Emulating lossless, one-way signaling protocols in OBS networks with traffic prediction

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Abstract— In this paper, we propose a new scheme for on demand reservation of capacity in OBS networks, emulating one-way signaling protocols. The proposed framework relies on the combination of a two-way reservation protocol and a burst assembly scheme with a burstification delay enforced to be the round-trip-time and which incorporates a Least Mean Square filter to predict burst length. Upon the arrival of the first packet in the burst queue, a control packet (setup message) is generated and transmitted to reserve resources, based on the prediction filter. In this way the reservation process starts/ends simultaneously with the burst assembly process. In this paper, we present the main features of the proposed scheme, evaluate its performance for both homogeneous and non-homogeneous traffic and we further propose an extension with aggressive over-provisioning of resources that can guarantee lossless operation even for extremely cases of bursty traffic.

***Index Terms*— Least Mean Square filter, traffic analysis, Optical burst switching.**

I. INTRODUCTION

Optical burst switching (OBS) has been introduced to couple the merits of packet and circuit switching [1]. One of the key developments of OBS was the introduction of one-way reservation schemes for the “on-demand” use of capacity. In one-way reservation schemes (also called “Tell-and-Go”), a setup packet is sent in advance to precede the arrival of a burst of packets by a time offset. This allows for minimizing the pre-transmission delay. The differences among the currently proposed one-way schemes lie mainly in the time instances that determine the setup and the release of resources. In general the setup of a connection can be explicit, when switch state is configured for the upcoming burst immediately after the arrival of the setup message or implicit when it is configured for the actual time that the burst will arrive at the node. A number of one-way reservation schemes have been proposed for OBS, including the just-enough-time (JET) [2], Horizon [3] and just-in-time (JIT), [4]. JIT protocol employs explicit setup and explicit or implicit release. In particular, an output port is reserved for a burst immediately after the arrival of the corresponding setup message; if a wavelength cannot be reserved at that time, then the setup message is rejected and the corresponding burst is dropped. Horizon and JET protocols employ estimated setup and estimated release. Further various scheduling algorithm have been proposed to better exploit bandwidth resources such as the LAUC with void filling scheme [3] and other variants of this scheme.

One-way schemes are very promising, when applied to a network operating at light load, but may result in a high burst loss ratio when load increases and there is limited or no buffering in the core. Various studies have been carried out to estimate the burst loss ratio when wavelength converters and/or FDL-based optical buffers are employed. However, all these are not yet matured solutions for deployment and therefore QoS provision schemes were proposed to assure a constant loss ratio. Such schemes include the offset-time-based scheme [5] that provides an extra time offset to isolate different classes of traffic, the composite-burst assembly scheme that mixes traffic classes during burst assembly and provides QoS via prioritized burst segmentation [6], the “*preemptive wavelength reservation mechanism*”, where each class is associated with a predefined usage limit, [7] and the “*early dropping mechanism*” that probabilistically drops bursts of a lower priority class in order to guarantee the loss probability of higher priority classes of traffic [8]. However, all these schemes require either optical buffer or additional scheduling /processing that make their deployment difficult.

On the other hand, two-way reservation protocols guarantee loss-less operation in a buffer less OBS network [9],[10], but however induce a large delay, associated with the establishment of an end-to-end connection. An interest hybrid scheme has been recently proposed in [11], that employs both two-way and one-way reservation across a network path for a given a source-destination pair.

In this paper, we propose a new scheme that differentiates from the abovementioned ones and which truly emulates one-way reservation. It relies on a two-way reservation protocol and a timer-based assembly scheme. The key idea is to tune the assembly timer to be equal to the time associated with the establishment of the end-to-end connection to synchronize the resource reservation with the assembly process. In this way, upon the arrival of the first packet in the queue, reservation of resources may start simultaneously based on a prediction of the burst length. In our study, we have used an N-order

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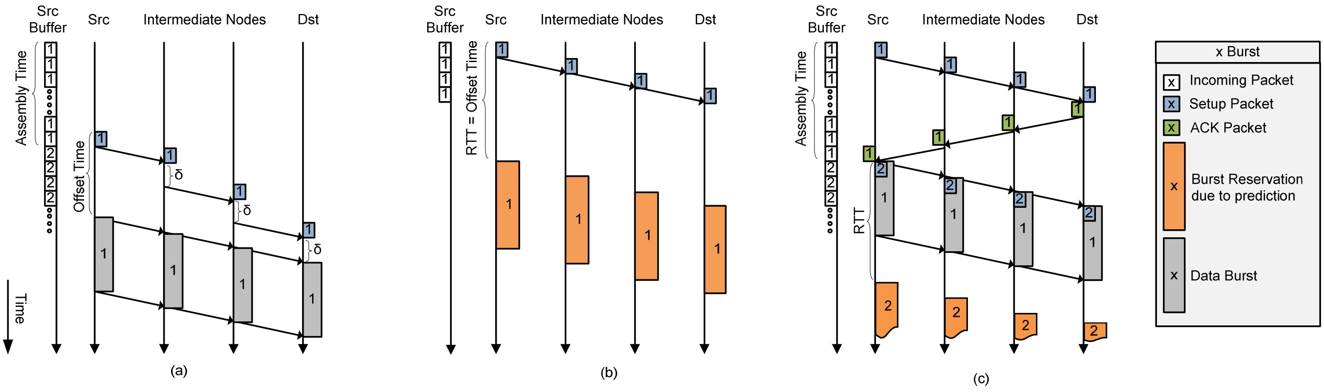

Figure 1: (a) Usual case of burst assembly process and one-way reservation where δ is the Processing time of the setup packet. (b) Proposed scheme – Reservation Phase. (c) Proposed scheme –Burst transmission phase and Reservation of the next Burst.

Normalised LMS (Least Mean Square) filter that provides adequate accuracy [12]. The overall scheme emulates one-way reservation in the sense that the burst is transmitted immediately after the assembly timer expires. The advantage of the scheme is that latency is reduced to the minimum possible, burst transmission is guaranteed to be lossless in the core, while data losses may only occur at the edge and only when prediction underestimates burst size.

The rest of the paper is organized as follows. Section II presents the main concept and the predicting burst size filter, while, Section III present evaluation results for both homogeneous and Non-homogeneous Poisson packet arrivals. In Section IV, we present an extension to the scheme in order to integrate losses in the prediction mechanism and provide lossless connectivity, avoiding full or partial burst drops. These drops are attributed to either filter under-estimations or failures in the reservation of resources.

II. BURST LENGTH PREDICTION AND NETWORK CONCEPT

OBS networks have been widely associated with the one-way signaling protocols. However, burst losses increase fast with the increase of network load and it is difficult or quite impossible to guarantee a certain level of QoS to end-users. In addition, assuming that each OBS edge router services concurrently thousands active TCP connections, QoS support becomes an unrivaled task that requires cross layer (transport, network and physical layer) processing. In the proposed framework, a two-way reservation protocol is used in combination with a timer-based assembly scheme, where the timer has been tuned to be equal to the round-trip time delay. Figure 1 illustrates graphically the proposed concept. In particular Figure 1a shows the usual case of an one-way protocol, where burst is transmitted with no guarantee immediately after the expiration of the assembly timer. In contrast, in Figure 1b, the assembler that in any case maintain a different queue per destination assigns to each queue, an assembly timer equal to the RTT of that source-destination pair. Upon the arrival of the first packet in the queue, a prediction mechanism estimates the size of the queue, at RTT time later and immediately transmits a setup packet to reserve resources according to that prediction. Upon the return of an acknowledge message (see Figure 1c) burst transmission starts immediately without the need of a control packet to precede. Thus, the time offset usually incorporated in between transmission and signaling is not needed in our case and therefore latency is further reduced.

The framework that we propose benefits from the parallel execution of the signaling messages and the assembly process, and for this a setup message requires a priori knowledge of the burst length. There is no doubt that to make a prediction algorithm practical for an OBS system, it should not only deliver good estimation performance, but also be simple and fast so the calculations can be done on-line. In general the actual burst size can be different from the predicted one and absolutely depends on the prediction mechanism. Within this framework, we have implemented an N-order Normalised LMS (Least Mean Square) filter that can provide such accuracy. Meanwhile, the LMS-based approach outperforms the other alternatives in terms of computational simplicity. Its time complexity for the coefficient calculation is $\boldsymbol{O}(N)$ (e.g is much less than that of Yule–Walker equations which is $\boldsymbol{O}(N^2)$**.** In what follows we provide a description of such a filter and how it is configured to predict burst size.

Let $\boldsymbol{L_d(k)}$ be the length (in the time scale) of the k^{th} burst. The length of the next incoming burst is then predicted according to those of the previous N bursts by

$$\bar{\boldsymbol{L}}(\boldsymbol{k}+\boldsymbol{1}) = \sum_{i=1}^{N}[\boldsymbol{h}(\boldsymbol{i}) \cdot \boldsymbol{L_d}(\boldsymbol{k}-\boldsymbol{i}+\boldsymbol{1})] \qquad \textbf{(Eq. 1)}$$

where, $h(i),\ i\,\epsilon\{1,\dots N\}$ are the coefficients of the predictive filter. We update the predictive filter coefficients by an efficient algorithm [13], where the coefficients for the $(\boldsymbol{k}+\boldsymbol{1})^{\boldsymbol{th}}$ prediction are defined as:

$$(\mathbf{h})^{k+1} = (\mathbf{h})^{k} + \frac{\mu \cdot e(k) \cdot (\mathbf{L_d})^{k}}{\|\,(\mathbf{L_d})^{k}\,\|^{2}} \qquad \textbf{(Eq. 2)}$$

where, $\mathbf{h}$ is the coefficient vector, μ is an adjustable parameter of the filter, $\boldsymbol{e(k)}$ the residual between the actual and the predicted length of the $\boldsymbol{k^{th}}$ data burst and $(\mathbf{L_d})^{\boldsymbol{k}}$ the vector of $\boldsymbol{L_d(j)}$, $(\boldsymbol{j}\ \boldsymbol{\epsilon}\ \{(\boldsymbol{k}-\boldsymbol{1})\cdot\boldsymbol{N}+\boldsymbol{1},\dots,\boldsymbol{k}\cdot\boldsymbol{N}\})$.

TABLE 1 – Performance of LMS filter for $\mu = 0.1, N = 8$

	Error during the change				**Error in steady state**	
λ (kpackets/sec)	Time (sec)	Bursts	AVE	VAR	AVE	VAR
100→200	1.16	27	12.9	408.5	1.72	4.32
100→400	1.25	29	17.2	776.7	1.48	3.22
100→600	1.37	32	17.5	860.8	1.32	2.13
100→800	1.42	33	17.7	924.23	1.21	1.49
200→100	1.24	29	17.6	985.5		
400→100	1.33	31	42.1	7081.5		
600→100	1.46	34	59.8	17235.7		
800→100	1.51	35	78.1	31810.4		

In order to evaluate the LMS-based prediction filter, we have carried out static experiments over a single edge router with constant as well as varying packet arrival rates. TABLE 1 summarizes our findings. In general, the prediction error was found to be ~1.5% in the case of constant arrival rates that translates to +/- 15KB per MB transmitted. The mean and variance of the prediction error for an arrival rate of 200, 400, 600 and 800 kpackets/sec are shown in the last two columns of TABLE 1. It can be seen that the LMS filter performs better for large arrival rates (i.e. 800kpacket/sec), primarily because of the higher number of samples that lends the prediction algorithm a higher accuracy.

In addition, TABLE 1 shows the performance of the filter against the instant changes in the packet arrival rates shown in the 1st column. In particular, TABLE 1 provides the elapsed time until the filter error, $\boldsymbol{e(k)}$ reaches a steady state with a variance below 10, the number of the bursts transmitted within that period as well the $\boldsymbol{e(k)}$ average and variance only for that period. It is clear that LMS filter exhibits a delay in following the traffic increase (or decrease) and which delay increases with the magnitude of increase (or decrease). For example, the filter mechanism needs 1.42sec to adapt to an increase from 100kpackets to 800packets/sec, while 18% less time (1.16sec) for an increase from 100kpackets to 200packets/sec. However a major difference is denoted in the mean and variance of the error in that period. In particular, in the latter case (100→200kpackets/sec) the mean error of the filter is only 12.9% with a variance of 408.3 while in the first case (100→800kpackets/sec) both values are by far larger.

This behavior is inherent with LMS-based algorithms since they constitute a good compromise of convergence speed and tracking performance. While applying LMS for traffic prediction, on one hand, a larger step size reduces prediction delay, but brings the problem of convergence that leads to increasing prediction error, while on the other hand, a smaller step size gives less prediction error but a longer prediction delay. Figure 2 shows the error variation per burst transmitted around the change for an increase/decrease of 100k to 800kpackets/sec in the arrival rate.

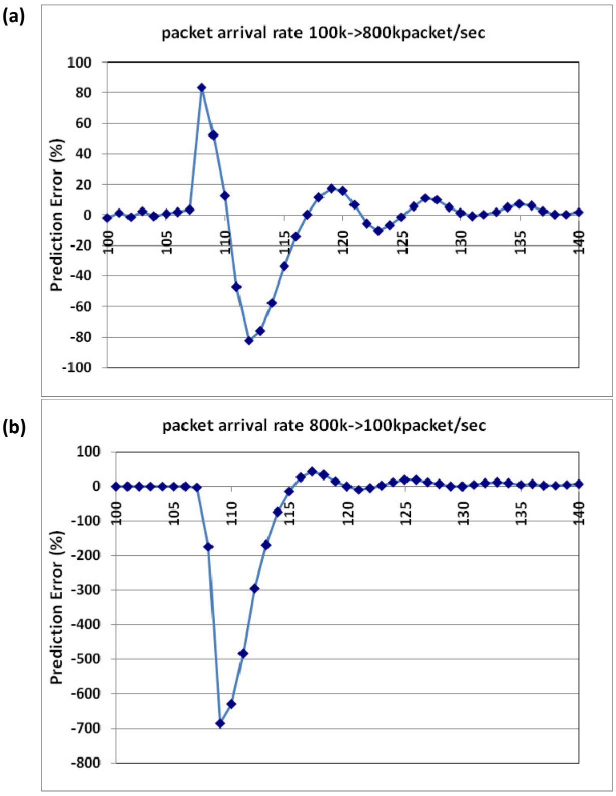

Figure 2: Error variation per burst transmitted for a rate change of (a) 100k to 800kpackets/sec and (b) 800k to 100kpackets/sec.

III. EVALUATION IN LARGE SCALE NETWORK TOPOLOGIES

We have evaluated the overall performance of the proposed scheme on the NSF network topology using ns-2 simulator. The NSF network consists of 8 edge and 6 core nodes, where each link was employing two wavelengths at 10Gbps. TABLE 2 summarizes the RTT delays per edge node that were used for assembling the bursts.

The packet generating source was modeled with a *Non-homogeneous Poisson process* (NHPP) model. A NHPP is a Poisson process whose arrival rate λ at time t is a function of time $\boldsymbol{\lambda_{NHPP}(t)}$. More specifically, the number of arrivals $\boldsymbol{N(t)}$ in the interval [0,t) follows the distribution:

$$\Pr\left(N(t)=n\right)=e^{-m(t)}\frac{\left(m(t)\right)^{n}}{n!}, n\geq 0 \ \ and \ \ m(t)=\int_{0}^{t}\lambda(s)ds$$

Taking into account the variations in the packet arrival rate during a day, [14], and the packet sizes drawn from an Internet mix size distribution [15], we have defined a representative stepwise function for *λ(t)* and developed a new traffic agent for ns-2. The above parameters were used so that the yielding average blocking probability to be less than 1%. In addition, we used a two-way signaling protocol with timed and delayed reservation [10].

Our study has been focused on the two cases, namely when prediction filter under-estimates and over-estimates the actual burst length and compared the performance of the overall

TABLE 2 – Round Trip Time delays(ms) per edge node for the NSF network topology

Edge Node	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Ave	30.4	36.9	22.1	23.4	23.4	28.6	29.4	32.6
Min	6.0	11.0	8.0	3.0	3.0	3.0	13.0	6.0
Max	49.0	59.0	41.0	46.0	46.0	59.0	51.0	46.0
Var	257.6	305.2	189.1	302.6	302.6	529.9	207.9	244.6

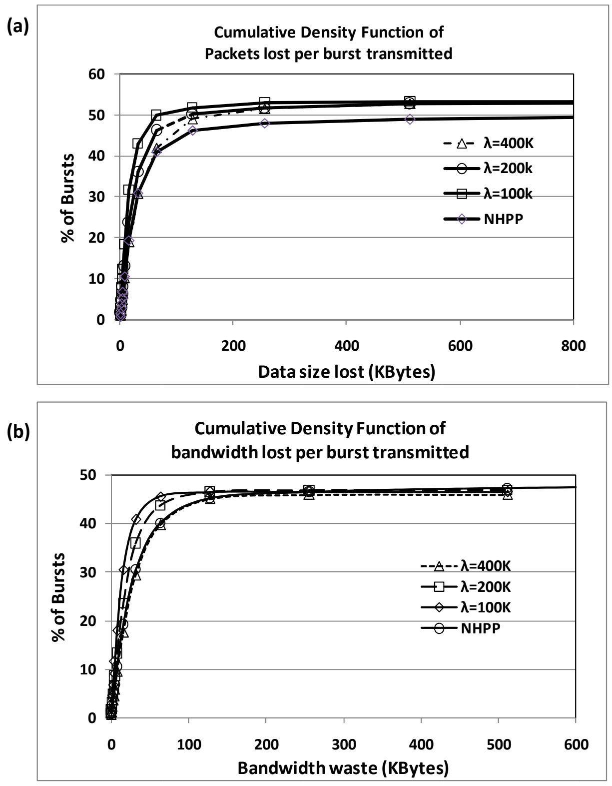

Figure 3: Cumulative density function of (a) lost data due to burst length under-estimation and (b) wasted bandwidth (in Kbytes) due to burst length over-estimation of all the transmitted bursts for homogeneous (λ=100,200,400kpackets/sec) and non-homogeneous packet arrival rates.

scheme with that of an one-way protocol. In general the prediction error can be positive or negative and different policies may apply here. In the first case, the actual burst size exceeds the predicted one and thus part of it has to be dropped (or transferred to the next assembly cycle). In the second case, burst can be transmitted but with a fraction of the reserved capacity being wasted. In both cases the error is negligible if packet arrival rate is constant and affects performance only during a change in the packet arrival rate for a certain period of time. It must be noted here that if the setup message fails to establish an end-to-end path, then all the data assembled till the arrival of the rejection message are dropped. In this way, one –way signaling is truly emulated.

Figure 3a shows the cumulative density function (CDF) of the data lost when the prediction filter under-estimates the burst size, while Figure 3b displays the corresponding results of the wasted capacity when the filter overestimates the burst size. It must be noted here that the results of Figure 3 corresponds to the burst transmitted and not the ones, whose setup messages were blocked. From Figure 3 it can be seen that more than 50% of the bursts transmitted omit less than 200kbyte data in the assembly queue, while the rest are transmitted with a bandwidth waste of less than 100kbyte. It is only an insignificant % of all the bursts (<0.5%) that drops a data set of more than 512kbyte. To this end, we may argue that prediction mechanism operates adequately and the small deviation can be corrected with a correction function as presented in the next section.

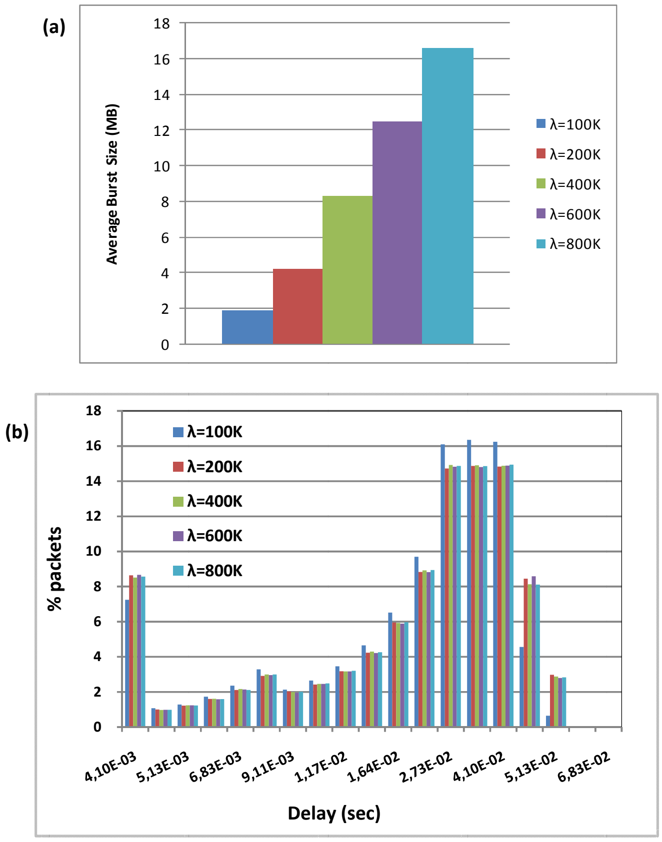

Figure 4: (a) Average lengths of the bursts transmitted for different packet arrival rates and (b) Packet delay distribution function in the case that the underestimated burst length data are transferred to the next assembly period to achieve lossless operation.

IV. AGGRESSIVE RESOURCE RESERVATION FOR LOSSLESS BURST CONNECTIVITY

In this section we modify the proposed scheme to integrate losses and data drops in the prediction mechanism. The goal is to provide lossless connectivity and avoid (full or partial) burst drops at the edge node. This is only possible if the underestimation error is added in the predicted length either in the same or the next round of reservation. In this way burst size may increase as well as the packet queuing time. In any case, our intention is to provide lossless communication and investigate which are the imminent effects. There are two cases to consider here, namely the failure of accurate predictions that induce a constant error and the failure of signaling messages to reserve resources, due to contention. A special case concerns the error caused by fast or slow changes in the packet arrival process. These induce non-constant erroneous burst length predictions that are difficult to be tolerated.

In the first case, we modified the filter to constantly add the underestimation error in the same assembly period [12]. This results to a continuous waste of resources but we may assume to be insignificant since the error is less than 1.5% of the burst size. In the second case, upon the failure of a reservation, and the reception of a rejection message at the edge, the assembly process resets and generates a new burst length prediction upon the arrival of the next packet in the queue. The extra packets resided in the queue are added to this new prediction, thus requesting sufficient resources for the oncoming larger burst. In this case, burst length may continuous increase and its yielding value depends on the blocking ratio in the core. It must be noted here that in this case filter does not update its coefficients, while in the first case does update them trying to compensate for its prediction error.

Figure **4**a shows the yielding mean size of the transmitted bursts in that case for different packet arrival rates, while Figure **4**b the corresponding packet queuing time. It can be seen that the size of the transmitted bursts increase from 2MB to more than 16MB, while the difference in the average queuing times is constant with the only exception the case of λ=100kpacket/sec. From Figure 4b, it can be seen that more than 90% of the total number of packets experience a delay smaller than the RTT time, which for the specific source-destination pair was 41.5msec. To this end, most packets are transmitted within the first two burst assembly periods, assuming that average waiting time in the queue is RTT/2. In particular, the 70% of the total packets exhibit a delay smaller than RTT time and half of them a delay smaller than RTT/2. In the case of λ=100kpacket/sec curve, average delay is smaller and it is the 95% of all the packets that experience a delay less than RTT time. This is because bursts transmitted are smaller and thus absolute error in terms of Kbytes insignificant. To this end, a very small percentage of the transmitted bursts leave data in the queue (see Figure 3).

The third case of this study corresponds to a more realistic network scenario, where packet arrival rate changes over time and this change can be either fast or slow. Absolute prediction error in such cases is not constant, depends on the differential change of the arrival rate and can be positive or negative. It is our goal to always over provisioning reservation of resources to avoid excess packet delays and guarantee lossless connectivity. To this end, we can allow an unconstrained burst size increase as long as a successful connection can be established to accommodate it.

To this end, we have extended the filter mechanism to accommodate large traffic violations and achieve faster overestimated predictions in the case that the residual error $e(k)$ varies vastly. We compensate for this problem by an aggressive resource reservation method to increase the probability of the filter to make an overestimation faster. Instead of making $L_r(k+1) = \tilde{L}_p(k+1)$ (where L_r is the reserved length and L_p is the predicted length), we define the reservation length as $L_r(k+1) = \tilde{L}_p(k+1) + \delta$, where δ is a correction parameter added. In [12], the root mean square (RMS) of the sample residuals of the filter, were used, which however performs good only for smooth traffic, with small variations in the load. Here, we propose the use of a more general function of the prediction error to adjust the correction parameter. In particular, the main idea is to estimate the traffic variation trend according to the sign continuity and absolute value of $e(k)$, [16]. Then, the estimated adjustment quantity $\delta(k)$ is added to the LMS prediction value, so that the new predictor could follow the variation of traffic trend more quickly, or even forecast it in advance. The general function considered here is as follows:

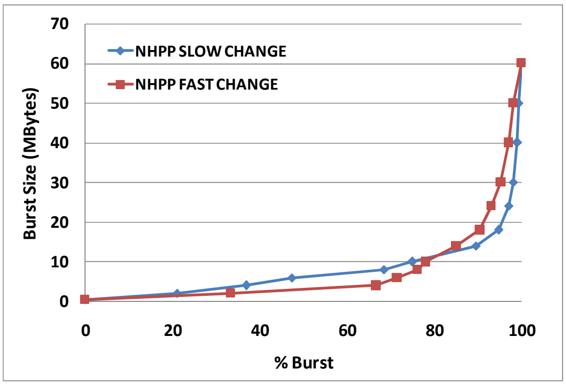

Figure 5: Burst length density functions for fast and slow rate changes.

$$\boldsymbol{\delta(k) = sign(k)^n \times f(e(k)) \times e(k)} \qquad \textbf{(Eq. 3)},$$

where $sign(k)$ is the sign continuity function and is decided based on the sign of the prediction error, $e(k)$. For example, if at several continuous moments, $e(k)$ has a same negative (or positive) sign, this is probably an indication of a persistence traffic increase in the variation trend. For such cases, the normal LMS predictor presents a delay in accommodating the new traffic trend (see TABLE 1). An exponential weight to the importance of the sign continuity function is given by rising $sign(k)$ to n.

Function $f(e(k))$ is decided by the absolute value of the prediction error, $e(k)$. For example if we set $f(e(k)) = {|e(k)|}/{\sigma_e}$, where σ_e is the error standard deviation, then error correction parameter is normalized by the mean value. In such a case, the prediction delay would be effectively reduced during a bursty increase in the packet arrival rate. However, too large $|e(k)|$ may lead to large error on prediction. So, it is necessary to provide a compromise and set an upper limit in relation to $|e(k)|$. For our analysis we have used the standard deviation of the average values measured in Figure 4, denoted here as $\sigma_{mean\,burst}$, and we set the function equal to $f(e(k)) = \sigma_{mean\,burst} \times |e(k)|$. This would compensate rapidly, fast incremental increases in the packet arrival rate with the minimum possible error. From Figure 4, we may calculate that $\sigma_{mean\,burst} = 5.2$.

We have evaluated the proposed aggressive resource reservation scheme (ARR) considering two cases of traffic violation, namely fast violations with an increase of 400kpacket/sec per 200msec and slow with an increase of 100kpacket/sec. What is of importance to measure is the yielding size of the transmitted bursts (Figure 5) and the queuing time of the assembled packets (Figure 6).

From Figure 5, the average sizes of the transmitted bursts were measured to be 7.8 and 7.3MB respectively for the two cases, while the 20% of the transmitted burst exhibited a very large size of more than 10MB. It is worth noting however, that only the 1% and 6% of them had a size larger than 30MB respectively for the two cases of slow and fast changes.

It is therefore clear that the fast changes in the packet arrival rate increases the yielding burst size. This increase is evidence that the queuing time of the assembled packets increases as

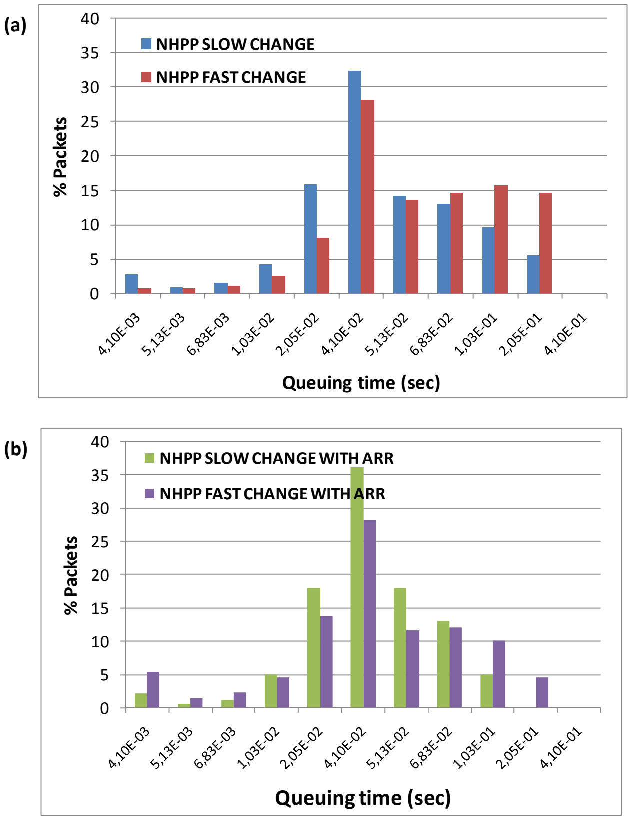

Figure 6: Packet queuing time distribution (a) without and (b) with the addition of the aggressive resource mechanism. Fast and slow changes correspond to 400kpacket and 100kpacket per sec increases in the packet arrival rate.

well, since a higher number of packets postpone for the next assembly cycle their transmission, and thus forming larger bursts. However, it is the packet delay that really matters since once a burst is transmitted, assembly process resets again. Figure 6(a) and (b) displays the corresponding distribution of packet queuing times with and without the aggressive resource reservation. It is clear that the percentage of packets with a delay higher than RTT is reduced. In particular for the case of a slow change in the arrival rate, 50% of the packets exhibited an average delay of 41msec (~RTT time), while the corresponding percentage for the ARR scheme rises to 63% (blue and green columns in Figure 6a and b). Similarly in the case of fast changes in the arrival rate, it is only the 41% of the packets with a delay smaller than RTT and it is significantly improved to 55% for the ARR case (red and purple columns in Figure 6a in b). The ratio of improvement is 9% and 34% respectively.

To this end, we may argue that the proposed aggressive resource reservation mechanism compensates rapidly bursty increases in the traffic load with an average packet queuing time that is comparable to that of one-way reservation. In addition, lossless operation is achieved at the cost however of increasing the probability of wasting bandwidth resources. In any case, it can be assumed that capacity in the core network is abundant, and it is the "on demand" use of this resource that delivers a performance advance.

V. CONCLUSIONS

In this paper, we have presented a novel scheme that emulates one-way signaling and provides lossless burst connectivity. It relies on the combination of a two-way reservation and a burst assembly scheme that incorporates a linear burst length prediction filter. In the proposed scheme the burstification delay is enforced to be equal to the round-trip-time delay, while the two-way reservation process starts immediately for the estimated duration of the burst, upon the arrival of the first packet in the queue. To this end, reservation and assembly process start and complete simultaneously.

In this paper, we have presented the main features of the proposed scheme and evaluated its performance with respect to data losses and latency induced. We have further proposed an extension to the scheme to provide lossless connectivity via the overprovision of resources. The scheme guarantees zero packet losses, on demand use of the available capacity with a packet delay that is comparable to that of one –way protocols.

REFERENCES

[1] C. Qiao and M. Yoo, "Optical burst switching (OBS)—A new paradigm for an optical internet", Journal of High Speed Networks, vol. 8, pp. 69–84, 1999.

[2] M. Yoo and C. Qiao, "Just-enough-time (JET): A high speed protocol for bursty traffic in optical networks," IEEE/LEOS Technol. Global Information Infrastructure, pp. 26–27, Aug. 1997.

[3] Y. Xiong, M. Vandenhoute, and H. Cankaya, "Control architecture in optical burst-switched WDM networks," IEEE Journal on Selected Areas in Communications, vol. 18, pp. 1838–1851, October 2000.

[4] J. Y. Wei and R. I. MacFarland Jr, "Just-In-Time signaling for WDM optical burst switching networks", IEEE/OSA Journal of Lightwave Technology, vol. 18, pp. 2019–37, Dec. 2000.

[5] M. Yoo, C. Qiao and S. Dixit, "QoS Performance of Optical Burst Switching in IP-over-WDM Networks," IEEE Journal on Selected Areas in Communications, vol. 18, pp. 2062-2071, October 2000.

[6] V. Vokkarane, and, J.P. Jue, "Prioritized Burst Segmentation and Composite Burst-Assembly Techniques for QoS Support in Optical Burst-Switched Networks", IEEE J. Select. Areas in Comm., vol. 21, no. 7, pp.1198-1209, Sept. 2003.

[7] W. Liao and C. Loi, "Providing service differentiation for optical-burst-switched networks", IEEE J. of Light. Techn., vol. 22, no. 7, 2004.

[8] Q. Zhang, V.M. Vokkarane, J.P. Jue, and Biao Chen, "Absolute QoS Differentiation in Optical Burst-Switched Networks", IEEE Select. Areas in Comm., vol. 22, no. 9, pp. 1781-1795, Nov. 2004.

[9] M. Dueser and P. Bayvel. "Analysis of a dynamically wavelength-routed optical burst switched network architecture", IEEE/OSA Journal of Lightwave Technology, 20:574-585, April 2002.

[10] K. Vlachos et al. "Relaxing Delayed Reservations: An approach for Quality of Service differentiation in Optical Burst Switching networks", in proceedings of BROADNETS, vol.1, pp. 1-8, Oct. 2006.

[11] R. Karanam, V. M. Vokkarane, and J. P. Jue, "Intermediate Node Initiated (INI) Signaling: A Hybrid Reservation Technique for Optical Burst-Switched Networks", Proceedings, IEEE/OSA Optical Fiber Communication Conference 2003, Atlanta, GA, March 2003.

[12] J. Liu, N. Ansari, and T.J. Ott, "FRR for Latency Reduction and QoS Provisioning in OBS Networks", IEEE Select. Areas in Comm., vol. 21, no. 7, pp. 1210-1219, Sept. 2003.

[13] J. R. Treichler, C. R. Johnson Jr., and M. G. Larimore, *Theory and Design of Adaptive Filters*. New York: Wiley, 1987.

[14] V. Paxson, S.Floyd, "Wide-Area Traffic: The Failure of Poisson Modeling", IEEE/ACM Transactions on Networking, vol. 3, no, 3, pp226-244, Jun 1995.

[15] Agilent Technologies. (2001, Aug.). "http://advanced. comms.agilent.com/insight/2001-08/Questions/ traffic_gen.htm

[16] Y. Xinyu, Z. Ming, Z. Rui and S. Yi, "A Novel LMS Method for Real-Time Network Traffic Prediction", Springer Lect. Notes in Computer Science, vol. 3046, pp. 127-136, 2004.