Provider Backbone Transport Technology

Zhang Zailong[1], *Fang Jun*[2], *Yu Jinghai*[2]
(1. Institute of Information and Network Technologies, Nanjing University of Posts and Telecommunications, Nanjing 210003, P. R. China;
2. ZTE Corporation, Shenzhen 518057, P. R. China)

Abstract:
The Metro Ethernet Forum (MEF) put forward the concept of Carrier Ethernet (CE) to improve Ethernet technology and make it a transmission convergence layer solution for Next Generation Network (NGN). Provider Backbone Transport (PBT) is the result of the enhancement and improvement of the early Ethernet technologies and it is the new version of CE implementation technology and standard which is promising. Through studying the PBT-related technologies, PBT network structure, PBT advantages as the transmission convergence layer solution and its trend of future development, it is concluded that PBT can be used as the preferred technology of the transmission convergence layer in the NGN, though there are some problems to be solved for PBT.

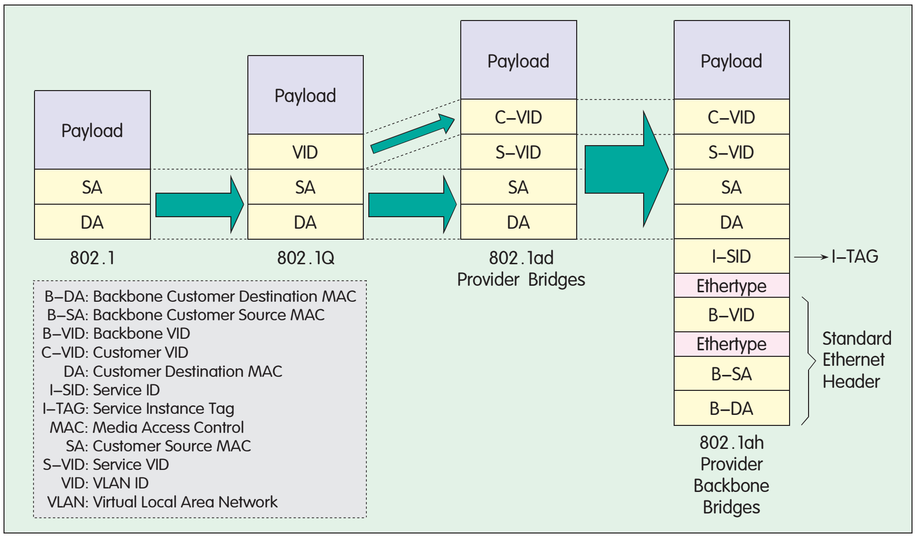
Metropolitan Area Network (MAN) is not only a bridge between Wide Area Network (WAN) and Local Area Network (LAN), but also a convergence area for transmission networks, access networks, and service networks. For the telecom MAN, it has to carry and converge various types of services now and in the future in addition to traditional telecom networks and data networks. As a result, fixed network operators and mobile operators are now competing intensively with each other in the field of MAN, attempting to find a technology that can improve network capacity and operation and maintenance efficiency greatly, support multiple service types and reduce operation and maintenance costs.

The next generation MAN should be able to transport both packet services and circuit services. The operators have been looking for a transmission convergence layer technology. There is wide recognition in the telecom community that IP protocol is helpful for transformation from circuit-based services to packet-based services and it should be used as the basis of new services. But there are still many problems to be addressed before IP routing technologies are applied into transmission convergence layer. Currently, IP/Multi-Protocol Label Switching (MPLS)[1] has been widely applied into telecom networks as a service layer and convergence layer technology, especially in telecom backbone and core networks. Meanwhile, the facts are that traffics of most data services of provider networks start and end with Ethernet, and that new service flows are increasing sharply, which makes many telecom operators consider Ethernet as a transmission convergence layer solution for their NGNs. Similarly, some problems have to be solved before Ethernet can really enter telecom markets and be accepted. For example, it must prove to be able to provide services of the same quality as current services. That is to say, it must be able to deliver carrier grade services. Consequently, the concept of Carrier Ethernet (CE) and related solutions are introduced. CE was first proposed by Metro Ethernet Forum (MEF) at the beginning of 2005. Its technologies are not specific to one kind of network technologies but include any technologies that meet the criteria regarding support for Ethernet service types and service performance. The criteria include:

(1) Standardized Ethernet services: Point-to-point and point-to-multipoint Ethernet connections should be established with certain means. The service types to be supported include Ethernet Private Line (EPL), Ethernet Virtual Private Line (EVPL), Ethernet Private LAN (EPLAN), and Ethernet Virtual Private LAN (EVPLAN).

(2) Scalability: Service bandwidth and scale should be flexibly expanded to support a wide range of Ethernet services, at rates from 1 Mb/s to 10 Gb/s.

(3) Carrier-grade reliability: The protection switching mechanism should recover a fault within 50 ms, leaving the users unaware of the fault. Traditional Ethernet uses link aggregation and Spanning Tree Protocol (STP) to provide protection. This method consumes lots of lines and ports, and any link failure has to be recovered within seconds, much more than 50 ms that carrier Ethernet requires. Any CE technology should ensure service protection switching time to be shorter than 50 ms. In addition to network protection, node devices adopt redundancy technology to enable active/standby switchover function. In case of failure, the active and standby devices can be quickly switched over in several milliseconds, with user services



▲Figure 1. Evolution of CE frame format.

not affected.

(4) Quality of Service (QoS): End-to-end service performance should be guaranteed. The performance indexes include call and connection setup speed (e.g. end-to-end delay and delay jitter), throughput that reflects available bandwidth and is related to bandwidth, error rate, cache capacity and processor's capability. The data services carried over early Ethernet in LAN are insensitive to delay, and at the same time, Transmission Control Protocol (TCP) retransmission mechanism can tolerate loss of few data packets in the Ethernet. As a result, differentiated QoS classes are unnecessary. But for CE technologies that are required to carry various services, the traditional "best effort" service model, which makes no attempt to differentiate between traffic flows, is difficult to guarantee QoS. CE uses Differentiated Service (Diff Serv) model to achieve QoS. The implementation processes of this service model include flow classification, mapping, congestion control, and queue scheduling.

(5) Carrier-grade service management: Quick service connection, Operations, Administration and Maintenance (OAM) and customer network management should be provided. CE can provide powerful and complete network management functions, as well as the capabilities for end-to-end unified network management, cluster management, stack management and visualized image management. In addition to performing regular operations such as configuration, monitoring, user data sampling and analysis, the network management function should implement the following operations: automatically discover network failures and repair them timely; automatically discover new service nodes and configure end-to-end services for them; measure end-to-end performance and learn the network status in real time.

There are many CE technologies, of which the three prevailing ones are Transport MPLS (T-MPLS), Provider Backbone Transport (PBT)[2] and Provider Virtual LAN Transport (PVT). Among the three technologies, T-MPLS is the maturest in standardization, while PVT and PBT compete with each other. PBT excels PVT in terms of compatibility with traditional Ethernet and interwork with other network technologies. On the whole, PBT, a connection-oriented Ethernet technology, is the most promising among all CE technologies.

1 PBT Overview

The concept of CE has attracted widespread concern of the telecom industry since it was proposed by MEF. It is defined as a solution for IP, Ethernet and Time-Division Multiplexing (TDM) service transport in the MAN. The instability of the quality of traditional IP technologies, the application of IP-based broadband services (e.g. network TV and video communications) and the strong demand for QoS urge the operators to plan the construction of the next generation MAN that meets new service requirements.

The main reason why traditional Ethernet cannot deliver carrier grade services lies in its non-connectivity. Besides, its scalability is restricted by limited VLAN numbers and Media Access Control (MAC) address structure which is difficult to expand. To offer high quality services, it is required to set up point-to-point connection; to improve the scalability, the flat address space must be changed into hierarchical one. Such technologies as VLAN[3], Provider Bridge (PB)[4] and Provider Backbone Bridge (PBB)[5] are designed to solve the scalability and management problems, while the protocols Ethernet in the First Mile (EFM)[6] and Connectivity Fault Management (CFM)[7] provide all-sided OAM solutions. As new technologies emerge continuously, an integrated technology is needed to effectively combine various technologies and make them suitable for current network operations as well as to provide operable telecom services. PBT is developed in such situation.

PBT comes from PBB, i.e. MAC-in-MAC technology. MAC-in-MAC is a technology based on MAC stacks. With this technology, the customer MAC address is encapsulated into the backbone MAC address, enabling the customer traffic flow to be isolated, thus improving Ethernet's scalability and service security. The key feature of PBB is that it introduces 24-bit I-TAG to identify services. Being quite suitable for interworking with other technologies, such as MPLS, I-TAG is now used to identify a service rather than a virtual network. The IEEE calls PBT as PBB-Traffic Engineering (PPB-TE). Figure 1 illustrates the evolution of frame formats of different technologies[8-9].

PBT is a connection-oriented Ethernet technology with telecom network characteristics, and it has the following technical features:

(1) PBT is based on MAC-in-MAC but not equivalent to MAC-in-MAC. Its core concept is to enable CE services to be de facto connective by means of

network management and control configuration, thus realizing telecom transport network functions, including protection switching, OAM, QoS and TE.

(2) It uses Backbone Customer Destination MAC (B-DA) and Backbone VLAN ID (B-VID) to forward services, allowing the operators to control CE and isolate customer flows. Hence, the Customer VID (C-VID) in the inner layer, is unnecessarily unique in the network. Different B-DAs can use the same C-VID for data frame forwarding without any conflict.

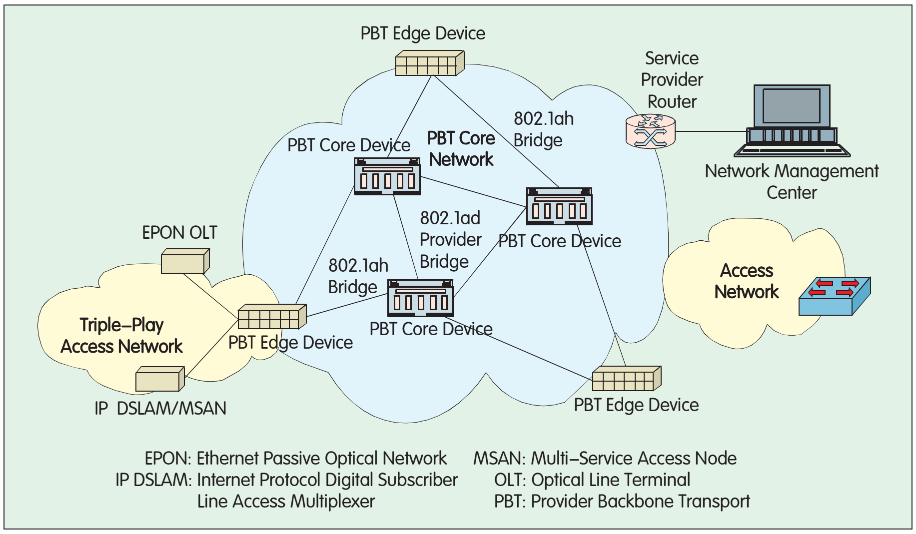
(3) It turns off MAC's self-learning function based on VLAN, thus avoiding the flooding of broadcast packets and dropping those data packets whose destinations cannot be found in forwarding table.

(4) It is compatible with traditional Ethernet bridge hardware. As a result, the data frame forwarding does not require updating the network's intermediate nodes or modifying data frames. Consequently, the forwarding is highly efficient.

(5) It supports such connection-oriented network specific functions as bandwidth management and Connection Admission Control (CAC) to manage network resources. It enables the connections set up by configuration at the network management center or via Network Controller (NC), thus flexible routing and TE are easily achieved.

PBT is basically an enhanced version of PBB; but it turns off some functions of PBB. For example, it turns off MAC self-learning function, allowing the PBT-based devices to discard the data whose destinations are unknown rather than flood them to all potential destinations; it disables multicast function, letting PBT drop rather than forward the multicast data; it turns off broadcast learning function because PBT paths are predefined; and it removes the protocols that are used to prevent loops in the network, which become unnecessary because the forwarding paths of data frames are preset, thus improving network utilization. Moreover, the operators can manage the loads on different routes to prevent unbalance.

PBT adopts CFM mechanism defined in IEEE 802.1ag to monitor the tunnels of the network in a continuous way. When an active tunnel fails to work, PBT will automatically transfer its services onto a pre-created standby circuit, providing the required resiliency. As a result, the device can gain a failure switching time of 15 ms. The purpose of PBT is to help the operators achieve the following objectives: deliver guaranteed, deterministic services in a large Ethernet architecture; ensure reliability, manageability and scalability of the network in order to transport multimedia services for the enterprises; allow the operators to make full use of metropolitan Ethernet's advantages in running and cost during their networks evolved to convergence architecture.



▲Figure 2. PBT network architecture.

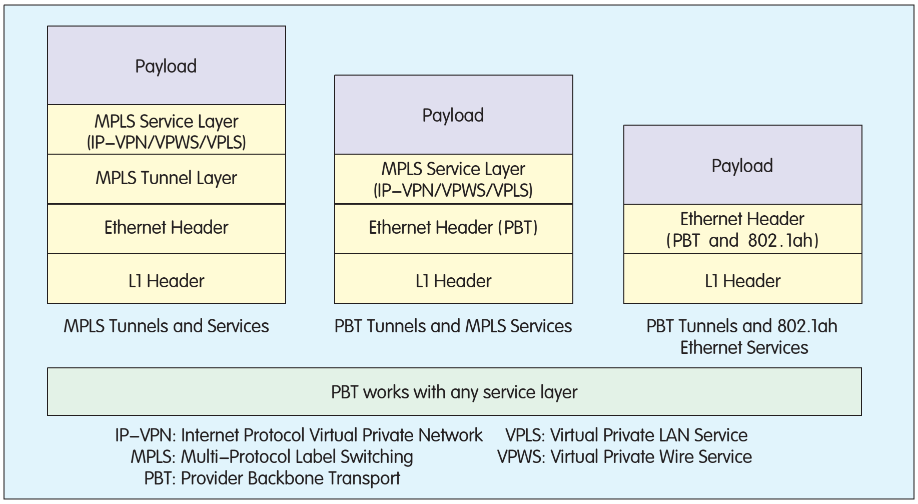
2 PBT Network Architecture

IEEE has made a series of new standards based on old Ethernet standards. These new standards, including 802.1Q, 802.1ad, 802.1ag, 802.1ah and 802.3ah, have supplemented the old ones. PBT is an Ethernet transmission solution based on these standards. Having an independent, connection-oriented and packet switching-based transmission layer, PBT can not only transport Ethernet services, but also transparently transport other services that are carried on it.

Figure 2 illustrates PBT network architecture[10]. Adopting MAC-in-MAC encapsulation, PBT encapsulates the Ethernet data frames of terminal user into CE frame header, thus two MAC addresses are generated. In the provider core network, the encapsulated data frames will be forwarded to the later MAC address. The application of MAC-in-MAC encapsulation greatly improves the Ethernet's scalability and its capability as a network transmission technology. In other words, with MAC-in-MAC used in Ethernet, network hierarchy and broadcast domain isolation are realized, making Ethernet operation possible. With PBT, it is possible to construct carrier grade networks based on Ethernet technologies without any other supporting network. PBT can meet the basic requirements for carrier applications, providing manageable and protected point-to-point connections. Its connections are directly provided by the network management system rather than with MAC self-learning mechanism of Ethernet, enabling a more reliable and simpler network.

3 Benefits of PBT

PBT enables the creation of connection-oriented Ethernet tunnels that allow service providers to offer dedicated Ethernet links with guaranteed, deterministic performance levels. PBT is designed to meet or exceed the functionality of MPLS Resource Reservation Protocol (RSVP)-TE[11] tunnels. With these capabilities, PBT offers service providers several new alternatives to deploying



▲Figure 3. MAN tunneling and services technology options.

next generation MANs in terms of both the "tunneling" technology and the "services" that it supports (Figure 3)[12].

As a traffic-engineered tunneling technology, PBT provides an alternative to deploying MPLS tunnels (e.g. RSVP-TE) in the MANs and supports multiplexing of any Ethernet or MPLS service inside a PBT tunnel. Therefore, service providers can deliver native Ethernet in addition to MPLS-based services over PBT tunnels. This flexibility allows service providers to deploy native Ethernet services initially, and MPLS services if and when they need to. As both a tunneling and services infrastructure technology, PBT delivers the following benefits to service providers:

(1) Scalability: By turning off the complicated MAC learning, broadcast and STP features of traditional Ethernet, PBT avoids the possible broadcast storms in customer networks, and removes the undesirable broadcast functionality that creates MAC flooding and limits the size of the network. Additionally, it takes effective measures to get rid of limitations on service scalability. For instance, it adopts full VID + MAC (60 bit) address as the globally unique address and destination-based forwarding, enabling 260 tunnels in the service provider network; it forwards data with MAC-in-MAC encapsulation scheme and "B-VID+B-MAC" mode. VID is used to identify a specific path, which is not unique in the network, so the address spaces of the customer and provider networks are expanded.

(2) Hard QoS: In PBT, the path for information forwarding is directly provided by the network management/control plane rather than depends on traditional flooding and learning. By specifying the path a packet takes across the network, service providers can now traffic engineer their Ethernet networks. Without over-provisioning network capacity, PBT achieves hard QoS, allowing bandwidth reservation and a protection switching time of 50 ms. This, in turn, allows the service provider to maximize network utilization and hence reduce the cost per bit carried.

(3) TDM Support: With two-layer encapsulation scheme providing simple point-to-point path, PBT can interwork with existing WAN technologies without a complex signaling mechanism. It supports various Ethernet services as well as MPLS-based services, including VPLS, virtual pseudowire services at Layer 2 and IP VPN services at Layer 3. Therefore, it is quite flexible. The very low latency of Ethernet switches is combined with the deterministic traffic flow of PBT, providing an ideal platform to emulate traditional TDM/circuit emulation services.

(4) Security: When using point-to-point Ethernet connection across the network, any misconfiguration or packet leakage becomes obvious immediately. This means the traffic is protected from incorrect operations, malicious intent or unintentional leakage of packets to its end-points for which they were not intended. PBT technology also shields the real MAC address of the customer.

(5) Network Management: PBT adopts many network management functions defined by IEEE and ITU, as well as existing mature operation and maintenance systems. With these network management functions being transplanted from physical layer or overlaid network layer into data link layer, PBT provides carrier grade network management functions similar to Synchronous Digital Hierarchy (SDH).

(6) Service Management: The fact that the Operation Support System (OSS) is aware of the route taken by each service enables alarm correlation, service-fault correlation, and service-performance correlation. It also enables protection switching for maintenance purposes to be performed in a controlled manner that guarantees performance against the Service Level Agreement (SLA).

PBT delivers the scalability, Traffic Engineering (TE), QoS and manageability that Ethernet does not support, allowing service providers to use Ethernet as an infrastructure for converged, next generation MANs to support business and residential voice, video and data services. The fact that PBT is enabled by making a small alteration to the normal Ethernet behavior means that this technology can be easily implemented on existing Ethernet hardware. As a result, there is no requirement to introduce complex and expensive network overlay technologies (e.g. MPLS) in the MAN. PBT combines the superiority of Ethernet with that of MPLS. With a simpler de-layered network and simpler devices, the initial CAPEX costs are reduced, so is the operational burden, which results in recurring savings.

4 Development Trend of PBT

Currently, the operators around the world are evaluating PBT/PBB technologies. Although PBT has not an effective automatic configuration system, which may have impact on its scalability, it can provide effective, connection-oriented and packet-based network capabilities.

However, PBT is far from perfect. For example, it has not the capability of point-to-multipoint transmission. In practice, PBT is often deployed in the provider backbone network; while in the convergence layer, PBB technology is used because it is able to transport point-to-multipoint services. Therefore, the combination of PBB and PBT can meet the requirement for point-to-multipoint services.

Those in favor of PBT technology think Ethernet switches are usually cheaper than IP/MPLS routers and this situation will not change in the future. Some manufacturers have developed special configuration and management systems for PBT, and claimed that their systems can minimize the configuration. Moreover, they do not think the standardization of PBT will lead to a great increase in complexity.

The standardization of PBT technology has started quickly and is now accelerating. So far, related drafts have been released successively. In June 2007, the interconnection between Provider Edges (PEs) was successfully demonstrated for the first time. This, from another aspect, proves that PBT technology can be easily deployed and implemented with existing Ethernet hardware, and its standardization related research is not complicated.

The attitudes and practices of some leading operators, as well as the PBT-related tests and commercialization made by some operators, show that PBT has gradually become a "through train" for transformation of global operator networks owing to its technical features and proven business cost model. Surely, the operators have to consider their own development strategies and networks before they decide whether to select and when to deploy PBT-based Ethernet solutions.

5 Conclusions

Telecom operators are facing a series of challenges, driving them to look for a new technology or solution to create their own competition edges. The introduction of PBT offers the operators certain opportunities. As an attractive network and technical concept, PBT has many advantages: based on PBB subsets and several Ethernet standards, PBT can provide a simple, connection-oriented transmission solution, which can meet the challenges the telecom operators face and can be used in existing provider networks; combining the superiority of Ethernet with that of MPLS, PBT can provide a new, flat, low-cost convergence architecture for MAN, avoiding excessive dependence on IP/MPLS core. It can be used to construct a network with technical advantages. In the next generation networks, PBT is no doubt a preferred technology for transmission convergence layer.

However, in praising the advantages of PBT, telecom operators have to keep a clear head on the challenges they face. For instance, PBT is a new technical concept, and there is not any off-the-shelf product to support it; PBT has not been standardized yet, and current standards are subject to change, hence it is difficult to find a solution that can solve all problems; the N-square problem of huge routing table in PBT results in lots of connection, which makes the management more difficult; PBT can only be used for ring networking, which restricts its flexibility; PBT has not any equity algorithm, not suitable for such heavy traffic and burst services as broadband Internet because the unfair occupancy of bandwidths among devices is likely to occur; the additional encapsulation in PBT and MAC-in-MAC would inevitably lead to an increase of hardware cost.

References:

[1] ROSEN E, VISWANATHAN A, CALLON R. Multiprotocol Label Switching Architecture [S]. RFC3031. 2001.
[2] IEEE 802.1Qay. Standard for Local and Metropolitan Area Networks—Virtual Bridged Local Area Networks, Amendment 7: Provider Backbone Bridge Traffic Engineering [S]. 2007.
[3] IEEE 802.1Q, IEEE Standard for Local and Metropolitan Area Networks—Virtual Bridged Local Area Networks [S]. 2005.
[4] IEEE 802.1ad. IEEE Standard for Local and Metropolitan Area Networks—Virtual Bridged Local Area Networks, Amendment 4: Provider Bridges [S]. 2005.
[5] IEEE Draft P802.1ah/D4.0. Standard for Local and Metropolitan Area Networks—Virtual Bridged Local Area Networks, Amendment 6: Provider Backbone Bridges [S]. 2007.
[6] IEEE 802. 3ah. 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 Network [S]. 2004.
[7] IEEE 802.1ag. Local and Metropolitan Area Networks—Virtual Bridged Local Area Networks, Amendment 5: Connectivity Fault Management [S]. 2007.
[8] ALLAN D, BRAGG N, MCGUIRE A, et al. Ethernet as carrier transport infrastructure [J]. IEEE Communications Magazine, 2006, 44(2): 95- 101.
[9] **毕立波, 卜哲, 赵峰**. PBT**技术的产生与发展** [J]. **电信技术**, 2007(10): 74-78.
[10] TPACK A/S. PBB-TE, PBT: carrier grade Ethernet transport [EB/OL]. http://www.tpack.com/fileadmin/user_upload/Public_Attachment/PBT_WP_v2_web.pdf. Jun 2007/May 2008.
[11] AWDUCHE D, BERGER L, GAN D, et al. RSVP-TE: Extensions to RSVP for LSP Tunnels [S]. RFC3209. 2001.
[12] NOTEL. White paper: Provider Backbone Transport [EB/OL]. http://www.nortel.com/solutions/collateral/nn115500.pdf. 2007/May 2008.

Biographies

Zhang Zailong

Zhang Zailong is a PhD student at the College of Telecommunications and Information Engineering, Nanjing University of Posts and Telecommunications (NJUPT). He received his bachelor's degree in Radio Technology from Tianjin University in 1988 and his master's degree in Computer Application from NJUPT in 1999. He is also an associate researcher of the Institute of Information and Network Technologies, NJUPT, and a member of China Institute of Communications. He is mainly engaged in the research and teaching of mobile communications and computer networks. His research interests include ubiquitous computing, computer communications and next generation telecom networks. He has published nearly 30 papers, 6 of which are indexed by EI Compendex.

Fang Jun

Fang Jun graduated from Nanjing University of Posts and Telecommunications with a master's degree and is now a standing member of Technical Expert Committee and the leader of IP Expert Team of ZTE Corporation. He has been engaged in the research of IP bearer network technologies, responsible for development of multiple routers/switches. So far, he has applied for over 100 patents and published nearly 10 papers, one of which can be indexed by EI.

Yu Jinghai

Yu Jinghai graduated from Nanjing University of Posts and Telecommunications with a master's degree and is now an engineer of ZTE Corporation. His research interests include carrier grade Ethernet technologies, IP routing, and service application. He has applied for over 10 patents and published 6 papers.