ATM-based optical access network toward multimedia era

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Abstract

This paper proposes an ATM-PON based optical access network architecture and relevant transmission technologies for providing multiple services. The motivation of this network is to realize a service platform and to provide multimedia services as well as POTS and ISDN to both businesses and homes. This paper also describes how the PON architecture will contribute to greater network economy, a smooth evolution from the narrow-band optical access network, and downsizing of the optical network unit (ONU). It also shows the configuration, system parameters, features of the system, hardware, and the experimental results. This ATM-PON system is actually working as a service platform for VOD experiments in our laboratory; more than ten types of servers and settop devices are currently connected. This system is to be used for multimedia experiments in a field environment.

Keywords

ATM, optical access network, multimedia, video on demand, digital CATV, IP routing

1 INTRODUCTION

Dramatic changes in the global marketplace suggest extraordinary telecommunications changes in the not-too-distant future. While basic telephony may remain a centerpiece of telecommunications for many years to come, several new information-networking services promise to have a profound effect on the next-generation telecommunications networks. These new services are being driven by several converging factors. Among them are: changes in the business climate, technology-driven change, and new consumer demands.

These changes validate several new information-networking trends: increased data networking, growth in public-carrier information networking, the use of a variety of diverse network services-on-demand through a common network interface, new applications requiring high-resolution graphics and images, visual telecommunications, and multimedia. In addition, the deployment of new network-based applications requires that networks provide increased service flexibility, a greater variety of services, higher service reliability, and high-speed performance.

At the same time, rapid advances in technology can be seen: the decreasing cost of processing power, decreasing memory costs, the decreasing cost of bandwidth, the increasing use of computing and "user-friendly" graphical interfaces, and the convergence of telecommunications and computing. These changes have not only intensified computing capabilities, but they have also spawned the development of many new applications involving graphical and visual communications. These new applications will greatly intensify interface-bandwidth requirements, a trend that is expected to continue for the foreseeable future.

Given the above situation, we urgently need to construct new computer communication oriented networks that can support various multimedia services. Thus the next generation access networks must provide customers with economical broadband access to any multimedia server and, at the same time, to support the conventional services. As the next generation access network in Japan, Fiber-to-the-home (FTTH) has been and will continue to be intensively pursued with the highest priority. Among FTTH access systems, Asynchronous Transfer Mode-Passive Optical Network (ATM-PON) systems seem to be the most appropriate to provide multimedia services economically and flexibly because ATM technologies are efficient at transporting data for computer communication and because the PON topology is very promising for reducing system cost, e.g. Ballance (1990), Tsuboi (1992), and Takigawa (1993).

In this paper, multimedia service requirements for access networks are first clarified. An ATM-PON system that meets these requirements is then presented together with basic specifications and features. This system will be utilized in multimedia service experiments and the Digital Audio-visual Council (DAVIC) interoperability test.

2 SERVICE CLASSIFICATION

A variety of services will be provided to customers over multimedia networks. Entertainment services such as CATV and VOD are preferred by residential users, while services such as IP routing are preferred by business users. The access network, the infrastructure of the next century, should serve all these users. Services can be categorized into four groups; each places different requirements on the telecommunication network as described in Table 1.

Group A is the contents service group, which includes Video-on-demand (VOD) and other data retrieval services. This group requires downstream access capabilities of up to 6 Mbps which is appropriate for transporting a single MPEG 2 video program. However, the upstream capability is assumed to be 1 Mbps, which requires asymmetric service bandwidth. Residential users will prefer this service group, and business users will also access this service group if useful business information is provided.

Group B is the broadcasting service group which includes CATV services. This service group basically requires the broadcasting bandwidth of about 600 Mbps which is sufficient to broadcast 80 channels x 6 Mbps or 160 channels x 3 Mbps MPEG2 video programs.

Table 1 Service Requirement

Service Type	Group A	Group B	Group C	Group D
Typical service	VOD (Data retrieval)	CATV (broadcasting)	IP routing CSCW Video phone (Data comm.)	POTS / ISDN (Conventiona)
Bandwidth (down)	6 Mbps	622 Mbps (broadcast) 6 Mbps (ch. selection)	1 - 10 Mbps	64 kbps $\times$ n
(up)	< 1 Mbps	< 1 Mbps	1 - 10 Mbps	64 kbps $\times$ n
Delay	-	-	-	< 1.5 msec (for access sys.) other
AAL Characteristics	type 5 MPEG 2	type 5 MPEG 2	type 5 High speed I/F MPEG 1/2	Cell assembly / disassembly

However, to reduce the access bandwidth and thus the cost, only a few channels should be distributed to each customer as requested.

Group C is the two way data communication service group. Examples include broadband IP routing services, Computer-Supported Collaborative Work (CSCW), and Video phones. For example, the broadband IP routing service provides an Ethernet-based UNI to each customer with the 10-Mbps highway being shared by many customers. A customer can access up to 10 Mbps for the tariff of, for example, the 100 kbps bandwidth. The average required access capability for this service is, then, a few Mbps per customer due to bandwidth sharing. The CSCW service, including video conferencing, text and graphics editing, will require around 3 Mbps to support video and conventional data transfer. This service can be achieved by the same access capability as IP routing. Group C will be used for computer-to-computer communication between ordinary customers. The ATM Adaptation Layer (AAL) type 5 will be used for the service groups mentioned above.

Group D is the conventional service group which includes, for instance, telephone and narrowband ISDN services. The bandwidth will be around $64 \times N$ kbps, and will be symmetric for upstream and downstream. This service group usually requires shorter transport delays than the other service groups. For instance, the maximum delay for the access system should be 1.5 ms. The users of this service group are both residential and business users.

3 REQUIREMENTS FOR AN ACCESS NETWORK

3.1 Access network platform

Multimedia networks are based on the architecture which, as shown in Figure 1, consists of information and communication service layers. The latter further consists of the ATM/STM bearer service layer, basic communication service layer such as IP routing and telephony, and the Value Added Network (VAN) service layer. The access network has only the communication service layer function, but it is required to operate as a platform for all types of services including information services. This allows us to define some requirements for the access network.

Fig.1 Multimedia Network Architecture

3.2 User Network Interface (UNI)

Group A, B, and C services can be provided in a combined way through a single ATM based UNI as defined by ITU-T Recommendation I. 432 or ATM Forum; different VPs are assigned to different services. In practice, LAN interfaces like 10 Base-T, which correspond to the S Reference Point in the ITU-T standard, may be provided directly.

3.3 Access capabilities

It is assumed that one of the service groups, A, B, and C, plus one conventional service (Group D) must be provided. Thus the access capabilities for one customer is about 7 Mbps including additional capabilities for network use, if only the selected program is transported in the CATV use.

3.4 VP/VC usage

At the UNI, different VPs are assigned to different services. These VPs are connected to corresponding servers through the ATM networks. Therefore, the access networks should basically provide VP connections between UNIs and Service Node Interfaces (SNIs). Between servers and customer terminals, various information streams such as the main contents, signaling, and OAM signals are exchanged by using VCs within the VP. In some services, VC

Figure 2 VP/VC allocation example

layer processes such as VC selection and VC multiplexing may be required within the access networks. A possible VP/VC configuration is illustrated in Figure 2.

4 ATM-PON BASED ACCESS SYSTEM

The requirements mentioned in section three have to be satisfied by the access system. Here, an ATM-PON based access system is presented.

4.1 ATM-PON system architecture

The system adopts the PON architecture, which helps reduce network cost, since the SLT and optical fiber are shared by many customers. This also enables a smooth evolution from the narrow-band optical access network using the same configuration. A schematic diagram of the ATM-PON system which meets the requirements mentioned above is shown in Figure 3. The SLT installed in the telephone office contains such functions as an ATM switch for path assignment, PON line terminator (LT), Cell assembler / disassembler (CLAD) to provide conventional services, CATV channel selector, and interface circuit to other intra-office equipment. The Optical Network Unit (ONU) in the customers premises contain such functions as ATM multiplexer (MUX), PON-LT, CLAD, and interfaces to the terminal. The system parameters are shown in Table 2.

Fig.3 Schematic Diagram of ATM-PON System

Table 2 Outline of ATM-PON system

Items	Contents
Services	ATM, VOD, Digital CATV, IP routing, ISDN/POTS, Leased Line, etc
Fiber topology	PON and Single Star
Line rate	155.52 Mbps
PON payload capacity	SLT: 106 Mbps (Upstream), 118 Mbps (Downstream) ONU (average): 6.6 Mbps (Upstream), 7.4 Mbps (Downstream)
Line code	Scrambled NRZ
Up & Down MUX	Wavelength Division Multiplexing
Wavelength	1.3 μ m (Upstream), 1.55 μ m (Downstream)
Maximum cable loss	25 dB
Maximum cable length	20 km
SLT capacity	about 500 ONUs / cabinet (1995)

4.2 Frame format

The ATM-PON transmission features are that all downstream signals are broadcasted continuously and an encryption mechanism is adopted to avoid tapping, and that all upstream signals are transmitted as controlled burst signals to avoid collision at the input point of SLT.

#n: Timeslot number DM: Delay measurement field (unavailable for information transfer)

Figure 4 ATM-PON frame format

Regarding upstream flows, the ATM-PON cells from each ONU are received by the SLT as a serial stream of signals, where each signal has its own bit phase and byte phase. Therefore, some bits for bit synchronization (Preamble) and some bits for byte synchronization (Delimiter) are necessary to ensure SLT synchronization with each burst. Since each ONU generates its own burst transmission timing, guard time between the adjacent bursts is also needed to avoid collision. Burst payload contains two types of information: user information and PON-OAM information. The information identification (II) field distinguishes these two types. Consequently, we find that the upstream ATM-PON cell header consists of a preamble (PR), a delimiter (DL), guard time (GT), and information identification (II), as shown in Figure 4.

Concerning downstream flows, a continuous signal is transmitted from the SLT, so that the upstream burst signal overhead bytes such as PR, DL, GT can be omitted. Due to fact that the downstream information is broadcasted to all ONUs, the destination address (DA) must be added to each cell to indicate the destination ONU. Since the information for each ONU should be encrypted, as discussed above, an encryption control (EC) field is added to show the encryption key. In addition, the SLT must indicate the upstream burst transmission timing to each ONU. This requires a burst signal control (BC) field, which contains the ONU identifier. Consequently, we find that the downstream ATM-PON cell header consists of a destination

address (DA), encryption control (EC), burst signal control (BC), and information identification (II), as shown in Figure 4.

4.3 CLAD design

One of the most important issues in CLAD design is delay characteristics. To fulfill the delay requirement, the partial filling method is adopted for cell assembly from a regular telephone signal. In this case, one ATM cell conveys only one eighth of its payload to reduce the cell assembly and disassembly delay. The total delay of the ATM-PON becomes approximately 1 ms, comparable to conventional telephone services.

4.4 System features

One of the features of the ATM-PON system is that it provides a simple permanent virtual path (VP) connection that can support all types of services without any complicated signaling software for on-call connection. For the time being, and in the near future, the number of multimedia service customers is expected to be quite limited and most services are of the distribution type. In this environment, the permanent connection of VPs between the customer and the server is simple and realistic. In fact, this ATM-PON system is actually working as a service platform for VOD experiments in our laboratory.

The second feature is that it provides the simple ATM interface specified in ITU-T Recommendation I.432. It requires no carrier modulator/demodulator nor tuner in the STB unlike the Hybrid Fiber Coax (HFC) system.

5 HARDWARE AND EXPERIMENTAL CHARACTERISTICS

The ONU provides ATM and basic ISDN interfaces; it is about the size of a VHS video player, as shown in Figure 5(a). The SLT occupies one shelf, and contains eight PON LT circuits. Four shelves compose one SLT cabinet, which then, contains 32 PON LT circuits, as shown in Figure 5(b). If a 16 branch splitter is adopted in each PON, one SLT set can support up to 512 ONUs.

One of the most important characteristics of the access system is the cell delay and its variation (CDV). The cell delay ranges from 62 to 204 μ s, and the CDV is about 140 μ s for the upstream cells in the 8 branch case. Regarding downstream flows, the cell delay ranges from 128 to 171 μ s, and the CDV is about 50 μ s, as shown in Table 3. These values were measured for a 155.52-Mbps interface, and can be regarded as harmless for ATM based multimedia services. The reason for the larger CDV of the upstream cells is that the upstream frame contains the delay measurement field which does not carry any user information cells. This field's duration is 100 ms, and it is used only for measuring the round-trip delay from the SLT to ONU.

The other characteristic is the CATV program selection delay. The maximum value measured in the experiments was 300 ms. This value is negligible compared to the software processing delay in the STB.

The bit error rate (BER) was measured, and the results are shown in Figure 6. As shown in this figure, this system is error-free in the 29-dB transmission loss range, which has a 4-dB margin to the objective and covers almost all of the customers from the telephone offices.

(a) ONU

(b) SLT

Figure 5 ONU and SLT of ATM-PON system

Table 3 Delay characteristics

Direction	No. of VOD branches per PON	VOD bandwidth [Mbps]	CATV bandwidth [Mbps]	ISDN bandwidth [Mbps]	VOD Delay [μ s]			
					Max	Mean	Min	CDV
Down	8	78	48	10	128	146	171	43
	4	106	24	5	128	145	168	40
Up	8	97	--	10	63	87	204	141
	4	88	--	5 Mbps	63	79	187	124

Finally, more than ten types of server-settop pairs are being operationally tested using the ATM-PON system as a platform. In these experiments, MPEG 1 and MPEG 2 transport stream formats are adopted for video coding, and DSMCC-UU for the high layer protocol for video control. Moreover, the ATM-PON will be used in the field trial between two locations; six hundred customers will participate in total. The bandwidth can be flexibly assigned to a customer within the limit of 120 Mbps. Each customer can receive any combination of VOD, CATV, and ISDN services simultaneously provided the total bandwidth does not exceed the limit.

Figure 6 Bit error rate characteristic example

6 CONCLUSION

An ATM-PON based optical access network architecture and relevant transmission technologies were proposed to provide multiple services in a cost effective manner. This system fulfills the service requirements discussed above and is an attractive service platform. This paper also showed the configuration, system parameters, system features, hardware, and experimental results. The ATM-PON system is actually working as a service platform for different pairs of servers and settops. This paper has provided clear evidence of the architecture's advantages and feasibility.

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8 REFERENCES

- Ballance, J. W. et al. (1990) A B-ISDN local distribution system based on a Passive Optical Network. *GLOBECOM '90*, **305.5**, 206_210.
- Tsuboi, T., Maeda, Y., Hayashi, K. and Kikuchi, K. (1992) Deployment of ATM subscriber line systems. *IEEE JSAC*, **10**, 1448-1458.
- Takigawa, Y., Aoyagi, S. and Maekawa, E. (1993) ATM based Passive Double Star system offering B-ISDN, N-ISDN, and POTS. *GLOBECOM i93*, **1.3**, 14-18.