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Feedback Burst Loss Ratio Control for Link Performance Improvement in Optical Burst Switching Networks

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ABSTRACT

*Known as an important criterion that evaluates performance of future high-speed backbone networks, burst data loss ratio is well-studied in Optical Burst Switching networks. Current literatures mostly focus on reduce burst loss ratio without considering the system stability and link utilization after reducing. In this paper, we propose a novel framework which comes from feedback theoretic to dynamically control burst loss ratio in OBS. The proposed scheme tries to track the pre-set values of burst loss ratio and increases the stability and link utilization degree. The simulation results show that measured burst loss ratio always tracks setup reference with small errors, wavelength channel utilization is increased up to 20% and the system stability is also improved.

Key words: Optical Burst Switching, Feedback Control, QoS, Burst Loss Ratio

1. INTRODUCTION

Optical Burst Switching (OBS) has been considered as a promising technique to increase bandwidth and support many types of future Internet traffic [1,2]. The main motivation for considering Optical Burst Switching is that some traffic in broadband multimedia services is inherently bursty. Recent studies have shown that, in addition to traffic in a local Ethernet and between remote Ethernets (i.e. WAN traffic), traffic generated by Web browsers, wide-area TCP connections (including FTP and TELNET traffic carried over TCP connections), and variable-bit-rate (VBR) video sources are all self-similar (or bursty at all time scales). Moreover, contrary to the common assumption based on Poisson traffic, multiplexing a large number of self-similar traffic stream results in bursty traffic [3].

In OBS networks, burst loss issue arises whenever two or more incoming optical bursts contend for the same output port at the same time. Existing research summarized three possible methods for dealing with burst contention. They are optical buffering [4,5]; wavelength conversion [6,7]; and deflection routing [8]. However, there are some limitations of these schemes. Firstly, the feasibility and cost of adding a new optical equipment have not been assured yet. Secondly, stability of system after adding new methods has not been considered.

In this paper, we propose a dynamic framework

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that compensates error of burst loss from the view point of classical control theory: "feedback control". We consider the whole OBS system as a black box without knowledge of system model and pre-data because no testbed and real data for it are available until now. The chosen tuned input signal is message frequency which is the time period between two sequence messages. The controlled output signal is burst loss ratio which is measured by number of dropped bursts over total sent bursts. In realistic, we can measure burst loss ratio at each edge node by putting an optical monitor device to monitor optical data. Here, we implement optical monitor block in simulator by using burst loss model with impatience features [9]. Our feedback control approach then computes message frequency at each controller based on the difference between reference value and measured value of burst loss ratio. Our main contributions and the differences of this paper and previous related works may be summarized as following:

- We propose a framework, called feedback burst loss ratio model, to solve the data burst loss problem in NSFNet OBS topology with self-similar traffic. The works in [10] also consider feedback control but the traffic is Poisson distribution only (Section III.A and IV).
- We build a simulator model for NSFNet based on OMNeT++ framework with OBS modules to verify our proposed control scheme (Section V).

The remainder of this paper is organized as follows. We present related works in section II. In section III and IV, we describe our considered system model and the dynamic feedback controller design specific steps. Section V gives our simulation results of the proposed scheme and section VI finally concludes the paper.

2. RELATED WORKS

Several models and algorithms have been proposed for OBS networks which try to reduce burst loss ratio as much as possible. Here we make the classification into three main approaches and compare to our approach.

From network optimization viewpoint, Li et al. [11] tried to schedule as many bursts as possible on wavelength channels so that the throughput is maximized and burst loss is minimized. They proposed a virtual offset-time channel reservation protocol to improve worst case information based on maximization throughput problem. Park et al. [12] visited burst contention resolution from view point of network utility maximization (NUM). Their new ideas are joint of congestion and contention control. While network throughput increases, burst loss ratio does not increase. Gauger et al. [13] viewed maximize utilization problem and burst loss ratio minimization under dynamic traffic. We notice that although extensive simulation results are available on the performance, they still lack theoretical analysis on convergence states of OBS system.

In queuing approaches, Xu et al. [14] considered an edge node only without buffering. The OBS node serves a number of users where each is connected to the switch over a fiber link that supports multiple wavelength. Each wavelength is associated with a 3-state Markovian burst arrival process. The arrival process permits short and long bursts to be modelled. Akar and Sohraby [15] developed Markov queuing model to a retrial queuing models for multi-wavelength optical networks but they did not focus on OBS networks. These mathematical efforts somehow have an disadvantage of algorithm complexity to implement in simulation and also in realistic scenarios. Moreover, to the best of our knowledge, the burst loss ratio stability and utilization convergence of algorithms in OBS network areas also have not been solved efficiently yet.

In feedback control approaches, authors in [10, 16,17] proposed a feedback controller for optical

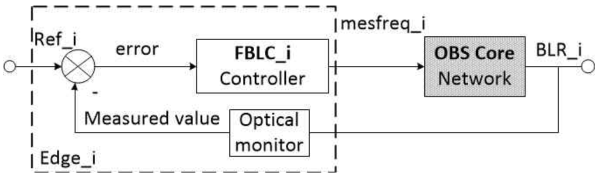

Fig. 1. OBS model with feedback BLR control.

networks also. However, the design of integral controller only made the oscillation degree at stable stage still large. Our proposed scheme in this paper improves stability by developing a proportional-integral-derivative (PID) controller to efficiently eliminate oscillation of burst loss ratio.

3. SYSTEM MODEL

3.1 Feedback burst loss ratio model (FBLR)

Our proposed work starts with discussion of feedback control model for OBS networks (Fig. 1). This represents a control loop associated with edge i (Edge_i). Inside we develop a burst controller (FBLC_i) and an Optical monitor. Message frequqency (mesfreq_i) is the time between two sequence messages. Each controller computes mesfreq_i based on the input error value (Ref_i - Measured value of BLR_i). Once the Measured value of BLR_i exceeds Ref_i then no more message will be injected into the network. Considering OBS core node network as a black box, we then use control theory to design a suitable controller for dynamical control burst loss ratio.

Each controller has gains to be designed based on feedback control theoretic techniques. In this work, we use empirical method from Zigler-Nichols, to choose gains' values for each. Due to complexity of different routing algorithms, a message can be sent from an arbitrary node to other destination node. Therefore, we put an optical monitor (OM_i) module at each edge node i to monitor burst loss ratio after bursts inside networks. This module only starts to collect and calculate burst loss ratio if the node i is the final destination of the using routing algorithm.

3.2 Self-similar bursty traffic generator model

In order to generate message as input signal, we consider the following self-similar burst traffic generation model. This model is implemented based on the on-off period of Pareto distribution. One of the important requirements for the simulation experiment is to model the network traffic as close to reality as possible. OBS networks need bursty traffic or self-similarity which is a main characteristic of Internet traffic now and future [1]. It has been shown in the literature that self-similar traffic can be generated by multiplexing multiple sources of Pareto-distributed *on-off* periods. In the context of an OBS network, *on* periods correspond to a series of bursts sent one after another, and *off* periods are periods of silence. The more details can be seen on [3]. Here we summarized the most important result that we will use for our simulation model development later.

$$b_{off} = \left(\frac{1}{L} - 1\right)\frac{\alpha_{on}\alpha_{off} - 1}{(\alpha_{on} - 1)\alpha_{off}} b_{on} \tag{1}$$

During the on period of the on-off source, bursts are sent back to back. L is average load of each on-off source. α is shape parameter, b is the distribution of on-off periods. Equation (1) is used to support the implemented code of the self-similar traffic generator module in OBS simulator.

4. FEEDBACK BURST LOSS RATIO CONTROLLER DESIGN (FBLRC-PID)

The classical controller design methodology consists of two steps. The first step is system identification which is to find a transfer function which relates past and present input values to past and present output values. These transfer functions describe a model of the system. The accuracy of this transfer function affects much to performance of the later designed controller. The second is controller design which is based on properties of transfer function and the desired objectives where a particular control law is chosen. Techniques from control theory are used to predict how the system will behave once the chosen controller is added to it. The following two subsections discuss these steps.

4.1 Identifying transfer function of OBS core model

The use of controllers is common in traditional engineering domains. Controllers use defined relationships between inputs and outputs that are defined mathematically. To relate inputs and outputs, this work consider the autoregressive, moving average model (ARMA) [18] which is an example of an empirical approach. The relationships described in this section are similar to those derived in [17]. The general form of the ARMA model is given by (2):

$$y(t)=\sum_{i=1}^{n}a_i y(t-i)+\sum_{j=1}^{m}b_j x(t-j) \tag{2}$$

The input $x(t)$ of the ARMA model represents a tuning parameter and the output $y(t)$ represents a controlled output parameter. The parameters n and m and the order of the model. The a_i, and b_j are constants that are estimated from data using *least square regression* method [19]. By identifying the values for n, m, a_i, and b_j, the transfer function can be derived. The ARMA model is used to relate the output of the model to the input and also to the history of the output.

ARMA models are in the discrete time domain. Control theory techniques are usually based on frequency domains. Therefore, we must do the step of conversion transfer functions from *time to frequency domain*. The frequency domain conversion is referred to as z-transform. We apply the following formula:

$$Y(z)=Zy[t]=\sum_{t=0}^{\infty}y[t]z^{-t} \tag{3}$$

Where t an integer, $y(t)$ is the output in the time domain, and z is a complex number, $z=Ae^{j\phi}=A(\cos\phi+j\sin\phi)$. This allows for the use of existing control theory principles that are usually based on frequency domains. Note that in the time domain, lowercase is used (e.g., $y[t]$) and in the frequency domain, uppercase is used (e.g., $Y(z)$). Applying to equation (2), we obtain the ARMA model in the frequency domain as:

$$H(z)=\frac{Y(z)}{X(z)}=\frac{\sum_{j=0}^{m}b_j z^{n-j}}{z^n-(\sum_{i=1}^{n}a_i x^{n-i})}$$

Related works [18], [19] show that the ARMA model is a good fit choice to model the OBS network burst manager. If we set $y(t)$ to the burst loss ratio $blr_i(t)$, the input $x(t)$ is set to the message frequency $mesfreq_i(t)$ from source s_i to destination d_i, and the ARMA model highest order is set to 1, (i.e., $n=1$, and $m=0$). Then, we can derive the following transfer function of OBS core network as equation (4):

$$OBS_i(z)=\frac{BLR_i(z)}{MESFREQ_i(z)}=\frac{zb_0}{z-a_1} \tag{4}$$

Where $OBS_i(z)$ models the OBS network for each edge node i. Least square regression is used here to estimate a_1, b_0 with different values of n and m. The fit of the model improves as n and m increases. We seek a model that has the most suitable fit and a low order to reduce complexity. Here, the first order ARMA model is used with $m=0$ and $n=1$. Finally, the ARMA model parameters are estimated to $a_1=1$ and $b_0=-1.03$. With those values in hands, we now move on to the next controller design step.

4.2 Designing controller

A control law describes how the controller changes the value of a tuning parameter. The choice of control law is based on what the system transfer function form you have, and what your control objective is. Here, OBS transfer function has a chosen form of first order ARMA model. Our objective is to track the reference values of burst loss ratio at all edge nodes and therefore improve system stability.

Taken those into account to design controller, we choose a proportional-derivative-integral (PID) control law to apply for OBS. In principle, PID controller produces control actions that track the reference values and continue to increase its corrective effect as long as the error exists. If error is small, the PID controller adjusts message frequency slowly to track the REF values. If error is large, the PID actions adjust message frequency rapidly, depend on error's positive or negative sign. Our controller has the following general time domain formula:

$$mesfreq_i(t) = K_{p_i}\left(blr(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d\frac{d}{dt}blr(t)\right) \tag{5}$$

Where $mesfreq_i(t)$ can be controlled over time. K_{p_i} is proportional gain associated with each burst controller at edge node i. T_i and T_d are integral and derivative time parameter. $e(\tau)$ is its associated error value that our controller wants to eliminate. From equation (5), we derive a discrete form as:

$$\begin{aligned} mesfreq_i(t_k) = mesfreq_i(t_{k-1}) + K_{p_i}[Ae_i(t_k) + \\ Be_i(t_{k-1}) + Ce_i(t_{k-2})] \end{aligned} \tag{6}$$

Where $A = 1 + \frac{\delta t}{T_i} + \frac{T_d}{\delta t}$; $B = -1 - \frac{2T_d}{\delta t}$; $C = \frac{T_d}{\delta t}$.

The PID control law used in this work states that a maximum rate of message allowed to be injected into the OBS network is adjusted dynamically based on the previous values of the burst loss ratio and the corresponding control error.

We have the z-transform of $mesfreq_i(t)$ and $mesfreq_i(t-1)$ are $MESFREQ_i(z)$ and $\frac{1}{z}MESFREQ_i(z)$, respectively. Thus, applying the z-tranform presented in equation (3) to the particular form in equation (6), we have:

$$\begin{aligned} MESFREQ_i(z) = \frac{1}{z}MESFREQ_i(z) + \\ K_{p_i}\left[AE_i(z) + B\frac{1}{z}E_i(z) + C\frac{1}{z^2}E_i(z)\right] \end{aligned}$$

where $E_i(z) = REF_i(z) - BLR_i(z)$. Taking $MESFREQ_i(z)$ as a common factor, we obtain the relationship formula between input and output of FBLRC-PID controller.

$$FBRLC-PID_i(z) = \frac{MESFREQ_i(z)}{E_i(z)} = K_{p_i}\frac{Mz}{z-1}E_i(z)$$

where $M = A + \frac{B}{z} + \frac{C}{z^2}$. M mainly depends on parameters T_i and T_d. Open loop transfer function is $BLR_i(z) = E_i(z)FBLC_i(z)OBS_i(z)$. Applying equation (4) and (7), the feedback closed-loop transfer function for the whole OBS system is:

$$TF_{OBS_i}(z) = \frac{BLR_i(z)}{REF_i(z)} = \frac{K_{p_i}Mz^2b_0}{(z-1)(z-a_1) - K_{p_i}Mz^2b_0}$$

In order to find parameters K_p, T_i and T_d, we use Zigler-Nichols empirical method to search for a suitable number set. These are specific steps to search for optimal parameters:

- Set T_i, $T_d = 0$.
- Increase $K_p = x$ until system starts to oscillate at oscillation period P_x.
- Applying Zigler-Nichols empirical formulas: $K_p = 0.6x$; $T_i = \frac{P_x}{2}$; $T_d = \frac{P_x}{8}$

We use System Control toolbox in MATLAB to evaluate the above method and find a suitable number set for our FBLRC-PID controller as: $K_p = 0.010224$, $T_i = 1.120056$, and $T_d = 0.285719$.

5. SIMULATION RESULTS

5.1 Simulation setup

In order to evaluate our proposed technique on the OBS network utilization, OMNeT++ simulation framework is used [20]. The OBS network topology used in this paper consists of 14 nodes, rep-

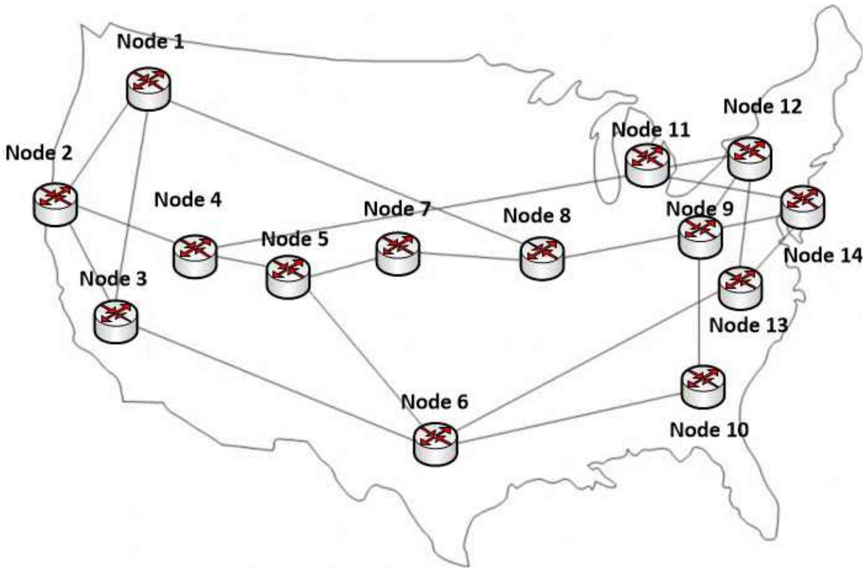

Fig. 2. NSFNet topology with OBS (14 nodes).

resents National Science Foundation Network (NSFNet) topology (Fig. 2). This is the most well known topology to investigate performance of optical backbone networks. We use OBS modules [21] to develop our simulator of NSFNet.

Each node generates packets using *self-similar traffic* model in Section III.B with controllable message frequency. In OBS networks, a node is composed of core node and edge node. Edge node is responsible for assembling packet into optical burst data, while core node delivers the optical burst data inside optical networks. When packets come to edge node, which is an interface between OBS networks and IP packet networks, packets with same destination will be collected into an optical burst. Burst assembly process is done by combining of three schemes: maximum size of burst, time-out in assemble queue, and number of packets in queue. Maximum burst size is $125 Kbytes$. Burst loss ratios are computed whenever a burst reach its final destination edge node using Optical Monitor modules. Burst Control Packet (BCP) size is $16 Bytes$. We apply full wavelength conversion and fixed shortest path routing. Each link is assumed to have 10 wavelengths operating at $1 Gbps$, one of which is used as a control channel and the rest are data channels.

5.2 Comparison to other approach

We conduct following comparisons with a related work's scheme, named as FCLR-I method, in [10], which is the most closed to our approach. This related work's scheme consider a closed-loop mechanism also. However, the difference of their *Integral* choice for controller and their chosen input tuning parameter is burstification rate which has not been able to be controlled in realistic environment yet.

Fig. 3 presents the comparison result after running simulation in OMNeT++ with OBS Modules.

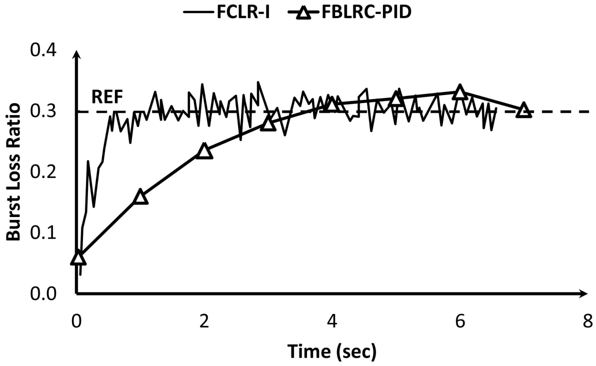

Fig. 3. BLR comparison to FCLR-I controller.

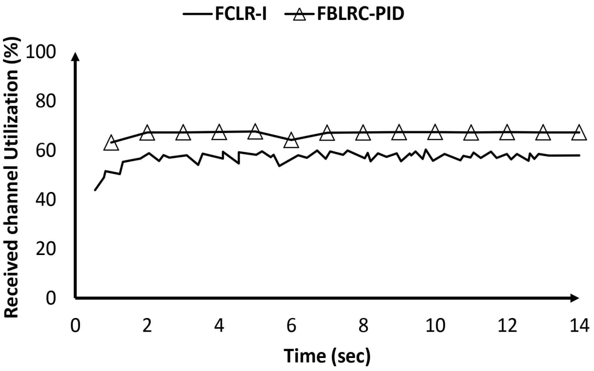

Fig. 4. Improve link utilization than FCLR-I.

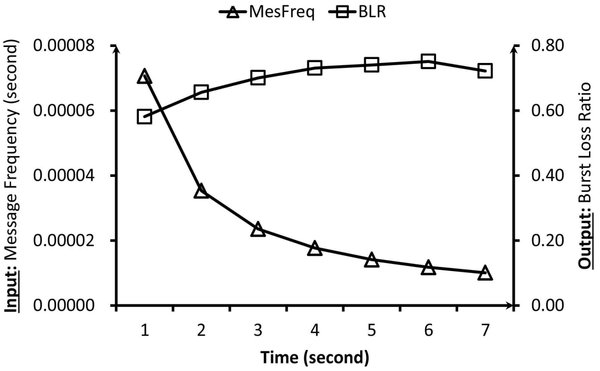

Fig. 5. Relationship - Input and Ouput of OBS.

The first advantage is that by taking into account both proportional and derivative gains, our FBLRC-PID compensates error rapidly and eliminate errors at convergence state better than FCLR-I method. Secondly, oscillation degree of Burst Loss Ratio output in our controller is much smaller. But a disadvantage which can be seen from Fig. 3 is that the convergence speed of algorithm is longer. This is because proportional gains K_p in our controller tries to remove the over-adjustment as much as possible. It takes long time to reach the stable state. However, our objective of OBS network is to get Burst Loss Ratio output as small and as stable as possible. Hence, FBLRC-PID controller works well for this.

Fig. 4 shows the network utilization degree at received channel associated with each burst type. Our proposed scheme achieves about 60% link channel utilization compared to 40% only in FCLR-I scheme. We can see that our proposed scheme brings a better utilization degree than the compared scheme. These utilization values could be used to make decision to choose reference values for the burst loss ratio at each edge node in the feedback controller in order to better utilize the underlying OBS network.

5.3 Extensive analysis

5.3.1 Relationship between MesFreq and BLR:

When designing a feedback control system, we always wonder whether *message frequency* is the only input to the system transfer function. To answer this question, Fig. 5 shows the relationship between the message frequency and the burst loss ratio. These experiments are conducted using message frequency which is increased step by step and the equivalent burst loss ratio is measured periodically. That is, the message frequency is increased by 100 messages per second every time interval of one second. The impact of the message frequency is clear, suggesting that the message frequency would be sufficient. Simulations show that the message frequency has a direct impact on the burst loss ratioi that is used as the controlled output parameter.

5.3.2 REF-BLR tracking feature:

We set the reference values for each edge node as following. $REF_1 = 0.05$ for edge 1, $REF_2 = REF_3 = 0.03$ for edge 2 and 3. Because edge 1 must carry much traffic flow than edge 2 and edge 3 (Fig. 2). Verifying using simulation with scenario of using single wavelength, we find the FBLRC-PID controller track the pre-set values of burst loss ratio for each edge node. In Fig. 6, we can see the error at stable stage of edge 1 is lower than edge 2 and edge 3 (0.1% compared to $\approx 0.4\%$). That is because our controller takes action more quickly with high traffic flow which is an advantage of PID controller in principle.

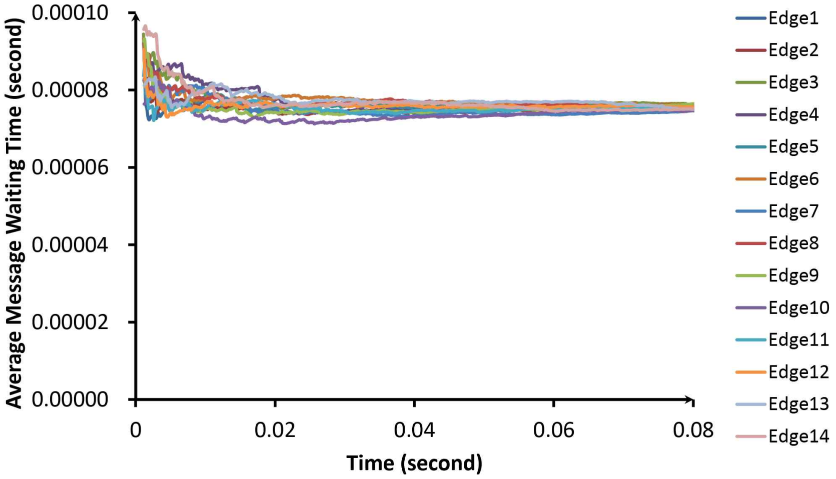

Fig. 7. Convergence of waiting time in OBS.

5.3.3 Convergence of message waiting time:

Finally, let us take a look at waiting time of a message before entering burst assembly process and FBLRC-PID burst controller. Message waiting time at assembler queue results are presented in Fig. 7. The average message waiting time in queue affect to collision of IP packets (messages) inside the OBS networks. Oscillated values of waiting time over simulation time at first steps imply that FBLRC-PID controller are dynamically adjusting message frequency to adapt with changing of burst loss ratio. Here, we measure average message waiting time at totally 14 edge nodes modules in NSFNet. From Fig. 7 we also can see the convergence of our proposed algorithm. All message waiting time are converged to the value $\approx 80\mu s$. It once again shows an advantage of our FBLRC-PID scheme which is the convergence of waiting time.

6. CONCLUSION

This paper proposes a novel model to control BLR in OBS networks. Feedback control theoretic techniques are used to achieve this goal. The tuning parameter used in this paper is the message frequency which is the rate of message injection into the network. The used controlled output parameter is the burst loss ratio BLR. The reference value for the burst loss ratio is selected based on the application requirements. Simulations of the NSFNet network topology show that the measured burst loss ratio tracks the desired reference values and the link utilization are also increased. This proves that our burst manager is well designed to generate the appropriate message frequency rate and to achieve desired values BLR.

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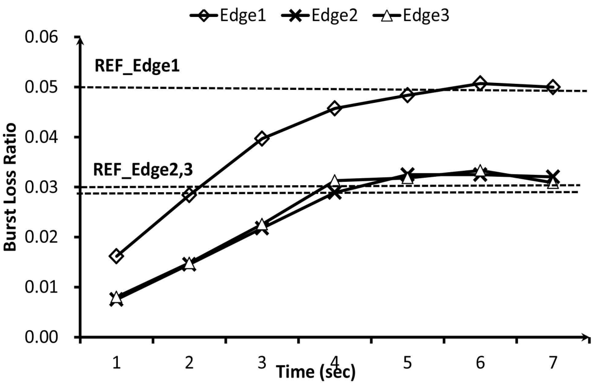

Fig. 6. BLR-REF tracking performance.

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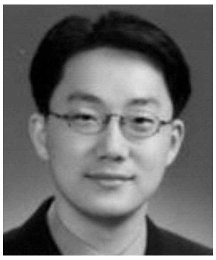

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