An ERICA+ Based Scheme to Regulate ABR Traffic and Support Multimedia applications

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Abstract: - A version of ERICA+ switch algorithm, used to regulate the flow control of the ABR traffic in an ATM network is derived and discussed. The network consists of a number of switches arranged in a tandem configuration that allows the Virtual Source – Virtual Destination (VS/VD) property. The switches monitor both, the load and the buffer occupancy on each link, by determining the available capacity and the number of active virtual channels respectively. Based on this information the algorithm advises the sources about the rates they should transmit. In particular, each Virtual Circuit (VC) acknowledges its Current Cell Rate (CCR) through the Explicit Rate Field (ERF) of the Backward Resource Management (BRM) cell received every round trip time. The model is analyzed through a non-linear system of Ordinary Differential Equations (ODEs) by assuming that the Allowed Cell Rate (ACR), the Mean Arrival Cell Rate (MACR) and VD buffer occupancy are modeled as fluids. A simple numerical method, by means of the Euler predictor corrector technique is used that allows the calculation of the MACR for the following time interval.

The new scheme achieves a target point operating at 100% utilization and a fixed non-zero queuing delay. This assumes the use of a suitable queuing control function that allows only a selected fraction of the available capacity to be allocated to the VS, while the remaining is used to drain the current queue. The scheme achieves both efficiency and fairness. In addition exhibits a very fast transient response towards the desired operating point.

The work has a profound interest in TCP/IP protocol, when it is combined with router mechanisms at the network layer to perform necessary traffic management functions. It is particularly important in cases where long file transfers and world wide web servers and clients with persistent data traffic use TCP as their transport layer. As it appears the proposed ERICA+ version enhances the existing end-to-end TCP protocol and provides a rate-based control mechanism suitable for Internet traffic management.

Key-Words: - ERICA+ algorithm, ABR traffic, ATM networks, Multimedia applications, traffic management

1 Introduction

Broadband networks based on Asynchronous Transfer Mode (ATM) technology, provide an adequate technological platform for high-bandwidth multimedia communication. ATM is a fast, cell-switching, connection oriented technology, developed originally for the public Broadband Integrated Services Digital Networks (B-ISDN). It is designed to support all types of traffic streams (voice, video and data), with various characteristics, and different performance requirements. The ATM Forum has already defined the following five services: 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). Depending on the class of service offered, connections provide a guaranteed Quality of Service (QoS) specified mainly in terms of delay and cell loss. In particular, CBR and rt-VBR provide delay and cell loss guarantees and therefore they can be used to transfer delay and loss sensitive multimedia information. In contrast UBR gives no guarantees, while nrt-VBR provides cell loss guarantees. However, in some cases, particularly when delay-insensitive data applications are used, or when it is more desirable to use whatever bandwidth is available than to get the connection rejected, the ABR service is used. Thus, link bandwidth is first allocated to the VBR and CBR classes and the remaining, if there is something left, is given to ABR and UBR traffic.

During the setup procedure of all new connections the user may specify the required QoS. Based on the information on the traffic characteristics declared (at least the Peak Cell Rate (PCR) should be provided), the network estimates the required resources and rejects the request if there are not sufficient resources.

Acceptance of the connection obligates the network to provide the specified QoS and throughput, while the user is obligated to limit its traffic rate according to the given parameters. This agreement forms the basis of the so-called traffic contract between the user and the network, which guarantees a specific service scheme, that when the user follows, shall gain the minimum cell loss. If there in an absence of feedback control during the connection, the approach is usually referred as open-loop control. This policy is applied for CBR and VBR connections and limits each connection's usable bandwidth according to a number of source traffic descriptors associated at a connection setup. Based on these descriptors, sufficient network resources are allocated to guarantee QoS demands during the connection's life time. The open-loop policy is also referred as preventive control.

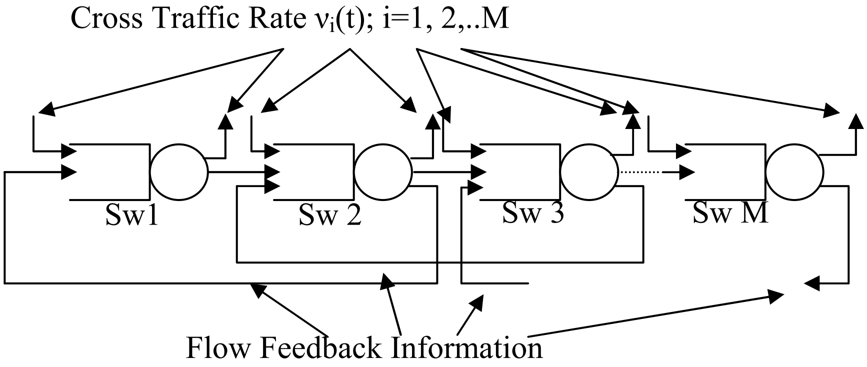

Fig. 1: The Hop-by-Hop model (M ATM switches in tandem)

However, the open-loop control approach is not appropriate for many data applications. Unlike voice and video, the traffic bandwidth requirements of data applications are very difficult to estimate. The PCR parameter may be the only predictable parameter, which is not enough information for the network to allocate resources efficiently. Moreover, the negotiated PCR cannot be exceeded, even when the network is in a low condition. As a result inefficient use of the network resources occurs since for non-real time data applications the cell transmission rate can be adjusted according to the current congestion status of the network. For these types of applications the ABR service guarantees a cell loss ratio only to those connections whose source dynamically adapts its traffic in accordance with feedback received from the network (closed-loop control). Due to the closed-loop feedback control, it is expected the queues in the network switches to be small and the cell loss low. Most of the queuing occurs at the end systems, while queuing delay may be bounded if part of the bandwidth is reserved for the ABR connections

The introduction of ABR service has been motivated by the need of sharing the available bandwidth among all active users, under traffic generated by highly burst data applications. Through the ABR service the network provides a new scheme, called the *best effort* service, in the sense that no hard QoS guarantees are given, but the network does its best to minimize both the Cell Loss Rate (CLR) and the queuing delay. A Minimum Cell Rate (MCR) is guaranteed in order to qualify the Virtual Path/Channel Connection (VPC/VCC) as active, provided that the connection is responding to congestion feedback indications from the network. Note, that the ABR traffic has access to bandwidth only when no CBR/VBR traffic is waiting for transmission, namely to bandwidth that would otherwise be unused, thus increasing the link utilization without affecting the QoS of CBR/VBR connections.

The traffic management group of the ATM Forum adopted the rate-based instead of the window or credit-based approach as a standard for congestion control for the ABR traffic. In window-based flow control schemes sources send at most a window of unacknowledged data into the network. The size of the window varies according to feedback or indication of data loss. TCP provides reliable transport using an end-to-end window-based control strategy [Jacobson]. In the contrary, rate-based schemes use feedback information from the network to regulate the rate at which the sources emit cells into the network. While the current research work deals primarily with rate-based control, techniques are under development in order to accommodate the rate-based flow control algorithms into window-based framework, including their implementation in the Internet.

Rate-based flow control schemes are applied in networks consisting of a number of switches in a tandem configuration (Figure 1) that allows the Virtual Source/Virtual Destination (VS/VD) property. This option permits the division of an end-to-end ABR connection into separately controlled ABR segments by acting like a destination on one segment, and like a source on the other. Due to the above property some hardware complexity may be added. The control information is conveyed to the endpoints through special control cells called Resource Management (RM) cells, which are sent periodically, after *Nrm-1* (default *Nrm* value is 32) data cells, by the sources and turned around by the destinations. The format of a RM cell and the behavior of the VS/VD has been defined by the ATM Forum, leaving the implementation of the switches to the vendors. Note, that the main task of the switches is to monitor their load, compute the available bandwidth and divide it fairly among active flows. Several distributed switch algorithms which provides explicit-rate feedback control have been proposed and proven to give fair and efficient allocation.

The current RM cell format has also been defined by the ATM Forum and includes many fields, such as the source Current Cell Rate (CCR), the MCR, the ERF, the Queue Length (QL), the Backward Explicit Congestion Notification (BECN), the Congestion Indication (CI) flag, the No Increase (NI) flag, e.t.c. Note that the ERF indicates the rate in which the source along the path should use after receipt of the RM cell at a particular time instant. The current specification is largely based on the ideas of the Enhanced Proportional Rate Control Algorithm (EPRCA) [10, 5] with the switch operating either in an Explicit Forward Congestion Identification (EFCI) or in an Explicit Rate (ER) mode. In the EFCI mode, if the queue length exceeds an upper threshold, the switch sets the EFCI bit in the header of data cells to indicate congestion, until the queue length drops below a lower threshold. The VD sets the CI bit in each BRM cell to the EFCI status of the data cell received last. Alternatively, in ER-based mode, switches are equipped with an intelligent marking and explicit rate setting capability. Thus, by marking the CI bit or by setting the ERF according to the degree of congestion in RM cells one may selectively reduce the rates of ABR sources. However, both types of switches may coexist in a single network environment and may optionally set the CI bit in BRM cells to ensure that the VS does not increase its rate. An interesting comparison between the two modes [Ritter] shows the superiority of ER-based mode in most of the cases.

Obviously, one of the advantages of the ER feedback is that each switch may calculate the rate it desires to allocate to the flow by its own method and reduce the ER field if necessary. The procedure is as follows: At connection setup an Initial Cell Rate (ICR) a MCR and a PCR are negotiated. The Allowed Cell Rate (ACR) may vary between the MCR and the PCR and the VS which is connected to the VD via a number of switches (see Fig. 1) is allowed to transmit cells with rate up to ACR. At the source, the initial value of ERF is usually set to the PCR, while the CI and NI flags are clear. If necessary, the switches along the path reduce the ERF to the maximum rate they can support and set CI or NI [7]. The switches are not allowed to increase the ERF. When the VS receives a Backward RM (BRM) cell, it computes its ACR based on the current ACR, the CI and NI flags and the ERF of the current RM cell [6].

Several switch algorithms have been developed and considerably influenced the design of the ABR switch [3] [1,35,69,62, 12,32,37,78]. Many of them are presented in the ATM Forum, including the well known Explicit Rate Indication for Congestion Avoidance (ERICA) scheme [8] which also cites as an example reference switch mechanism in the ATM Forum traffic management specification V.4.0 [2]. However, some switch algorithms are very slow to respond to traffic changes, while others may be too fast. Interesting to note that in almost all of the proposed schemes, the VS immediately modify its ACRs upon receiving a RM cell. The immediate adjustment may lead to overloading of the bottleneck switch, and hence cell loss. Using delay adjusted rate-based schemes, the source may not alter its ACR immediately. Thus, the bottleneck switch can be avoided and the peak queue length of the bottleneck switches can further minimized.

ERICA is a congestion avoidance algorithm and therefore the desired steady state operation may be achieved by means of combining a queuing delay target at the bottleneck and a link, or equivalently, an ABR utilization maximum. This is because the link capacity is shared by several classes, while the switch algorithm controls only the ABR class. In this point the system has a buffer which can be useful in keeping a link temporarily utilized when capacity suddenly becomes available. Note that when the system is in a state of high variation, we may never achieve the target queuing delay because the system itself has no steady state. Under these conditions, the aim is to keep the average utilization high, the average queue size small, and prevent queuing delays from becoming unbounded. Further the ERICA algorithm is concerned with fair and efficient allocation of the available bandwidth to all contenting sources. One commonly use criterion for describing fairness, particularly when the requested MCRs are zero, is the max-min criterion [Charny et al]. This criterion attempts to maximize the allocation of the minimum rate source, namely to provide each contending source a maximum equal share of the bandwidth.

ERICA algorithm is enhanced, by means of ERICA+ algorithm in order to support multimedia traffic. Although many interesting studies exist the problem of supporting multimedia applications has not been resolved in detail. Three are the main issues to be faced. The first issue requires ABR service to provide MCR guarantees. Thus, minimum QoS may be achieved by the multimedia applications. Since most of the current ABR switch schemes assume zero MCRs these schemes have to be modified in order to support nonzero MCRs. The second issue is related with the minimization in the delay and the variation in QoS. Since ABR service was designed to support delay-insensitive data applications there is a need to control the queuing delay and the cell loss. Finally, the third issue is related with the multicast problem by means of supporting ABR point-to-multipoint, multipoint-to point and multipoint-to-multipoint connections. This problem is also important for TCP applications over ATM and should be addressed.

In this paper, a new ER-based switch algorithm suitable for the ABR traffic is proposed. It is based on ERICA+ algorithm and attempts to face some of the issues related with the support of multimedia (or) Internet applications. The new scheme provides nonzero MCR and achieves a target operating point at 100% utilization with a fixed non-zero queuing delay. This assumes the use of a suitable queuing control function that allows only a selected fraction of the available capacity to be allocated to the VS, while the remaining is used to drain the current queue. The scheme achieves both efficiency and fairness. In addition exhibits a very fast transient response towards the desired operating point. Note, that in this study, issues related with the cell loss or multicasting will not be faced, but they are left to a future work.. However, there is a great interesting on some of the issues related TCP/IP protocol, particularly when it is combined with router mechanisms at the network layer to perform necessary traffic management functions. As it appears the proposed ERICA+ version enhances the existing end-to-end TCP protocol and provides a rate-based control mechanism suitable for Internet traffic management.

The organization of this paper is as follows. Section 2 describes the ER model and provides some of the most important features and parameters required in the model analysis. Various ER schemes have been proposed so far, but here, interest is given on the congestion avoidance schemes and, particularly, on the ERICA and the ERICA+ switch algorithms presented in the ATM Forum. The key issue of ERICA+, namely the derivation of a suitable queue control function $f(q)$ which controls the queuing delay in steady state is fully discussed. In Section 3, the new approach in the model analysis is presented. The analysis concludes with the derivation of an alternative queue control function that achieves controlled queue length, and consequently stabilizing the queuing delay at an appropriate level in steady state. The new algorithm is presented along with some fairness criteria. The proposed algorithm is numerically solved and tested in Section 4. Finally, the conclusions are presented in Section 5.

2 Model setup

In this section the ER scheme is described in some detail. The model is presented in Fig. 1 and consists of M switches and M-1 links arranged in a tandem configuration. Each link i is characterized by a transmission capacity $c_i = 1/t_i$ (cells/sec), a propagation delay τ_i, and a processing capacity $1/tpr_i$ (cell/sec), where tpr_i is the time the switch i needs to take a cell from the input and place it on the output queue. Note, that the bandwidth delay product τ_i / t_i , represents the number of *in flight* cells on the transmission link. Since the processing capacity of each node is generally much larger than the total transmission capacity of its incoming link the only reason causing congestion is the transmission capacity.

It is assumed that the network traffic is contributed by source/destination pairs of consecutive switches in the cascade queue and for each such connection there is a link associated on the path. There are two kinds of traffic. One is the uncontrolled traffic, which is not throttled at the source node since it conforms with the traffic contract. This traffic provides MCR guarantee and higher priority classes such as VBR and CBR. The other kind of traffic is the controlled traffic, which is transmitted only when congestion does not exist in the network. This is usually referred as best 'effort traffic' and is calculated from the excess bandwidth capacity after receiving bandwidth for the uncontrolled traffic. Note that, the flow control does not depend on traffic other than that found along the path of the link. This simplifying assumption means that the uncontrolled traffic entering a switch is not proceeded through the tandem queues but it is renewed at each stage, i.e., it immediately leaves the system. A link may consist of a number of VCs passing through it. Thus, if a separate queue is maintained for each VC, one way to analyze the dynamic behavior of each queue would be a deterministic fluid approximation. In such cases $q_{i,j}(t)$, denotes the occupancy (queue length) at time t of the queue associated with link i and VC j, while $qmax_{i,j}$ denotes the corresponding queue threshold level. However, this strategy may add some hardware complexity into the network and therefore it should be avoided in practice. An alternative is to use some fairness criteria in the analysis. Thanks to these criteria, the switch buffer is fairly divided among active connections. Clearly, in this case, the index j in the pre-described parameters may be dropped. In the sequel, the ER-based control algorithm, which regulates the source rates is presented.

2.1 The ER – based model

The state of the controlled connection at the corresponding switch (or link) i is fully captured by three state parameters, namely the $MACR_i$, the ACR_i and the q_i. Thus, the ERF_i of the corresponding BRM cell produced by the i^{th} switch, may be written as:

$$ERF_i(t_n) = F\{q_i(t_n), MACR_i(t_n), ACR_i(t_n)\} \qquad (1)$$

In the above, $ERF_i(t_n)$, $ACR_i(t_n)$ and $q_i(t_n)$ denote the corresponding parameters at the time $t_n = nT$, $n = 0, 1, 2, \ldots$, T is the sampling time and $MACR_i(t_n)$ is the mean arrival cell rate during the period $[(n-1)T, nT)$. Note, that according to the ATM Forum [2]:

$$ERF_i(t_n) = \min\{ERF_i(t_n), ERF_{i+1}(t_n)\} \qquad (2)$$

Moreover, in such systems $ACR_i(t_n) = MACR_{i+1}(t_n)$ for all i.

Without loss of generality the analysis may be restricted to the single hop, single VC model (see Fig. 2). Therefore, the index i, in the above parameters may be dropped as well. In this case, the Fixed Round Trip (FRT) time τ $(=\tau_1 + \tau_0)$ is the propagation delay experienced by the cells before they reach the bottleneck queue (τ_1) of the VD plus the propagation delay experienced by the BRM cells before returning to the VS (τ_0). As it appears, $ACR(t_n) = \mu - v(t_n)$, where μ denotes the fixed service rate of the switch and $v(t_n)$ is the uncontrolled traffic rate at time t_n and therefore, $ACR(t_n)$ may be a non-linear function of the parameters $MACR(t_n)$ and $q(t_n)$. The desirable $MACR(t_{n+1})$ of the next time instant is calculated at the switch and its value is passed to the VS through the ERF of the BRM cells delivered every FRT period. In this way, the VS is always able to adjust its transmission rate to the required level through the following function:

$$MACR(t_n + \tau_1) = \min\{MAR, \min\{PCR, \max\{MCR,\ ERF(t_n - \tau_0)\}\}\} \qquad (3)$$

In the above, MAR is the Maximum Allowed link Rate. Note, that in the worst case of traffic $ERF(t_n - \tau_0) = MACR(t_n + \tau_1)$, or

$$ERF(t_n) = MACR(t_n + \tau). \qquad (4)$$

2.2 Congestion Avoidance Schemes

Two are the main congestion avoidance algorithms, namely, the ERICA and the ERICA+. These algorithms will be discussed subsequently, in some detail. Congestion Avoidance using Proportional Control (CAPC) [3], or some other similar schemes like OSU or MIT introduced earlier, will not be discussed here since they have less performance and present several problems. In addition they usually require setting of many parameters. Incorrect setting may lead to performance degradation. Note that the use of queue length as overload indicator may lead to unfairness. As it appears, the sources that start up late are found to get lower throughput than the sources that start early. These schemes may also result in unnecessary oscillations [9].

ERICA and ERICA+ schemes are introduced in the ATM Forum, and they have taken a particular attention by the research and industry community. They are also important in our analysis and therefore these schemes will be described below in some detail.

2.2.1 The ERICA scheme

The main reason of introducing ERICA scheme [8] is to use the growth rate of the queue length as overload indicator. The switch periodically monitors the load on each link and determines the overload factor, the ABR capacity, and the number of currently active connections or VCs. The switch also measure its ABR input rate over a fixed averaging interval that is counted in cells, namely, as the number of cell arrivals, say N, per time period T. If the available capacity of the link is C cells per second and the desired target utilization is U, the overload (or under-load) state of the switch may be computed as:

*Overload = input_rate / target_rate = N /(T*U*C).*

Here, the target rate indicates the rate level at which an optional network performance can be achieved with high utilization and low buffer usage. At the end of the measurement time interval, the switch computes the overload factor and informs all the VCs passing through it to adjust their rates according to the overload factor. Values of overload factor around 1 indicate optimal bottleneck operating point (the system is in steady state), while high (low) values indicate high bottleneck utilization (link under-utilization) .

The scheme also takes fairness into consideration. Fairness is achieved by ensuring that every VC gets at least a fair share of bandwidth, $FS = (U*C)/k$, where k is the number of active VCs that where seen transmitting during the last measurement interval of N cell arrivals. In fact, to give a maximum possible equal share in each source ERICA allocates the maximum of FS and *VC_share,* namely, $VC\_share_i = CCR_i / Overload$ in every averaging interval. Thus, assuming that the measurements do not present high variation, the algorithm converges to a desirable operation point very rapidly. However, ERICA cannot always achieve max-min fairness [4]. To achieve max-min fairness the algorithm is extended by including the highest allocation achieved during one averaging interval in the possible values of all eligible sources.

The ERICA algorithm operates at each output port (link) of a switch as follows:

```
Initialization:
    max_alloc_prev ← max_alloc_curr ← FS
End of averaging interval:
    total_ABR_capacity ← Link_capacity - (VBR_capacity+CBR_capacity)
    target_ABR_capacity ← f(q) * total_ABR_capacity
    overload ← ABR_input_rate / target_ABR_capacity (:= N /(T*U*C))
    FS ← target_ABR_capacity / number_of_active_VCs (:= (U*C) /k)
    max_alloc_prev ← max_alloc_curr
    max_alloc_curr ← FS
When a FRM is received:
    $CCR_i$ ← CCR_in_RM_cell
When a BRM is received:
    $VC\_share_i$ ← $CCR_i$ / overload
    if (overload > $1 + \delta$) then
        $ERS_i$ ← max[ FS, $VC\_share_i$ ]
    else
        $ERS_i$ ← max[ max_alloc_prev, $VC\_share_i$ ]
    end if
    max_alloc_curr ← max[ max_alloc_curr, $ERS_i$ ]
    if ($ERS_i$ > FS and $CCR_i$ < FS) then
        $ERS_i$ ← FS
    end if
    ER_f ← min[ ER_f, $ERS_i$, target_ABR_capacity ]
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where, ERS_i is the switch's recommended ER value for the *i*_th VC and CCR_i is the current cell rate available from the most recently received RM cell of the *i*_th VC. When a returning RM cell for the *i*_th VC arrives at the switch, the switch first computes the ERS_i and then updates the ERF of the RM cell to the minimum of the current value in the ERF and ERS_i. When a source receives a BRM cell, its *ACR* is always set to the value of ER in the received RM cell. The variables *max_alloc_curr* and *max_alloc_prev* are used to find the maximum allocation in one interval and to use this value in calculating the allocation in the subsequent interval. The parameter δ, typically between 0.05 and 0.1, is used for the equalization of allocations when the *overload* factor is in the neighborhood of unity.

Finally, the queuing control function $f(q)$ allows only a selected fraction of the available capacity to be allocated to the source, while the remaining capacity is used to drain the queue. Constant functions restrict the system utilization to a maximum of U in the steady state. Thus, the system cannot achieve a queuing delay target and it does not provide compensation when measurement and feedback are affected by errors. The alternative is to vary $f(q)$, depending on the queue length. However, an interesting study is the design of such functions. This problem has been faced with the ERICA+ algorithm.

2.2.2 The ERICA+ scheme

As it has pointed out in the introduction, ERICA algorithm is enhanced, by means of ERICA+ algorithm, in order to support multimedia traffic. Three are the primary issues ERICA+ has to overcome, namely, the non zero MCR, the minimization of queuing delay and cell loss and finally the multicasting problem. However, before we discuss some of the problems related with the above requirements one should know that the algorithm, basically, operates in a similar fashion as the ERICA scheme. Thus, ERICA+ algorithm periodically monitors the load, the available ABR capacity, and the number of currently active VCs and calculates the overload factor. The algorithm also keeps track of the maximum allocation given as feedback during the previous averaging interval. An estimation of the fair share of a connection is obtained by dividing the available capacity by the number of connections. If the link is not overloaded, the algorithm gives the explicit feedback rate as the maximum of the current cell rate divided by the overloaded factor and the maximum previous allocation. If the link is overloaded, the maximum of the current cell rate divided by the overloaded factor and the fair share is given as the explicit rate.

The problem of non-zero MCR has been faced successfully at the earlier stages of the ERICA+ algorithm. As defined by ATM Forum V4.0, for non-zero MCRs several similar fairness criteria may be used. Basically, the problem has been reduced to the one with zero MCR by subtracting the MCR from each connection's current source rate to obtain the excess rate over the MCR of each source. Then the switch algorithm for zero MCR is applied to these excess rates to obtain the explicit rate. Finally, the MCR of the connection is added to the above explicit rate and indicated in the BRM cells. The algorithm has been tested and the simulations results show that the MCR guarantee is provided, and allocations converge to the desired general fair allocation [Vandalore et al, Proc. IEEE ICNP Oct. 1998].

However, the main problem related with the performance of ERICA algorithm is that the queuing delay of an ABR connection is not controlled. ERICA+ scheme [Jain Fahmy et al] modifies the ERICA scheme by taking into account the current queue length, namely, *target_ABR_capacity = f(q) * total_ABR_capacity* and by measuring the total ABR capacity as *Link_capacity = VBR_capacity + total_ABR_capacity* used in that interval. As it appears, the target ABR capacity is a fraction of the total ABR capacity and this fraction is actually a function *f(q)* which depends on the switch queue length, say *q*. Hence*,* a controlled queue length (or controlled delay) in steady state, may be achieved with the use of a suitable queue controlled function *f(q)*. The properties of such functions have been discussed in [.] and are summarized below:

- If the queue length is below a desired length q_0 sources are encouraged to increase their rates so that the scheme can maintain some small queue which may be used when link is under utilized. This *suggests f(q)*>1 in the range $0 \le q < q_0$.
- In steady state, the queue length should be constant (i.e., *f(q)*=1 in the range $q_0 \le q < q_1$) and the target rate to be max-min fairness rate.
- If the queue is lightly loaded sources are encouraged to decrease their rates. This suggests *f(q)*<1 in the range $q_1 \le q < q_2$.
- If the queue is heavily overload, part of the link capacity is used to drain large queues. However, it is desirable not to use all the capacity to drain such queues but a minimum portion of the available capacity should be used for carrying normal traffic. Thus, a threshold, known as Queue Drain Limiting Factor (QDLF) is imposed to limit the *f(q)* value, i.e. *f(q)*=QDLF in the range $q_2 \le q < \infty$.
- The function *f(q)* has to be continuous. Discontinuity imply sadden changes which give rise to oscillations.

The queue control function with the above properties will be of the form:

$$f(q) = \begin{cases} >1 & \text{if} \quad 0 \le q < q_0 \\ =1 & \text{if} \quad q_0 \le q < q_1 \\ <1 & \text{if} \quad q_1 \le q < q_2 \\ = QDLF & \text{if} \quad q_2 \le q < \infty \end{cases}$$

Four control functions, by means of the step, linear, hyperbolic and inverse hyperbolic have been introduced and already tested showing that the inverse hyperbolic function performs better than the other schemes [ ]. However, compared with the step and linear schemes this function presents hardware complexity. In particular, the step scheme is the simplest to implement in hardware since it does not require actual calculation. Also, the linear scheme may be implemented efficiently using shift operations for some of the parameter values of the linear function, while the hyperbolic scheme includes a division operation and therefore it needs more time for calculation. Note that the form of the hyperbolic function is given as:

$$f(q)=\begin{cases} > \dfrac{h_b q_0}{(h_b-1)q+q_0} & if \quad 0 \le q < q_0 \\ =1 & if \quad q_0 \le q < q_1 \\ < \dfrac{h_a q_1}{(h_a-1)q+q_1} & if \quad q_1 \le q < q_2 \\ = QDLF & if \quad q_2 \le q < \infty \end{cases}$$

It is interesting to observe the role of the parameter h_a. For high values the function approaches the step function while for values near 1 it approaches the linear function. However, although the linear function performs satisfactorily in most of the cases, it also presents some difficulties to achieve steady state in the case of burst traffic, like compressed video and voice.

3 The new scheme

In this paper, a new ER-based switch algorithm suitable for the ABR traffic is proposed. It is based on ERICA+ algorithm and attempts to face some of the issues related with the support of multimedia applications. The new scheme provides nonzero MCR and achieves a target operating point at 100% utilization with a fixed non-zero queuing delay which may be minimized(?). This assumes the use of a suitable queuing control function *f(q)* that allows only a selected fraction of the available capacity to be allocated to the VS, while the remaining is used to drain the current queue. Thanks to some parameter values that are always available in the switch, the new scheme uses an automatically adjusted control function in order to calculate the *ERF*.. In contrast, the original ERICA+ scheme uses a control function which depends on parameter values obtained by simulation.

The new scheme achieves both, efficiency and fairness. In addition exhibits a very fast transient response towards the desired operating point. However, the new scheme may be configured to use different fairness criteria, while the original ERICA+ uses only the max-min fairness criterion and its generalized version [ ].

To study the new scheme in the network configuration presented in Figure 2, we assume that there is a guaranteed MCR, and thus, there is always bandwidth available in every time period. The model also assumes an operational region for the allowed cell rate of the source, imposed by the traffic contract. Let $K(t)$ be the amount of outstanding unacknowledged cells emitted from the source.

Thus, in the single hop network and in a neighborhood of the switch allowed cell rate, the window K(t) of the source at time t, may be expressed as a function of the source transmission rate $MACR(t)$ as it arrives in the switch and on the queue length (buffer occupancy) $q(t)$ of the involved switch.

The change in the window size between consecutive time periods depends on the delayed acknowledgements received in the source.

Thus, we produce a system of Delayed equations family that follows:

$$K(t) = F_1(MACR\ (t+\tau_1),\ q(t+\tau_1)) \qquad \text{(a)}$$

$$\Delta\ K(t) = F_2(q(t+\tau_1))+O(1) \qquad \text{(b)}$$

Δικαιολόγηση της ανάλυσης του μοντέλου σύμφωνα με το Leaky bucket

Παραδείγματα εφαρμογής με έμφαση στα WCT

In order to study this case, it is proposed here to dynamically differentiate the threshold and adjust the source's emission rate, according the Leaky Bucket fluid flow model, assuming the Worst Case of Traffic of the ER-based switch algorithm. Since the buffer is produced and counted at the switch, we make the assumption that the threshold difference is depended on the switches buffer occupancy.

Further supposing the source threshold adjustment every Δt (depended on the acknowledgement received), it is provided the 1st derivative of the source threshold.

In the sequel a model analysis is presented using a new approach for the solution of the system of equations (a) and (b).

3.1 Analysis

Let $K(t_n)$ be the amount of the outstanding unacknowledged cells (window size) in the VS, at time $t_n = n\tau$, n=0, 1, 2.. . $K(t_n)$ presents the number of cells of the controlled traffic flowing to the switch during the time period $[(n-1)\tau, n\tau)$, plus the number of cells already waiting in the buffer. Thus, in case the observer is located in the VS site the system will be described through the following equation:

$$K(t_n) = \tau\, MACR(t_{n-1}+\tau_1) + q(t_n-\tau_0) \qquad (5)$$

Differentiating the equation above, one may obtain:

$$\frac{d}{dt}K(t_n) = \tau\frac{d}{dt}MACR(t_{n-1}+\tau_1) + \frac{d}{dt}q(t_n-\tau_0) = \tau\frac{d}{dt}MACR(t_n-\tau_0) + \frac{d}{dt}q(t_n-\tau_0).$$

Thus, assuming $\Delta K(t_n) = A\, q(t_n-\tau_0) + B$, and taking into account that $\Delta t = \dfrac{u}{ACR(t_n-\tau_0)}$ is the adaptation time period of the source rate, it follows:

$$\frac{d}{dt}K(t_n) \approx \frac{\Delta K(t_n)}{\Delta t} = \left[Aq(t_n-\tau_0)+B\right]\frac{ACR(t_n-\tau_0)}{u}.$$

In the above, B represents the internal processing delay, say *tpr,* of the switch and u is the number of BRM cells send by the VD to VS every FRT period. Therefore, in case $A \neq 0$, we obtain:

$$\frac{d}{dt}MACR(t_n-\tau_0) = \left[q(t_n-\tau_0)+\frac{B}{A}\right]\frac{A}{u\tau}ACR(t_n-\tau_0) - \frac{d}{dt}\frac{q(t_n-\tau_0)}{\tau} \qquad (6)$$

Similarly, assuming the observer is located in the VD site and using the equation (5), the system may be described through the following equation:

$$\frac{d}{dt}MACR(t_n) = \left[q(t_n)+\frac{B}{A}\right]\frac{A}{u\tau}ACR(t_n) - \frac{d}{dt}\frac{q(t_n)}{\tau} \qquad (7)$$

Note that under the hypothesis that the VS has always cells to send, $MACR(t_{n-1}) = ERF(t_n)$. Thus, the non-linear system of ODEs that control the rate of the VS and the buffer occupancy (queue length) on the switch at time t_n is given by the following equations (8) and (9), respectively:

$$\frac{d}{dt}ERF(t_n) = \begin{cases} \dfrac{B}{u\tau}ACR(t_{n+1}), & \text{if } qpr = 0 \quad and \quad MACR(t_n) < ACR(t_n) \\ \dfrac{B}{u\tau}ACR(t_{n+1}) - \dfrac{d}{dt}\dfrac{q(t_{n+1})}{\tau}, & \text{if } qpr = 0 \quad and \quad MACR(t_n) \geq ACR(t_n) \\ \left[qpr+\dfrac{B}{A}\right]\dfrac{A}{u\tau}ACR(t_{n+1}) - \dfrac{d}{dt}\dfrac{q(t_{n+1})}{\tau}, & \text{if } \begin{cases} 0 < qpr < q\max, \text{or} \\ qpr = q\max \quad and \quad MACR(t_n) \leq ACR(t_n) \end{cases} \\ \left[qpr+\dfrac{B}{A}\right]\dfrac{A}{u\tau}ACR(t_{n+1}), & \text{if } qpr = q\max \quad and \quad MACR(t_n) > ACR(t_n) \end{cases}$$

and

$$\frac{d}{dt}q(t_n) = \begin{cases} MACR(t_n) - ACR(t_n), & \text{if } \begin{cases} 0 < q(t_n) < q\max \text{ or,} \\ q(t_n) = 0 \quad and \quad MACR(t_n) \geq ACR(t_n) \text{ or,} \\ q(t_n) = q\max \quad and \quad MACR(t_n) \leq ACR(t_n) \end{cases} \\ 0, & \text{otherwise} \end{cases}$$

with

$$qpr = \begin{cases} q(t_n) + \left(MACR(t_n) - ACR(t_n)\right)\tau, & \text{if } \begin{cases} 0 < q(t_n) < q\max \text{ or,} \\ q(t_n) = 0 \quad and \quad MACR(t_n) \geq ACR(t_n) \text{ or,} \\ q(t_n) = q\max \quad and \quad MACR(t_n) \leq ACR(t_n) \end{cases} \\ q(t_n), & \text{otherwise} \end{cases}$$

Let $A = -u\,\tau/ACR(t_n)$. Then one may define $q_{st} := B/A = -B\,ACR(t_n)/(u\tau) = T_0{*}ACR(t_n)$, where $T_0 = -B/u\tau$ denotes the Target Queuing Delay negotiated at the time the session was established. Thus, the resulting system of ODEs described by the equations (8) and (9) above may be rewritten as follows:

$$\frac{d}{dt}MACR(t_n) = \begin{cases} q_{st}, & \text{if } q(t_n) = 0 \wedge MACR(t_n) < ACR(t_n) \\ q_{st} - \dfrac{d}{dt}\dfrac{q(t_n)}{\tau}, & \text{if } q(t_n) = 0 \wedge MACR(t_n) \geq ACR(t_n) \\ \left[q_{st} - q(t_n)\right] - \dfrac{d}{dt}\dfrac{q(t_n)}{\tau}, & \text{if } \begin{cases} 0 < q(t_n) < q\max, \text{or} \\ q(t_n) = q\max \wedge MACR(t_n) \leq ACR(t_n) \end{cases} \\ \left[q_{st} - q(t_n)\right], & \text{if } q(t_n) = q\max \wedge MACR(t_n) > ACR(t_n) \end{cases} \tag{11}$$

$$\frac{d}{dt}q(t_n) = \begin{cases} MACR(t_n) - ACR(t_n), & \text{if } \begin{cases} 0 < q(t_n) < q\max \text{ or,} \\ q(t_n) = 0 \wedge MACR(t_n) \geq ACR(t_n) \text{or,} \\ q(t_n) = q\max \wedge MACR(t_n) \leq ACR(t_n) \end{cases} \\ 0, & \text{otherwise} \end{cases} \tag{12}$$

The above system is solved numerically using the Euler method. The algorithm is as follows:

$$MACR(t_{n+1}) = \begin{cases} MACR(t_n) + q_{st}\tau, & \text{if } q(t_n) = 0 \wedge MACR(t_n) < ACR(t_n) \\ q_{st}\tau + ACR(t_n), & \text{if } q(t_n) = 0 \wedge MACR(t_n) \geq ACR(t_n) \\ \left[q_{st} - qpr\right]\tau + ACR(t_n), & \text{if } \begin{cases} 0 < q(t_n) < q\max, \text{or} \\ q(t_n) = q\max \wedge MACR(t_n) \leq ACR(t_n) \end{cases} \\ MACR(t_n) + \left[q_{st} - qpr\right]\tau, & \text{if } q(t_n) = q\max \wedge MACR(t_n) > ACR(t_n) \end{cases},$$

$$q(t_{n+1}) = \begin{cases} q(t_n) + \left(MACR(t_n) - ACR(t_n)\right)\tau, & \text{if } \begin{cases} 0 < q(t_n) < q\max \text{ or,} \\ q(t_n) = 0 \quad and \quad MACR(t_n) \geq ACR(t_n) \text{or,} \\ q(t_n) = q\max \quad and \quad MACR(t_n) \leq ACR(t_n) \end{cases} \\ q(t_n), & \text{otherwise} \end{cases}$$

$$\text{where } qpr = \begin{cases} q(t_n) + \left(MACR(t_n) - ACR(t_n)\right)\tau, & \text{if } \begin{cases} 0 < q(t_n) < q\max \text{ or,} \\ q(t_n) = 0 \wedge MACR(t_n) \geq ACR(t_n) \text{or,} \\ q(t_n) = q\max \wedge MACR(t_n) \leq ACR(t_n) \end{cases} \\ q(t_n), & \text{otherwise} \end{cases}$$

As it appears, starting with an initial buffer $q(t_0)$ and $MACR(t_0)$ and taking into account the equation (4), the procedure derives the $ERF(t_0)$ using the Euler predictor method. This value is used to calculate the new buffer $q(t_1)$ (presented above as *qpr*), which is then used to produce the new $ERF(t_1)$ and so on. Note that the switch sends *u* BRM cells every time period τ having the same ERF value. This is because the corresponding $ACR(t_n)$ is assumed constant during the time period [nτ, (n+1)τ).

Finally, in the worst case of traffic, the buffer, say $BO(t_n)$, overflows with rate given by:

$$\frac{d}{dt}BO(t_n) = \begin{cases} MACR(t_n) - ACR(t_n), & \text{if } q(t_n) = q\max \quad and \quad MACR(t_n) \geq ACR(t_n) \\ 0, & \text{otherwise} \end{cases} \tag{10}$$

However, one of the main targets of this work is to derive a suitable queue function *f(q)* to control the queuing delay in steady state. This will be achieved in the next section.

3.2 The proposed *f(q)*

R. Jain et al. [11], proposed the ERICA + switch algorithm with a target rate given as:

$ER(t_n) = f(q(t_n), q_{st}, MACR(t_n), ACR(t_n)) * ACR(t_n)$.

Kalyanaraman in his Ph.D thesis [12] simplified the function f by taking into account only the queue length qpr, or equivalently, the target queuing delay, say T_0. The strategy developed here is extended in order to include other factors as well, namely, the processing queuing delay, denoted by tpr given as qpr/ACR, the target queuing delay T_0, the growth rate of the queuing delay $BORF$ and finally on the load factor $z(t_n) = MACR(t_n)/ACR(t_n)$ at time t_n. Thus,

$ER(t_n) = f(tpr, T_0, BORF, z) * ACR(t_n)$.

Generally speaking, the control function f depends not only from the queue length but also

Let $A = -u\,\tau/ACR(t_n)$. Then one may define $q_{st} := B/A = -B\,ACR(t_n)/(u\tau) = T_0 * ACR(t_n)$, where $T_0 = -B/u\tau$ denotes the Target Queuing Delay negotiated at the time the session was established. Thus, the equation (8) of the resulting system of ODEs may be rewritten as follows:

$$\frac{d}{dt}ERF(t_n) = \begin{cases} T_0 ACR(t_{n+1}), & \text{if } (a) \\ T_0 ACR(t_{n+1}) - \dfrac{BORF(t_{n+1})}{\tau}, & \text{if } (b) \\ [qpr + T_0 ACR(t_{n+1})] - \dfrac{BORF(t_{n+1})}{\tau}, & \text{if } (c) \\ [qpr + T_0 ACR(t_{n+1})], & \text{if } (d) \end{cases} \tag{11}$$

where $BORF(t_{n+1}) = \dfrac{d}{dt} q(t_{n+1})$

The resulting system of non linear ODEs described by the equations (11) and (9) may be solved numerically using the Euler method. It is assumed here that the parameter ACR remains fixed at least for a period equal to h. The algorithm works as follows:

$$ER(t_n) = \begin{cases} MACR(t_n) + X_{st} h, & \text{if } (a) \\ MACR(t_n) + X_{st} h + \dfrac{h}{\tau}\dfrac{d}{dt} X(t_{n+1}), & \text{if } (b) \\ MACR(t_n) + [X_{st} - Xpr]\tau + \dfrac{h}{\tau}\dfrac{d}{dt} X(t_{n+1}), & \text{if } (c) \\ MACR(t_n) + [X_{st} - Xpr]\tau, & \text{if } (d) \end{cases} \tag{12}$$

which for the specific case that h equals τ, it makes as follows:

$$ER(t_n) = MACR(t_{n+1}) = \begin{cases} MACR(t_n) + X_{st}\tau, & \text{if } (a) \\ X_{st}\tau + ACR(t_n), & \text{if } (b) \\ [X_{st} - Xpr]\tau + ACR(t_n), & \text{if } (c) \\ MACR(t_n) + [X_{st} - Xpr]\tau, & \text{if } (d) \end{cases}$$

Thus, in the steady state the buffer occupancy is given by:

$$X(t_{n+1}) = \begin{cases} X(t_n) + (MACR(t_n) - ACR(t_n))\tau, & \text{if } (e) \\ X(t_n), & \text{otherwise} \end{cases}$$

Here it is notable that R. Jain et al. [11], propose that an ERICA + switch algorithm, should use a target rate as follows:

$ER(t_n) = f(X(t_n), X_{st}, MACR(t_n), ACR(t_n)) * ACR(t_n)$,

and S. Kalyanaraman in his Ph.D Thesis [12] simplified this function by depending it only on the queuing and on the target queuing delay. Here, this strategy is extended by depending the functional parameter f (which is a pure number), from the parameters: queuing delay (denoted by Tpr that is the predictable queuing delay for the time t_{n+1}, given as Xpr/ACR), target queuing delay ($T0$), the growth rate of the queing delay ($BORF$) and finaly on both $MACR$ and ACR, represented here by the load factor z (given as $MACR/ACR$),:

$$ER(t_n) = f(Tpr, T0, BORF, z) * ACR(t_n) = f * ACR(t_n).$$

Thus, equalizing the two parts it follows that the proposed by R.Jain et al., and by Kalyanaraman, function *f* is derived here analyticaly as follows:

$$f = \begin{cases} z + T0 * h, & \text{if } (a) \\ z + T0 * h - BORF * \dfrac{h}{\tau}, & \text{if } (b) \\ z + [T0 - Tpr]h + BORF * \dfrac{h}{\tau}, & \text{if } (c) \\ z + [T0 - Tpr]h, & \text{if } (d) \end{cases},$$

The new version of ERICA switch algorithm is presented as it follows follows:

The scheme operates at each output port (or link) of a switch. The switch periodically monitors the load on each link and determines the load factor *z,* the *BORF*), the ABR capacity and the number of the currently active VCs (*N*). He always knows the parameters *T*0 (predicted by VC establishment negotiation). A measurement or “averaging” time interval (*h*) is used for this purpose. These quantities are used to calculate the feedback indicated by the BRM cells. It is noticable here that these measurements are made in the forward direction, when the feedback is given in the reverse direction. Further, the switch gives at most one new feedback per source, per *h*. Depending on the specifications of the switch, the parameter *CCR_of_VC* can either be measured the as the rate of the currently arrived cells over the period *h*, or accepted as it is in the specific field of the FRM cell acknowledgement accordingly. In the sequence, it is assumed that the switch do not measures the arrived cells, for simplicity. The Key steps of the AUA-scheme are as follows:

From the CAC algorithm

```
SUM_MCR ← Σ(MCR(i))
SUM_PCR ← Σ(PCR(i))
(MCR(i) IS ALSO IN EVERY  MCR_in_RM_Cell
PCR(i) IS ALSO IN EVERY PCR_in_RM_Cell)
```

Initialization

```
ABR_Input_Rate ← Σ(CCR_of_VC)
```

End of Averaging Time Interval:

```
Total_ABR ← Link – (VBR + CBR )
z ← ABR_Input_Rate / Total_ABR
IF ((e) is true) THEN
    BOR ← ABR_Input  – Total_ABR
ELSE
    BOR ← 0
ENDIF
BORF ← BOR / Total_ABR
IF (case (a) is true) THEN
    F(q) ← z + T0 * h
ELSEIF (case (b) is true) THEN
    F(q) ← z + (T0 - Tpr) * h + BORF * h / τ
ELSEIF (case (c) is true) THEN
    F(q) ← z + (T0 - Tpr) * h + BORF * h / τ
ELSE
    F(q) ← z + (T0 - Tpr) * h
ENDIF
ER ← F(q) * Total_ABR
```

1. With Max-Min Fairness Criterion

```
FairShare ← INT(ER / N)
```

2. With Max-Min Fairness Criterion, with MCR

```
FairShare ← MCR(i)+ INT((ER – SUM_MCR) / N)
```

3. With equally weighted Fairness Criterion, with MCR

Θ(*i*)=(*PCR*(*i*) – *MCR*(*i*)) / (*SUM_PCR* – *SUM_MCR*)

FairShare ← *MCR*(*i*)+ INT(*Θ*(*i*)**ER*)

When a FRM cell is received

CCR(i) ← *CCR_in_RM_Cell*

When a BRM cell is received

VC_Share(i) ← *CCR(i)/ z * F(q)*

ERS(i) = max(*FairShare*, *VC_Share(i)*)

ER_f = min(*ER_f*, *ERS(i)*)

It is notable that the above *scheme* is self-controlled in case of overload periods. Therefore, (depending on the buffer occupancy and on the target queuing delay) this scheme is growing up or drawing down the record, to be included in the ER Field of the BRM cell, accordingly. Comparing this scheme with the already proposed scheme of Kalyanaraman's (ERICA +), it is used the load factor, the target queuing delay, and the queuing delay only. Further, all the parameters that were approximated by simulation only, now are useless. These are: a) the Queuing Drain Limit Factor (*QDLF*), b) the parameters "*a*" and "*b*" characterizing the queuing drain/growth hyperbolas that were approximating the functional parameter *f*) and c) the equalizing parameter *δ* (used to absorb extended periods of overload and sharp load changes).

Finally, the calculation of the variables Max_Alloc_Previous, and Max_Alloc_Current, is no more needed for the specified ER-based switch algorithm, byt only for the simulation purpose.

NUMERICAL RESULTS

Numerical results are given in Figs. 3 (a) and (b), where the MACR and the buffer occupancy versus the time are presented. From the above analysis one may point out that the linear branch of the system of ODEs (8) and (9) has a stable focus point (the relevant theory may be seen in [1]), provided the $ACR(t_n)$ remains constant for some time period and the bandwidth overflow rate in equation (10) is zero (steady state conditions). The same results (Fig.3) verify that the system has a stable focus point given by:

$(MACR, X) = (ACR(t_n), X_{st}) = (ACR(t_n), -B / A)$,

where the optimal value for the parameter A is given as $A = -(u * \tau / ACR(t_n))$, when the parameter $B = T0 * u * \tau$.

SIMULATION RESULTS

We simulated the AUA-scheme versus the basic ERICA and the ERICA + as well, using the same simulation environment. The tutorial results are presented in the **Table 1**.

4 Numerical results

The resulting system of ODEs described by the equations (8) and (9) may be rewritten as follows:

$$\frac{d}{dt}MACR(t_n)=\begin{cases} q_{st}, & \text{if } q(t_n)=0 \wedge MACR(t_n)<ACR(t_n) \\ q_{st}-\frac{d}{dt}\frac{q(t_n)}{\tau}, & \text{if } q(t_n)=0 \wedge MACR(t_n)\geq ACR(t_n) \\ [q_{st}-q(t_n)]-\frac{d}{dt}\frac{q(t_n)}{\tau}, & \text{if } \begin{cases} 0<q(t_n)<q\max, \text{or} \\ q(t_n)=q\max \wedge MACR(t_n)\leq ACR(t_n) \end{cases} \\ [q_{st}-q(t_n)], & \text{if } q(t_n)=q\max \wedge MACR(t_n)>ACR(t_n) \end{cases},$$

$$\frac{d}{dt}q(t_n)=\begin{cases} MACR(t_n)-ACR(t_n), & \text{if } \begin{cases} 0<q(t_n)<q\max \text{ or,} \\ q(t_n)=0 \wedge MACR(t_n)\geq ACR(t_n) \text{or,} \\ q(t_n)=q\max \wedge MACR(t_n)\leq ACR(t_n) \end{cases} \\ 0, & \text{otherwise} \end{cases}$$

The above system is solved numerically using the Euler method. The algorithm is as follows:

$$MACR(t_{n+1}) = \begin{cases} MACR(t_n) + q_{st}\tau, & \text{if } q(t_n) = 0 \wedge MACR(t_n) < ACR(t_n) \\ q_{st}\tau + ACR(t_n), & \text{if } q(t_n) = 0 \wedge MACR(t_n) \geq ACR(t_n) \\ [q_{st} - qpr]\tau + ACR(t_n), & \text{if } \begin{cases} 0 < q(t_n) < q\max, \text{or} \\ q(t_n) = q\max \wedge MACR(t_n) \leq ACR(t_n) \end{cases} \\ MACR(t_n) + [q_{st} - qpr]\tau, & \text{if } q(t_n) = q\max \wedge MACR(t_n) > ACR(t_n) \end{cases},$$

$$\text{where } qpr = \begin{cases} q(t_n) + (MACR(t_n) - ACR(t_n))\tau, & \text{if } \begin{cases} 0 < q(t_n) < q\max \text{ or,} \\ q(t_n) = 0 \wedge MACR(t_n) \geq ACR(t_n) \text{ or,} \\ q(t_n) = q\max \wedge MACR(t_n) \leq ACR(t_n) \end{cases} \\ q(t_n), & \text{otherwise} \end{cases}$$

As it appears, starting with an initial buffer $q(t_0)$ and $MACR(t_0)$ and taking into account the equation (4), the procedure derives the $ERF(t_0)$ using the Euler predictor method. This value is used to calculate the new buffer $q(t_1)$ (presented in the algorithm as qpr), which is then used to produce the new $ERF(t_1)$ and so on. Note that the switch sends u BRM cells every time period τ having the same ERF value. This is because the corresponding $ACR(t_n)$ is assumed constant during the time period $[n\tau, (n+1)\tau)$. Further, in the steady state the buffer occupancy is given by:

$$q(t_{n+1}) = \begin{cases} q(t_n) + (MACR(t_n) - ACR(t_n))\tau, & \text{if } \begin{cases} 0 < q(t_n) < q\max \text{ or,} \\ q(t_n) = 0 \wedge MACR(t_n) \geq ACR(t_n) \text{ or,} \\ q(t_n) = q\max \wedge MACR(t_n) \leq ACR(t_n) \end{cases} \\ q(t_n), & \text{otherwise} \end{cases}$$

Numerical results are given in Figs. 3 and 4, where the MACR and the buffer occupancy versus the time are presented. From the above analysis one may point out that the linear branch of the system of ODEs (8) and (9) has a stable focus point (the relevant theory may be seen in [1]), provided the $ACR(t_n)$ remains constant for some time period and the bandwidth overflow rate in equation (10) is zero (steady state conditions). The results also verify that the system has a stable focus point (see fig. 5) given by:

$(MACR, q) = (ACR(t_n), q_{st}) = (ACR(t_n), -B/A)$,

where the optimal value for the parameter A is given as $A = -(u\ \tau/ACR(t_n))$.

5 Conclusion

In this work two ER-based with congestion avoidance switch algorithmic schemes (namelly the CAPC and ERICA) presented, plus a new ER-based switch algorithm. It is derived and discussed, based on a hop-by-hop strategy for the flow regulation of the best effort (Available Bit Rate) traffic in an ATM network. The network configuration consists of M switches in tandem, with multiple VCs, allowing the VS/VD property. The analysis restricted to a single hop, in which the background traffic immediately leaves the switch and has a priority over the tagged stream cells. For the shake of hardware simplicity and low cost implementation, the proposed algorithm share a common buffer, with FCFS service discipline and it uses only the parameters that are available on the switch.

The proposed algorithm may dynamically adjust the adaptive VS window size by regulating its emission rate, through the ERF of the BRM cells. The model is analysed to a non-linear system of ODEs, assuming that the ACR, MACR, and the VD buffer occupancy are modeled as fluids. It is also shown that in steady-state conditions those systems are stable foci. A simple numerical method for solving such a system derived. This method is based on the Euler predictor numerical method. Using this method as an ER-based switch algorithm, the oscillating behavior of the Hop-by-Hop system is eliminated. Thus, it may be used as a powerful tool for achieving fairness and best possible performance. The numerical results agree with the theory. Extended simulation results will be presented in a future work.

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3 Problem Solution

It is assumed that a switch may serve two types of ABR traffic streams; a tagged traffic having the highest priority and a background traffic, which immediately leaves the switch. Every VS in the switch acknowledges the ERF of the BRM cell and adjusts its transmission rate every round trip time. Thus the switch may calculate the Mean Arrival Cell Rate (MACR) for the following time interval. The proposed ER-based switch algorithm utilizes almost 100% of the explicitly ordered bandwidth for the ABR service, when corresponded ERICA targets from 80% to 90% of the available bandwidth [8].

Figures and Tables should be numbered as follows: Fig.1, Fig.2, … etc Table 1, Table 2, ….etc.

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2.1.1 Sub-subsection

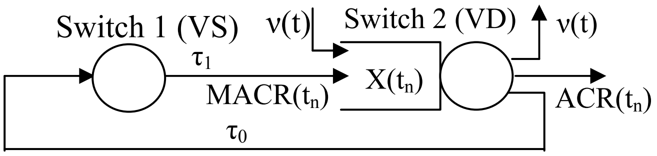

Fig. 2: The single Hop single VC model. Here, the background traffic has a priority rate $\nu(t_n)$. Fixed Round Trip time FRT = $\tau = \tau_0 + \tau_1$.

When including a sub-subsection you must use, for its heading, small letters, 11pt, left justified, bold, Times New Roman as here.

CONCLUSIONS

Please, follow our instructions faithfully, otherwise you have to resubmit your full paper. This will enable us to maintain uniformity in the CSCC'99 Proceedings. The better you look, the better we all look. Thank you for your cooperation and contribution. We are looking forward to seeing you at the IMACS/IEEE CSCC'99 International Multiconference in Athens, Greece.

References:

[1] X1. Author, Title of the Paper, *International Journal of Science and Technology*, Vol.X, No.X, 19XX, pp. XX-XX.
[2] X2. Author, *Title of the Book*, Publishing House, 19XX