

Combining Medium Access Control and Traffic Management in ATM Passive Optical Networks ¹

C. Blondia[†], O. Casals[‡], J. Garcia[‡] and F. Panken^{*}

[†]University of Antwerp
Dept. Mathematics and Computer Science
Universiteitsplein 1, B-2610 Antwerpen (Belgium)
Phone: + 32 3 8202404, Fax: + 32 3 8202421
E-mail: blondia@uia.ua.ac.be

[‡]Polytechnic University of Catalonia
Computer Architecture Department
c/Gran Capitan, Modulo D6, E-08071 Barcelona (Spain)
Phone: +34 3 4016985, Fax: + 34 3 4027055
Email: olga@ac.upc.es

^{*}Lucent Technologies
Postbus 18, NL-1270 AA Huizen (The Netherlands)
Phone: + 31 35 6874707, Fax: +31 35 6875954
E-mail: frans@lucent.com

Abstract

In a shared medium environment, such as an ATM Passive Optical Access Network, both the MAC protocol and the Traffic Management functions are responsible for allocating resources to users of the shared transmission medium such that the QoS objectives are met and that the resources are used efficiently. To illustrate this common goal and its influence on the system design, we define a MAC protocol for an ATM Passive Optical Network (APON) that is able to support the different service categories proposed by the ATM Forum : CBR, VBR, ABR and UBR. The protocol is centralized and uses a request/permit mechanism to control the access to the shared medium. The bandwidth allocation algorithm gives priority to the CBR/VBR traffic, ensures a minimum cell rate for the ABR traffic and allocates the unused bandwidth to the UBR traffic. This protocol is an enhanced version of a system that was implemented in the European RACE programme (BAF project).

1 Introduction

In this paper we show that during the design of a MAC protocol for an ATM PON, traffic management consideration may be taken into account in order to enable the system to guarantee the required QoS of the connections and to use the available resources in an efficient way.

¹The first author was supported by Vlaams Actieprogramma Informatietechnologie under project ITA/950214/INTEC "Design and Control of Broadband Networks for Multimedia Applications"

1.1 Medium Access Control

The purpose of the MAC protocol is to resolve contention when more than one user tries to make use of a common medium. Such a protocol is intimately related to the topology of the access network. In this paper, we confine ourselves to an ATM Passive Optical Network (APON) having a tree structure. In the downstream direction there is no access control mechanism required, as the traffic is broadcasted to all users. Furthermore, the tree structure of the access network suggests a centralized control at its root. Apart from avoiding collisions, such a MAC protocol should fulfill a number of additional requirements :

- *Efficiency* : the overhead introduced by the MAC protocol should be low (a typical value is 5 percent of the bandwidth).
- *Fairness* : a particular user should not be subject to more access delay than another.
- *Performance* : the cell transfer delay, cell transfer delay variation and cell loss introduced by the MAC protocol should be kept within the bounds defined by the Quality of Service (QoS) requirements of that particular type of traffic.
- *Simplicity* : the algorithm and its implementation should be kept simple.

Since the APON is an integral part of the ATM network, the MAC protocol should be based on the ATM principles, i.e. a flexible allocation of the available bandwidth of the shared medium supporting a guarantee of the required QoS.

1.2 ATM Traffic Management

The primary goal of Traffic Management procedures is to protect the network and the user in order to achieve network performance objectives and additionally to optimize the use of network resources. To this end, ITU-T ([6]) and ATM Forum ([2]) have defined a number of ATM layer traffic control and congestion control parameters and procedures which support a set of ATM layer QoS classes for all foreseen ATM services. There has been defined an ATM service architecture by means of service categories (called ATM transfer capabilities in ITU-T terminology) : Constant Bit Rate (CBR), Real-Time Variable Bit Rate (rt-VBR), Non-Real-Time Variable Bit Rate (nrt-VBR), Available Bit Rate (ABR) and Unspecified Bit Rate (UBR) (ITU-T also considers ATM Block Transfer (ABT)). Currently another category is under discussion in the ATM Forum for TCP/IP type of applications, namely Guaranteed Frame Rate (GFR). For each service category, a number of QoS parameters are defined. Negotiation of a specific ATM layer QoS class takes place at connection establishment and the result is part of the traffic contract. The traffic contract is a commitment for the network to meet the requested QoS, as long as the user complies with the traffic parameters agreed in the contract. We distinguish between ATM traffic control, which is related to the ability of the network to provide appropriate differentiated QoS to different applications and ATM congestion control, which is related to minimize the intensity, spread and duration of congestion, where congestion is defined to be a state of network elements in which the negotiated network performance objectives for the established connections are not met anymore (due to unpredictable statistical fluctuations of traffic flows or network fault conditions).

1.3 MAC and Traffic Management

From the above description of both functions, it follows that MAC and Traffic Management have a number of goals in common : both are responsible for allocating resources (bandwidth, buffers) to connections (users) in such a way that the QoS objectives are met and that these network resources are used in an efficient way. Although these functions belong to different layers, the designer may try to combine them when designing an access network and the related protocols. In what follows, we illustrate this by means of a MAC protocol for an APON defined in the European RACE II project Broadband Access Facilities (BAF, project R2061) (see [1], [5] for more details), and extensions of the protocol proposed in [8] and [9].

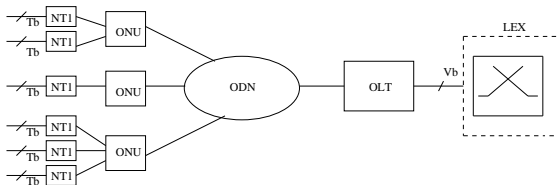


Figure 1: Reference configuration of the APON system

2 Medium Access Control and Traffic Management in an APON

2.1 Basic Mechanisms of the MAC protocol

In this paper we consider a Passive Optical Network with a tree structure, the reference configuration of which is depicted in Figure 1. It consists of an Optical Line Termination (OLT) located at the root of the tree and a fiber which is split into branches connecting the OLT with the Optical Network Units (ONU) serving a number of Network Terminations (NT1) (Fiber To The Curb case) or directly with the NT1s (Fiber To The Home case). The access control protocol for this network has a centralized control located in the OLT. Furthermore it is defined by

- the way the central control is informed about the bandwidth needs of the NT1s
- the way the NT1s are informed about the permission to access the medium (i.e. to send information upstream)
- the way the bandwidth is distributed among the NT1s (i.e. the bandwidth allocation algorithm).

In view of the goals of ATM traffic management, it is the bandwidth allocation algorithm that establishes a relationship between access control and traffic management. This will be discussed in detail in the next sections. Let us first discuss the first two characteristics of the MAC protocol. The MAC protocol uses a request/permit mechanism. Each NT1 declares its required bandwidth by sending *requests* to the master of the protocol in the OLT. We distinguish between two types of requests. The first type of request is coupled

to upstream ATM cells. When an NT1 is allowed to send a cell into the network, it adds a request containing the number of cells that are waiting for transmission in its buffer. Since this mechanism would allow an NT1 to inform the OLT about its bandwidth needs only when it is allowed to send a cell, a second type of request is needed. The so called *Request Blocks* (RB) contain requests originating from different NT1s, not coupled to upstream ATM cells. They could be issued during idle periods (i.e. when no NT1s are permitted to send upstream cells) (see [1]) or could be issued on a periodical basis (see [8], [9]). The NT1s are informed about the received bandwidth by means of *permits*. Such a permit allows the NT1 to send a single cell. The address of the NT1 that is receiving the permit is broadcasted downstream and is coupled with an ATM cell.

2.2 Medium Access Control and Traffic Profile

The MAC protocol may alter the traffic profile of the upstream traffic for the following reasons.

(i) *Alteration due to the Request/Permit mechanism*

When a cell arrives at the NT1 buffer, it takes at least a complete round trip NT1-OLT before this cell leaves the buffer. Moreover, this delay is not constant. For example, the first cell of a burst of cells arriving at an empty NT1 buffer has to wait for the next Request Block before it can inform the OLT about its arrival. This delay is variable, depending on the load of the system as the RBs are generated during idle periods.

To avoid this problem, the frequency of generating RBs may be increased, or RBs may be generated on a periodical basis. This would decrease the alteration of the traffic profile, but increase the protocol overhead.

(ii) *Alteration due to the Bandwidth Allocation Algorithm*

In order to alter as less as possible the traffic profile, permits should be generated according to the timing they arrive at the NT1 buffers. However, as the requests only contain the number of arrivals since the last request, and not any timing information, some approximation has to be made. A possible solution consists of putting the permits in a global FIFO queue before sending them to the corresponding NT1.

2.3 Medium Access Control and Cell Rate

The traffic contract of CBR, VBR resp. ABR traffic specifies values for the Peak Cell Rate (PCR) resp. the Minimum Cell Rate (MCR). The PCR should not be exceeded, while the MCR has to be guaranteed. The MAC protocol may contribute to this traffic management requirements as follows.

(i) *Enforcing the PCR*

Generate permits according to the requests for CBR/VBR traffic, but at a frequency not higher than the one corresponding to the PCR. In this case, the MAC protocol fulfills a spacing function. Note that for the APON system in this paper, request information arrives at the OLT per NT1. Hence, traffic may originate from a number of VCs, each having their traffic contract, and in particular their PCR. Spacing the permits of these VCs according

to the sum of the PCRs of the different VCs, would lead to unacceptable cell transfer delay and cell transfer delay variation. The MAC protocol should act as *bundle spacer*, spacing the cells of the bundle of VCs carried by an NT1 according to a value based on the sum of the PCRs and an additional tolerance factor. For a detailed investigation, we refer to [4].

(ii) *Guaranteeing the MCR*

The ABR service category is assumed to be a best effort service, using the remaining bandwidth after CBR and VBR traffic is transmitted, but with a guarantee of a MCR. The MAC protocol should operate accordingly and generate permits for the ABR VCs with at least a rate which corresponds with the MCR.

2.4 Medium Access Control and Congestion Control

Traffic Management functions are responsible for minimizing the intensity, the spread and the duration of congestion in the ATM network. Congestion in case of an APON could be that there is more upstream traffic offered to the APON than the capacity of the upstream link, resulting in an increase of the buffer occupation in the NT1s. The MAC protocol may contribute to control the congestion by distributing the available bandwidth among the active connections taking into account the agreed QoS of the connections and the knowledge about which connection(s) is causing the congestion.

Moreover, as integral part of the ATM network, the APON should implement the congestion control mechanisms as proposed by the ATM Forum (e.g. computation of the Explicit Rate in case of ABR traffic).

3 A MAC Protocol with Traffic Management Capabilities

In this section we define a MAC protocol, the design of which is based on the principles explained in the previous section. For a more detailed description of the protocol, we refer the reader to [9].

The information flow between the OLT and the NT1s consists of requests coupled with upstream cells, request blocks and permits coupled with downstream cells. Their structure is given in [9]. We just mention that for both requests and permits, the system makes a clear distinction between CBR/VBR, ABR and UBR traffic. We discuss in some detail the bandwidth allocation algorithm and the congestion control mechanism.

3.1 The Bandwidth Allocation Algorithm

The bandwidth has to be allocated on two different levels : among the different NT1s connected to the APON and among the different service categories supported by the APON (CBR/VBR, ABR and UBR). The algorithm used to allocate the available bandwidth is called the Bandwidth Allocation Algorithm. The main characteristics of the algorithm are:

- (i) For the allocation of permits among the NT1s, an approximation of a global FIFO discipline is used (for fairness reasons and to minimize the delay variance).

- (ii) For the allocation of permits among service categories, the highest priority is given to the CBR/VBR traffic, but with a guarantee of a minimal cell rate for the ABR traffic. When neither CBR/VBR, nor ABR traffic is present, then the remaining capacity is used for the UBR service.
- (iii) The available buffer capacity in the different NT1 buffers is used to store the cells that wait for transmission (distributed buffering).

Now we summarize the operation of the bandwidth allocation algorithm for the various service categories.

(i) CBR/VBR Traffic

The OLT computes the number of new CBR/VBR-cell arrivals in the NT1s (based on the information in the requests) and generates the necessary number of permits. These permits are put in the global FIFO queue. Due to the fact that, apart from the requests sent with upstream cells, every NT1 is given on a periodical basis the opportunity to inform the OLT about its bandwidth needs by means of periodically issued request blocks, the number of back-to-back permits generated by one request is limited. Hence, the number of cells originating from one NT1 that are sent back-to-back is small and can only occur with very high bit rate sources. Therefore, unlike in the original MAC protocol proposal (see [3], [1]), where no periodic request blocks are defined, spacing of permits is not needed.

(ii) ABR Traffic

The minimal cell rate (denoted MCR) of an NT1 is calculated as the sum of the MCRs of each of its ABR connections. The OLT computes the number of new ABR-cell arrivals (deduced from the requests) and assigns the necessary ABR-permits to the NT1. These permits are sent to the NT1 according to the following rules :

- when the number of slots since the last permit for an ABR cell of that NT1 was put in the global FIFO equals $1/\text{MCR}$, and there are ABR cells waiting for transmission, then a permit for an ABR cell is generated and put in the global FIFO. The remaining number of ABR cells to be sent is decreased by one.
- When the Global FIFO queue is empty, then an ABR permit can be generated for an NT1 which has ABR cells waiting for transmission. This NT1 is determined on basis of a cyclic service order.

(iii) UBR Traffic

When the NT1s have no CBR/VBR cells nor ABR cells to transmit, the remaining bandwidth can be used for UBR traffic. In order to keep the mechanism for UBR traffic simple, permits for UBR cells are distributed to the NT1s in a cyclic order. Remark that when an NT1 has no UBR cells to send and it receives a permit for a UBR cell, then the corresponding upstream slot is lost.

3.2 ABR Congestion Control

The ABR congestion control mechanism periodically advises the source end stations about the rate at which they should transmit their information. As an integral part of the B-ISDN, the ATM PON has to implement a congestion control mechanism for ABR traffic.

In [8] a binary feedback mechanism is proposed, while in [9] an Explicit Rate scheme is analysed. In what follows we describe the Explicit Rate scheme.

The APON has to compute the available bandwidth and distribute it fairly among the active NT1s. The feedback from the APON to each NT1 is indicated in backward Resource Management (RM) cells. The congestion control scheme proposed uses the Explicit Rate (ER) field of the RM cell to indicate the rate that the APON can support at that time. The algorithm is based on the congestion control mechanism implemented in the ERICA switch (see [7]). Therefore, the switch keeps track during an observation period, say T time slots, of both the number of CBR/VBR arrivals (N_c) and the number of ABR arrivals (N_a) per NT1. Using these values, the new rate which is written in the ER field of the next Backward RM cell is computed as follows.

$$\text{ABR Input Rate} := N_a/T$$

$$\text{CBR/VBR Input Rate} := N_c/T$$

$$\text{Target ABR Capacity} := \text{Max}\{0, \text{Target Utilization} \times \text{net APON rate} - \text{CBR/VBR Input Rate}\}$$

$$\text{Overload Factor } O := \text{ABR Input Rate} / \text{Target ABR Capacity}$$

Each T timeslots the value of O is updated and stored in a memory. When an RM cell passes through the OLT, then the ER field is updated using the last computed value of O as follows.

$$\text{FairShare} := \text{ABR Capacity} / \text{Number of active NT1s}$$

where

$$\text{ABR Capacity} := \text{Max}\{0, \text{net APON Rate} - \text{CBR/VBR Input Rate}\}$$

$$\text{Number of active NT1s} := \text{Number of NTs which have open ABR requests}$$

The NT1Share is obtained using the Current Cell Rate (CCR) field of the RM cell and last computed value of the overload factor O as follows

$$\text{NT1Share} := \text{CCR} / O$$

The ER value to be put in the RM cell is then calculated

$$\text{ER Calculated} := \text{Min}\{\text{ABR Capacity}, \text{Max}\{\text{FairShare}, \text{NT1Share}\}\}$$

$$\text{ER in RM Cell} := \text{Min}\{\text{ER in RM Cell}, \text{ER Calculated}\}$$

4 Conclusions

In this paper we have shown that taking into account considerations w.r.t. traffic management in the design of a MAC protocol for an ATM PON, may lead to an efficient solution, able to support the different ATM service categories. This enables the system to offer differentiated QoS to different applications and participate in congestion control mechanisms. These principles are illustrated by means of a MAC protocol proposed for a tree structured ATM PON with centralized control. Part of this protocol has been implemented in a demonstrator of the Broadband Access Facilities (BAF) project of the European RACE telecommunications research programme.

References

- [1] T. Apel, C. Blondia, O. Casals, J. Garcia and K. Uhde *Implementation and Performance Analysis of a Medium Access Control Protocol for an ATM Network*, Proceed-

ings Architecture and Protocols for High Speed Networks, Dachstuhl Seminar 1993, Kluwer Academic.

- [2] ATM Forum, *ATM Forum Traffic Management Specification*, Version 4.0, 1996.
- [3] O. Casals, J. Garcia and C. Blondia, *A medium access control protocol for an ATM access network*, Proceedings 5-th International Conference on Data Communication Systems and their Performance : High Speed Networks (Raleigh, North Carolina, USA, 1993)
- [4] J. Garcia, C. Blondia, O. Casals and F. Panken, *The Bundle-Spacer : A Cost Effective Alternative for Traffic Shaping in ATM*, Proceedings International Conference on Local and Metropolitan Communication Systems, Kyoto, Japan, December 1994
- [5] U. Killat (Ed.), *access to B-ISDN via PONs*, Wiley Teubner, 1996
- [6] ITU-T, Study Group 13, *Recommendation I.371, Traffic Control and Congestion Control in B-ISDN*, July 1995
- [7] R. Jain, S. Fahmi, S. Kalyanaraman, R. Goyal, *ABR Switch Algorithm Testing : A Case Study with ERICA*, ATM Forum contribution number 96-1267, October 1996
- [8] F. Panken, C. Blondia, O. Casals and J. Garcia, *A MAC Protocol for ATM PONs Supporting Different Service Categories*, Proceedings 15th ITC, Washington, June 1997
- [9] F. Panken, C. Blondia, O. Casals and J. Garcia, *A MAC protocol for an ATM PON supporting explicit rate congestion control for ABR traffic*, 1997, submitted for publication