AN ONLINE RENEGOTIATION-BASED BANDWIDTH MANAGEMENT WITH CIRCUIT ASSIGNMENT FOR VBR TRAFFIC IN COMMUNICATION NETWORKS

Fatih Murat Porikli   Zafer Sahinoglu

Mitsubishi Electric Research Labs
Murray Hill, NJ 07974

Abstract

We propose a system that selects a circuit to service an application request to transmit data over a network. The network includes one or more low and high bandwidth circuits. The system provides admission control of routing an applications traffic, upon initialization of service request with network among dual channels each with different transmit capacity based on the applications statistical properties and link conditions. We also adapted a method that renegotiates network resources allocated to an application's variable bit rate traffic in dynamic time intervals and optimizes the number of resource renegotiations by minimizing cost functions utilizing graphical analysis. The results show that the introduced scheme minimizes both under-utilization of the available capacity and queuing delays.

1 Introduction

Important considerations in network operation are admission control and resource allocation. Typically, admission control and resource allocation are ongoing processes that are performed periodically during transmission of bit streams. The admission control and resource allocation determinations may take into account various factors such as network topology and current available network resources, such as buffer space in the switches and the bandwidth capacity of the circuits, any quality-of-service commitments (QoS), e.g., guaranteed bandwidth, and delay or packet loss probabilities.

If the network resource requirements are overestimated, then the network will run under capacity. Alternatively, if the network resources requirements are underestimated, then the network may become congested and packets traversing the network may be lost [1], [2]. Admission control and resource is generally done at the ”edges” of the network in order to conserve computational resources of the network switches. While off-line systems can determine the exact bandwidth characteristics of a stream in advance, in many applications, on-line processing is desired or even required to keep delay and computational requirements low. Furthermore, any information used to make bandwidth decisions should be directly available in the compressed bit stream.

ATM networks provide connection-oriented services with guaranteed bandwidth. To carry an IP datagram in such networks, a virtual circuit (VC) has to be setup with an indicated bandwidth requirement. Once a VC is open, the adaptation layer has to decide how long to keep the VC open with the initial bandwidth assignment. If the rate of the incoming packets matches the specified bandwidth allocation, VC is kept open [3], [4], [5]. However, if packets arrive at a higher or lower rate, there is a need to readjust the allocated resource or even to close the VC. Periodic algorithms adjust the bandwidth allocation in fixed time intervals. On the other hand, adaptive algorithms respond whenever a change is necessary as long as the updating process is not frequent. Readjusting can be done in two different ways either closing the existing VC and opening a new one with new allocation or changing the allocation of the current VC in lieu of closing it

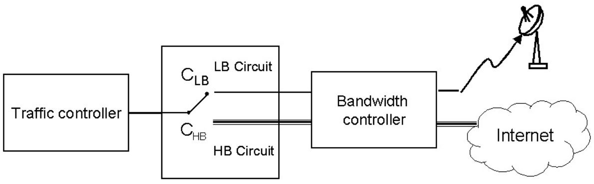

Figure 1: Circuit assignment and bandwidth renegotiation for dual-channel VBR.

[4]. The second option, if preferred, must be supportable by the network. Indeed, the Q.2963 series of recommendations belongs to the DSS 2 family of ITU-T Recommendations and specifies the procedure of the modification of traffic parameters of a call/connection in the active state. Recommendation Q.2963.3 defines the procedure of the ATM Traffic Descriptor modification with renegotiation that is equivalent to that specified in Recommendation Q.2962. Therefore, we can expect that network provides such a support and bandwidth allocation to a VC can be updated without closing it. To follow temporal variations in bandwidth demand of VBR sources, we propose a method for dynamic bandwidth allocation with minimal number of renegotiations. Each renegotiation process involves a signaling between network and a source. The renegotiation frequency is a trade-off between signaling overhead and high bandwidth utilization. High renegotiation frequency loads the network with heavy overhead. On the other hand, long inter-renegotiation intervals make the follow-up of the traffic bit rate pattern difficult. Renegotiation is only feasible in time scales of several seconds [6]. In [7], it is suggested that minimum of 1 sec and an average of 5 seconds or more for renegotiation is a good compromise. It is crucial that optimal number of bandwidth renegotiations must be performed under predetermined cost constraints such as under utilization ratio and packet/cell transmission delay.

As shown in Fig. 1, the proposed method consists of two main parts: the admission control unit (ACU) and the renegotiation decision unit, RDU. Section II describes the assignment of a new request to low and high bandwidth channels. Section III explains the cost functions and strategies in determination of the resource renegotiation time and amount. Section IV gives performance results when a real time MPEG-4 coded video trace is transmitted.

2 Admission Control

As a characteristic, the various circuits of the network have different bandwidth capacities. For example, the wireless circuit connects to the network via a low bandwidth capacity (C_l) base station of the wireless network, and the circuit to the network via a high bandwidth capacity (C_h) circuit of the Internet. In the method according to the invention, the switching is based on properties of the applications and circuit conditions.

Figure 2 shows one embodiment of the proposal where the traffic controller makes circuit assignments knowing properties of an application making the service request. The traffic controller includes an admission control unit (ACU). The analyzer measures an average utilization U_h of the high bandwidth circuit within the last M time slots. The ACU is provided with the circuit capacities C_l and C_h, and a guard bandwidth δ provided via the switch. The guard bandwidth is to prevent circuit saturation. In other words, the guard bandwidth is an excess bandwidth available at any instant in time when the data rate is bursty. The ACU is also provided with the bandwidth request λ from the application. The analyzer also provides the ACU with the mean data arrival rate μ_r and the standard deviation σ_r of the data arrival rate of traffic with the identical application type as that of the request, and with the mean data rate μ_h and the standard deviation σ_h of the aggregate traffic on the high bandwidth circuit. This information is stored in a look-up table (LUT) of the analyzer and is updated based on the bit arrival amounts in every predetermined time slot. These statistical parameters, $\mu_r, \sigma_r, \mu_h, \sigma_s$, are considered to be, but not necessarily, according to a Gaussian distribution for ease of analysis. In computation of the parameters, the bit arrival amounts in the last M consecutive time slots are used.

The ACU determines a probability of exceeding a predetermined utilization threshold for each circuit, and selects the circuit with the lowest probability to

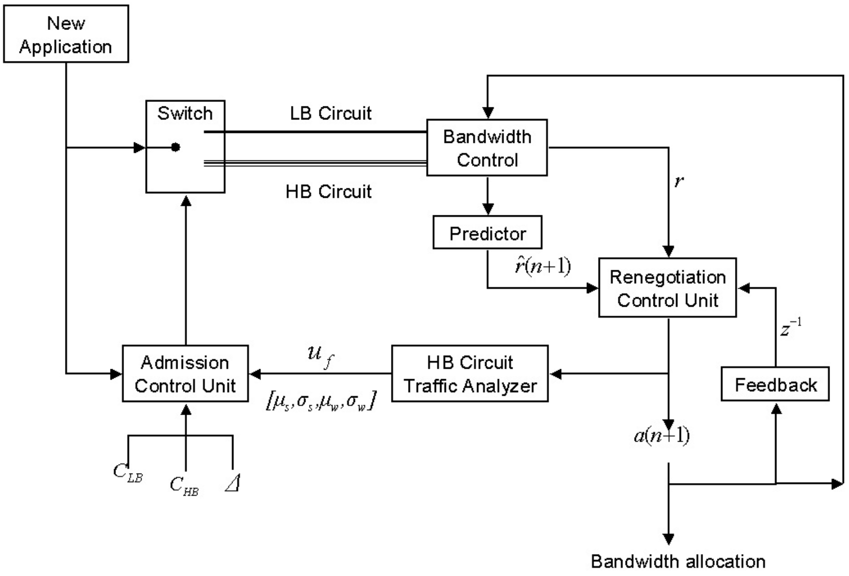

Figure 2: System design.

service the request provided that the selection criteria of the ACU are also satisfied for the circuit with smallest probability so not to cause an over-utilization on the selected circuit. Let P_h P_l be the probabilities of exceeding the capacity of the high-bandwidth and low-bandwidth circuits respectively. Then, the new request is assigned to the circuit that has smaller probability. For instance, if the probability of exceeding a predetermined utilization threshold on the low bandwidth circuit is smaller than that on the high bandwidth circuit

$$\begin{aligned} P_h &= P\left\{\frac{r(n)+h(n)}{C_h} > 1-\delta\right\} && (1)\\ &= erf\left(\frac{C_h(1-\delta)-\mu_r-\mu_h}{\sqrt{\sigma_r^2+\sigma_h^2}}\right), && (2)\\ P_l &= P\left\{\frac{r(n)}{C_l} > 1\right\} && (3)\\ &= erf\left(\frac{C_l-\mu_r}{\sigma_r}\right) && (4)\end{aligned}$$

then the low bandwidth circuit is selected to service the request. This method can also be applied to the communications networks with a single low bandwidth circuit, and multiple high bandwidth circuits between a client and a server in downstream direction.

3 Bandwidth Renegotiation

In order to avoid under allocation (buffering) and under utilization of the bandwidth, the allocated bandwidth should be dynamically adapted to follow-up of the traffic bit rate pattern. However, each adaptation (renegotiation) process involves a signaling between the network and the source. High renegotiation frequency loads the network with heavy overhead. On the other hand, long inter-renegotiation intervals make the follow-up of the traffic bit rate pattern difficult. Therefore, optimal number of bandwidth renegotiations must be provided under constraints such as the cost of under utilization, cost of renegotiation, and buffer size as shown in Fig. 3.

We determine an optimum bandwidth allocation $a(n+1)$ for real-time traffic at a future time $n+1$ given a current traffic bit arrival rate $r(n)$, and current allocated bandwidth $a(n)$ at time n. To attain the optimum solution, we design a total cost function J that includes costs of under utilization in terms of $u(n)$,

Table 1: Notation of parameters and functions

n	time
β	buffer size
$a(n)$	bandwidth allocation at time n
$r(n)$	bit arrival rate at time n
$\hat{r}(n)$	predicted arrival rate at time $n+1$
$w(e)$	bandwidth cost function
$b(n)$	size of the queue (buffered bits)
$u(n)$	size of the under-utilized bandwidth
$e(n)$	bandwidth error function (bits)
$T(n)$	cost of the renegotiations
$J(n)$	total cost function
C_l	capacity of low bandwidth circuit
C_h	capacity of low bandwidth circuit
$U(n)$	Utilization of circuit at a time instant
μ_h	Mean data rate of traffic on HB circuit
σ_h	Standard deviation of traffic on HB
μ_r	Mean of data arrival rate of traffic
σ_r	Standard deviation of traffic
δ	Guard bandwidth

under allocation in terms of $b(n)$, and renegotiation as $T(n)$. The cost function J is defined as

$$\begin{aligned} J &= w_b b(n) + w_u u(n) + T(n) & (5) \\ &= w(b(n) + u(n)) + T(n) & (6) \\ &= w(e(n)) + T(n) & (7) \end{aligned}$$

where the $e(n)$ is the bandwidth error such that

$$\begin{aligned} e(n) &= \sum_{i=0}^{n} r(i) - a(i) \\ &\quad + \hat{r}(n+1) - a(n) & (8) \end{aligned}$$

In the cost function, the size of the queue $b(n)$ and the size of the under used bandwidth $u(n)$ are weighted by shaping functions w_b and w_u, and then added to the cost of renegotiation $T(n)$. Using separate cost terms for under utilization and under allocation enables us to adapt the optimization method for various types of applications; weighted fair queuing (WFQ) algorithms, ATM switches, etc. In addition, one cost term can be preferred to the other with respect to the changing network conditions, i.e., buffer cost can have nonlinear dependence on the current queue size, cost of bandwidth can be alternating at the certain times of the day. The under allocation happens if the allocated bandwidth is not enough to handle the bit arrival rate. Incase of under allocation, the excess bits are queued in the buffer. The buffered bits are sent when the arrival bit rate is less than the allocated bandwidth, thus, there is available bandwidth to forward bits from buffer. The under utilization $u(n)$ occurs when the allocated bandwidth is greater than the bit arrival rate and the buffer is empty. Therefore, the allocated bandwidth is not fully used. The bandwidth error function $e(n)$ is the $u(n)$ for under utilization, and $b(n)$ for under allocation, and it also includes the predicted bandwidth error for time $n+1$ to include the effect of keeping the same bandwidth allocation level. Obviously, the bandwidth cost function $w(e(n))$ corresponds to the under allocation cost if $e(n)$ is more than zero, and under utilization cost vice versa.

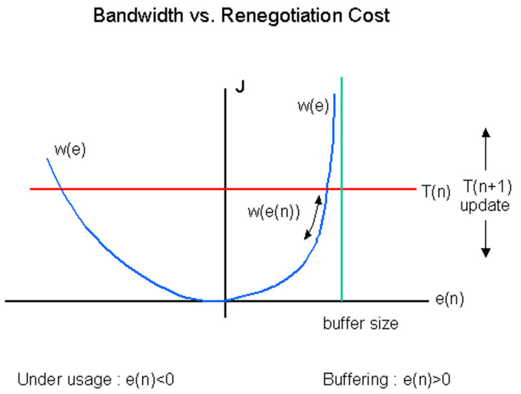

Figure 3: Analytic representation of cost functions.

While optimizing J, the renegotiation step size and time are obtained. The determination for $a(n+1)$ is made by minimizing the cost function

$$\begin{aligned} a(n+1) &= \arg\min J \\ &= \arg\min[w(e(n)) + T(n)] & (9) \end{aligned}$$

To understand the properties of minimization, let us investigate the impact of each cost term on J. It is worthwhile to realize that the renegotiation cost $T(n)$ should be high if there was another bandwidth renegotiation made recently at time $n - \delta$ where δ is a small time period. By the increasing values of δ, which also means that the last renegotiation was made long past; the cost of renegotiation should be decreasing because renegotiation becomes more affordable. Therefore, the time period δ between the current time and the very last renegotiation determines the magnitude of the variable cost function $T(n)$:

$$T(n) = \begin{cases} \alpha^+ T(n-1) & a(n) \neq a(n-1) \\ \alpha^- T(n-1) & a(n) = a(n-1) \end{cases} \tag{10}$$

If the bandwidth cost function $w(e(n))$ becomes larger than renegotiation cost for the predicted traffic, it becomes advantageous to renegotiate to prevent from the expansion of $w(e(n))$. Fig. 4 presents this analogy. Incase a constant renegotiation cost is preferred over to variable cost term, the number of renegotiations may multiply if the newly allocated bandwidth is incapable of reducing the under allocation or under utilization costs quickly. The J fluctuates close to the decision boundary; each time bandwidth cost function becomes higher than renegotiation cost, a new renegotiation is made.

Considering the under utilization and under allocation, we form w(e(n)) as

$$w(e(n)) = \begin{cases} e^K & e(n) > 0 \\ |e^L| & e(n) \leq 0 \end{cases} \tag{11}$$

We choose $K > L > 1$ to weight under allocation cost more. For the hard buffer size constraint case (i.e. no buffer overload permitted), $w(e(n))$ becomes infinity at β by asymptotically converging to the $e(n) = \beta$. In the above equations, the cost of bandwidth $w(e(n))$ is assigned as a combination of polynomial functions, still it can be defined by piece-wise continuous or exponential functions.

There are several different strategies in dynamic bandwidth allocation to predict the future bandwidth demand of a traffic source. Each new allocation consists of a prediction and a correction term based on previous updates [8]. The simplest bandwidth predictor is the previous value of the bit rate as an estimate.

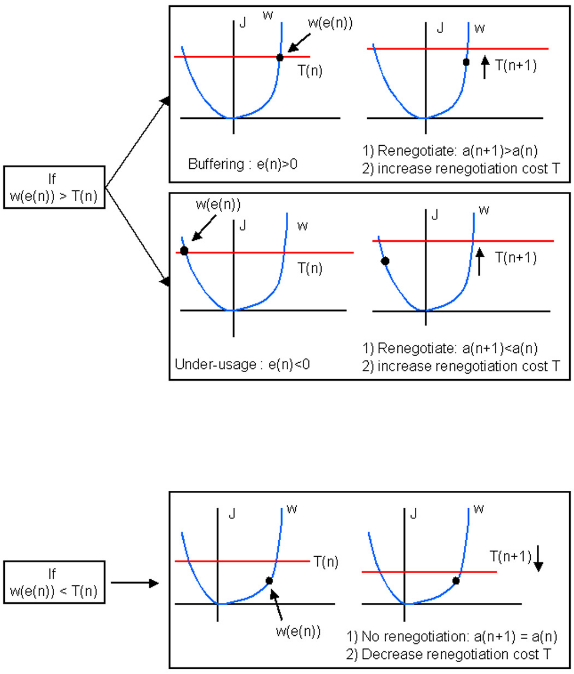

Figure 4: Relation between $w(e(n))$ and $T(n)$.

4 Conclusion

Sample simulation results for a typical MPEG-2 video sequence is presented in Fig.5. The computation time of the bandwidth renegotiation method is negligible; the process is real-time. A hard buffer model that does not permit overshoot of the queue size is utilized. We simulated bandwidth allocation for different severity degrees of the renegotiation cost and buffer size. Fig.5-a presents the very high renegotiation cost $\alpha^+ = 4.0$ and $\alpha^- = 0.99$ scenario result. The number of renegotiations is 6 for 250 seconds of data sequence, and the bandwidth utilization ratio is 71.10%. This is the ratio of the total arrived data bits to the total allocated bandwidth; the ratio of areas under each functions in the figures. The following rows, Fig.5-b,c,d, are the results for high ($\alpha^+ = 2.0$, $\alpha^- = 0.95$), medium ($\alpha^+ = 1.3$, $\alpha^- = 0.95$), and low ($\alpha^+ = 1.3$, $\alpha^- = 0.85$) renegotiation cost scenarios. The number of renegotiations increases to 15, 33, 64, respectively because the renegotiation cost is assumed to be lower. The utilization ratios are found as 83.14%, 82.56%, 86.05%.

We observed that by selecting smaller renegotiation costs, we increase the number of renegotiations that leads the higher utilization ratios. Furthermore, using larger buffer size allow the network to renegotiate less.

We are able to allocate optimal bandwidth to the variable bit rate video traffic over the ATM switches dynamically in real-time. In addition, the method attains high utilization ratios while achieving the minimum total cost. Another significant advantage of the method is the ability of adapting to the network conditions as the constraints may change, i.e., buffer cost can have nonlinear dependence on the current queue size, cost of bandwidth can be alternating at the certain times of the day, etc.

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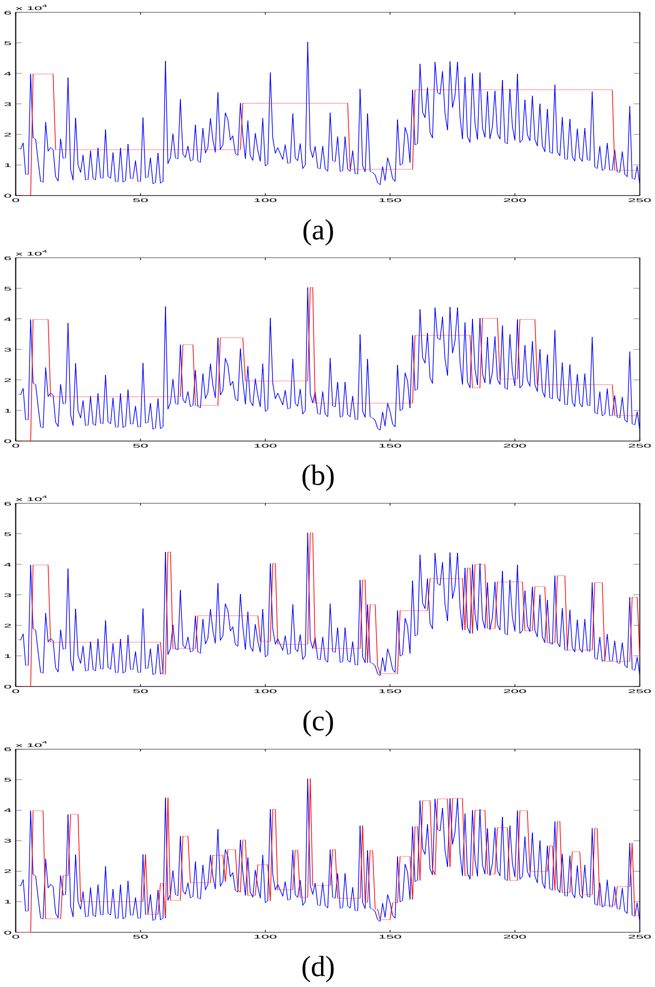

Figure 5: (a-b-c-d) Optimum bandwidth allocations for different levels of renegotiation cost scenarios; very high (α^{+}=4.0, α^{-} =0.99), high (α^{+}=2.0, α^{-} =0.95), medium (α^{+}=1.3, α^{-} =0.95), and low (α^{+}=1.3, α^{-} =0.85). The number of renegotiations are 6, 15, 33, 64 respectively.