ABR Traffic Control in Satellite ATM Networks

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Abstract— **ABR service relies on a feedback from the network, therefore it strongly suffers from the long propagation delays characterizing satellite networks. In fact, it has been shown that the high delay, in combination with high bandwidth, can deceive ABR sources and make them falsely believe that a break occurred somewhere in the path. Since ABR sources respond to breaks by reducing their cell rate, the resource utilization decreases drastically. The solution to this problem considered up to now has been to reduce the cell rate only when the feedback from the network is missing for a period longer than the round trip delay. However, this delay in reducing the cell rate causes many additional cell losses if a break actually occurs. In this paper we show the conditions in which the long propagation delay deceives the ABR sources and then propose a new ABR scheme that avoids the reduction in network utilization without causing additional losses.**

Keywords: *Satellite Networks, ATM Networks, Congestion Control.*

I. Introduction

Initially, ATM was not designed to work for satellite network environment. Thus, several problems need to be overcome so that satellite ATM networks can become fully operational [1]. One of these problems is the effect of long propagation delays in satellite networks on the congestion control of ABR traffic.

The ABR service discipline relies on a feedback from the network which is conveyed through special control cells called *Resource Management* cells [2]. If an ABR source sends a certain number, CRM, of Resource Management cells without receiving any feedback from the network, then it believes that a break occurred somewhere along the connection and reduces the cell rate in order to limit losses [2]. However, the long propagation delays characterizing satellite networks can deceive the ABR sources and make them falsely believe that a break occurred. As a result, the resource utilization decreases drastically [3]. The solution suggested in [3] is to set CRM to an appropriate value in order to delay the reduction of the cell rate until the time when the feedback from the network is missing for a period longer than the round trip delay. Although this approach is successful in preventing the unnecessary reduction of the cell rate, the delay in the ABR source's response to the actual breaks causes many additional losses. For this reason, we do not believe that this is the correct way of achieving high resource utilization in satellite networks.

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In this paper, first we show the conditions in which ABR sources are deceived by the long propagation delays and then present a new scheme that avoids the reduction in the resource utilization in long propagation delay networks. The main features of our scheme are:

- It does not cause additional losses.
- It requires modifications only on the behavior of the switches which are directly connected to satellite links, i.e., the behavior of the ABR source, ABR destination and the other switches are not required to change.
- It differs from the congestion control scheme standardized by the ATM Forum [2], only when strictly needed.

The scheme is based on the switches' capability of generating backward *Resource Management* cells standardized by the ATM Forum [2]. In particular, in our scheme, the switch downstream the satellite generates backward Resource Management cells so that, as long as there are no breaks along the connection, it is impossible that the ABR source sends CRM Resource Management cells without receiving any feedback from the network. The paper is organized as follows. In Section II we briefly review the basics of the ABR service needed for the comprehension of the rest of the paper. In Section III, we show the conditions in which the long propagation delay deceives the ABR source and causes the reduction in the resource utilization. Then, in Section IV we present our new scheme for ABR congestion control in satellite networks and assess its performance in Section V. Finally, in Section VI, some discussions conclude the paper.

II. The ABR Service

In the ABR service [2], the source adapts its rate to changing network conditions. In fact, the ABR service gives a guaranteed *Minimum Cell Rate* (MCR), and a certain amount of unused bandwidth to each connection. The cell rate assigned to a connection cannot be higher than the *Peak Cell Rate* (PCR). Both MCR and PCR are specified by the source at the call setup time. The call admission control function rejects a connection request, if MCR cannot be guaranteed. Also ABR service does not guarantee limits on the delay because it is not intended to support real-time applications [2]. As a result, MCR is often set to 0. The *Initial Cell Rate* (ICR) is the cell rate at which the source begins its transmission. It is specified and negotiated also at the call setup time. An ABR source is allowed to transmit at an *Allowed Cell Rate* (ACR) dependent on the congestion conditions in the network:

$$MCR \leq ACR \leq PCR \quad (1)$$

The network makes ABR traffic sources aware of its condition by means of *resource management cells* (RM-cells). The source sends RM-cells, called *forward* RM-cells, every $(Nrm-1)$ data cells, where Nrm is a power of 2 ranging from 2 to 256 which can be specified either by the source, or its default value is 32. The destination sends back the received RM-cells, known as *backward* RM-cells, to the source. On their round trip through the network, the RM-cells collect congestion information and provide to the source as feedback.

Upon receiving a backward RM cell, the ABR source reads octets 8-9 in this cell indicating the *Explicit Cell Rate* (ER), sustainable by all network resources involved in the connection, i.e.,

- If $ACR > ER$, then $ACR = ER$.
- If $ACR < ER$, then the ACR is updated as follows:

$$ACR = \min\{ACR + RIF \cdot PCR, ER, PCR\} \quad (2)$$

where RIF is the *Rate Increase Factor* and is a power of two, ranging from 1/32768 to 1.

Note that the ABR sources are subject to 13 rules [2]. A source complying to all of them is expected to be subject to a low cell loss rate. In the following, we focus on the 6-th rule because it may cause very low resource utilization in long propagation delay networks, as satellite networks [3]. Rule 6 is intended to limit the number of cell losses if any link along the path breaks. It states that before generating and sending a forward RM-cell, if at least CRM forward RM-cells have been sent since the last backward RM-cell was received, the transmission rate must be reduced at least by $ACR \cdot CDF$. CDF is the *Cutoff Decrease Factor* ranging between 1/64 and 1, and CRM is an integer number dependent on the application [2]. A typical value of CRM for terrestrial applications is 32. However, this value causes very low resource utilization in long propagation delay (such as satellite) networks where the forward RM-cell emission rate may be much higher than the backward RM-cell reception rate because of a sudden and high increase of the ACR value.

This problem is recognized in [3], where the authors suggest that the value of CRM should be set to an appropriate high value. For example, for a 155 Mbps GEO satellite link with a propagation delay of 275 msec, they [3] suggest to set CRM to 6144, and for a 622 Mbps GEO satellite link, to 24576. These large CRM values cause high cell losses, if a break occurs somewhere in the connection. For example, the value $CRM = 6144$ may result in additional 195584 cell losses, and $CRM = 24576$ in additional 785408 cell losses.

For this reason, we believe that setting CRM to a high value is not the correct way of achieving high resource utilization in long propagation delay networks. Here, we propose to keep CRM at a low value, e.g. 32 as in terrestrial networks, instead modify the ABR discipline in such a way that Rule 6 will not trigger if no break occurred along the path.

We try to keep the new ABR service discipline as close as possible to the standard one [2]. The modifications we propose (presented in Section IV) intervene only when they are needed, i.e., Rule 6 will trigger also if no break occurred along the path. In the next section, we show the conditions under which Rule 6 as proposed in [2] triggers unnecessarily.

III. The ABR Service in Long Propagation Delay Networks

Rule 6 triggers if the following two conditions hold [3]:

- **Condition 1:** *The reception rate of the backward RM-cells at the source is less than* $(1/CRM)$*-th of the emission rate of the forward RM-cells.*
- **Condition 2:** *The round trip delay is longer than the time needed to transmit* CRM *forward RM-cells.*

Note that, if a break occurs in the connection, the backward RM-cell reception rate becomes 0 and the round-trip delay becomes infinite. Thus, both Conditions 1 and 2 are satisfied. However, Conditions 1 and 2 are also satisfied even if no break occurs along the connection [3]. We demonstrate this fact next.

Due to dynamic changes in the network, the ACR values and consequently the forward RM-cell emission rate may change. Consider an ABR source allowed to

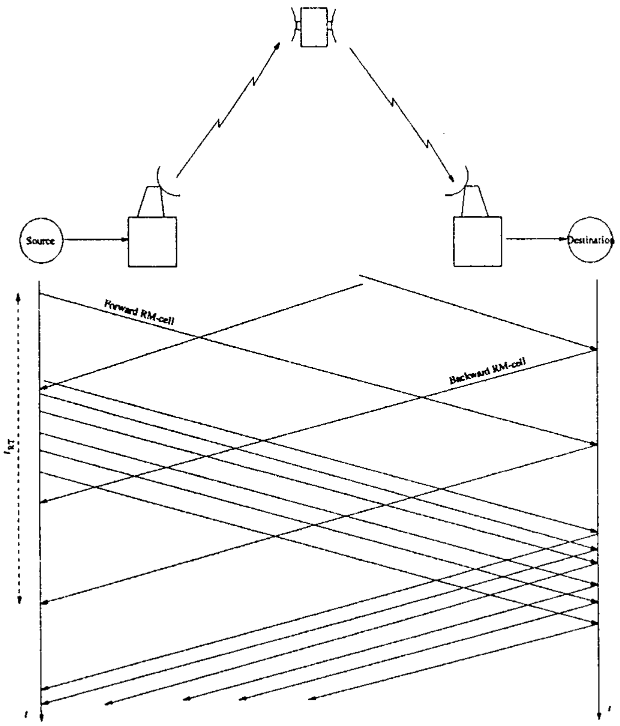

Figure 1. RM-Cell Flow in Long Propagation Delay Paths.

increase its ACR from a value ACR_1 to a value ER, and let t^* be the time at which the ACR reaches the value ER.

As shown in Figure 1, the backward RM-cell reception rate at time t is equal to the forward RM-cell emission rate at time $(t - t_{RT})$ where t_{RT} is the round trip delay. Also the forward RM-cell emission rate is proportional to the ACR. If the allowed cell rate at time t is denoted by $ACR(t)$, then Rule 6 triggers if there exists a $t' \in [0, t^*]$ such that, for Condition 1:

$$\frac{ACR(t')}{ACR(t' - t_{RT})} \geq CRM \tag{3}$$

and for Condition 2:

$$t_{RT} \geq \frac{CRM \cdot Nrm}{ACR(t')} \tag{4}$$

Note that a sudden increase in cell rate occurs in the beginning of a new connection, i.e., the cell rate jumps from 0 to ICR. If the source emits more than CRM forward RM-cells, before receiving the first backward RM-cell, then Rule 6 triggers, i.e.:

$$t_{RT} \cdot ICR > CRM \cdot Nrm \tag{5}$$

In Table I, we give the minimum values of ICR, such that Rule 6 triggers, assuming different values of CRM, $Nrm = 32$ and $t_{RT} = 0.55$ sec. The minimum values of ICR are computed by using equation (5).

CRM values	min $\{ICR\}$
32	790 kbit/sec (1.86 kcell/sec)
128	3.16 Mbit/sec (7.45 kcell/sec)
512	12.6 Mbit/sec (29.9 kcell/sec)

TABLE I

BOUNDING VALUES OF ICR FOR RULE 6 TRIGGERING.

If the condition (5) or the conditions (3) and (4) hold, the Rule 6 triggers and the resources utilization decreases drastically. To solve this problem, we propose to modify the standardized ABR service discipline in long propagation delay networks in the next section.

IV. The New ABR Service Discipline for Satellite Networks

The solution presented here exploits the possibility of dividing the connection into different segments. In fact, the ATM standard allows switches to divide an ABR connection into separately controlled segments [2].

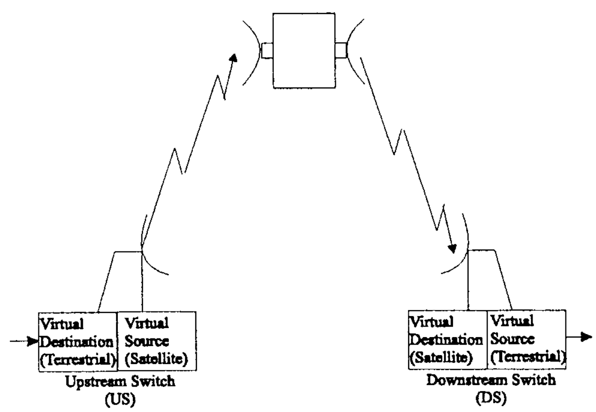

Figure 2. System Representation.

As shown in Figure 2, in our architecture we consider the upstream switch (US) to the satellite and from the satellite to the downstream switch (DS) as one segment. Thus, the US and DS perform the roles of virtual source and virtual destination, respectively, of the segment [2]. First we consider the behavior of DS because it plays the key role and then the behavior of US which simply supports DS.

A. The Downstream Switch Behavior

The DS as virtual destination may assume the role of an ABR destination end point and is allowed to generate backward RM-cells [2]. The US can increase its ACR only if it receives a backward RM cell from DS authorizing this increase. DS keeps generating backward RM-cells, so that the forward RM-cell emission rate at the US is always lower than CRM times the backward RM-cell reception rate.

To detect the occurrence of breaks in the connection, the DS can estimate the time at which the next forward RM-cell should be received. If the forward RM-cell is not received during this time plus a suitable time interval taking the cell receipt delay variance into account, then the DS assumes that there may be a break in the connection and stops generating backward RM-cells.

As shown in Section III, Rule 6 can easily trigger in the beginning of a new connection. If condition (5) holds, in the beginning of a new connection DS generates backward RM-cells with a rate of $ICR/[(CRM-1)\cdot Nrm]$ until the time when the first forward RM-cell is supposed to be received. Although it may seem that these backward RM-cells can cause decrease in efficiency, they prevent unnecessary triggering of Rule 6 in the beginning. As a result, the overall efficiency will increase.

To avoid triggering of Rule 6 for a sudden increase of the cell rate after the initial phase, the DS checks the authorized ER value before sending backward RM-cells. If the ER value satisfies the conditions in eq. (3) and (4), the DS performs the procedure which is given in pseudocode form in Figure 3.

```
DS_Virtual_Destination( )
    OK=1;
    R=min(ER, R+RIF*PCR, PCR);
    t_A=t+Nrm/r;
    t_E=t+(Nrm*(CRM-1))/R;
    do
        if (t>=min(t_E, t_A+dt))
            if (t>=t_A+dt)
                OK=0;
            end;
            if (t>=t_E)
                Emission_Procedure();
            end;
        end;
        if (RM_CELL_ARRIVAL==1)
            RM_Cell_Arrival_Procedure();
        end;
    while (ACR<=(CRM-1)*ER);
end.
```

Figure 3. DS Behavior: DS_Virtual_Destination.

The events that can occur are:

• *An expected forward RM-cell does not arrive.* This event may occur when the actual time, t, is larger than t_A (which is the time when the next forward RM-cell is expected to arrive) plus a suitable interval taking the cell receipt delay variance, dt, into account. In this case, in Figure 3 the variable OK is set to 0 indicating that something has gone wrong in the path, such that the generation of a backward RM-cell by the DS is not allowed.

• *A backward RM-cell is generated.* This event may occur when t is greater than or equal to t_E (the time when a backward RM-cell should be generated if we want to avoid the triggering of Rule 6). If this is the case and OK is equal to 1, as shown in Figure 4, a backward RM-cell is generated and sent to the US, and R (which is the value of the cell emission rate at the US at time t+t_D where t_D is the propagation delay) and t_E are updated.

• *A forward RM-cell arrives.* In this case, as shown in Figure 5, the arrived forward RM-cell is sent back to the US, and t_A and t_E are updated.

Note that in Figures 3 and 5, CCR is the *Current Cell Rate* advertised by the last received forward RM-cell.

```
Emission_Procedure()
    if (OK==1)
        Emit_Backward_RM_Cell();
        R=min(ER,R+PCR*RIF,PCR);
        t_E=t+(CRM-1)*Nrm/R;
    end;
end.
```

Figure 4. DS Behavior: Emission_Procedure().

```
RM_Cell_Arrival_Procedure()
    Read_Cell();
    OK=1;
    t_A=t+Nrm/min(CCR, ER(t-t_D));
    t_E=t+(CRM-1)*Nrm/R;
    Send_Backward_RM_Cell();
end.
```

Figure 5. DS Behavior: RM_Cell_Arrival_Procedure().

If the satellite transmits directly to the actual ABR destination there is no DS. In this case, the Network Control Center (NCC) which is a key component in satellite systems, generates the backward RM cell instead of the DS.

B. The Upstream Switch Behavior

The US assumes the role of an ABR source end point [2]. The behavior of US differs from that of a conventional standardized ABR source in such a way that Rule 6 will not be triggered falsely.

As shown in Section IV-A, the DS stops generating backward RM cells if an expected forward RM-cell is missing. The time at which this expected cell is supposed to arrive is determined from the information in the last received forward RM cell. Let τ_{Last} be the time when the last forward RM-cell was received by the DS. This cell was generated by the US at time $\tau_{Last} - \mathtt{t\_D}$. The next forward RM-cell is expected by the DS at time $\tau_{Last} + \mathtt{t\_A}$ and is supposed to be generated by the US at time $\tau_{Last} + \mathtt{t\_A} - \mathtt{t\_D}$. In the time interval $]\tau_{Last} - \mathtt{t\_D}, \tau_{Last} + \mathtt{t\_A} - \mathtt{t\_D}]$, something unexpected may occur in the terrestrial part of the connection feeding the US, causing a decrease in cell rate. This unexpected event delays the transmission of the forward RM-cell and may deceive the DS. As a result, the DS stops generating backward RM-cells when it did not receive the expected forward RM-cells on time. Rule 6 may then trigger.

In order to avoid this problem, we suggest to modify the US behavior. When the cell rate decreases, the US will transmit a forward RM-cell and inform the DS about this change in the cell transmission rate. Accordingly, DS updates the value of $\mathtt{r}$ and estimates the time, $\mathtt{t\_A}$, when the next forward RM-cell is expected to arrive.

V. Performance Evaluation

We simulate an ABR connection on a 155 Mbps GEO satellite ATM network. The system parameters are: $t_{RT} = 550$ msec, $Nrm = 32$, $RIF = 1/16$, $CDF = 1$, $PCR = 155$ Mbps ($3.5 \cdot 10^5$ cell/sec), $MCR = 0$.

We assume that ACR is allowed to increase from $ACR_1 = 10$ kbps (24 cell/sec) to PCR. In Table II we give, for different values of CRM the number of backward RM-cells generated by the DS which will avoid the triggering of Rule 6 according to our new ABR scheme. In Table II we also show the additional number of cells transmitted using our ABR scheme. In Table III we give the number of backward RM-cells generated by the DS in order to avoid the triggering of Rule 6 in the beginning of a new connection. In Table III we also give how many more cells can be transmitted using our scheme compared to the standardized ABR scheme [2] for different values of CRM.

CRM	Backward RM-cells	Cells Gained
32	145	$2.86 \cdot 10^7$
64	52	$1.30 \cdot 10^7$
128	8	$5 \cdot 10^6$
256	1	$4.34 \cdot 10^5$

TABLE II
Simulation Results.

CRM	Backward RM-cells	Cells Gained
32	183	$3.1 \cdot 10^7$
128	45	$7.7 \cdot 10^6$
512	12	$1.9 \cdot 10^6$
2048	3	$3.5 \cdot 10^5$

TABLE III
Simulation Results.

VI. Conclusions

To increase the resource utilization of satellite networks, we introduced a new ABR scheme that masks the effects of the long propagation delays to Rule 6. In this way, Rule 6 which is developed to limit the losses when breaks occur along the path, does not trigger in the beginning of a new connection or for a high and sudden increase of the allowed cell rate.

The main contribution of our new ABR service discipline for GEO satellite networks is that it does not require high values of CRM and, therefore, it does not cause additional losses.

In the ATM standard [2], the generation rate of the backward RM-cells by a virtual destination must be limited to 10 cells/sec. The practical reason of this limitation is to avoid excessive control traffic that can reduce the efficiency of the network. In our simulations (see Tables II and III), the value of this rate can be higher but on the other hand, each of the backward RM-cells transmitted by the DS helps the satellite network save many resources. Moreover, the backward RM-cells generated by DS are removed by US, and therefore, they do not interfere with the functions of the rest of the connection in the terrestrial part.

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