Support for ATM Traffic Classes in HFC Networks

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ABSTRACT: The Hybrid Fiber Coax (HFC) network represents the last mile in the delivery of multi-media information to the home. Recently the IEEE 802.14 committee has started the process of standardizing the protocols to be used in these networks. One important protocol that HFC networks have to support is ATM. Thereby HFC networks can take advantage of the support for multi-media sources that is inherent in ATM networks. One potential problem in HFC networks, is that in the upstream direction (from the home to the cable headend, see Fig 1), multiple sources may try to contend for the channel at the same time. This leads to the necessity for Medium Access Control (MAC) protocols below the ATM layer. The objective of this paper is to point out techniques by means of which the various ATM classes of service may be supported by frame based MAC protocols in an HFC network.

1.0 Introduction

The Hybrid Fiber Coax (HFC) network represents the last mile in the delivery of multi-media information to the home. Recently the IEEE 802.14 committee has started the process of standardizing the protocols to be used in these networks. One important protocol that HFC networks have to support is ATM. Thereby HFC networks can take advantage of the support for multi-media sources that is inherent in ATM networks. One potential problem in HFC networks, is that in the upstream direction (from the home to the cable headend, see Fig 1), multiple sources may try to contend for the channel at the same time. This leads to the necessity for Medium Access Control (MAC) protocols below the ATM layer. The objective of this paper is to point out techniques by means of which the various ATM classes of service may be supported by frame based MAC protocols in an HFC network. These service classes are [1]:

- **CBR (Constant Bit Rate):** This is intended for real-time applications, such as voice and video. The consistent availability of a fixed quantity of BW is considered appropriate for CBR service.
- **VBR (Variable Bit Rate):** This is further classified into real-time and non-real time VBR. This is intended for applications that can precisely characterize their traffic to the network, and request specific QOS guarantees from it. More details about this service are provided in Section 5.0.
- **UBR (Unspecified Bit Rate):** This is intended for non-real-time applications, which do not require tightly constrained delay or delay variation. The source may transmit at any rate that it wishes, and the network responds to congestion by either dropping cells or by marking the EFCI bit. The manner in which the source responds to this feedback is not specified in the standards, and is vendor specific. Typically UBR service would be used in cases when a higher level flow control mechanism, such as TCP, is present to react to network congestion.
- **ABR (Available Bit Rate):** This is also intended for non-real-time applications, but provides a more reliable pipe than UBR, since it tries to provide fairness and low cell loss ratio. This is achieved by means of explicit feedback from the network to the source (by means of special cells called *Resource Management* (RM) cells). The source then adapts it traffic in response to the feedback, the algorithm for doing so has been specified by the ATM Forum. In addition the source may also specify a Minimum Cell Rate (MCR), such that the network is always able to accept at least MCR cell/s from it, without reducing its rate further.

The MAC layer in the HFC network should have appropriate mechanisms defined in it, so that it is

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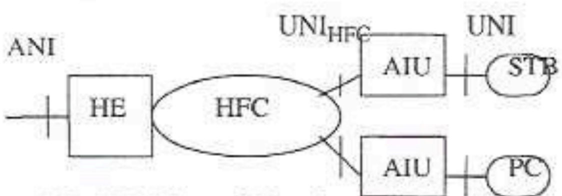
capable of supporting these service classes. The IEEE 802.14 committee has received several proposals for the MAC layer, several of whom claim support for some or all of these ATM service classes [2], [3]. We will explore one of these, the *Adaptive Digital Access Protocol* (ADAPt) from AT&T [2], and the UniLINK-2 protocol from LANCity Corp. in some detail, to see whether it has the mechanisms necessary to support the ATM service classes. The considerations in this contribution are applicable more generally to all MAC protocols that are frame based at the MAC layer.

The rest of this contribution is organized as follows: In Section 2 we present the reference configuration, in Sections 3, 4, 5 and 6 we consider UBR, ABR, VBR and CBR services

2.0 Reference Configuration



ANI: ATM Network Interface

AIU: ATM Interface Unit

Fig 1(a): ATM over HFC Reference Architecture

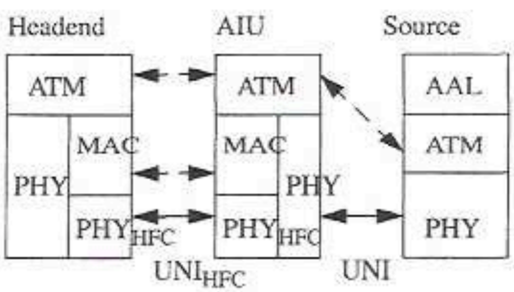
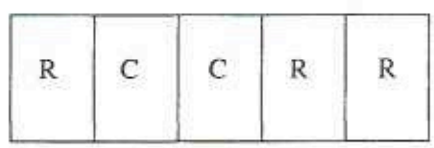


Fig 1(b): ATM over HFC Transport Protocol Model

We will consider the following reference configuration (Fig 1a), which has been borrowed from [4] (Baseline Text for the Residential Broadband Sub-Working Group). The ATM Transport Protocol Model corresponding to this configuration is also included in Fig 1b. The AIU is a networking device that is the demarcation point between the HFC network and the Home network.

We will assume that MAC protocol between the AIU and the Headend has a periodic frame based structure, as is the case for ADAPt and UnilINK-2 (see Fig 2). Each frame has a fixed duration (2 ms for the AT&T proposal), and consists of a number of fixed size slots, each of which contains an ATM cell and some header information. Each slot can be either a contention slot or a reservation slot, with the following properties (which are the same as in the AT&T proposal):

- For the case of reservation slots, there is a BW controller in the headend which informs the AIUs whether a slot is reserved or not, and if reserved then the designated source. This is done by means of control messages sent in the downstream direction. The BW controller assigns reservation slots for CBR and VBR sources, with a frequency which depends upon their requested bit rate.
- For the case of contention slots, once again the BW controller assigns certain slots to be of the contention type, and AIUs can then try to send their ABR and UBR cell traffic in those slots. The BW controller then broadcasts the results of the contention in the next downstream frame and in case of a collision, the AIUs may resort to some contention resolution algorithm such as tree based contention resolution or slotted ALOHA.



R: Reserved Slot
C: Contention Slot

Fig 2: Structure of an Upstream Frame

3.0 Support for CBR Service

At the time of connection set up, a CBR source signals its Peak Cell Rate (PCR) and Cell Delay Variation Tolerance (CDVT) Traffic descriptors across the UNI to the AIU, and requests QOS parameters such as Cell Transfer Delay (CTD) and Cell Delay Variation (CDV) from the network. This information is sent to the BW Controller in the headend, which reserves PCR amount of BW for the source by means of the reservation slots in the upstream frames. The headend also signals these parameters to the rest of the ATM network by means of signalling across the ANI.

The ADAPt protocol specifies that the BW controller may assign one time slot per frame, or multiple time slots per frame, or j time slots in every kth frame, in order to meet the BW requirements. This scheme leads to the following two issues:

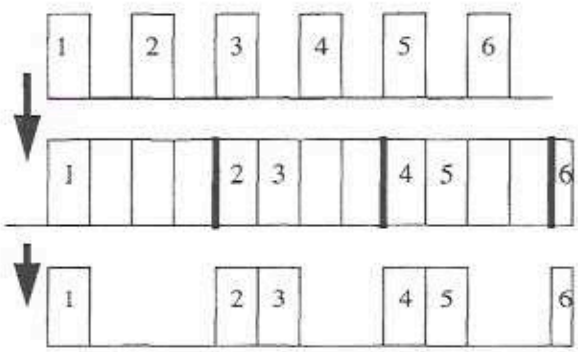


Fig. 3: Illustration of cell jitter caused due to frame encapsulation in the MAC layer

- **Cell Jitter**. This has the potential of introducing additional jitter into the cell stream, as we now illustrate: Consider the case when the PCR for a source is given by 1000 cells/s. Moreover, the source has a traffic shaper, so that cells arrive at the AIU once every 1 ms, so that two cells arrive at AIU for every MAC frame time. Lets assume that two cells are assigned to successive reservation slots in the MAC frame by the BW controller, as illustrated in Fig 3. It is clear from this picture that this procedure leads to the situation in which the cell stream that is presented to the ATM network is jittered by 1 ms (In this example we ignored the cell transmission and propagation delays in the HFC network). When the headend negotiates CBR CTVD parameter to the ATM network across the ANI, it should make sure that this jitter is included in the CDVT calculation, so that the ATM network can put appropriate traffic policing functions in place. Note that the BW controller may reduce this jitter by more uniformly spacing out successive slots from the same CBR source, in each MAC frame. From this point of view the ADAPt scheme is preferable to the UniLINK-2 scheme, since the UniLINK-2 scheme bunches all reservation and contentions slots in their own contiguous portions of the frame while the ADAPt scheme freely intermixes reservation and contention slots. Thus the UniLINK-2 scheme restricts the latitude that the BW controller has in spacing out successive reservation slots.
- **Granularity of achievable bit rates.** When the transmission media has a slotted structure, such that successive slots occur at Link Cell Rate (LCR), the source is still able to transmit at arbitrary constant bit rates by appropriately varying the inter-cell gap between successive cells. However, it is not clear whether the same may be possible with the frame based MAC proposals such as ADAPt or UniLINK-2. This is due to the fact that if the BW controller were to vary the inter-cell gap, then a slot that was of the contention type in frame n, may be changed into a reservation type in frame n+1. This may adversely affect ABR and UBR traffic streams, which may still be trying to resolve the contention in that slot. A consequence of the fact that arbitrary bit rates are not achievable, is that the BW controller may have to overbook the link capacity for a CBR session to the next highest PCR rate that is available. This may lead to inefficient use of the link BW.

4.0 Support for VBR Service

At the time of connection set up, a VBR source signals the following traffic descriptors to the AIU across the UNI:

- Peak Cell Rate (PCR)
- Cell Delay Variation Tolerance (CDVT)
- Sustainable Cell Rate (SCR)

- Maximum Burst Size (MBS)

There are two kinds of VBR sources as defined by the ATM Forum:

1. **Real time VBR sources**: These requests QOS parameters such as CTD, CDV and CLR (Cell Loss Ratio) from the network. Examples of these sources would be compressed video streams.
2. **Non-Real time VBR sources**: These sources do not have real time delivery constraints, hence the only QOS parameter they care about is CLR. Examples of these sources would be transaction processing applications.

Note that in contrast to a CBR source, both kinds of VBR sources specify the SCR which is an upper bound of the average bit rate of the source and MBS which quantifies the burstiness of the source. The BW controller at the headend uses these extra pieces of information to reserve less than PCR bandwidth in the HFC network, while at the same time guaranteeing the QOS parameters.

At present UniLINK-2 does not specify its support for VBR sources to a sufficient level of detail. The following mechanisms have been provided for VBR support in ADAPt:

- The VBR source specifies its PCR and a fixed value, say N, for the maximum number of cells in a burst to the BW controller. Whenever it has a burst to send, it signals this to the headend by means of a contention slot, and the headend then reserves N reservation slots in succeeding frames, so that the burst gets to it at a rate, say R, sufficient to satisfy QOS requirements.
- In case the number of cells in a burst is not known in advance, then the VBR source only specifies its PCR to the BW controller. Once again, if it has a burst to send, it signals this to the headend by means of a contention slot. The headend then reserves reservation slots in succeeding frames at a rate R sufficient for it to satisfy QOS constraints. The AIU also inserts the number of ATM cells presently queued at the MAC layer (for upstream transmission) into the BRF field of the time slot. The BW controller uses this information to reserve slots in future frames, until the burst is finally exhausted.

In both cases, after the burst is over, the slots can be re-assigned to other sources. ADAPt does not specify the exact algorithm that the BW controller uses for carrying of admission control of VBR sources or equivalently, specifying the rate R that a VBR connection is allocated to make sure that its QOS guarantees are satisfied, and these will left out of the scope of the 802.14 standards.

We have the following comments on this scheme:

- The first mechanism is not very realistic, since a typical VBR source does not have fixed sized bursts whose size is known in advance. Moreover there is no mechanism in ATM for the source to inform the BW controller about the size of its bursts at the start of each burst (even if the source knows these sizes).
- The second mechanism probably suffices for non-real time VBR sources, but may not be sufficient for real-time VBR sources. For example, when a new burst comes in, the source takes an indeterminate amount of time in getting access to the channel, since it uses a contention slot for this purpose. This may prevent the real time delay guarantees from being met.

We now propose an alternate VBR mechanism which may be more appropriate for supporting real-time VBR sources: Define a variable σ by

$$\sigma = MBS(PCR - SCR)$$

Let the end-to-end delay requirement for the connection be given by CTD. Then if the BW controller reserves an amount of BW equal to SCR on the upstream link, then the delay that the cells will experience will be upper bounded by

$$D_{HFC} = \frac{\sigma}{SCR} + TD + PD$$

where TD and PD are the transmission and propagation delays across the HFC link. Hence the cell transfer delay for the rest of the ATM network, CTDD is given by CTDD = CTD - D_{HFC}. Moreover the traffic descriptor changes from (SCR, MBS) to (SCR,0) at the output of the HFC network. Hence in this mechanism we achieve the following:

- Give an explicit formula for the BW R to be reserved as a function of the ATM traffic descriptor parameters. This can be used to carry out connection admission decisions.

- Since the BW is dedicated to the VBR source for the duration of the connection, the connection does not suffer additional delays due to contention resolution at the start of each burst. The price to be paid for this is that link utilization will probably be lower, but in exchange we are able to guarantee real-time delay guarantees to the VBR connection.

The problem of achievable bit rates and BW granularity which was pointed out for CBR sources also applies to VBR sources, so that it may not be possible to reserve exactly SCR amount of BW, but the next higher value that is allowed by the framing scheme. This will also lead to additional jitter, which will have to be accounted for.

5.0 Support for ABR Service

ABR service is suitable to be used for non-reserved non-real time sources, whose behavior is not known in advance. At present neither ADAPt or UniLINK-2 has specified any mechanism for the support of ABR traffic in an HFC network. It is very important to support ABR services for the following reason: Since CBR and VBR traffic is accorded higher priority than non-reserved data traffic, it may happen that suddenly most of the link BW is taken away from data sources, due to sudden activity of the CBR or VBR sources. In this case data cells will begin to fill up the buffers in the MAC layer at the AIU, and if no provision is provided to back-pressure the source, then cells may be dropped. The ABR service remedies this situation by specifying the following:

- A feedback mechanism from the AIU to the ATM layer at the source, that informs the ATM layer about the presence of congestion at the AIU. This feedback is carried by means of special ATM cells known as Resource Management or RM cells.

- A rate based mechanism at the ATM layer at the source, that continuously monitors the RM cell feedback, and accordingly reduces the source rate in response to network congestion. Hence the point of congestion moves from the AIU to the ATM layer at the source, which can than directly back-pressure the higher layers and thus prevent cell loss.

The following mechanisms, in increasing level of complexity, can be implemented at the AIU in order to support ABR traffic (assuming that the source has also implemented the ABR source/destination behavior algorithms in its ATM adaptor)

1. EFCI Marking: If the upstream link is congested, the AIU marks the EFCI bit in a passing data cell from the ABR connection. The marked cell gets to the destination, which then sets the CI (Congestion Indicator) bit in the next RM cell that is headed towards the source. This mechanism is not very efficient since there is a long latency between the time the congestion occurs and the time the feedback gets back to the source.

2. RM cell marking: If the AIU is given enough intelligence to recognize RM cells, then in case of congestion, it can directly mark the CI bit of the next backward RM cell that is heading towards the source.

3. Generation of BECN RM cells: In case 2), the AIU still has to wait for a backward RM cell before it can get the congestion information back to the source. If the AIU is given the power to generate backward RM cells on its own, then this would speed-up the feedback process considerably.

4. Implementation of *Explicit Rate* algorithms: In this case the AIU keeps track of the actual cell rates of the ABR cell streams, and in case of congestion it computes the fair share rate for each VC and communicates it back to the source via RM cells. This mechanism has been put into ABR since source rate increase/decrease algorithms by themselves are not enough to guarantee fairness between VCs in case of congestion.

We now discuss the issue of appropriateness of the use of reservation or contention time slots for ABR traffic. The ATM ABR specification allows an ABR source to specify a Minimum Cell Rate (MCR) parameter, such that the network has to guarantee that it can always support at least MCR cells/s, so that the source never decreases its cell rate below MCR. As a result, the HFC network will have to use a mixture of reservation and contention time slots in order to support ABR sources. One way in which this can be done in the context of the ADAPt protocol is as follows: The BW controller at the headend reserves MCR cell/s rate for the ABR source using reservation time slots. If the source needs to send at a higher rate than MCR, it can do so by means of contention time slots. Hence it may happen that in a single frame, some ABR cells are sent by means of reservation time slots while others are send as contention time slots.

An aspect of the ADAPt protocol that needs to be clarifies is the set of rules for determining whether an ABR source can contend for more than one contention slot in a frame. If it is allowed to contend for only one slot pert frame, then it restricts the bit rate to about 200,000 bps. In order to achieve higher bit rates it should be allowed to contend for more than one slot per frame. The AIU can get the Allowed Cell Rate (ACR) number from the RM cell, and use it to estimate how many contention cell slots it should contend for.

6.0 Should UBR Service be Supported by HFC Networks?

For the case of UBR service, the source can transmit cells at any rate that it wishes into the network. These cells should be transmitted over the upstream HFC link with the use of contention time slots, such that a contention resolution algorithm such as slotted ALOHA may be used to resolve the contention. In case the HFC link is congested, then the queue length at the MAC layer in the AIU will start to fill up. The AIU may then start to drop cells and optionally mark the EFCI bit in the cells that it does forward.

There are two problems in supporting UBR service in HFC networks:

- Note that the MAC protocol provides feedback about congestion to the AIU, but unlike in the ABR case, there is no mechanism for this feedback to propagate back directly to the ATM layer at the source. Marking the EFCI bit is not a very efficient way for providing feedback to the source, since the marked cells travel all the way to the destination and back before they can impart this information. Moreover the UBR service does not specify any mechanism at the ATM layer to react to the feedback. It is upto the higher layers, such as TCP, to reduce their window sizes in response to the congestion. This leads to the fact that VCs using UBR service may experience a large and uncontrolled degree of cell loss. This situation is excarbated by the fact that VBR services are given higher priority. Hence when a VBR burst arrives it takes up the upstream link BW and existing UBR traffic will overflow its buffers.
- The other more serious problem is that both ABR and UBR traffic would contend for the same contention slots, and there does not seem to be a way by which ABR sources would be given a higher priority than UBR sources (unless the BW controller allocates a specific number of contention slots for ABR and the remaining to UBR, but this would be equivalent to reserving some of the link BW for ABR sources). If both type of sources are accorded equal priority, then in the presence of congestion, the ABR sources will back-off in response to RM cell feedback, however UBR sources will not do so. Hence at any time, there will be more UBR cells waiting for transmission at the AIU as compared to ABR cells, which will lead to the situation that UBR sources would get more of the contention BW and ABR sources would be unfairly penalized for being for responsive to link congestion.

In light of this, we would recommend that HFC networks support ABR service only, rather than both ABR and UBR.

7.0 Another Reference Configuration

The discussion in this report so far has been based on the reference configuration in Fig 1, which was taken from the Baseline Text for the ATM Forum RBB Sub-Working Group. This document also contains a simpler configuration, in which the UNI does not appear, i.e., the STB or PC directly signal to the headend by means of UNI_{HFC} signalling (Fig 4)

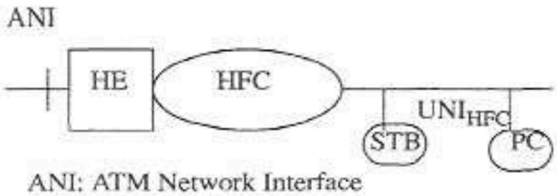


Fig 4(a): ATM over HFC Reference Architecture

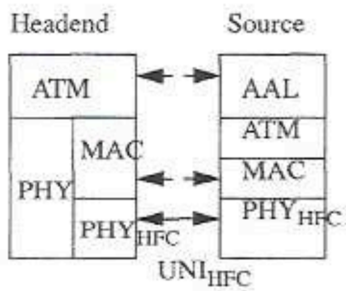


Fig 4(b): ATM over HFC Transport Protocol Model

. The following issues arise for this configuration:

- There is more flexibility by way of signalling, since the source is no longer restricted to UNI 4.0 signalling to the headend, but can potentially include some HFC specific parameters in signalling. For example, for the case of VBR sources the source can signal the burst size directly to the BW controller, everytime there is a new burst.

In this reference configuration, since the MAC layer is located directly on the source adaptor, it can potentially back pressure the source directly without having to rely on ABR feedback based control. This can be done for example by terminating the ABR service at the headend by means of the Virtual Source/Virtual Destination (VS/VD) mechanism, and just relying on MAC based feedback in the HFC part of the network. Hence the question arises whether we can do away with the presence of the ABR mechanisms in the MAC layer for this configuration (thus reducing the cost of the HFC adaptors). This scheme is subject to the following problem: Consider the case when the link between the headend and the first ATM switch is congested in the upstream direction. Then the ABR flow control in the ATM network will push the point of congestion to the headend, which will begin to fill up its buffers. However, the headend does not have any means for relaying the congestion information back to the source, since the MAC layer feedback is only in response to HFC link congestion, not in response to congestion at the headend. There are two ways to resolve this problem:

1. Require the ABR feedback mechanism to be operating at the ATM layer
2. Rely on the flow control mechanism in higher level protocols such as TCP

Hence if we choose option 2 above, then we can dispense with the ABR mechanism in the MAC layer at the source.

References

[1] S.S Sathaye, "ATM Forum Traffic Management Specification Version 4.0," ATM Forum Document No. ATMF95-0013 R8, Oct. (1995).

[2] K. Sriram,"An Adaptive Digital Access Protocol (ADAPt) for Multiservice Broadband Access Networks (Part I): Protocol Description," IEEE 802.14 Document No. 802.14-95/046, June (1995).

[3] J.M. Ulm, "UniLINK-2 as Media Access Control Protocol for Community Cable TV," IEEE 802.14 Document No. 802.14-95/079, July, (1995).

[4] L.F. Wojnaroski, "Baseline text for the Residential Broadband Sub-working group," ATM Forum Document No. ATMF95-0458R1, Aug. (1995).