

QoS Field Equivalence Classification in Optical Burst Switched Networks

Benon K. Muwonge, *Student Member, IEEE* and Anthony H. Chan
Department of Electrical Engineering, University of Cape Town

Abstract— This paper proposes a QoS Field Equivalence Classification (FEC) scheme for Optical Burst Switched (OBS) networks. The proposed FEC scheme assembles bursts, based on the QoS requirements of the individual packets. To model a realistic assembly scheme, we simulate a network of queues with two queues and an assembler. The first queue receives the packets, which is served by the assembler, which in turn serves the second queue with the assembled bursts. In our simulations we use self-similar traffic for the incoming packets, and wavelength converters on both the ingress/egress and core nodes. We use ns-2 for our simulations.

Index Terms— Self-Similarity, Field Equivalence Classification, Burst Assembly

I. INTRODUCTION

THE unprecedented and continual growth of Internet traffic in recent years is pushing current electronic switching technologies to their limits. The alternative to electronic switching is the use of all-optical switching, but this technology is still in its early research stages. An available alternative to all-optical switching is Optical Burst Switching (OBS), which was first proposed in [1] and has generated a lot of research interests. OBS uses all-optical switching for the payload data bursts and optical-electrical-optical switching for the burst header packet (BHP). The payload and header packet are separated by an offset time.

There are three main areas of study in OBS: burst assembly, scheduling of the assembled bursts, and routing of bursts to egress nodes. In this paper, we focus on burst assembly and include setting of the offset times for the assembled self-similar traffic at the ingress node.

The increase in Internet traffic has led to important changes in traffic distribution that must be considered during assembly. Leland *et al.* in [2] and [3] showed that Internet traffic has indeed deviated from the traditional Poisson distribution to a heavy tailed distribution exhibiting Long Range Delays (LRD). The LRD characteristic implies that Internet traffic has an infinite variance, which in turn implies that the probability under the heavy tail of the distribution accumulates to a non-negligible probability. The modeling of Internet traffic using the Poisson distribution, which exhibits Short Range Delays

(SRD) - with finite variance - implies neglecting a significant probability that resides in the tail.

The Hurst parameter H , which is used as a measure of burstiness of traffic relates to LRD of traffic with the equation, $H = (3-\alpha)/2$, with $0.5 < H < 1$, $1 < \alpha < 2$, (1) where α is the shape of the tail of LRD traffic. The burstiness of traffic increases as H and α tend to 1. Between 1 and 2, the shape parameter has a finite mean and an infinite variance.

Studies on the impact of the burstiness of traffic on queuing models using the Poisson distribution have shown that with increase in self-similarity, performance is significantly degraded. Results in [4] and [6] demonstrate how self-similarity is critical to traffic engineering. The self-similar characteristic must be taken into account during assembly of bursts to avoid excessive delays due to long queues.

The Pareto distribution is one of several heavy tailed distributions known and simplest to implement in modeling self-similarity. It has been shown in [5] that aggregated streams of Pareto ON/OFF streams results in self-similar traffic. Qiao in [7] shows that self-similarity of traffic does not reduce significantly after burst assembly. This is contrary to reports in [8] and [9], where self-similarity is reported to reduce significantly. However several studies have been published to support results in [7]. In this study we assemble self-similar traffic into Pareto-like streams, to generate bursts and offset times.

In our assembly scheme, we take delay tolerance of each individual packet to be the primary QoS parameter for packets being assembled. The assembly scheme assembles bursts without violating the delay tolerance of the packets. The scheme also ensures that sent bursts are not too short, which would compromise the performance of the OBS network.

In the simulation, we use ns2 to generate packets that are assembled into bursts, aggregate Pareto distributed traffic sources to get self-similar traffic.

We assume wavelength conversion is available at every Label Switch Router (LSR) node in the core, and a Just Enough Time reservation scheme proposed in [1] is used. The Latest Available Unused Channel with Void Filling (LAUC-VF) scheduling scheme is used in our analysis. No electronic buffers at the LSR nodes are used. No Field Delay Lines (FDL) are used either.

We discuss the delay constraints and bursts offset times, as

related to QoS in OBS (Section II) and highlight previous work done in burst assembly (Section III). We then propose an FEC-based assembly scheme and describe its functionalities (Section IV). The simulation set-up used is then detailed (Section V) and presentation and discussion of results done (Section VI). We finish this paper with a conclusion of our study (Section VII).

II. OFFSET AND DELAY TOLERANCE

In this section we outline the relation between offset time and burst assembly when QoS of traffic is to be maintained.

Assembly time is inversely proportional to the offset time, that is, the longer the assembly time, the less time will be available for setting an offset at the burst queue. Assembly time has implications on delay of traffic and therefore on QoS as well. While a burst is being assembled, or after its assembly, a BHP is transmitted and begins to reserve resources for the burst. While the BHP is propagating into the core network to the time the burst is transmitted, the offset time is increasing. At the point of transmission, the offset reaches its maximum, off_{max} .

Besides packet drops due to buffer overflow, and contention, QoS also depends on the delays incurred by the packets, from the moment of entry into the ingress to the time of exit at the egress node. Each traffic type has a delay tolerance range within which transmission of the packet should be done. Table I shows several applications whose delay constraints we use in this study to represent Internet traffic.

TRAFFIC TYPE	ONE WAY DELAY TOLERANCE
Video conferencing	0≤80ms
Conversation	0≤80 (by ITU-T) 0-150 (Preferred)
	150-400 (with degradation in Quality)
Video streaming (MPEG)	150-400ms
Audio streaming	10ms
Two-way control	250ms
Telemetry	
Interactive gaming	250ms
Web-browsing	2-4 secs per page 0.5secs (preferred)
E-commerce	2-4 s
SMS, Fax	30 s
e-mail	Greater than 1min

TABLE I SHOWING THE DIFFERENT TRAFFIC TYPES AND THEIR DELAY REQUIREMENTS – FROM ITU-T

In this study we use the different delay tolerances of packets at the time of arrival at the ingress node to assign priority to the packet. To assign priority for each of the packets, we assume there are infinite priorities. We use equation (2) to assign each packet a priority $q_p(\mathbf{t})$.

$$q_p(t) = (t - \tau) b_p \quad (2)$$

Equation (2) was proposed for time shared systems in [16], where τ is the time of arrival of the packet, \mathbf{t} is the current time of service, and b_p is a rate of service of the packets. In this

study we let b_p to be equal to the inverse of the assigned delay tolerance of the packet. We use this method of assigning priority at both the packet and burst buffer of the queue network.

III. PREVIOUS RELATED WORK

In this section highlight some of the work done in burst assembly and offset based QoS schemes.

Burst assembly schemes are broadly classified into three major categories: Burstlength-based, Timer-based and mixed timer/burstlength-based [1]. Recent research efforts have been focused on assembly of bursts using schemes that supports QoS.

In [9] a Composite Class Burst (CCB) assembly scheme that takes into account delay tolerance is proposed. CCB defines burst classes with respect to different assembly times after which a burst is transmitted. Assembly of bursts using CCB allows for different packets to be assembled in the same burst.

An *extra offset time* QoS scheme is proposed in [10] using FDLs and in [11] without FDLs. In [12] two classes are considered, real time and non-real time. It is shown that by assigning longer offset times to real time applications their probability of blocking reduces significantly. In [13] it is argued that assigning long offset times to high priority bursts results in prolonged end-to-end delays. This is true, though a re-definition of long offset time should be limited to fall within the end-to-end delay tolerances of a given burst class.

In [14] a threshold assembly scheme is proposed instead, and contention resolution done using priority based segmentation. Segmentation policies demand that each field of a burst have a specified length, and burst classes have fixed lengths. This method would result in long queues at the ingress nodes due to the slow generation and transmission of bursts. This scheme would especially not perform well with bursty traffic.

From previous work we argue that offset based schemes can be modified to cater for QoS in OBS networks by appropriately controlling long offset times to be within delay tolerance limits of a burst. Assembly schemes need to assemble bursty traffic, and still maintain QoS.

IV. PROPOSED QoS SCHEME

In this section, we propose an assembly algorithm that takes into account the effects of self-similarity on the performance of an OBS network.

The aim of this scheme is to achieve equilibrium between the incoming packets to the transmission of the bursts. Achieving an equilibrium implies that the rate of arrival packets at the ingress node corresponds to the rate at which the bursts are formed and transmitted. By using FEC we hope to make assembly faster.

During the assembly, at each of the three stages at the LER, we make several considerations for both the packet and burst

queues. From the given considerations, we can then optimally design a queuing scheme that will address QoS at the LER.

A. FEC Packet Classification

Each of the packets entering the packet buffer has QoS requirements that are independent of the other packets in the buffer. We discuss how the packets are classified into four FEC burst classifications proposed in this study. We use decision theory [17] to classify the packets into the appropriate burst. The decision making is based on the fact that every packet has a delay tolerance that allows for flexibility during packet routing, and on the assumption that no packet has a delay tolerance less than the amount of time it takes to route the packet through the OBS network, using the shortest route to its destination.

We shall refer to the four different packet types as packet type 1, packet type 2, packet type 3, and packet type 4. We shall refer to the four different FEC classifications as FEC A, FEC B, FEC C and FEC D with FEC A giving priority to the shortest delay tolerant packets in the packet buffer, and FEC D giving priority to the longest delay tolerant traffic. The decision as to which FEC a burst should take is continually made and updated as the burst is being assembled, and a final decision made when the burst has been fully assembled.

We shall use the symbol \succ to indicate strict preference of one FEC to another and $\succ\sim$ to indicate relative preference. On arrival into the packet buffer, packets have their individual FEC preference, and each packet's preference is first considered separately. Once assembled, the packets, though initially with different FEC preferences, take on a single FEC preference. The FEC classification we make takes on two stages, first the packet advertises its FEC preference, depending on the joint FEC preference of the partial burst being assembled, the packet may then either be given its preferred FEC choice, or a different FEC that does not violate its QoS requirements. On the other hand, should the packet be the first burst being assembled, then no comparisons are made.

We first consider packets with strict FEC preferences in Table II:

	FEC Preference
Packet type 1	$A \succ_1 B \succ_1 C \succ_1 D$
Packet type 2	$B \succ_2 A \succ_2 C \succ_2 D$
Packet type 3	$C \succ_3 B \succ_3 A \succ_3 D$
Packet type 4	$D \succ_4 C \succ_4 B \succ_4 A$

TABLE II: PACKET TYPES AND THEIR CORRESPONDING FEC PREFERENCES

Table II strict preferences show Packet type 1, first prefer to be classified in FEC A then FEC B if the former is not available, then FEC C and finally FEC D. An FEC may not be available if a packet requesting for the FEC finds packets of the

same or higher priority in the queue ahead of it that add up to more than the maximum burst length of the current burst being assembled. Packet type 2 preferences are first FEC B, which adequately serves its QoS demands, with a secondary option of FEC A, which would still maintain the QoS demands, then FEC C and FEC D respectively are the next preferred FECs. For Packet types 1 and 2, the preferences of FECs C and D are on condition that the burst being assembled will be transmitted in a time limit within the Packet 1 and 2's requirements. This will involve preempting the transmission of a burst at the LER during assembly. The set offset would then have to set to meet the requirements of the shorter delay tolerant packets. FEC preferences of Packet type 3, are FEC C, which adequately meets its QoS requirements, then FEC B and A, which still meet its QoS demands, and finally FEC D if available, which would have to be preempted for transmission. Packet type 4 have preferences in the reverse order of delay tolerance, and dependent on the availability of the FECs.

Strict FEC preferences do not allow for flexibility during assembly. Consider a case where at time t , a burst of FEC C assembled to a length x , greater than the minimum required burst length but less than the maximum burst length, with timeout for burst assembly not having expired. The assembly scheme should allow for preemption of burst transmission, or padding of the burst with packets of a different packet type, and preempting of transmission. In this study we assume that the packet queue is never empty, therefore the latter condition is applied. Padding of bursts allows for flexibility of the assembly routine. To accommodate burst padding, we have to use relative preference as well. Table III shows packet type preferences.

	FEC Preference
Packet type 1	$A \succ_1 B \succ_1 C \succ_1 D$
Packet type 2	$B \succ\sim_2 A \succ_2 C \succ_2 D$
Packet type 3	$C \succ\sim_3 B \succ\sim_3 A \succ_3 D$
Packet type 4	$D \succ\sim_4 C \succ\sim_4 B \succ\sim_4 A$

TABLE III. PACKET TYPE PREFERENCES GIVING RELATIVE PREFERENCES

Table III shows that only packets with higher delay tolerances will take preferences to higher order FEC classes which would still not violate its QoS requirements. For instance, Packet type 3 will be allowed to pad FEC B and A if and only if they are idle and timeout for burst transmission is pending. Should padding options not be available, packet type 3 then takes the option of FEC D, which may result in the burst being preempted for transmission.

The proposed FEC scheme results in the assembly of bursts that may have multiple packet types while guaranteeing the QoS for each of the individual packets. By meeting the QoS demands for each of the packets, we do not compromise

network performance, therefore, all bursts transmitted must have the minimum and maximum burst lengths.

V. SIMULATION SET-UP

We simulate two general classes to simplify the simulations; traffic with delay constraints, FEC 1-3, and traffic without delay constraints, FEC-4. Table IV shows the simulation environment used.

Computer processor	3 GHz Pentium 4 processor
Total hard disk space available	80GB
Operating system	Fedora Core 3 Linux system
Simulation platform	Ns-2.28
Programming languages	C++ and TCL
Base simulator	OBS.o.9a

TABLE IV SHOWING ENVIROMENT SETTINGS FOR THE SIMULATION

We use the topology in Fig 1 for our simulation. Each ingress node has 30 connections of Pareto distributed traffic to get self-similar traffic. We use a 1.85 shape parameter, consistent with findings in [5]. Each link has a 1Gbps capacity, 20 wavelengths per link and a 1ms length.

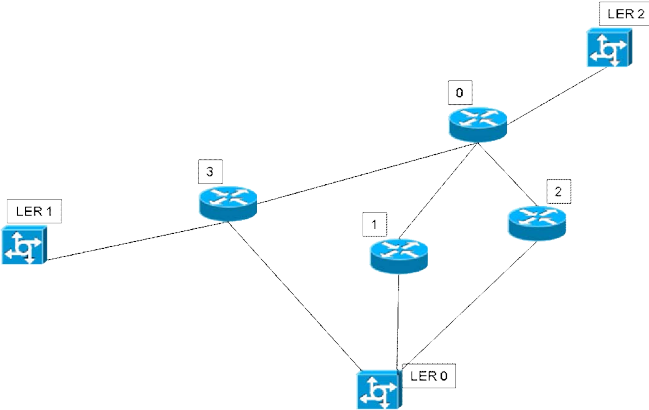


Fig. 1. Topology used for simulation, with 3 ingress/egress nodes and 4 core nodes.

VI. RESULTS

Our simulations show that contention is reduced at the LSR nodes resulting in less burst loss by about 16%. However, delay at each of the LERs is increased in the proposed scheme due to the queuing involved. Though the delays are increased, this is a more realistic scenario compared to schemes that do not consider buffering at the LER.

The proposed FEC-Based assembly scheme results in bursts with burst length distributions shown in Fig 3. In Fig 3 we show a sample of bursts of FEC 4, and FEC 1-3. Though most proposals allow for bursts to have a maximum of 4000 bytes, we allow for bursts of FEC 4 to have burst lengths up to 5000 bytes, and a minimum 4000 bytes. This is because for FEC-4 bursts, delay is not a major constraint, and burst lengths of up

to 5000 bursts can be assembled without violating time delay constraints. It should be noted that though FEC-4 bursts are assembled using a constant length based scheme, and burst lengths vary. The varying of burst lengths is due to the design of the assembly scheme, which dictates that when the threshold of 4000 FEC-4 packets are assembled, and there exist in the buffer FEC 1-3 packets, these packets are used to pad the burst up to a maximum of 5000 bytes in length. Pre-emption must therefore occur if padding of packets with FEC 1-3.

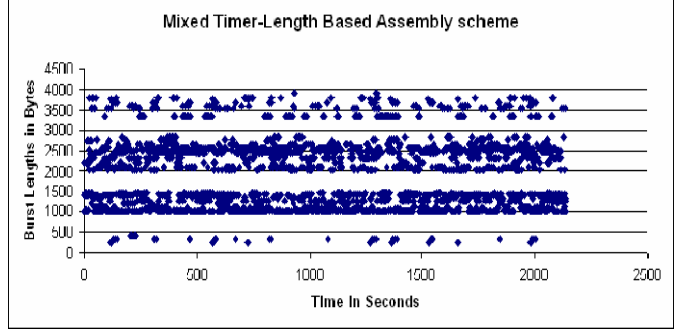


Fig. 2. Burst lengths when a mixed-timer-length based scheme is used for assembly without FEC.

The proposed FEC-based assembly scheme shows that less bursts are dropped compared to length, timer, and mixed-timer length based schemes. This result is expected since bursts in the FEC-based scheme are on average longer due to the isolation of FEC 4. Compare Fig 2 with Fig 3, where bursts are assembled using the mixed-timer-length based assembly scheme. Bursts from the FEC-Based scheme are generally longer than those from the Mixed-timer-Length based scheme. No FEC is used in Fig 3. Generally, the longer the bursts, the less probability number of bursts in the core, more efficient use of wavelengths and therefore less resource contention.

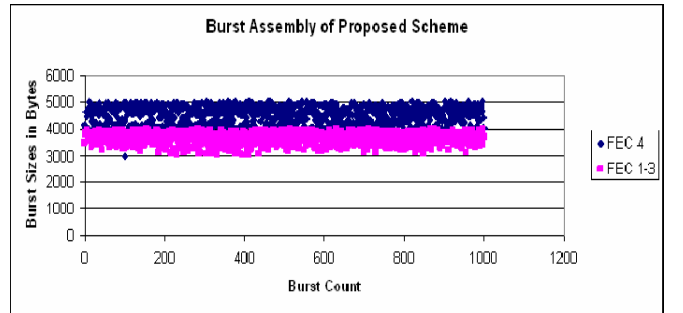


Fig. 3. Distribution of assembled bursts using the proposed FEC-Based Assembly scheme.

VII. CONCLUSIONS

We have proposed an FEC classification scheme for OBS networks at the ingress node. We find that the proposed assembly scheme assembles bursts more efficiently compared to a purely mixed-timer assembly scheme without FEC. We also found that assembled traffic maintains self-similarity and performance is affected by the self-similarity of the incoming traffic.

From the presented results, we have shown that, though most of contention resolution must be resolved in the core, a significant amount of contention can be reduced by using an FEC-based burst assembly scheme.

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, no. 1, pp. 69-84, Jan. 1999.
- [2] W. E. Leland, M. S. Taqqu, W. Willinger, and D. V. Wilson. "On the self-similar nature of Ethernet traffic." *A CM/SJGCOMM Computer Communications Reuzew*, Vol. 23, pp. 1S3-193, 1993. Proceedings of the ACM/SIGCOMM'93, San Francisco, September 1993. September 1993.
- [3] W. E. Leland, M. S. Taqqu, W. Willinger, and D. V. Wilson. "On the self-similar nature of Ethernet traffic (Extended Version)." *IEEE/ACM Transactions on Networking*, Vol. 2, pp. 1-15, 1994.
- [4] V. Paxson and S. Floyd, "Wide-area Traffic: The Failure of Poisson Modeling," *IEEE/ACM Transactions on Networking*, pp. 226-244, June 1995
- [5] W. Willinger, V. Paxson and M. S. Taqqu, "Self-Similarity and Heavy Tails Structural Modeling of Network Traffic," *A Practical Guide to Heavy Tails: Statistical Techniques and Applications*, pp. 28-53
- [6] M. J. Fisher "A Method for Analyzing Congestion in Pareto and related Queues", *The 2005 Telecommunications Review*, 2005
- [7] X. Yu, Y. Chen, and C. Qiao. "Study of traffic statistics of assembled burst traffic in optical burst switched networks." *In Proceeding of Opticomm*, pages 149-159, 2002.
- [8] A. Ge, F. Callegati, and L. S. Tamil "On Optical Burst Switching and Self-Similar Traffic", *IEEE Communication Letters* March 2000
- [9] V. M. Vokkarane et al., "Generalized Burst Assembly and Scheduling Techniques for QoS Support in Optical Burst-Switched Networks", *Proceedings, IEEE GLOBECOM 2002, Taipei, Taiwan*, Nov 2002.
- [10] M. Yoo, C. Qiao and Sudhir Dixit, "QoS performance of optical burst switching in IP-over-WDM networks", *IEEE J. Select. Areas Commun.*, vol. 18, No. 10, pp. 2062-2070, Oct. 2000.
- [11] K. Long, R. S. Tucker and C. Wang "A New Framework and Burst Assembly for IP DiffServ over Optical Burst Switching Networks" *Elsevier Science Direct Journal*, August 2005
- [12] L. Xinwan et al. "An Experimental Study of an Optical Burst Switching Network Based on Wavelength-selective Optical Switches", *IEEE Communications Magazine*, May 2005, pp. S3-S11
- [13] M. Yoo and C. Qiao, "A new optical burst switching (OBS) protocol for supporting quality of service," *ISPIE Proc., "All Optical Commun. Syst.: Architecture, Control Network Issues"*, vol. 3531, Nov. 1998, pp. 396-405.
- [14] V. M. Vokkarane, K. Haridos and J. P. Jue, "Threshold-Based Burst Assembly Policies for QoS Support in Optical Burst-Switched Networks" *Proceedings, Optical Networking and Communication Conference (OptiComm) 2002*, Boston, MA, July-Aug 2002.
- [15] D. Gao, H. Zhang, "Reservation information sharing enhancement for deflection routing in OBS network," *Optical Society of America*, 2005
- [16] L. Kleinrock, *Queueing Systems, Volume II: Computer Applications*, vol. 2, Wiley-Interscience, 1976.
- [17] S. French "Decision Theory: an introduction to the mathematics of rationality." Ellis Horwood Limited 1988.

After joining the former AT&T Bell Labs in 1986, his work moved to industry-oriented research in areas of interconnection, electronic packaging, reliability, and assembly in manufacturing, and then moved again to network management, network architecture and standards for both wireless and wireline networks. He had designed the Wireless section of the year 2000 state-of-the-art Network Operation Center in AT&T. He was the AT&T delegate in several standards work groups under 3rd generation partnership program (3GPP). During 2001-2003, he was visiting Endowed Pinson Chair Professor in Networking at San Jose State University. In 2004, he joined University of Cape Town as professor in the Department of Electrical Engineering.

Prof. Chan is Administrative Vice President of IEEE CPMT Society and had chaired or served numerous technical committees and conferences. He is distinguished speaker of IEEE CPMT Society and is in the speaker list of IEEE Reliability Society since 1997.



Benon K. Muwonge is a postgraduate student in the Department of Electrical engineering, University of Cape Town.



H Anthony Chan (M'94-SM'95) received his PhD in physics at University of Maryland, College Park in 1982 and then continued post-doctorate research there in basic science.