restoration. The restoration applies to any topology structures, and it can also coordinate with other transport network technology layers, such as SDH, OTN, and WDM.

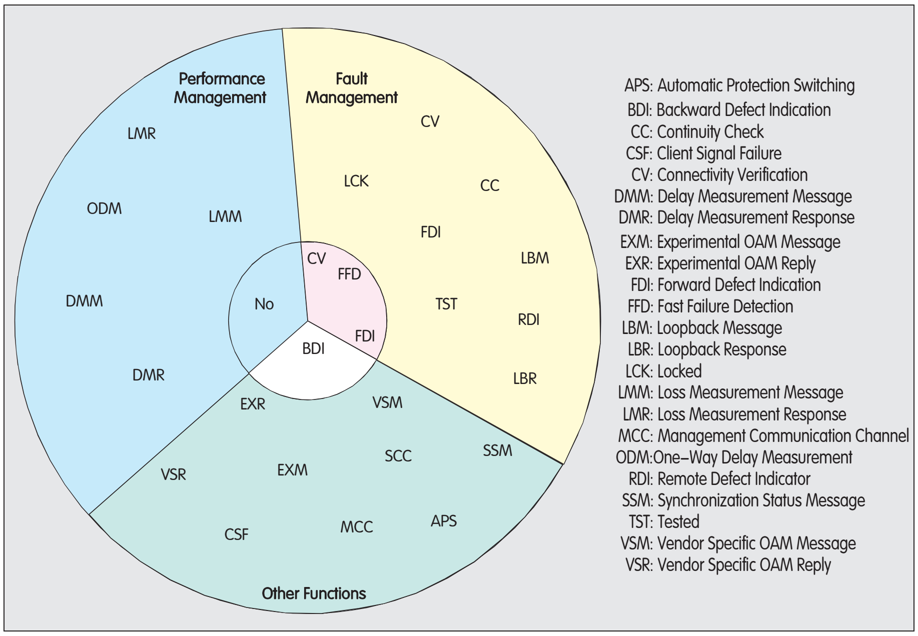
There are still many problems to be solved for T-MPLS survivability, including the trigger mechanism, multi-ring protection function, service-oriented restoration, multi-domain restoration technology, and dynamic path restoration function.

5 T-MPLS OAM

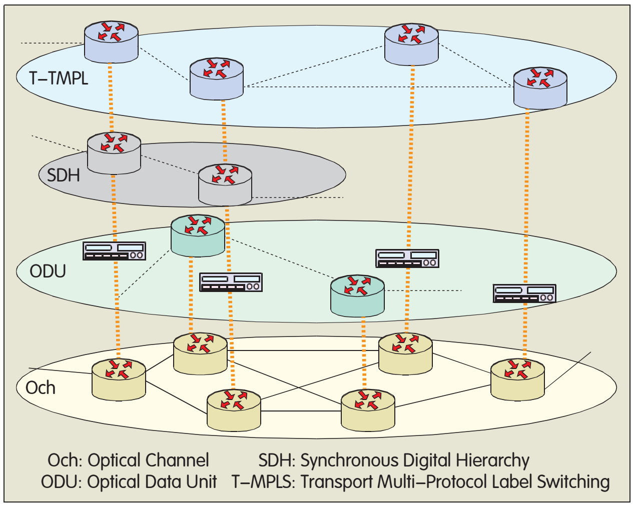
Another important characteristic of T-MPLS is that it boasts of powerful OAM capabilities. ITU-T Y.Sup4[12] elaborately defines the T-MPLS OAM mechanism so that the transport entities at all layers, no matter if they belong to the user, service provider or carrier, are able to perform fault detection, fault isolation, and performance monitoring, as well as to learn about the completeness and path status of sending and receiving information on their own layers. This is what makes T-MPLS extraordinary as compared to other Packet Transport Network (PTN) schemes.

The T-MPLS OAM mechanism comprises three parts: fault management, performance management, and other functions, as shown in Figure 6, where the MPLS OAM functions of are given in the small circle while the fans outside the small circle are dedicated to the three parts of T-MPLS OAM functions.

Figure 6 clearly shows that T-MPLS OAM expands MPLS OAM. According to the comparison, T-MPLS has many more types of OAM Protocol Data Unit (PDU) than MPLS, and each PDU performs one function. The functions together are enabling T-MPLS OAM to support error



▲Figure 6. OAM mechanism of T-MPLS.



▲Figure 7. T-MPLS over OTN.

management and performance management, while also minimize service interruption, restoration time and operation resource. These T-MPLS OAM functions are basically equivalent to those of the traditional transport network, hence making the T-MPLS OAM capable of providing carrier-class services.

6 T-MPLS Applications

As an MPLS-based connection-oriented packet transport technology, T-MPLS is supported by many telecom vendors including ZTE, Huawei, Cisco, Juniper and Alcatel-Lucent. These vendors are able to make equipment with sophisticated Internet Protocol/Multi-Protocol Label Switching (IP/MPLS) functions, and their products account for a major market share. They also support the MPLS-based evolutions, such as T-MPLS. Other telecom vendors who used to support PBT only are also showing interests in T-MPLS, by supporting both PBT and T-MPLS in their products, in a bid to meet carrier requirements and increase market share. ZTE has developed the T-MPLS functions on its multi-service transport product ZXMP S385, which, with European standard-compliant structure design, can meet requirements of various current and future services. In 2007, ZTE passed the global interoperability test of T-MPLS in the CE interoperability test hosted by European Advanced Network Test Center (EANTC).

T-MPLS can be carried over SDH and OTN. With the evolution of optical network, however, OTN will ultimately replace SDH to form the integrated packet/Optical Data Unit (ODU)/wavelength network. Therefore, ITU-T improved G.709, the original OTN interface protocol, in November 2007, and put forward G.709/Y.1331 Amendment 2[13] that expanded the client signal of ODU with T-MPLS added to it[14]. Figure 7 shows the T-MPLS over OTN structure, where T-MPLS is carried over the optical channel either by way of ODU via SDH or directly through ODU.

7 Conclusion

Being the completely connection-oriented packet transport technology, T-MPLS boasts of the packet network characteristics, including flexibility, high efficiency and the capability to carry multiple services. It is endowed with the advantages of the transport network, for example, good survivability and OAM, and is able to support CE favorably. However, T-MPLS is also facing challenges from other packet transport technologies, including VPLS and PBT. As an emerging technology, T-MPLS is yet to get mature with the support of standardization organizations, network carriers and equipment vendors.

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Biographies

Qu Hua

Qu Hua, PhD, is a professor at Xi'an Jiaotong University and Xi'an University of Posts and Telecommunications. His research interests include broadband communication networks and network management and control technologies. He presided and participated in ten-plus projects, some of them funded by the National Natural Science Foundation of China, the National High-Tech Research and Development Plan ("863" program) and the Ministry of Industry and Information Technology of the People's Republic of China. He has published more than 50 papers, 15 of which are listed in SCI/EI.

Zhao Jihong

Zhao Jihong is a professor at the Engineering Department of Xi'an University of Posts and Telecommunications. She is engaged in the study of new generation key network technologies, network management and control technologies, network survivability and Ad hoc networks. She presided and participated in 5 projects funded by the National Natural Science Foundation of China and the National High-Tech Research and Development Plan ("863" program).

Mao Hongbao

Mao Hongbao is studying for his master's degree at the Engineering Department of Xi'an University of Posts and Telecommunications. His research direction is communication networks, and he has published 5 academic papers.