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An ATM-PON architecture for multimedia services

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Abstract

An ATM-PON system for an access network is proposed to support multimedia service efficiently. An ATM emulation layer (ATME) is newly defined above the PON section layer and placed on the same level as the ATM layer to carry ATM payload directly. The bi-directional 54 byte cell format including 6 byte header realizes high throughput. The grant for upstream transmission is controlled by VP level and yields flexible bandwidth allocation considering the Quality of Service.

Keywords

ATM, access network, passive double star, passive optical network

Management of Multimedia Networks and Services R. Boutaba & A. Hafid (Eds.)

1 INTRODUCTION

In the last ten years, Asynchronous Transfer Mode (ATM) has been studied from wide viewpoints to realize multimedia services such as voice, data, and image efficiently. An ATM terminal adapter has been developed, and ATM activities in the local area network are expected to increase rapidly. This means that the role of the access network will become more important in connecting to both the local area network and the wide area network. Recommendation G.902 in ITU-T defines the access network between user network interface (UNI) and service node interface (SNI) (ITU-T, 1995). The access network is expected to support different traffic patterns and several connection types effectively.

The passive optical network (PON) has been studied as a key to the access transmission system because it is thought of as a cost-effective system. It shares optical fiber cables and telephone office equipment among many users by using optical power splitters. A PON system is also expected to support B-ISDN services economically even in low traffic situations.

Accordingly, ATM based PON systems are most promising in terms of both flexibility and cost-effectiveness. The standardization activity is also hot in the major organizations such as ITU-T and the ATM-Forum.

This paper proposes an ATM-PON system for a multimedia access network. An ATM emulation layer (ATME) is newly defined above the PON section layer and placed on the same level as the ATM layer to carry ATM payload directly. The ATME layer definition yields a flexible and efficient access network.

2 An access network for multimedia service

Figure 1 shows an access network architecture for multimedia services. An optical network unit (ONU) is placed in a user's house or an office and supports several different UNIs. An optical line terminal (OLT) is placed in the carrier's office and plays the role of multi-service platform to access B-ISDN, N-ISDN and Internet through SNIs.

The requirements for the multi-service access network are the capability to set up several connection types such as point-to-point connections and point-to-multipoint connections flexibly and to support several traffic patterns efficiently, not only constant bit rate (CBR) service, but also burst traffic such as VBR, ABR and UBR services. The star coupler between the OLT and the ONUs has a maximum branch number of 32 because major services are covered by 5 ~ 10 Mb/s bandwidth. This shared transmission system leads to high cost-effectiveness.

Recently, the FSAN (Full Service Access Network) has been established to accelerate the introduction of optical access networks by network operators (Warzanskji, 1996). One of the hottest issues in access network design is to specify the ATM-PON system.

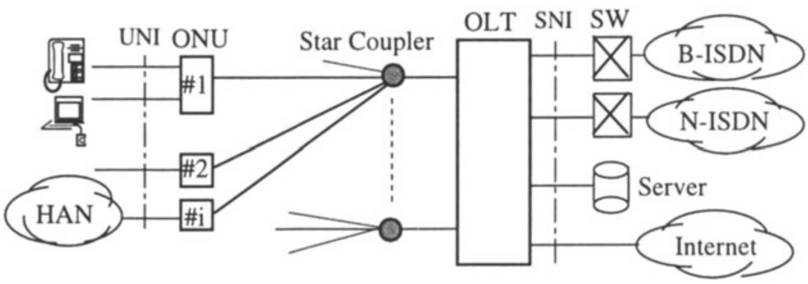


Figure 1 An access network architecture for multimedia service

3 ATM-based PON systems

3.1 Conventional methods

Figure 2 shows the basic configuration of existing ATM-PON systems (Takigawa,1993)(Gert,1992). PON Layer is defined below the ATM layer and constructs a PON digital layer guaranteeing ATM cell transparency. To handle this layer, a 1~7 byte PON header precedes the ATM header (Takigawa,1993)(Gert,1992).

Grant information for upstream transmission must be transferred from the OLT to each ONU in addition to user data. This information is defined in the PON header field or in the payload of the physical OAM cell. In the case of physical OAM cell transfer, an ATM cell can be transferred directly without attaching a PON header. In conventional methods, upstream cell slots are allocated based on ONU#, and plural VPs are multiplexed and transmitted from the ONU, where the priority among the VPs is determined by the ONU.

In upstream transmission, the PON header contains guard time, preamble, and delimiter. Guard time provides enough distance between two consecutive cells to avoid collision. Preamble is needed to extract the bit phase of the arriving cell transmitted using the local timing of the OLT. Delimiter has a unique pattern indicating the start of the ATM cell. The length of delimiter pattern is determined by detection performance considering that some bit errors may occur in the preamble and delimiter fields. Because of the Hamming distance effect, the preamble must be more than 6 bits to offer the ability of one bit error correction.

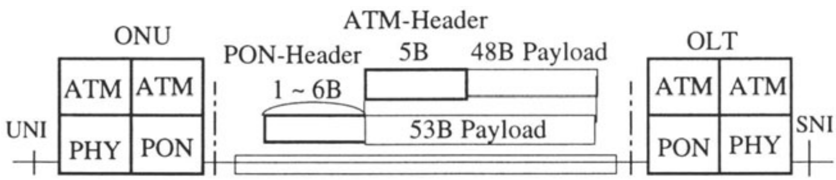


Figure 2 The conventional configuration

3.2 Proposed ATM-PON

3.2.1 Architecture

Figure 3 shows the architecture of the proposed ATM-PON system. The biggest difference with conventional methods lies in the ATM layer. An ATM emulation layer, called ATME is newly defined above the PON section layer. It directly carries ATM cell payload and is placed on the same level as the ATM layer. We call it ATME because the ATME cell also has a header and 48 byte cell payload. The ATME cell header is 6 bytes long, similar to the ATM header.

The conventional methods create a PON layer without modification of the ATM layer to keep the layers independent. However, this causes somewhat disjointed network management in that each ATM connection involves a contract while the traffic is administrated by the PON layer. The proposed system permits both service contract issuance and management in the same ATME layer and can keep the contracted Quality of service (QoS) easily.

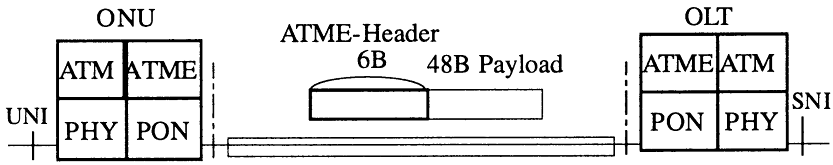


Figure 3 Architecture of the proposed method

3.2.2 Frame and cell format

Figure 4 shows the downstream and upstream cell/frame formats. The former uses a 1 ms frame to set the basic timing for upstream transmission. 360 ATME cells can be allocated per frame because the transmission rate of 155.52 Mb/s equals 19440 bytes/ms and ATME cell length is 54 bytes.

$$19440 \text{ [byte]} \div 54 \text{ [byte]} = 360 \quad (1)$$

The capacity of the ATME payload is 138.240 Mb/sec which is larger than VC4 (135.63 Mb/s). This means that the access network bandwidth does not restrict downstream transmission when the bandwidth is allocated across a transport network.

$$48 \text{ [byte]} \times 8 \times 360 \times 1000 \text{ [ms]} = 138.240 \text{ Mb/s} \quad (2)$$

In upstream transmission, there is the case that some of the 360 time slots can not be used due to the ranging window. This is described in section 3.2.3.

To define the ATME cell header, the following functions should be considered, destination address, grant identification, downstream encryption control, and the fields of guard time, preamble and delimiter for upstream transmission.

Accordingly, the fields of the ATME cell header are defined as follows. Here, VPI and VCI are virtual path identifier and virtual channel identifier respectively. PTI, CLP and HEC follow the definitions established for ATM cells.

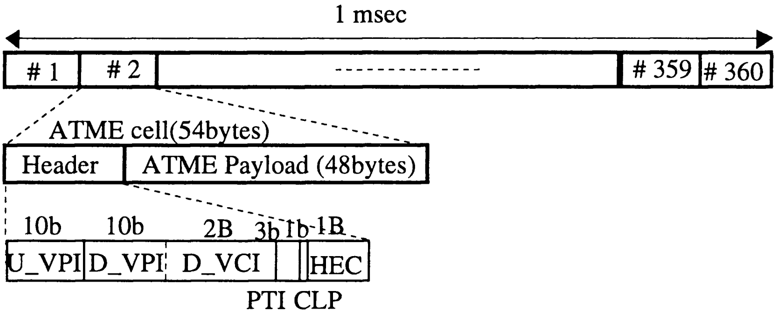
D_VPI(10 bit) - the downstream VPI
D_VCI(16 bit) - the downstream VCI
U_VPI(10 bit) - the upstream VPI and grant identifier which specifies to the upstream VP for the designated ONU
U_VCI(16 bit) - the upstream VCI
PTI (3 bit) - payload type identifier
CLP (1 bit) - cell loss priority
HEC (8 bit) - header error correction
G* - guard time
PR* - preamble   * : Sum of G and PR should be less than 14 bits.
DL (6 bit) - Delimiter

As shown above, each definition and function almost mirrors those of ATM cells. The downstream cells are transmitted continuously and the upstream cells are transmitted as bursts. Cell header is checked by HEC and 1 bit error correction is applied. The biggest difference with the ATM cell is that the U_VPI is part of the downstream header. This is needed because this is also specifies the upstream VP for the designated ONU. By this definition, this field also offers 1 bit error correction. There is no field for U_VPI in upstream transmission as shown in figure 4, because ONU specifies the U_VPI by the timing at which the ATME cell is transmitted. As a result, we can enlarge the guard time and preamble fields leading to better performance.

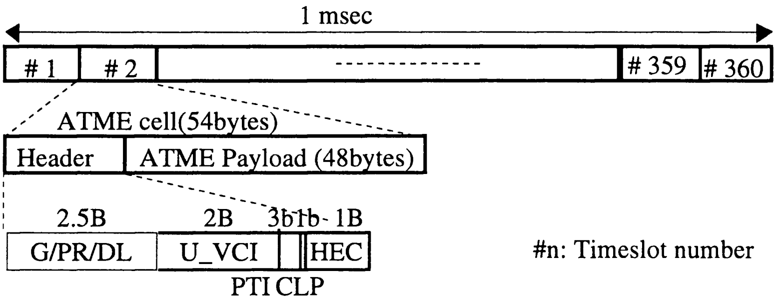
The 10 bit U-/D-VPI is also different from normal ATM cells. This field is 2 bits shorter than ATM cells to make a 54 byte cell. However, the management of 10 bit connections is adequate in an access network. The validity of this is shown in detail in section 4.1.2.

3.2.3 Ranging protocol

An ATME cell is burst-transmitted upstream as permitted by the OLT. To avoid cell collision, an ONU must transmit a cell at the correct timing. A ranging protocol is required for a new ONU to determine its timing without interfering with other active ONUs. In the proposed system, the OLT transmits a physical layer OAM (PLOAM) to inactivate ONUs at regular intervals to initialize the ranging protocol. When a PLOAM cell for ranging is transmitted, an upstream window



- the downstream frame and cell format at 155.52 Mb/s interface



- the upstream frame and cell format at 155.52 Mb/s interface

Figure 4 Frame and cell format of ATME

should be opened to receive the signal for distance measurement. This window size depends on the transmission delay time. When the longest transmission line is 10 km, the window should be larger than 100 μs.

The basic ranging protocol is as follows. When an ONU that has just entered the active state receives a PLOAM for ranging from the OLT, a distance measurement signal should be returned at the basic time (T_b) notified in advance. The OLT then receives the distance measurement signal and calculates the differential time (T_Δ) and notifies T_Δ to the ONU which ONU sends a cell at T_b+ T_Δ.

3.2.4 Block diagrams of OLT and ONU

Table 1 shows the main functions of each layer in the OLT and ONU. Figure 5 also shows block diagrams of ONU and OLT.

In downstream transmission, an ATM cell is converted into an ATME cell in OLT and ATME cells are transmitted continuously to ONUs. An ATME cell is received in ONU and after the header error check is performed, user cells and OAM

Table 1 The main functions in OLT and ONU

	OLT	ONU
ATME Layer	OAM (F4, F5), grant	OAM (F4, F5)
TC sublayer	OAM (F1~F3, ranging), HEC	OAM (F1~F3, ranging), HEC
PON Layer	Synchronization (bit, byte)	Synchronization (frame)

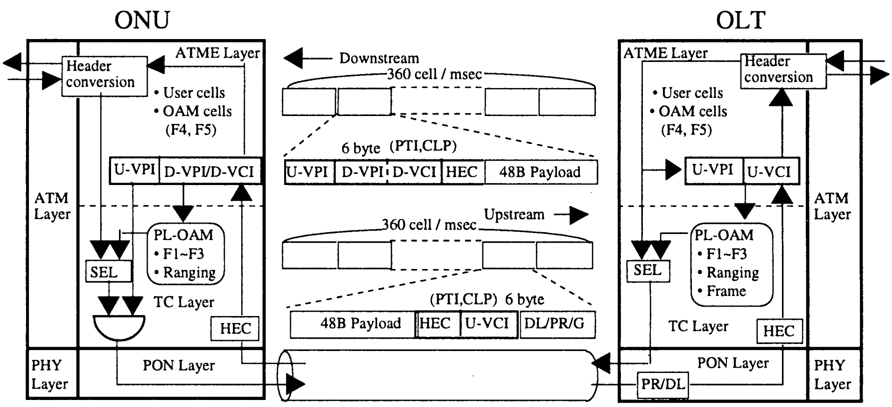


Figure 5 Block diagram of ONU and OLT

cells for F4 and F5 flows are transmitted to ATME layer. An ATME cell is converted into an ATM cell and transmitted to UNI. If the header shows Transmission Convergence (TC) sublayer cell for PLOAM or ranging, these procedures are activated in the TC sublayer. A queuing cell should wait for transmission until the U_VPI is received.

In upstream transmission, as each cell is burst transmitted, preamble and delimiter are activated for bit and cell synchronization. After the header error check is performed, an ATME cell is transmitted across the ATME layer. In this layer, the U-VPI is attached to the received cell, user cells, and OAM cells are transmitted to ATM layer after header conversion. If the header shows a PLOAM cell, it is terminated in the TC sublayer.

These procedures transparently transmit ATM cells between SNI and UNI.

4 Bandwidth allocation management

4.1 VP grant identification

Upstream bandwidth allocation can be carried out by the following two methods;

a) ONU grant : upstream cell slots are allocated based on ONU#, and plural VPs are multiplexed and transmitted by the ONU, where VP priority is determined by the ONU.

b) VP grant : upstream cell slots are allocated based on VP#, and VP cells are transmitted according to the cell slot allocation.

The proposed system uses VP grant and U_VPI in downstream cells is used for U_VP grant identification. This VP grant is a new concept. This simplifies ATM variable bandwidth allocation, since the PON layer does not need to sum the bandwidth of all VPs.

VP grant is needed for the following reasons.

• the consistency of traffic management layer

The network operators and users make a contract with each other about the service based on VP connections including some properties such as PCR (peak cell rata), CDV (cell delay variation), CBR, VBR, ABR and UBR. Therefore, it is reasonable to allocate not only the downstream but also the upstream bandwidth based on to the contract without being disturbed by the other services on the same ONU.

• maximizing upstream payload capacity

In downstream transmission, 6 bits are needed for ONU grant if the maximum number of ONUs is 32 while 10 bits are needed for VP grant. In upstream transmission, 12 bit VPIs must be conveyed to identify the paths for ONU grant while no VPI field is required for VP grant because the OLT knows the VPI from the cell's reception timing. For this reason, the proposed system can use a 12 bit shorter overhead field for upstream transmission compared to other systems, and can enlarge Guard time, Preamble, and Delimiter. This leads to a maximization of the upstream payload even with the 54 byte upstream cell slot size.

• cell transmission control by OLT

In the case of VP grant, an ONU does not need to know the service property (CBR, VBR, etc.) of the connection. On the other hand, in the case of ONU grant, an ONU needs to know the service property and queues the cells according to the properties to transmit time critical cells; OAM cells must be sent ahead of non time critical cells.

Furthermore, in the case of ONU grant, since plural VPs are multiplexed and transmitted on the allocated upstream cell slots, there may be a case that one specific VP consumes all the allocated bandwidth for the ONU. In this case, cells may be discarded by UPC in the OLT because of over-rate transmission even though the ONU is allowed to transmit the cells. In the case of VP grant, cell discard by

UPC is avoided, since the OLT assigns the upstream cell slot allocation based on the service contraction.

4.2 VPI - U/D_VPI conversion

The maximum existing VP connections is 8192 in an access network.

$$256\ (\text{UNI}) \times 32\ (\text{ONU}) = 8192 \tag{3}$$

In this system, the maximum U-/D-VP connection number is 1024 because 10 bit fields are used. In an actual situation, the following three connection management functions are assumed.

• 1 : 1 conversion of VPI and U/D_VPI

This converts an ATM VP is converted into an U/D_VP in the ATME layer as shown in figure 6 (a). This is realized by VPI and U/D_VPI conversion in ONU. In this case, at least 32 VPs can be handled by each ONU.

• service multiplexing

Several ATM services are considered, such as CBR, VBR, ABR, and UBR. This function multiplexes VPs of the same service as shown in figure 6 (b). In this case, 10 U/D_VPIs for each ONU are adequate.

• N : 1 conversion of VPI/VCI and U/D_VPI/VCI

This function conveys VPs in one ONU are conveyed in one U/D_VP. This is realized by VP/VC and U/D_VPI/VCI conversion in ONU as shown in figure 6 (c). In this case, the maximum number of U-/D-VPIs per system must be 32.

From the viewpoint of bandwidth, 10 ~ 100 connections per ONU is the upper number considering that most service rates are of the mega bit/sec order and the 155.52 Mb/s transmission line rate.

From above reasons, there is no possibility of consuming all 1024 connections at the same time in an access network. Thus handling up to the maximum of 1024 VP connections is adequate in the access network.

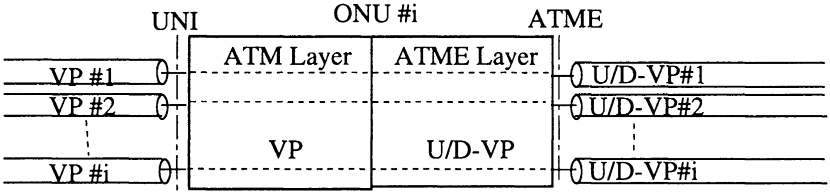
4.3 Dynamic bandwidth allocation

Time slots for an ATME cell can be reassigned dynamically and this realizes a flexible bandwidth allocation. There are two main methods for dynamic bandwidth allocation.

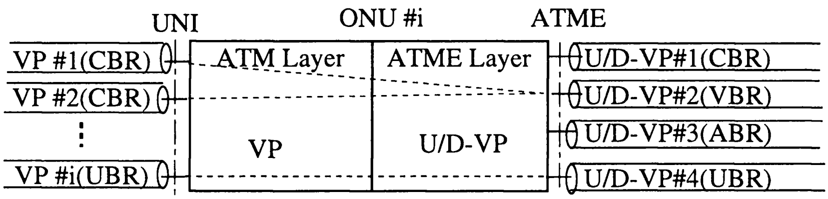
method 1 : the bandwidth allocated to inactive VPs can be used for ABR and UBR services fairly.

method 2 : an OLT receives bandwidth requests from ONUs and allocates the bandwidth according to these requests.

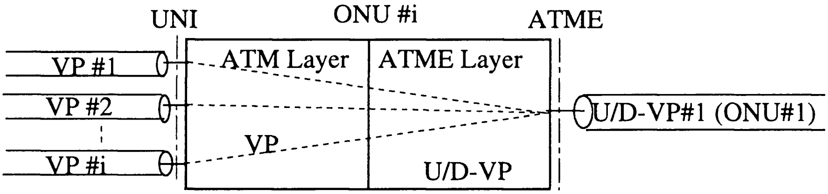
Method 1 needs to monitor ONU activation state. This is realized by the ONU sending a signal when the electrical power is off. The OLT calculates the



(a) 1:1 VPI - U/D VPI conversio



(b) Service multiplexing



(c) N:1 VPI - U/D VPI conversion

Figure 6 Examples of VPI - U/D_VPI conversion

sum of these unused bandwidths and reassigns the bandwidth to ABR and UBR fairly as shown in figure 7.

$$Rate_{ABR/UBR} = (155.52 \text{ Mb/s} - Rate_{PLOAM} - (Rate^{*}_{window}) - \Sigma Rate_{active\ CBR/VBR}) \div n \quad (4)$$

$$n = \Sigma terminal_{ABR/VBR} \quad (5)$$

* : for a new ONU if any

Method 2 seems to be attractive for local area networks because the transmission delay time is low and the network and the terminals belong to the same owner. In case of public access networks, the farthest ONU is 10 ~ 20 km from the OLT. The effect of this method seems to be low because of the long response delay time. If this method is adopted in a public network, it is possible that requesting VPs are allocated more bandwidth than non-requesting VPs. This

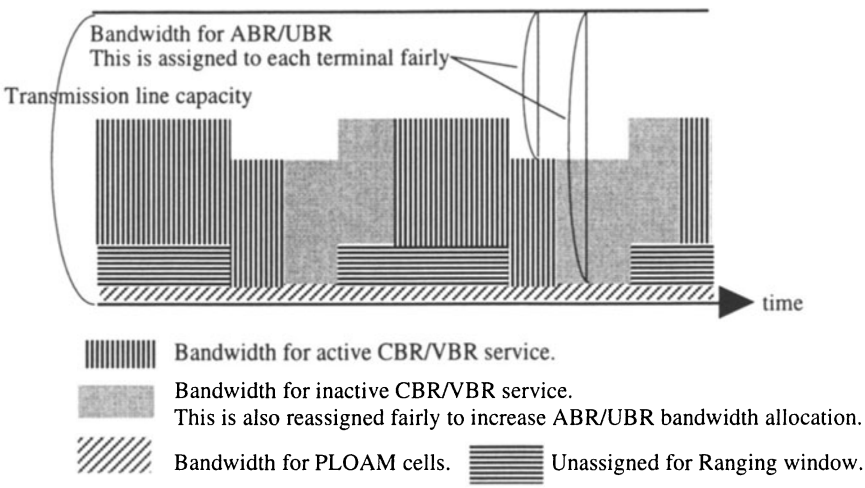


Figure 7 An example of dynamic allocation for upstream

means that the bandwidth is allocated unfairly. Even if this unfairness is accepted, it would lead to a more complex mechanism.

Accordingly, the proposed system adopts the method 1 from the viewpoints of its simple implementation and fair bandwidth allocation.

5 Conclusion

A new ATM-PON system for multimedia access network was proposed. It uses an ATM emulation layer that is newly defined above the PON section layer and placed on the same level as the ATM layer. The proposed system can realize an access network efficiently and effectively.

The proposed system has the following characteristics.

- VCI transparency
- 1024 U/D_VPs handling which is adequate for an broadband access network
- Bi-directional 54 byte cell format including 6 byte header to realizes high throughput
- 20 bit assignment for guard time and preamble which realizes low cost devices
- VP grant to guarantee the Quality of Service
- Dynamic bandwidth allocation for available rate service

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BIOGRAPHY

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