Carrier Ethernet Services and Technologies

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Abstract:
Carrier Ethernet (CE) services generally refer to the standardized carrier-class transfer services that feature in excellent scalability, reliability, manageability and Quality of Service (QoS) guarantee, and are offered by carriers to users based on Ethernet technologies. One of the important characteristics of CE service is the diversity of its implementation technologies. Enhanced Ethernet technologies consider scalability as their chief objective so as to extend conventional Ethernet bridge technologies; the latest Provider Backbone Bridge Traffic Engineering (PBB-TE) emerges as the technical trend of CE technology. Multi-Protocol Label Switch (MPLS) offers reliable Pseudowire (PW) connections for CE based on Label Switching Path (LSP). The convergence of MPLS and PBB is one of the important evolution trends for CE. Making full use of the existing Optical Transport Network (OTN) infrastructure, the optical ring network technology is the most cost-efficient and effective way to deliver CE services; its future development trend is characterized by enhancing the Operation, Administration and Maintenance (OAM) function and the control plane.

As a type of Local Area Network (LAN) technology most widely used in computer networks, Ethernet technology features in easy-to-use, low cost and excellent flexibility. Originally designed for LAN environment, Ethernet technology is oriented to enterprise Intranet and thus is "enterprise-class". Ethernet technology must be improved in terms of security, scalability and manageability for applying in carrier networks oriented to public users. Aiming at delivering carrier-class Ethernet services, the Metro Ethernet Forum (MEF), founded in 2001, proposed a method for using enhanced Ethernet technologies in MAN and brought forward the concept of metro Ethernet. In 2005, the MEF changed the name of metro Ethernet into Carrier Ethernet (CE) to further specify that it is a type of Ethernet technology used in carrier networks.

The MEF has defined CE as ubiquitous, standardized, carrier-class networks and services with five technical features that distinguish CE from LAN-based Ethernet. CE makes use of Ethernet's compelling cost-effectiveness advantage to achieve significant benefits, and enables fast deployment of new distributed applications for enterprises. All CE Network Elements (NEs) must pass certification tests so that they can serve users worldwide. CE technology can also apply to the Wide Area Network (WAN) though the concept was originally proposed for MAN. A lot of carriers are making such technical attempts and trying to accumulate experience in this regard.

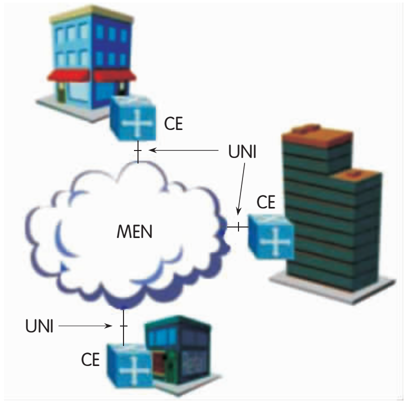
CE involves two aspects: Services and technologies. Oriented to users, the CE service plane is independent of used technologies and is defined by the MEF. Oriented to networks, the CE technology plane is proposed by such standardization organizations as IEEE, ITU-T and IETF to provide defined CE services. It should be noted that CE technology, instead of being a specific network technology, actually refers to any technologies that meet MEF-defined CE technical features. Carriers may opt for a specific type of CE technology by taking into account such factors as service requirements, network environment, deployment cost and existing facilities.

The five MEF-defined technical features of CE are standardized services, scalability, reliability, Quality of Service (QoS) and service management[1].

1 CE Services

1.1 CE Service Model

In the basic model of CE services[2], shown in Figure 1, the Metro Ethernet Network (MEN) refers to the carrier network built based on Ethernet technologies (that is, CE), and consists of MAN and backbone network. Like communication networks, the MEN also contains two types of interfaces: User Network Interface (UNI) and Network Network Interface (NNI). User equipment accesses network through UNI using 10 Mb/s, 100 Mb/s, 1 Gb/s or 10 Gb/s Ethernet interface, while carriers offer CE services to users through UNI. Different transport technologies are adopted to support CE services within MEN, such as



▲Figure 1. Basic model of CE services.

Synchronous Optical Network (SONET), Dense Wavelength Division Multiplexing (DWDM), Multi-Protocol Label Switch (MPLS) and Generic Framing Protocol (GFP). But from users' perspective, the network connection at the UNI user side is simply Ethernet.

Like an IP network, CE is also a packet network offering global connections. The difference between them lies in the fact that IP network offers global connections between any two hosts, while CE offers global connections for predefined network interfaces so as to construct multiple dedicated Ethernets within a wide area, as shown in Figure 2. Therefore, a CE service is provided by setting up connections between specified UNIs, and these connections are known as Ethernet Virtual Connections (EVCs), that is, logical channels capable of statistical multiplexing between UNIs, similar to the Frame Relay (FR) and Permanent Virtual Connection (PVC) in Asynchronous Transfer Mode (ATM).

An EVC is used to connect multiple user sites (that is, UNIs) for transferring Ethernet frames among these sites and simultaneously blocking data communication with the sites that do not belong to this EVC. The basic rule of frame transport is that the transferred service frame is not returned to the originating UNI, and the Media Access Control (MAC) addresses and the frame content remain unchanged during the transport. The CE service type is subject to different connection configurations of EVC.

1.2 Classification of CE Services

The MEF defines three types of CE services: E-Line, E-LAN and E-Tree. As the simplest basic service type, E-Line corresponds to the point-to-point connection configuration of EVC. Often known as private line service, E-Line can be used to transfer any packets defined by "Ethertype". E-LAN offers unicast, multicast, MAC address learning and IP packet transfer capabilities of LAN, and corresponds to the multipoint-to-multipoint connection configuration of EVC. It makes full use of the inherent technical features of Ethernet to implement multicast. As a simplified form of E-LAN, E-TREE refers to a type of service in which data frames are sent from a specific source to all destinations, and also corresponds to the point-to-multipoint connection configuration of EVC. Typical E-Tree applications include video broadcast to family users as well as Layer 2 (L2) isolation among users in the access network. Each of the abovementioned service types applies to either UNI or certain Virtual Local Area Network (VLAN) in UNI. Therefore, each service type can be further partitioned into Private one and Virtual Private one, for example, Ethernet-Private Line and Ethernet-Virtual Private Line services.

The MEF describes characteristics of each specific service using the "Type-Attribute-Parameter" mode and defines the following nine attributes, each of which contains several parameters:

(1) Ethernet physical interface: Physical media, rate, transfer mode and MAC layer type;

(2) Bandwidth parameter: Committed rate and excess rate of UNI/EVC/ Class of Service (CoS);

(3) Performance parameters: Availability, frame delay, frame jitter and frame loss rate;

(4) CoS: Service classes classified based on different standards;

(5) Service frame transfer: Frame types allowed to be transferred and UNIs available;

(6) VLAN tag support: VLAN tag support capability and tag handling mode;

(7) Service multiplexing: UNI's support of multiple EVCs;

(8) Binding: Many-to-one mapping of VLAN ID to EVC;

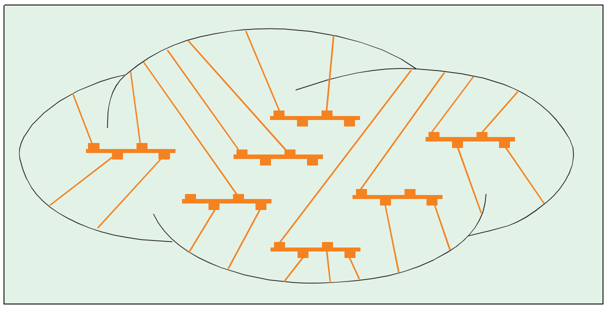
(9) Security filter: Access filtering control.

Service instances are defined by the "Type-Attribute-Parameter" mode, and data frames of each service instance are transported through one EVC.

2 CE Technologies

The issue that must be addressed with first priority is the scalability of CE technologies, that is, enabling carrier networks to support a large amount of co-existent CE service instances. For enterprise users, a large-scale MAN needs to support tens of thousand EVCs, and hundreds of thousand EVCs across the WAN; for family users, a large-scale MAN usually needs to support hundreds of thousand or even millions EVCs. With regard to E-LAN services, a large-scale MAN needs to support tens of thousand or even hundreds of thousand MAC addresses, and worldwide across-WAN applications should support hundreds of thousand or even millions MAC addresses. Another important issue is that CE must have reliability and Operation, Administration and Maintenance (OAM) capability, originally absent in legacy Ethernet.

To address the above issues, IEEE, IETF and ITU-T have proposed several CE solutions respectively based on Ethernet technologies, MPLS technologies and optical transport technologies. These CE technologies can be generally classified into enhanced Ethernet, MPLS, and optical ring network technologies. Furthermore, they have



▲Figure 2. CE connections.

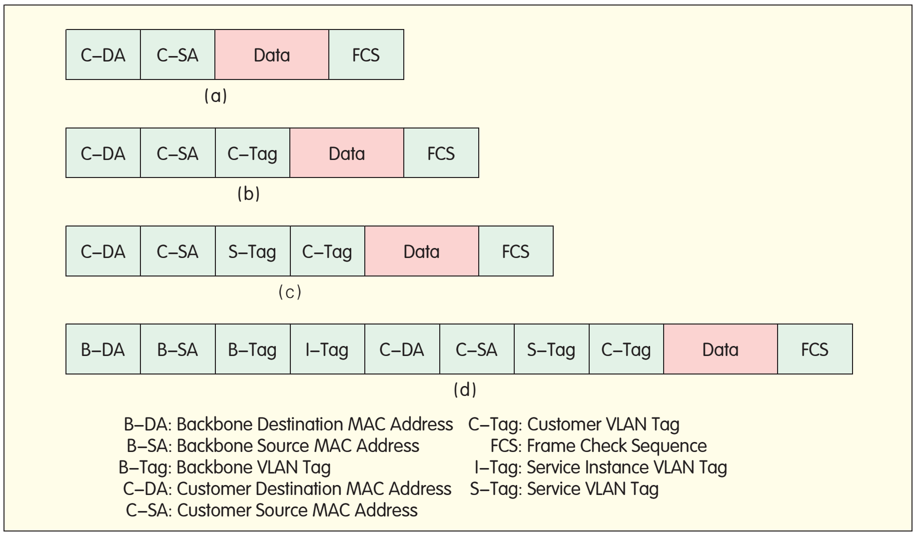
also proposed the OAM technology for CE.

2.1 Enhanced Ethernet Technology

Proposed by IEEE, the enhanced Ethernet technology, based on VLAN technology, enhances Ethernet scalability by adopting such methods as hierarchical architecture and simplified bridging, aiming to be applied in carrier networks. Its technical evolution route is 802.1 (legacy Ethernet) →802.1Q (VLAN) →802.1ad (PB, Q-in-Q) →802.1ah (PBB, MAC in MAC) →802.1Qay (PBB-TE). Figure 3 shows the frame formats corresponding to various standards.

The legacy Ethernet used in LAN is a shared media, and it mainly uses bridging technology to implement interconnection and data forwarding. The loop-free minimum spanning tree connecting all bridges is established using the Spanning Tree Protocol (STP). The bridges establish forwarding tables to all nodes through MAC address learning, and send unicast or multicast data frames to destination nodes along the spanning tree to acquire the zero-configuration "Plug and Play" capability. Such bridges are generally called transparent bridges. Figure 3(a) shows the frame format of legacy Ethernet, in which data are transferred based on Customer Destination MAC Address (C-DA) and all end devices are interconnected through LAN to form a single broadcast domain.

The concept of VLAN[3] is introduced in 802.1Q to isolate different user groups and ensure communication security. As shown in Figure 3(b), Customer VLAN Tag (C-Tag) is added into the frame format by the source bridge, containing Customer VLAN Identifier (C-VID). All bridges are only allowed to transfer data frames to the ports that have the same VLAN configuration and tag. In this way, a physical network can be divided into several mutually isolated broadcast domains, and only end devices in the same VLAN can transfer data between each other. Furthermore, data frames only need to flood within one VLAN while bridges are conducting MAC address learning, which effectively reduces bandwidth consumption. This protocol aims at medium-scale LANs, and



▲Figure 3. Various Ethernet frame formats.

therefore the length of C-VID is defined as 12 bits, that is, a maximum of 4,096 VLANs can be defined.

With the introduction of VLAN, carriers can offer CE services for different users by using bridges, for example, offering LAN interconnection for multiple enterprises, as long as they assign a different C-VID for each CE user. However, the C-VID settings are subject to users, and carriers have to coordinate the assigning of C-VIDs to avoid conflicts, which definitely increases system operation complexity. To solve this problem, the concept of VLAN stacking[4] is introduced in 802.1ad, which adds a Service VLAN Tag (S-Tag) before C-Tag in the frame format. The S-Tag contains the Service VLAN Identifier (S-VID) used by the carrier network, as shown in Figure 3(c). Having two VLAN tags, VLAN stacking is also known as Q-in-Q, and related carrier networks are called Provider Bridge Networks (PBNs). The bridges in a PBN transfer data frames based on the S-Tag that corresponds with the CE service instance; C-Tag is not used and C-Tags of different service instances can be identical. The ingress edge bridge adds an S-Tag into the frame when a data frame is injected into the PBN, and deletes the S-Tag before this frame is leaving PBN.

The VLAN stacking technology makes C-VIDs and S-VIDs mutually independent, but still fails to address the scalability issue of CE because the length of S-VID is still 12 bits, that is, a maximum of 4,096 service users are supported. The scalability issue limits the service scale of carrier networks and affects carriers' revenue. In addition, although S-Tag is the unique ID of a service instance, the PBN bridge still needs to learn C-DA before data forwarding. The exceedingly large number of end users also limits the scalability of carrier networks. In this situation, the hierarchical architecture of carrier networks[5] is introduced in 802.1ah. That is, one layer of Provider Backbone Bridge Network (PBBN) is added above the PBN, and accordingly one Service Instance VLAN Tag (I-Tag) is added in the frame format, as shown in Figure 3(d). An I-Tag corresponds to a service instance in PBBN, and this I-Tag contains a 24-bit service ID (I-SID), therefore, the PBBN can support a maximum of 16,000,000 (2^{24}) CE service instances. Furthermore, three other fields of Backbone Destination MAC Address (B-DA), Backbone Source MAC Address (B-SA) and Backbone VLAN Tag (B-Tag) are added in addition to I-Tag, in which B-DA and B-SA refer to the backbone MAC addresses of egress and ingress edge bridges of PBBN respectively. It is noteworthy that the backbone MAC addresses are assigned by carriers and are independent of user MAC addresses. When a data frame is injected into a PBBN, the ingress edge bridge determines and adds B-DA and B-SA into the frame, so the bridges in

PBBN only need to learn backbone MAC addresses instead of user MAC addresses before transferring data frames. The limited number of edge bridges addresses the scalability issue of MAC address learning. B–Tag is a valid VLAN ID in PBBN and is 12 bits in length. It is used to further divide PBBN into several broadcast domains to improve bandwidth utilization efficiency and realize PBBN load sharing. The ingress edge bridge of PBBN first learns the C–DA and C–SA of data frames to determine B–DA and B–SA, then obtains I–Tag based on C–Tag/S–Tag mapping, and finally binds I–Tag to B–Tag. The PBBN bridges then transfer data based on B–DA and B–Tag. 802.1ah is also known as MAC in MAC because there are two–layer MAC addresses in the frame format. PBBN actually supports multi–layer MAC address, so it can addresses the scalability issue of CE.

The abovementioned PBB technologies solve the problem of CE scalability, but data forwarding is still in the connectionless mode. To enhance QoS performance, IEEE made a few revisions of 802.1ah, and proposed the Provider Backbone Bridge Traffic Engineering (PBB–TE) technology, that is, 802.1Qay standard[6]. 802.1Qay reserves the MAC in MAC frame format, but disables Ethernet spanning tree and MAC address learning functions. It establishes connection–oriented tunnels for data forwarding, and enhances certain carrier–class OAM functions. Therefore, PBB–TE enables hard QoS similar to the reliability and manageability of SDH technology, and offers dedicated Ethernet links with carrier–class performance; it transforms the connectionless Ethernet into a connection–oriented network and fulfills end–to–end service provisioning and management in Ethernet.

PBB–TE data forwarding no longer hinges on the conventional flooding and learning scheme; instead, it is directly provided by the network management or control plane. This eliminates the broadcasting function of unknown address flooding so as to further enhance network scalability. In addition, a large amount of the physical– or network–layer network management functions defined by IEEE and ITU are migrated to the data link layer to enable hard QoS without over–provisioning of link capacity, achieving SDH–alike carrier–class network management functionality of bandwidth reservation and protection switching in 50 ms. Furthermore, as a type of L2 tunneling technology, PBB–TE can interwork with existing WAN technologies, and support various Ethernet services as well as MPLS–based services including L2 Virtual Private LAN Service (VPLS) and Pseudowire (PW) services and Layer 3 (L3) Virtual Private Network (VPN) services. In practical deployment, PBB and PBB–TE technologies can be combined through B–Tag partition resulting in part VLANs in PBBN using PBB and the others using PBB–TE.

PBB–TE technologies available fulfill connection–oriented data forwarding by adopting static pre–configuration scheme. The increase of network scale may bring about the N–square problem, so the IETF is working towards the introduction of Generalized Multi–Protocol Label Switching (G–MPLS) as the control plane.

2.2 MPLS Technology

A significant technical feature of MPLS is its support of the combination of connectionless and connection–oriented technologies. It can not only establish and maintain IP packet transport paths by adopting L3 routing protocols, but also re–use various L2 switching technologies such as frame relay, ATM and Ethernet to realize fast packet forwarding. Over the past decade, the global telecom industry has made a huge investment in creating more developed and mature MPLS technologies to provide both carrier–class QoS and excellent scalability. MPLS has become a globally recognized mainstream transport technology of the core network. It supports a lot of functions absent in Ethernet, including large–scale network routing, resource reservation, VPN, Traffic Engineering (TE) and across–area and across–operation–domain networking. It will take a couple of years for Ethernet to reach the same technical maturity as MPLS. Therefore, it is not feasible for the above Ethernet bridge technologies (including PBB), the effective transport solution for access networks and MANs, to replace MPLS, a core network transport technology applicable in a wider area. Instead, they are complementary to implement end–to–end transport of data frames in the wide area.

As far as CE technologies are concerned, the MPLS technologies involved include VPLS, Hierarchical VPLS (H–VPLS) and Transport MPLS (T–MPLS) technologies.

As a technical standard proposed by the IETF, VPLS[7] constructs virtual Ethernet by using L2 VPN of MPLS and connects multiple sites at the network edge. VPLS is an extension of point–to–point L2VPN Virtual Private Wire Service (VPWS). VPLS can be deemed as a logical bridge broadcast domain consisting of a group of Virtual Switching Instances (VSIs). Similar to the bridge function defined in 802.1Q, each VSI forwards data frames based on the destination MAC address and L2 VPN member ID, and floods unknown address frames, broadcast frames and multicast frames to all ports of the VSI.

As an extension of VPLS, H–VPLS aims at improving the scalability of VPLS. H–VPLS breaks down an MPLS network into a core network and several access domains interconnected through the core network. The edge equipment of the core network is called Network Provider Edge Equipment (nPE), and the edge equipment of access domain and user interfaces is called User–Facing Provider Edge Equipment (uPE). uPE only learns local nPE, and connects with local nPE through PWs. There is fully meshed VPLS connectivity only among nPEs of the core network. The core MPLS network can be further divided into several VPLS subnets fully meshed through PWs, so as to effectively reduce network complexity and multicast overhead.

It is a cost–effective CE solution with good performance to combine Ethernet bridge technology with H–VPLS. In this case, 802.1Q, 802.1ad or 802.1ah can be adopted in the access domain.

Defined by the ITU–T SG15, T–MPLS is a connection–oriented packet transport MPLS–based technology used to provide manageable point–to–point L2 connection for various service networks[8]. MPLS and T–MPLS have identical label structure as well as label switching and forwarding mechanism. But TMPLS abandons the connectionless transport mode, removes unnecessary IP-based connectionless forwarding processes and all L3 functions, and simplifies the control plane to lower network construction and maintenance costs. On the other hand, T-MPLS adds end-to-end OAM and performance monitoring functions. Bidirectional symmetric LSPs are set for T-MPLS to remain consistent with communication networks. Similar to SDH paths, bidirectional symmetric LSPs feature in long-term stability, and support protection switching and OAM mechanisms. Linear and ring protection standards have been defined by ITU to ensure excellent network operation and maintenance and protection recovery capability. Similar to PBB-TE, T-MPLS currently adopts the pre-configuration based service management mode and will introduce G-MPLS as the control plane in the future.

To a large extent, the architecture of existing circuit switched networks is an important reference for T-MPLS standardization. T-MPLS system has similar structure and similar management and operation model with the circuit switched network, which facilitates carriers to fulfill smooth evolution of MAN and access network from circuit switching to packet switching. In terms of technology, T-MPLS enhances transport performance by adopting the connection-oriented mode, lowers costs by simplifying protocols and functions, and fulfills manageability and reliability by enhancing OAM mechanism. In terms of service, T-MPLS supports packet transport in various service networks, including reliable transport of Ethernet data frames. Therefore, T-MPLS is also one of the significant CE technologies.

2.3 Optical Ring Network Technology

Enhanced L2 Ethernet technology, represented by PBB/PBB-TE, is an important technological foundation of CE. Its combination with MPLS technology is the future development trend of CE, while a variety of applicable optical transport technologies are used for the physical transport of Ethernet data frames. Based on the live transport networks, various SDH-based optical ring network technologies are still important transport approaches for CE on account of operating cost and reliability.

The fundamental optical ring network technology is to transport Ethernet data frames over an existing SDH transport system, and mainly includes two access and encapsulation technologies. According to the Link Access Protocol for SDH (LAPS)[9] proposed by China, Ethernet data frames are directly encapsulated in SDH packets using High-Level Data Link Control (HDLC) encapsulation. The specific application model of LAPS is described as follows:

(1) Configure an Ethernet interface in the SDH system.

(2) Configure a Synchronous Transport Module Level-N (STM-N) interface on the Ethernet switch.

(3) Install Ethernet Over SDH (EOS) transfer equipment between the SDH system and Ethernet switch.

The other technology is the Generic Framing Protocol (GFP)[10] developed by European and American vendors. It can encapsulate multiple types of frames and transport them through diversified optical transport technologies. The specific application model of GFP is to deliver Ethernet services on Multi-Service Transport Platforms (MSTPs).

Resilient Packet Ring (RPR) is a highly efficient optical transport technology[11], with the following advantages:

(1) RPR can send service data directly into the physical-layer frames or bare fibers through the new-added MAC layer. In RPR, non-landing packets can be directly forwarded, thereby significantly improving switching capability. Hence, this is the best possible option for packet services. Besides, RPR also supports Time Division Multiplexing (TDM) services.

(2) RPR supports automatic topology discovery, and guarantees protection switching in 50 ms, thus ensuring the QoS of circuit-switched services and dedicated line services.

(3) RPR supports two-fiber bidirectional ring topology. In both directions of the ring, RPR enables dynamic statistical multiplexing for various services. In this way, the fiber bandwidth is utilized to full degree and network configuration and operation is simplified.

(4) In terms of cost, RPR stands in between SDH and Gigabit Ethernet technologies. Hence, RPR is most suitable for the access layer of MAN, especially for applications in which bandwidth demand from Ethernet services takes absolute precedence.

RPR also has a few disadvantages. RPR only supports ring networking and falls short of cross-ring standards. Moreover, it has only one-layer MAC address forwarding, and does not provide hierarchical address structure and user address isolation. Therefore, network and service scalability is somewhat limited.

The Multi-Service Ring (MSR) put forward by China is also a bidirectional symmetric two-fiber ring[12]. Inheriting the technological advantages of RPR, MSR defines a new L2 redundancy protocol, which can be deemed as an optimized version of the RPR MAC layer. According to this protocol, each node can add/drop tributary signals. In addition, more carrier-class features are added to the protocol. The MSR design aims to build new or reconstruct carrier networks at a relatively low cost, and establish a Carrier Ethernet Multi-Service Platform (CESP). MSR is supposed to support such services as Ethernet, Gigabit Ethernet, Digital Video Broadcasting (DVB), ATM, and Packet Over SDH (POS), and also support packet forwarding as routers. With QoS guaranteed, MSR can support integrated transport of different formats of data, voice and video services with lower costs. In this way, MSR works as a ring formed by multi-service add/drop multiplexers. MSR can be applied to ring, link and star topologies, and it also supports in-service plug-in/plug-out, changeover, and upgrade functions.

MSR integrates data transport and exchange, and supports multi-service point-to-point, multicast and broadcast applications. Moreover, it solves the problem of transport of CE services and TDM tributaries, and implements the transport, protection, multicast and performance monitoring of multiple Ethernets and TDMs on RPR. Hence, it is an important technology regarding CE.

In recent years, the telecom industry started the research on the Ethernet ring, which features in lower costs and better compatibility compared to RPR. In particular, the Ethernet Automatic Protection Switching (EAPS) technology is a new cost-effective CE solution[13]. Aiming at the Ethernet ring topology, EAPS provides a simple and feasible protection method against line fault to realize the automatic protection of the Ethernet ring. In EAPS, Q-in-Q encapsulation is adopted to meet the CE requirements, but nodes still use standard Ethernet hardware, so only software upgrade is required. In EAPS, there are two fault detection modes: alarm mode (fast mode) and ring polling mode (packet detection mode). The ring protection switching period is less than 1 s, and usually less than 50 ms, so the Ethernet ring is almost as reliable as the SDH ring.

EAPS features in low technological costs and excellent compatibility with legacy Ethernets, so it is suitable for the services with small traffic and fixed direction, for example, enterprise VPN and Softswitch services.

However, EAPS also has disadvantages. It only supports ring networking, so it lacks flexibility. Moreover, it has large frame loss ratio and limited scalability owing to multiple data forwarding hops to a remote node.

2.4 OAM Technology

Ethernet can transport data at different transport layers, and also has diversified customer layers. Neither the OAM function of the bottom layer (for example, SDH) nor that of the upper layer (for example, IP) of non-Ethernet can replace the OAM function of Ethernet.

Crucial for CE, Ethernet layers must be provided with an OAM mechanism completely independent of the customer layer and the service layer to achieve the following objects:

- To determine the connectivity of EVC at the Ethernet layer.
- To effectively detect and locate network faults originating from the Ethernet layer.
- To measure the network resource utilization and network performance.
- To provide satisfactory services for users according to the Service Level Agreement (SLA).

Through joint efforts, IEEE, ITU-T and MEF work out Ethernet OAM standards, among which IEEE 802.1ag[14] and ITU-T Y.1731[15] are mature. These Ethernet OAM standards introduce the concept of hierarchical maintenance domains into Ethernet. A maximum of 8 levels of maintenance domains can be divided, and respectively and independently maintained by customers, network carriers and service providers, but they have identical OAM mechanism.

Ethernet OAM has two functions: Fault management and performance monitoring. Fault management refers to the detection, verification, location and notification of various faults. Performance monitoring refers to the measurement of such performance as frame loss, delay and jitter. The IEEE standards mainly define the fault management, including connectivity check, loop-back test, link-trace and remote defection indication. Besides, The ITU-T standards define many other OAM functions, including the alarm indication signal, lock signal, test signal, automatic protection switching, maintenance communication channel, frame loss test, frame delay test and throughput test.

3 Development Trend of CE

The further research on CE may contain:

(1) Scalability, including the scalability improvement of MPLS technology, 802.1ah improvement, VPLS/802.1ah interconnection, and system software/hardware scalability improvement;

(2) Standards and technologies for carrier-class QoS guarantee, including QoS, OAM, high availability, TE, and fast rerouting;

(3) Network management system and control plane, for which IETF and IEEE are working on new uniform control plane technologies to replace the conventional Ethernet STP mechanism, and one possible option is to use GMPLS as the foundation of control plane signaling;

(4) Analysis on Capital Expenditure (CAPEX) and Operating Expenditure (OPEX) to maintain the simplicity and cost-effectiveness of CE with increasing new functions;

(5) Offering more fast-configurable, flexible and reliable services based on user demands, apart from existing E-Line, E-LAN and E-Tree services.

For carriers, the key is to decide on the optimal solution from numerous existing CE technologies to adapt their specific situation, by taking account of such factors as costs (CAPEX and OPEX), scenarios (building a new network or expanding existing one), existing network technologies, maintenance personnel experience, required services, technological maturity, ease of operation, and preferred management mode, among others.

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Biography

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Mi Zhengkun is a professor of the College of Telecommunications and Information Engineering, Nanjing University of Posts and Telecommunications. He is also a fellow of China Institute of Communications. His current research interests lie in Next Generation Networks (NGNs) and heterogeneous network convergence technologies. Owing to his research achievements, he won the second prize of Scientific and Technological Progress Award granted by Jiangsu province, and the second and third prizes of Scientific and Technological Progress Award by Ministry of Industry and Information Technology of the People's Republic of China. He has published more than 30 journal papers indexed by SCI and EI, 8 monographs and state-level textbooks, and applied for more than 10 national patents.