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Broadband Access Network Providing Reliable Ethernet Connectivity

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Triggered by the explosion in the Internet population and traffic, broadband access has become one of the central issues in telecommunication systems. The requirements for new access networks are not only the provision of broadband services but also reliability as a social infrastructure. Taking account of these requirements, in this paper we propose the virtual Ethernet switch architecture (vESW), which can provide reliable Ethernet connectivity. We also describe an implementation of vESW using ATM technology. The system provides broadband services using optical subscriber lines based on ATM-PON technology. The system also provides multiple QoS, including IP and ATM QoS. Also, a ring network architecture provides efficient use of bandwidth and fast fault recovery. In this paper, the key mechanisms that achieve these features are described.

1. Introduction

It was only a few years ago that the World Wide Web (WWW) triggered the ongoing explosion of the Internet population and traffic. Before the explosion, the Internet was a research topic for academics. The WWW and the start of commercial Internet services have led to a growing population of people who use the Internet for entertainment. Nowadays, the Internet has become a key social infrastructure because it is a platform for new network-based businesses such as electronic commerce (EC) and Internet-based data centers (IDCs). Because of this rapid change, the telecommunication systems, which were built mainly for telephone services, now need to support traffic and services based on the Internet Protocol (IP).

Figure 1 shows an up-to-date network model for IP-based services. The key elements of this model are the Internet, the Internet Service Providers (ISPs), the IDCs, and the access networks that are the focus of this paper. In this model, there are two types of users: residential users and business users. The residential users are connected to the Internet via the access network and ISP networks. Most of these residential users use network services such as e-mail and Web

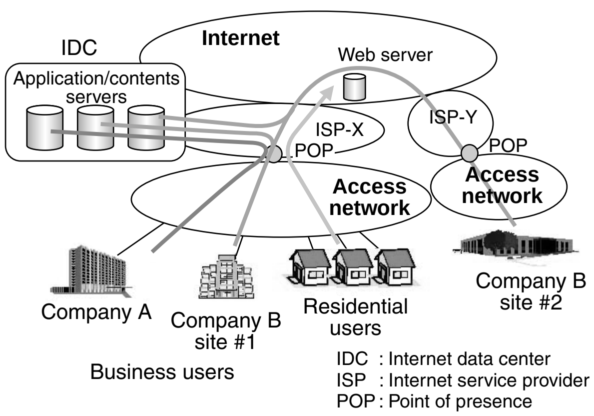


Figure 1
Up-to-date network model for IP-based services.

browsing for their private needs. On the other hand, business users connect to not only the Internet but also to IDCs to operate their business. For many of these business users, the overall network and its services form an indispensable business infrastructure.

This situation has changed the requirements for IP networks, which are now quite different from the original Internet. The Internet originally provided only narrowband, best-effort, and non-secured packet transfer services. These services were acceptable for personal, recreational use, but businesses require richer capabilities, for example, broader bandwidth and guaranteed quality, reliability, and security.

Taking account of today's networks and the service models described above, we propose a virtual Ethernet switch architecture for new broadband access networks. The proposed system can provide reliable Ethernet connectivity between users and IP backbone networks.

In this paper, we first describe the requirements for a next-generation access network for broadband services. Then, we describe our proposed virtual Ethernet switch architecture. For the first implementation of the proposed architecture, we propose using the Asynchronous Transfer Mode (ATM) technology, which is a well-established and reliable layer 2 technology. In this paper, we describe the mechanisms for realizing our architecture, including the optical access technology, multiple-QoS (Quality of Service) handling, and ring networking.

2. Requirements for broadband access networks

As we mentioned above, the demands for access networks are changing. The current key requirements can be summarized as follows:

1) Provision of broadband access

At the end-user side, the rapid development of the fast, Gigabit Ethernet has led to the establishment of high-speed Local Area Networks (LANs) in offices and homes at low cost. Also, Dense Wavelength Division Multiplexing (DWDM) technologies have been successfully applied to backbone networks to achieve an enormous increase in network bandwidth. However, the access networks that connect the end-users' LANs and backbone networks still present a bandwidth bottleneck. The most essential requirement now is to provide low-cost, mega-bit-per-second access services.

2) Provision of multiple grades of service quality

The most popular services used by residential users (e-mail, Web browsing, etc.) can be provided using the best-effort packet transfer service of the networks. However, many business users require both best-effort and guaranteed service qualities, because they depend on the network to perform mission critical tasks. Therefore, access networks must provide a wide range of QoS in terms of bandwidth, loss ratio, and delay to fulfill all the needs of its users.

3) High reliability

Because business users rely on the networks as a communications infrastructure, a network malfunction can cause serious problems, for example, a suspension of production or a missed business opportunity. To achieve a high reliability and availability, access networks must have safety mechanisms such as redundant network resources and automatic protection switching for fast fault recovery.

4) Security

As shown in Figure 1, different companies share the same networks. Therefore, to prevent unlawful access to a company's data, we must ensure that the virtual connections of each user (e.g., between a data center and offices) can coexist securely.

3. Virtual Ethernet switch architecture

To meet the requirements described above, for reliable broadband access services we propose the virtual Ethernet switch architecture, or vESW, shown in **Figure 2**.

The vESW consists of nodes in a ring network. The ring provides end-to-end Ethernet connectivity. The end-user interfaces are Ethernet-based (10-base-T, 100-base-T, 1000-base-T, etc.), but the intra-ring protocol is not a pure Ethernet. In order to enhance the reliability of packet transfer services, incoming IP packets and Ethernet frames are encapsulated into an intra-ring format. At encapsulation, a logical connection identifier is added to the packets. These identifiers identify each user to provide secured logical connections. Also, to monitor the status of the connections, including any link failures and quality degradations, management packets are inserted among the user packets. The management packets are used to detect failures, and when a failure is detected, an automatic-protection mechanism is invoked to quickly recover from the fault. Because of this mechanism, the network achieves a high reliability and availability.

The key component for establishing the proposed network is a dependable layer 2 switching technology. The candidate technologies are ATM and Multi-Protocol Label Switching (MPLS). We currently favor ATM instead of MPLS, because ATM is already well-established, has been widely deployed in large-scale carrier networks, and provides very-well managed services using its standardized Operation, Administration, and Management (OAM) functions. Also, multi-service and multi-QoS capability is mandatory for the access system, because users need an access line which can provide a wide range of services and qualities. At this moment, ATM is the only technology that can achieve this using well-standardized mechanisms.

Figure 3 shows an implementation example of vESW using ATM technology. The key components of the system are the Broadband Service Multiplexers (BSXs). The BSXs compose an access ring network to aggregate traffic from users within a certain area (e.g., a city or town). Both residential and business users can obtain multi-mega-bit-per-second broadband services using Asynchronous Transfer Mode Passive Optical Network (APON)[1),2)] or Asynchronous Digital Subscriber Line (ADSL)[3),4)] technologies.

The ring network has been used in conjunction with Synchronous Optical Network (SONET) or Synchronous Digital Hierarchy (SDH) technologies all over the world. One of the advantages of the SONET/SDH ring is its high reliability, which is achieved by automatic protection functions such as Unidirectional Path Switched Ring (UPSR) and Bidirectional Line Switched Ring (BLSR). SONET/SDH rings have two types of paths or lines: work and protect. In the event of a failure, the traffic is switched from the work path/line to the protect path/line to preserve the services. Our proposed ATM ring also uses this mechanism to improve reliability. We will describe another benefit of the ATM ring in Section 4.

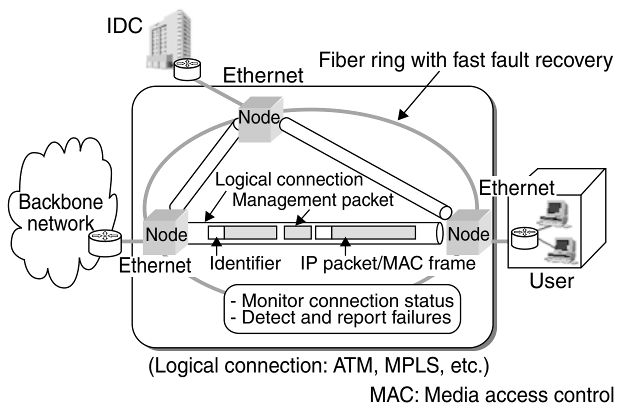


Figure 2
Virtual Ethernet switch architecture (vESW) for broadband access network.

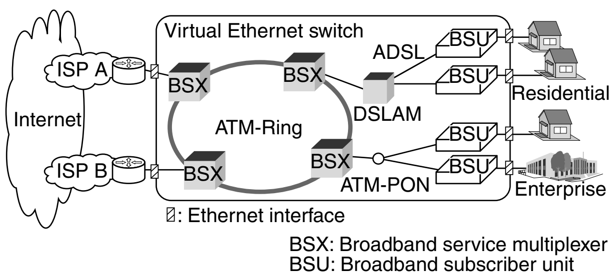


Figure 3
vESW implementation using ATM Technology.

The ATM-based access network can convey each user's IP traffic separately using ATM Virtual Path/Virtual Channel (VP/VC) connections, because the ATM is a layer 2 protocol independent from the layer 3 protocols (i.e., IP). This feature results in highly secure networks.

Although ATM meets the requirements of the access network, end users prefer an Ethernet interface rather than an ATM interface because it is widely deployed in offices and homes. Therefore, the Broadband Subscriber Unit (BSU) provides an Ethernet User Network Interface (UNI) and also has ATM-Ethernet interworking functions. As a result, the access network that interconnects Ethernet interfaces performs like a virtual Ethernet switch to achieve reliable Ethernet connectivity.

4. Transmission technologies for subscriber lines

ADSL has been internationally standardized and widely installed to provide broadband services. The reason why ADSL is attracting so much public attention is that it achieves a higher service bit-rate than dial-up modems with a relatively low installation-cost by using existing copper-wire facilities. However, ADSL does not fulfill all the needs for broadband access, because of its limited transmission distance, low maximum bit rate, and sensitivity to noise.

To complement the copper access, optical fiber access using PON technology is now gaining in importance. APON technology has been standardized by the International Telecommunication Union - Telecommunication Sector (ITU-T) and is widely deployed by Full Service Access Network (FSAN) operators to provide practical services. The advantages of APON compared to ADSL are that APON has a longer available distance, has a broader bandwidth, and is electric-noise-proof. Also, APON overcomes the high cost of providing fiber access by sharing optics and bandwidth between multiple users.

As shown in **Figure 4**, ADSL and APON have different coverage fields. For short-distance and mid-bit-rate needs, ADSL has a cost advantage. But for longer-distance and broader bandwidth needs, APON is superior. Therefore, we believe that ADSL and APON complement each other.

From the above considerations, we propose using both ADSL and APON as transmission technologies for subscriber lines in our access system.

5. Provision of multi-QoS

Although the access network can handle the multiple QoS classes of ATM,[5)-7)] the IP QoS should also be considered because a major part of traffic is now IP-based packet flows. The Internet Engineering Task Force (IETF) has defined two methods for providing multiple QoS for IP-based services: Integrated Service (IntServ)[8)] and Differentiated Service (DiffServ).[9)] Generally speaking, IntServ is difficult to apply to large-scale networks, but DiffServ is not. Because we assume that there will be large-scale public access networks in use, we investigated DiffServ as a principal IP-QoS mechanism for our ATM-based access network.

DiffServ provides two categories of QoS: Expedited Forwarding (EF) and Assured Forwarding (AF). The EF classes may be used for guaranteed services. It is easy to provide a guaranteed service over an ATM network by mapping it onto the Constant Bit Rate (CBR) of the ATM service class. On the other hand, the AF class is usually divided into sub-classes, for example, gold, silver, bronze, and best-effort. The differences between

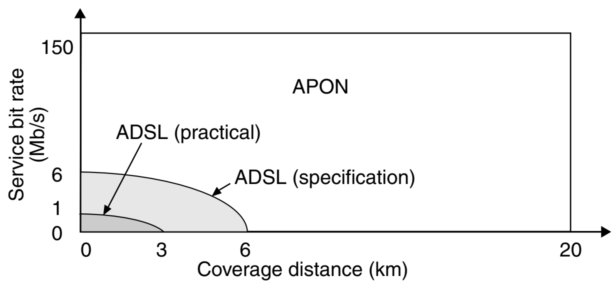


Figure 4
Coverage fields of ADSL and APON.

these sub-classes is in their priorities for packet forwarding, especially under congested conditions. However, ATM cannot meet this criterion by itself. In order to provide AF over an ATM network, we introduced the prioritized Unspecified Bit Rate (UBR) class[10] into our system and mapped the AF sub-classes onto the sub-classes of the prioritized UBR class.

Figure 5 shows how our system achieves multiple QoS, including ATM and IP QoS.

The BSUs at the end user sites connect users' terminals and routers to the access network via an Ethernet interface. They also map the IP QoS to the ATM QoS. When an IP packet arrives at the BSU, it is classified into an appropriate QoS class based on a classification policy. The policy may be a classification rule to distinguish a packet's QoS using the packet header information, which includes the source and destination IP addresses, Type of Service (TOS) field, protocol type, and port numbers. The classified packet is then sent to an ATM connection according to its QoS class.

The BSX itself has a switching function which is capable of multiple QoS. The switch fabric in the BSX has queues corresponding to the ATM and IP QoS. The CBR queue has the highest priority, and its cells are read prior to the UBR queues. Cells in the UBR queues are read-out in the order of their priorities when there are no cells in the CBR queue. **Table 1** shows an example of mapping the QoSs between the IP and ATM.

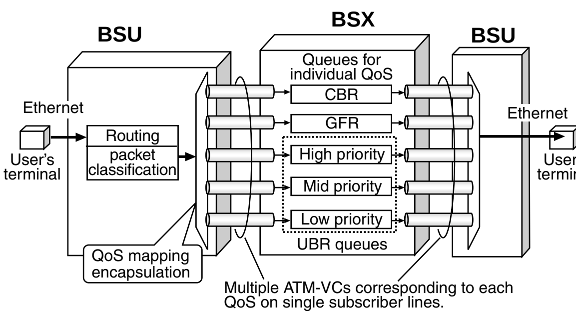


Figure 5
Provision of multiple QoS in ATM-based vESW.

By utilizing the classifier in the BSU and the QoS-capable switch fabric in the BSX, our proposed access system provides multiple QoS.

6. Ring networking

Building an access ring with ATM-ADMs[11] and the Bi-directional Line Switched Ring (BLSR)-based protection technique results in efficient usage of network resources and reliable connectivity. **Figure 6** shows the ring network configuration and the protection mechanisms.

For the protection of guaranteed traffic such as CBR and traffic less than the Minimum Cell Rate (MCR) of the Guaranteed Frame Rate (GFR), the guaranteed bandwidth must be less than 50% of the total link bandwidth. The residual bandwidth can be allocated for best-effort traffic such as UBR and for traffic exceeding the MCR of the GFR. When a link failure occurs and each VC

Table 1
Mapping QoSs between IP and ATM.

IP QoS		ATM QoS
EF		CBR
AF	Gold	UBR H-priority
	Silver	UBR M-priority
	Bronze	UBR L-priority
Best effort		UBR
N/A		GFR

EF: Expedited forwarding
AF: Assured forwarding

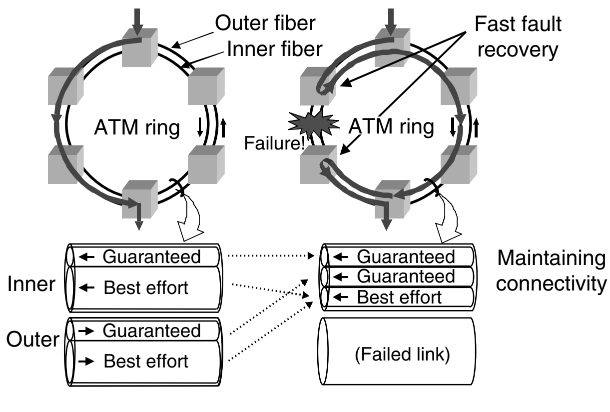


Figure 6
Fault recovery on ATM ring network.

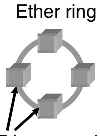
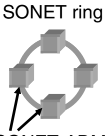
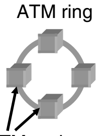
needs to be loop-backed, the bandwidth used by the best-effort traffic shrinks and the residual bandwidth in the fiber is used to transport the loop-backed guaranteed traffic. This feature provides not only reliability of guaranteed services, but also efficient resource utilization in the normal and loop-backed state using the nature of the best-effort service. The key point is that the ATM ring can maintain the connectivity of best-effort connections in the case of a link failure.

The existing SONET ring has a similar function. It achieves guaranteed bandwidth with a loop-back function and provides an "extra service." In normal operation, the extra service can be used as a kind of best-effort service on the protect line. Once a link failure occurs, the connections of the extra service are terminated so that the protect line can be used as the loop-backed path. However, this feature does not meet the needs of Internet applications that prefer to maintain connectivity even when the bandwidth becomes narrow.

Conventional Ethernet switches can also be used to build a ring network. However, although an Ether ring may be able to maintain reduced-bandwidth operation for Internet applications, the only Ethernet-native technology that can be used for fault recovery, the Spanning Tree Protocol (STP), performs a relatively slow recovery and is therefore unsuitable for carrier-grade systems and infrastructures.

Table 2 shows a comparison of the three kinds of ring network technologies.

Table 2
Comparison of ring networks.

	Ether ring	SONET ring	ATM ring
Configuration	 Ethernet switch	 SONET-ADM	 ATM node
Base technology	Ethernet	TDM	ATM
Time for recovery	Slow (30 to 45 s)	Fast (< 50 ms)	Fast (< 50 ms)
Availability for best-effort services	Good	Fair	Good

7. Conclusion

In this paper, we summarized the requirements for new access networks for the IP networks of the social infrastructure. To offer the benefits of IP networks and their services to all users, including businesses and residential users, the access networks need to provide not only a broad bandwidth but also multi-QoS capability, high reliability, and high-security.

Taking account of these requirements, we proposed a virtual Ethernet switch architecture (vESW) which provides reliable Ethernet connectivity. We also described an implementation of vESW using ATM technology. In the proposed network, the APON and ADSL provide broadband connectivity to end-users. The two key elements, the packet classifier on the edge of the access network and the QoS-capable switch fabric in the BSX, achieve a multiple QoS capability for both IP and ATM services. The ATM ring achieves a high efficiency and reliability.

We believe that our proposed architecture can be used to build a reliable and dependable access network.

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