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An Adaptive Leaky-Bucket Mechanism for Traffic Management in OBS Networks

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Abstract

In Optical Burst Switched networks, each light path carry huge amount of traffic, path failures may damage the user application. Hence fault-tolerance becomes an important issue on these networks. Blocking probability is a key index of quality of service in Optical Burst Switched (OBS) network. The Erlang formula has been used extensively in the traffic engineering of optical communication to calculate the blocking probability. A combined preventive/reactive control scheme improves the condition of packet loss due to congestion in networks. The transmission delay and the throttling rate are the major parameters which affect the performance of the reactive control. High throttling rates are most efficient for fast congestion recovery, although sometimes resulting in underutilization of the link. A combined reactive/preventive congestion control mechanism is investigated in this paper with emphasis on the Leaky Bucket (LB) mechanism chosen for source traffic policing in computer networks. The fluid-flow model is used to analyze the performance of both buffered and un-buffered LBs. It is proposed that one LB is not sufficient to manage all the source traffic parameters. If tight control, fast reaction time and a small queuing delay are required then according to the analysis done, the proposed triple LB mechanism is an effective solution. According to the delayed congestion feedback information received from the network the LB parameters are dynamically changed. The preventive control policy is compared with the adaptive control scheme. The results show that even for large propagation delays, major performance improvements are possible by using an appropriate feedback policy.

Keywords: Leaky Bucket, Routers, Network congestion, Optical Burst Switch, Usage Parameter Control.

Introduction

Due to the great popularization of the Internet, the traffic has increased exponentially. For the explosive growth of multimedia traffic, a serious problem that is the shortage of network capacity has occurred. For resolving this problem, the backbone networks need high speed and high performance with the throughput of over hundreds of Gbps .Optical Burst Switching (OBS) is a technique to support bursty traffic over wavelength-Division- Multiplexed (WDM) networks [1].WDM offers the capability to handle the increasing demand of network traffic. Today up to several T bits/sec traffic can be carried by the optical link over long distance. With the introduction of WDM in optical communication, the discrepancy between optical transmission capacity and electronic switching capability increases. An OBS network is a collection of interconnected OBS nodes [2]. An ingress OBS node assembles packets from local access network, for example, Internet Protocol (IP) packets, into burst and sends out a corresponding control packets (CP) for each data burst. The optical networks have the capacity to carry terra bytes of data per second through each node. The edge routers feed data into these networks. In the OBS networks, intermediate nodes have no optical memories. It is difficult for intermediate nodes to cope with temporally fluctuations of the network load. It is hard to prevent the burst contentions by using only deflection routing, when the network roads are high in the OBS networks [3].

When congestion occurs at a router, some cells may be dropped at the output buffer while other cells of the packets that contain the dropped cells will still be transmitted. These transmitted cells waste network resources because their packets cannot be assembled at the destination and this may cause a decrease in packet throughput. In order to prevent this phenomenon from occurring, the early packet discard (EPD) drops all the cells of a newly arriving packet when the queue length of the output buffer is greater than a given threshold. The Connection Traffic Descriptors (CTD) plays an important role in the preventive control scheme. The Connection Admission Control (CAC) has to consider the CTD in order to allocate the necessary network resources for the connection. It has been shown that the effective bandwidth of a source assigned by the CAC depends on the customers expected mean rate.

Emphasis is therefore given to control the mean bit rate of the source [4].

In this paper, we deal with a packet-based leaky-bucket algorithm, which functions like the early packet discard (EPD), and study its characteristics from the viewpoint of performance assuming it to be used as the mechanism of usage parameter control (UPC) in routed networks. The Leaky Bucket (LB) type policing mechanism is generally agreed to achieve the best performance for UPC. The aim of this paper is to determine the parameters of the LB and to optimize the mechanism, which is monitoring and controlling the traffic in terms of conformity with the agreed traffic contract at the user access.

Preventive control is an open loop control policy since no feedback information is sent from the network to the sources and the policing device. Thus in the case of congestion in the network no action can be taken. Reactive control, which is used to recover from a congested state, is not effective in routed networks when used alone. This is due to the large propagation time. The fact that the ratio of the propagation time to transmission time increases drastically in high bandwidth networks, leads to the result that the state of network congestion can change too quickly for the feedback information to arrive at the source. Since neither preventive nor reactive control alone seems to control congestion in routed networks successfully this paper investigates a congestion control mechanism based on both.

Packet-based Leaky-Bucket Algorithm

A generalized packet-based leaky-bucket algorithm is represented as the queuing model with the cell and token buffers shown in Figure-1, where tokens are generated according to a given process and a cell that can get a token departs from the cell buffer. Notations are defined as follows:

- $AC(t, s)$: The number of cells arriving during $(t, t + s]$.
- $LC(t)$: The number of cells in the cell buffer at time t.
- CC: The capacity of the cell buffer.
- $Cthr$: A given threshold for packet acceptance.
- $LT(t)$: The number of tokens in the token buffer at time t.
- CT : The capacity of the token buffer.

We assume that the first cell (or last cell) of each packet can be identified only by using cell level information. For example, this can be achieved by using the values of the payload types (PTs) of cells when ATM adaptation layer (AAL) type 5 is used [5]. A packet-based cell acceptance algorithm is defined as follows, like the EPD:

- Assume that the first cell of a packet arrives at t. If $LC(t) < Cthr$ ($Cthr > 0$) or $LT(t) > 0$ ($Cthr = 0$), then the first cell enters the cell buffer and the other cells of the packet also enter the cell buffer as long as it is not full at their arrival times.
- If $LC(t) \geq Cthr$, then all the cells of the packet including the first cell are discarded (do not enter the cell buffer) even if the cell buffer is not full.

Hereafter we call a cell entering the cell buffer “an accepted cell” and a packet whose first cell is accepted “an accepted packet.”

Letting $U(t)$ be defined by $U(t) = LT(t) - LC(t) + Cthr$, we can replace the condition “$LC(t) < Cthr$ ($Cthr > 0$) or $LT(t) > 0$ ($Cthr = 0$)” of the packet-based cell acceptance algorithm with “$U(t) > 0$.”

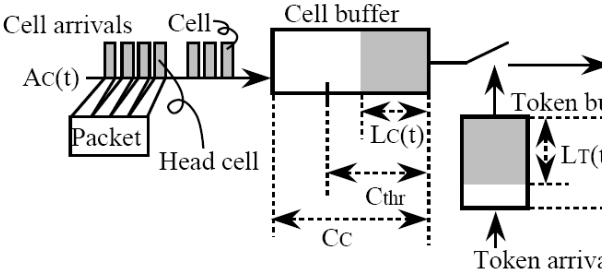

Figure 1: A packet-based leaky-bucket model.

The Leaky Bucket (LB) is generally agreed to achieve the best performance compromise of the mechanisms studied for policing. It was first introduced in [6]. Since then a number of variants have been proposed.

Considering that the GCRA is equivalent to a continuous-state LB one can understand the importance of this mechanism. The basic idea behind the LB mechanism is that each incoming cell needs a token to enter the network. Tokens are generated at constant rate r. The size of the bucket imposes an upper bound on the burst length and determines the number of cells that can be transmitted back to back, controlling the burst length. Provided that the burst is short, the bucket will not empty and no action will be taken against the cell stream. However, if a long burst of higher-rate cells arrives, the bucket will be emptied and the UPC function will take actions against cells in that burst. The tolerance allowed for the connection depends on the size of the token buffer (M) and the token generation rate (r). Conceptually, the tokens can be viewed as arrivals to a finite-capacity, single-server queue with deterministic service time. It is also obvious that the LB enforces the rate r and allows temporary bursts above the rate r depending on the bucket size (M). The implementation requires a simple up/down counter to reflect the contents of the token bucket.

Optical Burst Switching

The basic principle of OBS is to separate channels into a control channel which transmits control packets and data channels. Control packets are converted into electricity and set switches by using O/E conversion at intermediate nodes. Oppositely, data bursts can pass through whole network in optical domain without O/E conversion. In OBS networks, transmission links have a number of WDM channels, and the cannels are assigned dynamically to data bursts. A control packet is transmitted for carrying control information of following a data burst. At an edge node of the network, a data burst is transmitted after waiting for the interval time called offset time. Control packets are transmitted with the unique channel called control channel. Data bursts are transmitted with one of the other data channels. Generally, the length of data bursts is variable and longer than the packet length of optical packet switching. Hence the overhead of the control packet becomes relatively small. The efficiency of bandwidths is high because wavelengths are set free after data bursts in OBS networks are transmitted. B. Problems of OBS One of the major problems in OBS is the burst contention. Burst contentions occur when more than two bursts which want to reserve the same wavelength of the same output link simultaneously in an intermediate node. We may prevent the burst contentions by using optical buffers. But we cannot use optical buffers because they have not achieved the level of the practical use yet. Thus the deflection routing has been designed. Fig. 1 shows the basic operation of the deflection routing. Two data bursts which have the same destination node B arrive at node A at almost same time. The two data bursts try to reserve the same wavelength to node B. Here, we assume that data burst 1 arrives at node A earlier than the data burst 2 and reserves Link A-B. Then the data burst 2 cannot reserve Link A-B. The data burst 2 has to choose the deflection routing. The data burst 2 reserves Link A-C-B. In this method, unused links are regarded as virtual link buffers. Contention bursts are detoured onto those links. The overall network efficiency and network performance are improved because the network load is spread to the network which is not used relatively. When the network load is low, most links are unused and several links are reserved. It is possible to reduce the burst loss probability efficiently. However, as the network load becomes high, burst contentions increase. So the number of bursts which are applied to the deflection routing increases. Therefore the burst loss probability increases and the efficiency of OBS networks decreases.

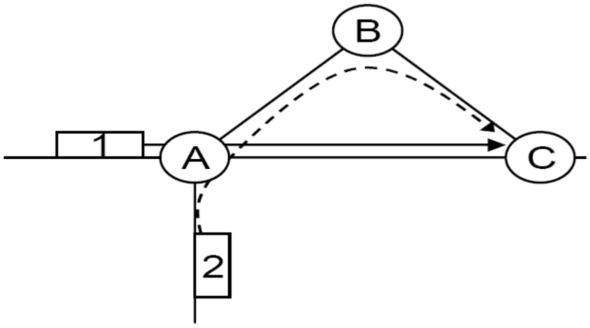

Figure-1 Basic operation of the deflection routing

Although there are a lot of improvements of the deflection routing, most of them cannot resolve the burst contention effectively when the network load is high. In OBS networks, data bursts are not stored at intermediate nodes because there are no optical buffers. So it is difficult to control the burst contention effectively by the deflection routing only. We need to implement an admission control into OBS networks in order to resolve the problem of the burst contention effectively.

Fluid-Flow Analysis Of The Leaky Bucket

Traditionally, AQM algorithms assume that routers have only output queues. However, practical switches have input queues as well, in order to lower the required speedup. We aim to investigate why and how an AQM algorithm will be affected by the presence of input queues in routers in addition to output queues. The question is how AQMs need to be modified to incorporate the fact that switches have both input and output buffers.

The fluid-flow model of the LB mechanism shown in Figure-4 was used for the analysis. The source model differs from the on-off model only in the assumption of uniform generation and transmission of information. Here information is considered to have a continuous nature, as if it were a fluid. l*i* is the rate at which fluid is generated by the source when it is in state *i*. Thus l*1=0* and l*2=p*. The steady-state probabilities of the source are p*1=b/(a+b)* and p*2=a/(a+b)*.

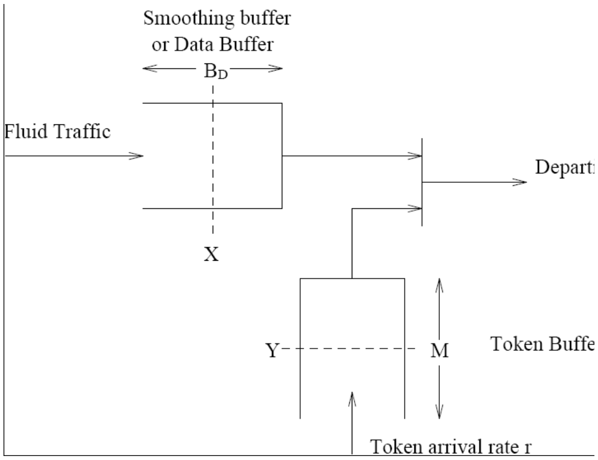

Figure-2 Fluid-Flow Model of the LB mechanism

Following the approach of [10] we define W=X-Y+M as the Virtual buffer content so that 0 ≤ W ≤ B where X is the data buffer content, Y is the token buffer content and B=M+BD.

Let

$$Fi(x)=Pr[W \le x, S=i] \quad (1)$$

with S=i the state of the input source. Following the procedure of [15], it is straightforward to obtain the system's stationary state distribution:

where

$$F_1(x)=\pi_1\frac{\Delta(x)}{\Delta(B)} \qquad F_2(x)=\pi_2\frac{1-e^{(zx)}}{\Delta(B)} \quad (2)$$

Where,

$$\Delta(x)=1-\frac{a}{b}\frac{(p-r)}{r}e^{(zx)} \quad (3)$$

z = -(a+b)(1-ϱ)/(p-r) where ϱ=p·a/[(a+b)r] = ı

is the LB load. Since F(x)=F1(x)+F2(x) we obtain

$$F(x)=Pr[W\preceq x]=\frac{1-\rho e^{zx}}{\Delta(B)} \qquad (0\preceq x\preceq B) \quad (4)$$

The throughput [10] is given by

$$\gamma=r\left[1-\frac{1-\rho}{\Delta(B)}\right] \quad (5)$$

The CLP can be found using the identity

$$\gamma=\sum_{i=1}^{2}\lambda_i\pi_i(1-CLP)=\frac{a}{(a+b)}p(1-CLP) \quad (6)$$

Hence we obtain

$$CLP=1-\frac{\gamma/r}{\rho}\approx\left(\frac{1}{\rho}-1\right)\frac{a}{b}\left(\frac{p}{r}-1\right)e^{(zB)} \quad <<1 \quad (7)$$

Since z<0 in this range, the loss probability decreases exponentially with B=M+BD. Thus the cell loss performance of the leaky bucket algorithm depends only on the sum of the buffer sizes (Note, that the token buffer is only a model representation. The data buffer, on the other hand, is a real buffer). For the un-buffered leaky bucket, the cell loss probability can be obtained by setting the data buffer BD=0.

The CLP formula of [11] and [12] (also derived using fluid analysis) gives the same results for dimensioning the LB. Since we are not only interested in the CLP but also in the delay introduced by the data buffer and the reaction time we continue the analysis. Having found the distribution of W, we can now find the distribution of the token buffer content Y and the data buffer content X. Specifically,

Pr (data buffer full)=1-F(B)

Pr (token buffer full)=F(0)

Pr (X ≤ x,S=i)=Fi(x+M) (0 ≤ x ≤ M)

Pr (Y ≤ y,S=i)=π_i-Fi(M-y) (0 ≤ y ≤ M)

The mean length of the token buffer (in cells) can be found as:

$$\overline{Q_M}=\int_0^{M^-}yd[1-F(M-y)]+MF(0)=\frac{\rho\ (1-e^{zM})}{z\ \Delta\ (B)}+\frac{M}{\Delta\ (} \quad (8)$$

The mean reaction time of the leaky bucket is given by:

$$T_R=\frac{\overline{Q_M}\ n_C}{(Y-E)m} \quad (9)$$

where Y is the increase factor in the mean rate of the source, n_C=424 the number of bits per cell and E*m is the token generation rate.

The mean length of the data buffer is:

$$\overline{Q_{B_D}}=\int_0^{B_D^-}xd[F(x+M)]+B_DF(B_D)=\frac{\rho\ (e^{zB_DM)}-e^{zM})}{z\ \Delta\ (B)}+B_D(1-- \quad (10)$$

Thus the mean delay which is introduced when using a data buffer is given by:

$$\overline{D_{B_D}}=\frac{\overline{Q_{B_D}}\ n_C}{(1-P_L)\,r} \quad (11)$$

The accuracy of the fluid-flow model was already investigated for some sources in [11].

The Adaptive Leaky Bucket

While Connection Admission Control (CAC) and Usage Parameter Control (UPC) are functions to prevent congestion, there may still be a small probability of congestion caused by temporary overload of buffers within the network. Congestion control tries to minimize the effects and duration of congestion by reacting after congestion has occurred. LB deflection method is the basic protocol. Figure-3 shows an OBS network with the leaky bucket algorithm. At an edge node of the network, a data burst attempts to get a token. It is transmitted if it is successful to get a token. Tokens are generated with a constant rate and are accumulated at the token buffer of the edge node. If the edge node recognizes the arrival rate of data is over a definite rate, the data bursts are stored in the data burst buffer while they are waiting for getting tokens. The delay time for transmitting data bursts to OBS network is called admission delay.

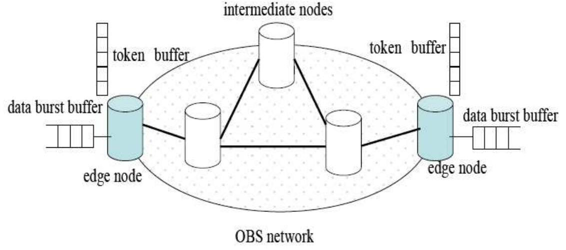

Figure-3 OBS network with Leaky Bucket method

The effectiveness of this scheme depends on the robustness against instantaneous and rapid fluctuations of the buffer contents, the frequency of feedback transmission from the congested node back to the source and the propagation delay. The first constraint can be met by employing a large buffer (in the order of a few hundred cells) such that a congested state is detected when the queue contents reaches a certain upper threshold. The second constraint is satisfied by choosing appropriate values for the upper and lower threshold.

Figure-4 shows a separate LB deflection method at an edge node. In the separate LB deflection method, a generated data burst is classified into two, reliable class and real-time class. The data of reliable class can permit the delay but cannot permit the burst loss. On the other hand, the data of real-time class can permit the burst loss but cannot permit the delay. TCP data communications have the characteristics of reliable class. Packets consisted of voice or video have the characteristics of real-time class. The separate LB deflection method applies leaky bucket to the data bursts of reliable class at edge nodes, but not to real-time class.

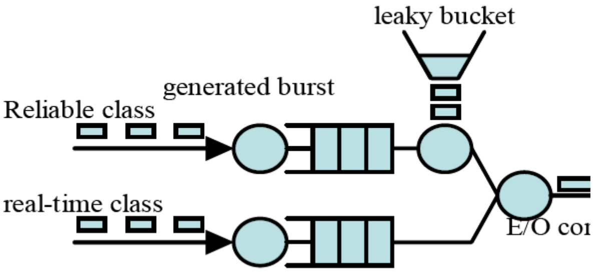

Figure-4 Separate LB deflection method at edge node

The value of the lower threshold (TL) should be relatively smaller then the value of the upper threshold (TH) to avoid oscillations of the transitions between congested and normal state. Previous work has shown that TL should not be more than 80% of TH [14]. A general broadband source is used as the traffic source for the simulations and calculations. Equation (1), was used to evaluate the BW required for each source for a certain CLP. The equation was derived using the fluid flow approach and gives accurate results for the superposition of *N* identical ATM sources on an ATM link [16]. The BW allocated to each source is called Effective BW (EBW) and is equal to (link BW/*N*). In order to observe the performance improvement of feedback using simulation, an EBW of 5 Mbit/s for N=10 sources and a multiplexing buffer of 100 cells was chosen. This gives us a total link BW of 50 Mbit/s for a CLP of 10-3. The reason for choosing a rather high CLP is to make comparison with simulation results possible. TH was set to 70 and TL was set to 5 in order to minimize feedback information due to oscillation between normal and congested state. Figure-5 shows the CLP of the multiplexing buffer as a function of the propagation delay for various source throttling rates.

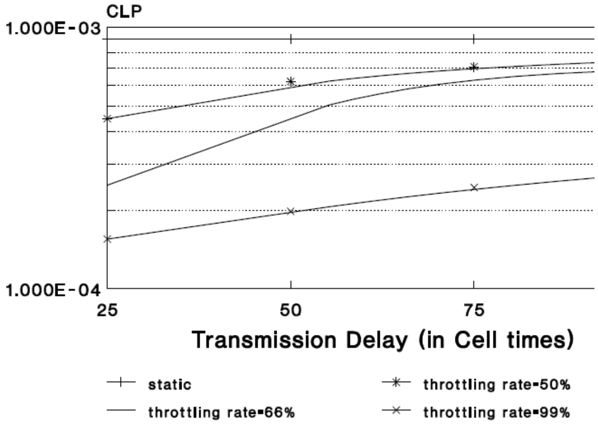

Figure-5 CLP of Preventive/Reactive and Preventive Congestion Control Scheme

The simulation results show that the feedback policy results in a lower CLP than the static policy. It can be seen that for increases in the throttling rate the CLP of the multiplexing buffer decreases. As expected the CLP increases with the transmission delay reaching the value of the static policy as the transmission delay exceeds 100 cell times. It was also observed that high source throttling rates (>50%) resulted in a fast recovery from a congested state. However for larger propagation delays (>50 cells) the source was still receiving delayed congestion information, leading to underutilization of the link (as a result of low multiplexing buffer occupancy). This may not be a major consideration for LANs but not the same can be said for its wide-area counterpart where a high link utilization is essential from the point of view of the network manager.

Conclusion

The peak cell rate of the source is easily controlled using one LB. The leaky rate is simply set near to the peak rate and the Buffer for the required CLP is found from equation (7). Note that this buffer is very small and therefore has a negligible effect on the performance of the mechanism. However one LB is not effective for policing both the peak rate and the mean rate of the traffic source at the same time. To solve this problem two LBs in series can be used (Dual LB mechanism). The first LB should control the peak rate (inter-arrival time between cells). After ensuring the control of the peak rate, the mean rate of the source can be controlled by another LB in series. The parameters of both LB‘s can be determined from equation (7). As stated there is a trade-off between fast reaction time and high sensitivity in detection of violating cells. If both are required then a mechanism consisting of a LB to control the peak connected in series with two LB’s in parallel to control the mean bit rate can be used (Triple LB mechanism). As mentioned the drawback of the triple LB configuration shown in Figure-6 is that tight control and fast reaction are provided, but not both together. One LB provides fast reaction to larger increases in the mean whereas the other has slower reaction providing tight control.

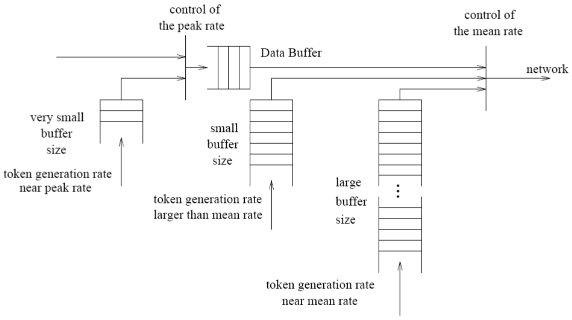

Figure-6 Triple Leaky Bucket Mechanism

It has been shown that faster reaction can be achieved by using a data buffer which introduces a delay to the source traffic. Using equation (11) one can easily find the max. size of the data buffer according to the delay requirements. The size of the LB’s controlling the mean rate is simply B-BD providing much faster reaction the configuration without the data buffer. It has also been shown that a combined preventive/reactive control scheme improves the cell loss due to congestion. The transmission delay and the throttling rate were the major parameters which affected the performance of the reactive control. High throttling rates were most efficient for fast congestion recovery, although sometimes resulting in underutilization of the link. Although this proposed mechanism requires 3 LB’s to control the source parameters it performs very well and is not too complex.

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