Quadratic Shaping For Dynamic Bandwidth Allocation

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Abstract

This paper proposes a traffic control mechanism built upon a specific spacer controller wich allows more flexible and dynamic ressource allocation strategy. As usual the proposed spacer controller implements a policy function to monitor the negociated data rates. But our spacing functing is quadratic in opposition to usual spacing function which deals with fixed period : our quadratic spacer enables variable (quadraticaly) data rate when usual spacer only allows constant one. At the input, both spacers tolerate and absord small cell delay variation around their negociated data rates. At the output, the data stream respects the spacing policy, respectivly quadratic or constant.
The associated dynamic bandwidth allocation consists in approximating variable data rate with a suite of steady data rate plateau. Knowing of the acceleration factor enables the maximum data rate which can be reach during the following period to be estimated. The period is based on the maximum negociation delay which is due to allocation message transmission delay.
The two proposed mechanisms collaborate tightly. Actually the spacer enables the throughput to be efficiently predict and the bandwidth controller uses this prediction to closely follow the data rate and to renegociate if necessary the bandwidth allocation.

1. Introduction

Distributed applications, potentially supported by ATM networks, present distinct tolerances for delay, jitter and cell loss and distinct requirements for throughput. To be able to integrate this spectrum of needs, standard organizations have defined service profiles [1]. The Constant Bit Rate (CBR) service was intented to address applications, like (audio) circuit emulation, with constant throughput and low delays. The Variable Bit Rate (VBR) service was intented for applications whose bit rates vary significantly over time, but with strict delay and other quality of service requirements. The Available Bit Rate (ABR) service is the support of applications with vague requirements for throupgput and delays. The main motivation for the development of this service has been the economical support of data traffic. The last service, Unspecified Bit Rate (UBR), was intented for applications with minimal (no) service requirements.

Traffic contracts beetween the users and the network are emerging concerning traffic management. Contracts are negociated at the connection establishment phase (It's rendered possible since ATM is a connection oriented network). The constract allows traffic's parameters such as : throughput, delay and cell loss to be defined.

Vague requirements for throughputs and delays are requirements nonetheless and can be expressed as ranges of acceptable values. The ABR service allows a user to specifiy, at the connection setup, a lower and upper bound on the bandwidth alloted to the connection. In the same way, while explicit requests for bounds on delay are not planned

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as part of the setup procedure for individual ABR connections, network providers are expected to advertise delay bounds for the ABR connections as a whole. The ABR service includes the support for cell loss control. Hence, the set of control mechanisms considered for the ABR service has been restricted to those, based on feedback from the network to the traffic sources, that could tightly control cell loss.

Connection agregation can significantly increase the efficienty of data networks. The opportunistic behavior of ABR in utilizing unused (but sometimes allocated to other connections with distinct service classes) bandwidth actually increases the efficiency of ATM network. But the convergence of many cells from (too) opportunistic ABR connections can lead to network resource congestion.

One goal of current proposals for support of the ABR service, is to define a flexible framework of rate-based closed-loop schemes for congestion control. It includes, as particular instances, a broad range of possible implementations characterized by varying degrees of cost and complexity. Following alternative functions are proposed : supports end-to-end flow control and/or local network segment flow control; allows switches to provide full detailed feedback using Resource Management (RM) cells and/or enables them to limit their participacition to single bit Explicit Forward Congestion Indication (EFCI) mechanism.

In our proposal, data flows are no more characterized by constant parameters (as minimum, sustainable, and peak cell rate parameters) but can be described in more flexible way. Each parameter is described by its evolution law. We choose quadratic law for adequacy and simplicity. So each parameter is described by three constants : its initial value, it initial speed (slope), and its speed up (acceleration).

Known proposals have introduced some parameters (Additive Increase to Rate (AIR), Rate Decrease Factor (RDF), and Initial Cell Rate (ICR)) which enable some flexibility [7]. These parameters characterize the process for dynamicaly updating rates. The rate at which an ABR source is allowed to schedule cells for transmission is denoted by Allowed Cell Rate (ACR). The ACR is initially set to the ICR and is always bounded between the MCR and PCR. The ACR is increased (resp. decreased) using AIR (resp. RDF) parameters following the source end behavior and the chosen algorithm.

Our proposal is more generic and introduces more flexibilty. We will show that our proposal can gain some substantial advantages : first we allow to characterize more precisely the behavior of some data streams, second, this way of doing enables us to predict the future values which can be reached by the contract parameters, third, introduction of the quadratic controler enables unspecified or lightly bursty data flows to be taken into account, without too much shape distortion and delay in the original flow.

In the following section, we describe the quadratic conformance function with its algorithm and specific paramaters. Then, the renegociation function which monitors the data flow and takes the decision to renegociate the data rates, is introduced. We propose an extension of the Fast Reservation Protocol to support our proposition. Finally we emphasis on the architecture integration of the proposed functions due to their numerous interactions.

2. Quadratic Conformance Testing

The approach chosen, as the best match for the goals of the ABR service, is to control the bandwidth of connections directly. Since each ATM cell contains the same number of bits, control of a connection's bandwidth is achieved by controlling its cell rate.

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Policing functions in ATM networks have been identified by the ITU-T [3]. In particular, these functions are implemented in the so-called Usage (resp. Network) Parameter Control (UPC, resp. NPC).

The primary goal of cell conformance testing is to compute, on a per connection basis and at the cell scale, the number of cells which are non-conforming with respect to the traffic characteristics specified in the traffic contract. The secondary goal is to enforced the traffic parameters either in dropping or in tagging the cells belonging to the exceeding traffic.

Several UPC/NPC mechanisms have been implemented by equipment providers. Nevertheless the ITU-T has defined one monitoring algorithm equivalently viewed as the Virtual Scheduling Algorithm (VSA) or the Continuous-state Leaky Bucket [5], and also known as Generic Cell Rate Algorithms (GCRA) within the ATM Forum [1]. Continuous-state Leaky Bucket corresponds to the well known Leaky Bucket introduces by Turner [6] but, with credits based on fractional numbers.

The algorithm keeps track of when the cells should have arrived if the source were shapping traffic to the *allowed rate*. It then identifies cells as non-conforming if they arrive in advance of their expected arrival times by more than the *delay tolerance* selected for the connection. We primarily limit our discussion of policing algorithms to extensions of the GCRA, altough scheduling disciplines also can play a role in limiting how a non-conforming source can effect other traffic.

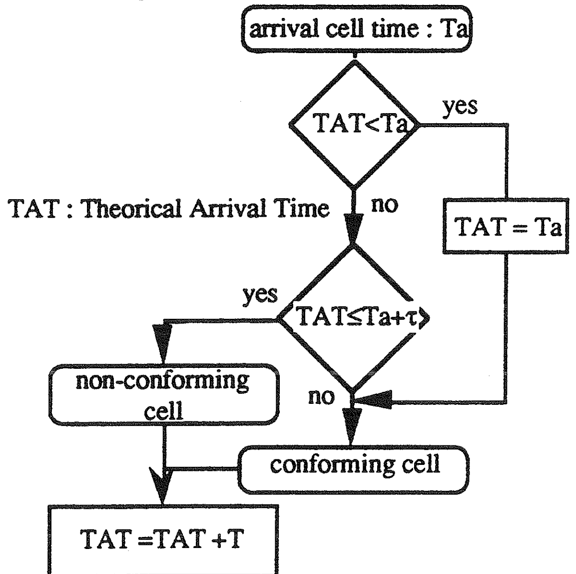

Figure -1 Usual conformance testing

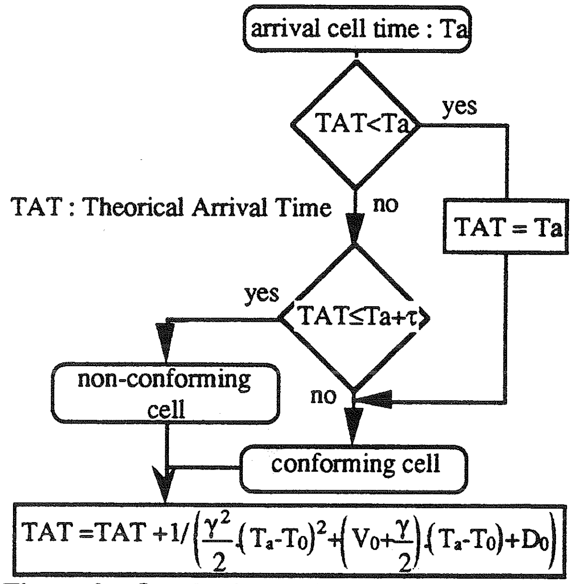

Figure 2 - Quadratic conformance testing

Usually the GCRA(T,τ) algorithm depends on two parameters, namely the allowed inter-cell delay T and delay variation τ (Figure 1), and it maintains a internal variable, called Theorical Arrival Time (TAT). The actual arrival process is then compared to the ideal arrival process by computing for each cell the difference beetween its actual arrival time Ta and the current TAT. If the actual arrival time is beyong the TAT, or if the actual arrival time precedes the TAT for less than the tolerate delay variation then the cell conforms to the CGRA(T,τ) algorithm, else it doesn't. The new TAT is computed in function of the cell arrival time. If the cell, according to the current TAT, arrives earlier then the next TAT is exactly T later the current TAT, else the next TAT is exactly T later the arrival cell time.

Our proposition can be seen has an improvement or generalization of the monitoring process (Generic Cell Rate Algorithm) proposed by the ATM Forum for the Usage Parameter Control. The quadratic algorithm depend on four parameters, namely the acceleration factor γ, the slope factor V_0 and the rate D_0 at the initial instant T_0, and the delay variation τ (Figure 2). We notice, first, the initial rate can be seen as the previous allowed rate (D_0=1/T), and second, with null acceleration factor and null initial slope, quadractic conformance testing algorithm works as usual one.

Obviously the quadratic controler can be used for traffic control : for testing cell conformance, or for tagging non conforming cells, or for shaping the data traffic.

3. Bandwidth negociation

We propose to manage data streams with variable bandwidth requirements. But the proposed control scheme only deals with parabolic data streams. Parabolic streams are streams with bounded cell rate acceleration. Obviously, cell rate acceleration are computed from the second differential of cell rates.

The cell rate can be predicted, if the cell transmission process follows the parabolic law (γ,V_0,D_0) from the instant T_0 : $D(t) = \gamma^2/2.(t-T_0)^2+(V_0+\gamma/2).(t-T_0)+D_0$.

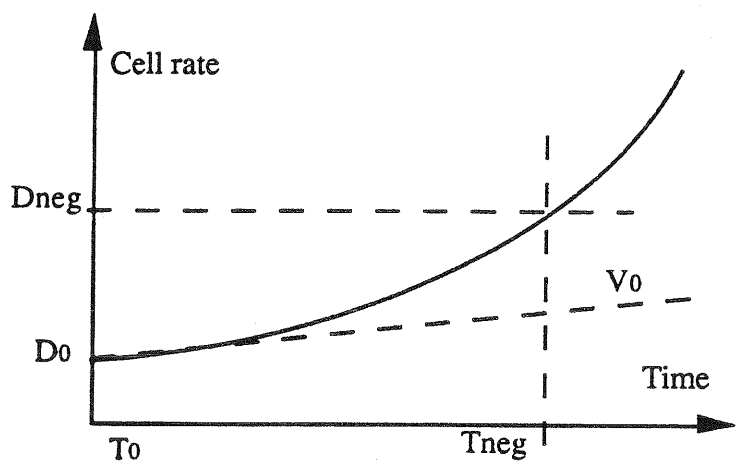

Figure 3 - Bandwidth negociation

The responsiness of the bandwidth renegociation process is based on the propagation delay. The predictability of the rate enables the bandwidth renegociation to be anticipated. Let T_0 be the actual time, Tneg is the time of bandwidth renegociation process. We can predict the maximum data rate (D(Tneg) = Dneg) which can be reach from the initial rate D_0 and the tendency V_0, knowing the acceleration factor assciated with the connexion.

The renegociation process takes an increase (resp. decrease) decision in function of the tendency (positive or negative). The level of increasing (resp. decreasing) can be determined from the prediction made and from the available bandwidth in the switches. ATM Resource Management cells (RM) are used by the bandwidth renegociation protocol. The format and the content of the RM cells used within the ATM services are not completely determined today, various authors have proposed numerous fields. An effort toward the global standardization of such a format is beyong the scope of this paper.

The renegociation process places the current rate and the rate at which the source wishes to transmit cells in the appropriate fields of the RM cell. RM cell travels forward the

network providing the switches in its path with the information in its content for their use in determinig the allocation bandwidth among the connections. Switches may decide to reduce the wished rate based on local information. The destination should return the RM cell to the source. It could reduce the rate to whatever rate it can support. When the RM cell arrives back to the source, the source should reset its rate, based on the information carried back by the RM cell.

To assure the traffic conformance in relation to negociation process requirements, a quadratic controller has to be placed before the negociation controller. General source traffic may not follow the quadratic required traffic. In that case, the quadratic controler have to shaped the variable traffic according to the accelaration factor negociated during the connection establishment phase.

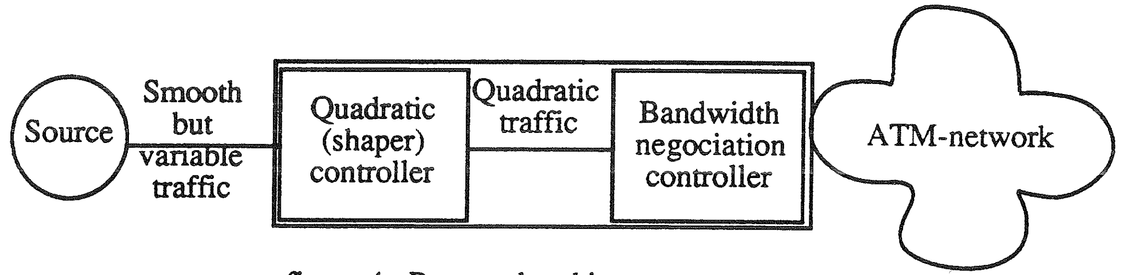

figure 4 - Proposed architecture

4. Conclusion

The proposed traffic control uses, generalizes and integrates already known mechanisms. In fact, the idea behind this work is to distinguish three data rate components in the initial data stream : first the constant (mean) data rate, second the quadratic acceleration data rate (the tendency), and third the residual data rate (the jitter). Previous approaches take into account only the first and the third components. The spacer controller is used to treat (remove) the third component from the initial data stream. But we use the informations extracted from the second component to estimate the future of the data stream. Obvioulsy, with an null acceleration factor, quadractic spacer controller work as usual spacer controler and the algorithm of bandwidth dynamic renegociation leads to static bandwidth management.

Prediction of how well a bandwidth control scheme will work requires a model for the behavior of network traffic. It might involve characteristics of applications or high-level protocols. For our purposes it is enough to distinguish between constant, smooth and bursty traffic. Constant traffic assumes the same data rate for the total duration of the connection. A smooth traffic offers predictable load, that changes in time scales that are large compared to the amount of time the bandwidth control mechanism takes to respond. Such traffic is easy to handle; the rates which are assigned to sources, corespond to fair shares of the available bandwidth with little risk that some of the sources will stop sending and lead to underutilized links. The aggragate effect of a large number of bursty sources may also be smooth, particulary in a wide-area network where each sources are relatively low-bandwidth and uncorrelated. Bursty traffic lacks any of the predictability of smooth traffic. Some kind of bursts stem from applications. The quadratic spacer controler can be enable to smooth the bursty traffic, using a small amount of buffer, and introducing minimal delay.

Our further work will characterize which sort of bursty traffics can be really smoothed by the quadratic spacer controler, and if so, to quantifies the amount of buffer and the delay introduce.

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