Forward Error Correction:
A Loss Recovery Mechanism for Optical Burst-Switched Networks

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***Abstract*— Optical burst switching is one of the most promising next-generation all-optical data transport paradigms. In this paper, we discuss *forward error correction* as a candidate for providing loss recovery in an optical burst-switched network. We develop a network-level analytical model to evaluate the packet loss probability of forward error correction loss recovery mechanism. We also develop a simulation model to investigate the proposed forward error correction loss recovery mechanism and to compare the performance of our proposed mechanism with the existing burst retransmission loss recovery mechanism. Our results show that the proposed mechanism significantly reduces the packet loss in an optical burst-switched network.**

***Keywords:* WDM, TCP, IP, OBS, and FEC.**

I. INTRODUCTION

In wavelength division multiplexed (WDM) networks, channels are created by dividing the bandwidth into a number of wavelength bands, each of which can be accessed by the end-user at peak electronic rates. WDM networks are able to offer huge bandwidths on the order of 50 THz at optical fiber links. In order to efficiently utilize this bandwidth, we have to design efficient transport architectures and protocols based on the state-of-the-art optical device technology [1]. This transport method must be also able to handle asynchronous bursty traffic by quickly provisioning resources while also minimizing the use of optical buffering. Optical burst switching (OBS) is one such method for transporting traffic directly over a bufferless optical core network [2], [3].

In an OBS network, a data burst consisting of multiple IP packets is switched through the network all-optically. A burst header packet (BHP) is transmitted ahead of the burst in order to reserve the data channel and configure the switches along the burst's route. In a popular OBS signaling technique called just-enough-time (JET) [2], the burst transmission follows an out-of-band BHP after a predetermined offset time. The offset time allows the BHP to be processed before the burst arrives at the intermediate nodes; thus, the burst does not need to be delayed at the intermediate nodes. The BHP also specifies the duration of the burst so that each node knows when the resources being used by the burst will be released. Other OBS signaling techniques, such as just-in-time (JIT) [4], [5], [6] are also implemented in an one-way unacknowledged manner.

Optical burst-switched networks are typically connectionless in nature; thus, it is likely that there will be contention for resources in the core network, leading to packet loss. Contention resolution is an important research issue in OBS networks. When two or more bursts are destined for the same output port at the same time, contention occurs. When a contention cannot be resolved, one of the contenting burst is lost. If the dropped burst cannot be recovered at the OBS layer, higher layers (such as TCP) will need to handle the retransmission of the lost data at a later time.

In order to satisfy the low-loss requirement of higher-layer applications and to overcome the lossy nature in OBS networks, a reliable OBS network must be developed. In this paper, we provide an overview of loss minimization and loss recovery mechanisms that improve the reliability of the OBS network. We propose a novel loss recovery mechanism that combines burst segmentation [7] with forward error correction. In the proposed loss recovery mechanism, forward error correction code packets are generated for a group of data packets, and the code packets are assembled with their original data packets into a single burst at the ingress nodes. In the OBS core network, we assume that if a burst experiences contention, segmentation is employed so as to drop only the overlapping segments of one of the contenting bursts. The dropped segments of a burst can be recovered using the FEC code packets at the OBS egress node, resulting in lower packet loss. We develop a network-level analytical model to evaluate the packet loss probability of forward error correction loss recovery mechanism. We develop a simulation model to investigate the proposed FEC loss recovery mechanism and to compare the performance of our proposed mechanism with the existing burst retransmission loss recovery mechanism.

The rest of this paper is organized as follows: Section II provides a brief overview of loss minimization and loss recovery mechanisms necessary to support a reliable OBS network. Section III proposes the forward error correction (FEC) loss recovery mechanism. In Section IV, we analyze the packet loss probability of the FEC mechanism over an entire network. Section V evaluates the performance of the proposed FEC mechanism. Section VI concludes the paper.

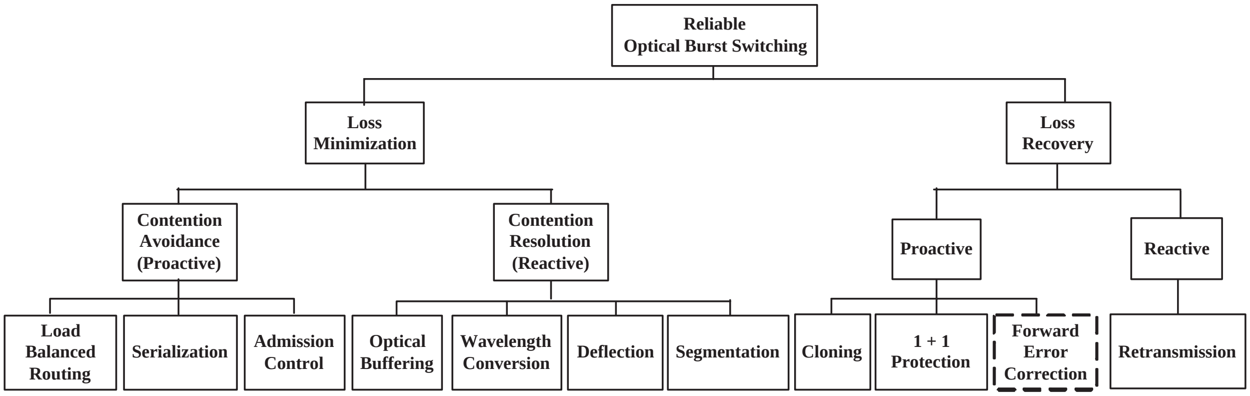

Fig. 1. Reliable Optical Burst Switching Framework.

II. BACKGROUND: RELIABLE OBS

In this paper, we focus on the goal of implementing a reliable optical burst-switched network using loss minimization and loss recovery mechanisms. In this section, we classify and describe the different loss minimization and loss recovery mechanisms. The entire framework for supporting a reliable OBS network is shown in Fig. 1.

A. Loss Minimization: Contention Resolution Vs. Contention Avoidance

We classify all loss minimization mechanisms into two broad categories, namely, *Contention Resolution* and *Contention Avoidance*. Contention resolution mechanisms attempt to minimize data loss when a contention has already occurred. On the other hand, contention avoidance mechanisms attempt to minimize the occurrence of contentions. Now let us discuss the mechanisms in the two categories respectively.

1) Contention Resolution Mechanisms: The primary contention resolution mechanisms are optical buffering [8], wavelength conversion [9], deflection routing [10], [11], [12], and burst segmentation [7]. These mechanisms minimize data loss when a contention has already occurred. Since we will apply burst segmentation in our proposed mechanism, we now briefly describe burst segmentation.

In burst segmentation [7], the burst is divided into basic transport units called *segments*. Each of these segments may consist of a single IP packet or multiple IP packets, with each segment defining the possible partitioning points of a burst when the burst experiences contention in the optical network. All segments in a burst are initially transmitted as a single burst unit. However, when contention occurs, only the overlapping segments of one of the bursts in contention will be dropped, as shown in Fig. 2. If switching time is not negligible, then additional segments may be lost when the output port is switched from one burst to another. There are primarily two approaches for dropping burst segments during a contention. The first approach, tail dropping, is to drop the tail of the original burst (Fig. 2(a)), and the second approach, head dropping, is to drop the head of the contending burst (Fig. 2(b)) [7].

Segmentation is a well accepted contention resolution mechanism that combines the benefits of a relaxed switching constraint based optical burst switching with the optimal packet-level loss granularity of photonic packet switching [7], [13], [14], [15], [16], [17], [18], and [19]. Through extensive simulations and analytical modeling, it has been previously shown that segmentation can reduce the loss probability by up to 50% in optical burst-switched network [7].

2) Contention Avoidance Mechanisms: The contention resolution mechanisms minimize packet losses based on the local information at the nodes where contentions occur, but do not address the more fundamental problem of congestion in the OBS core. In [20], two dynamic load-balanced routing techniques are proposed to avoid burst contentions. The simulation results show that the proposed contention avoidance techniques improve the network utilization and reduce data loss. In [21], [22], and [23], the authors investigated similar load-balancing routing (or path switching) approaches using adaptive alternate path routing and concluded with similar observations as [20]. In [24], a proactive scheduling algorithm referred to as burst overlap reduction algorithm

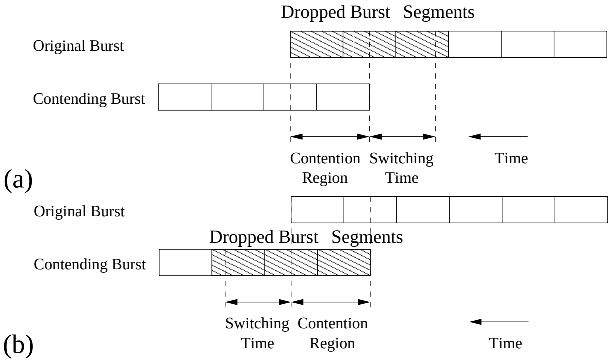

Fig. 2. Selective segment dropping for two contending bursts (a) tail-dropping policy (b) head-dropping policy.

(BORA) is proposed. The basic idea is to serialize the bursts on outgoing links to reduce the burst overlapping degree (and thus burst contentions and burst loss at downstream nodes). The biggest side-effect of BORA is that it introduces significant delay at the edge during serialization of bursts. In addition, several other edge-based admission control techniques can be incorporated to minimize the number of contentions in the core.

B. Loss Recovery: Reactive Vs. Proactive

Burst loss may still occur after using the different loss minimization mechanisms. Hence, loss recovery mechanisms are essential in addition to loss minimization mechanisms to support a reliable OBS transport network. We classify all loss recovery mechanisms into one of two categories, namely, *Reactive* and *Proactive*. Reactive loss recovery mechanisms are generally optimistic about the successful reception of the transmitted burst at the destination. Hence, reactive mechanisms only attempt to recover when they receive an explicit failure message. On the other hand, proactive loss recovery mechanisms are generally pessimistic about the successful reception of the transmitted burst at the destination. Proactive mechanisms transmit additional information (overhead) along with the original burst so as to handle certain loss scenarios. Broadly speaking, reactive mechanisms are better suited when burst loss is rare and bandwidth utilization needs to be optimized. Proactive mechanisms are better suited when burst losses are high and delay needs to be optimized.

We now describe the different loss recovery mechanisms shown in Fig. 1. We first describe the only reactive OBS loss recovery mechanism, namely, *retransmission*. We then describe the proactive loss recovery mechanisms, such as burst cloning and $1+1$ protection. Note that a combination of loss recovery mechanisms can be implemented to further reduce the loss in the OBS network.

1) Retransmission: The basic idea of burst retransmission is to allow contending bursts to be retransmitted in the OBS layer. In this scheme, BHPs are sent out prior to data burst transmission in order to reserve resources. After an offset time, the burst is transmitted. At the same time, the ingress node stores a copy of the transmitted burst for possible retransmissions. As the BHP traverses through the core nodes, if the channel reservation fails due to a burst contention, the core node will send an *Automatic Retransmission Request* (ARQ) to the ingress node in order to report the reservation failure. Upon receiving an ARQ, the ingress node retransmits the corresponding duplicate preceded by its duplicate BHP. Additional details about retransmission can be found in [25]. We now briefly discuss the proactive loss recovery mechanisms.

2) Burst Cloning: In burst cloning [26], the idea is to replicate a burst and send duplicated copies of the burst through the network simultaneously. If any one of the burst copies is lost, the destination egress nodes can recover from the core loss using the other duplicate burst. Additional information needs to be stored in the BHPs to identify duplicates. So that, in the case both original and duplicate burst reach the destination, the destination will select one of the bursts, disassemble the burst, and forward the constituent packets on to the corresponding destination hosts. Based on the load on different links in the network, the original and the clone could be sent on different paths. Primary design issues in burst cloning are to select the optimal node at which to clone and to prevent cloned bursts from contending for resources with their original bursts.

3) $1+1$ Protection: $1+1$ protection for OBS is discussed in [27]. Here, premium data traffic is protected by routing two copies of the data over disjoint paths. The authors show that a sufficiently large difference in the propagation delays can cause performance degradations that may result in an unsatisfactory quality-of-service on the protected connection.

In this paper, we propose a forward error correction based loss recovery mechanism for the OBS network. The FEC mechanism does not involve extra signaling overhead as in the burst retransmission mechanism. Also, FEC mechanism can provide a flexible level of reliability (or redundancy) for each burst, unlike burst cloning and $1+1$ protection mechanisms that only provide a fixed 100% redundancy for each burst. In the following section, we describe the FEC loss recovery mechanism.

III. FORWARD ERROR CORRECTION

Forward error correction (FEC) is a type of error correction that improves on simple error detection schemes by enabling the receiver to correct errors once they are detected. Furthermore, FEC codes can ameliorate or even eliminate the need for feedback from receivers to senders to request retransmission of lost packets. FEC works by adding check bits to the outgoing data stream; adding more check bits reduces the amount of available bandwidth, but also enables the receiver to correct for more errors. In general, FEC makes it possible to transmit at much higher data rates if additional bandwidth is available. FEC is particulary well suited for optical transmissions, where bandwidth is reasonable but end-to-end latency across long-haul networks is significant [28].

In a communication system that employs forward error-correction coding, a digital information source sends a data sequence to an encoder. The encoder inserts redundant (or parity) bits, thereby outputting a longer sequence of code bits, called a *codeword*. Such codewords can then be transmitted to a receiver, which uses a suitable decoder to extract the original data sequence. FEC codes can be implemented using several different approaches, such as block codes and convolutional codes. In block

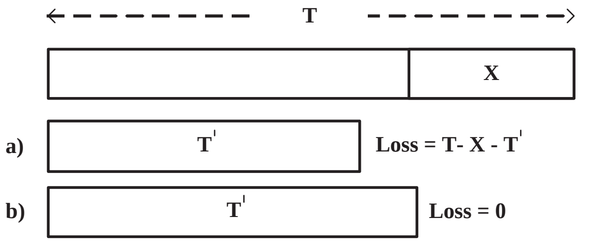

Fig. 3. Burst with FEC code packets. Two possible loss scenarios, a) when $T' < T - X$: loss of $T - X - T'$ bytes is incurred, and b) when $T' \geq T - X$: packet loss is completely recovered (loss is zero).

coding, the encoder intersperses parity bits into the data sequence using a particular algebraic algorithm. On the receiving end, the decoder applies an inverse of the algebraic algorithm to identify and correct any errors. While convolutional codes process the incoming bits in streams rather than in blocks. The paramount feature of such codes is that the encoding of any bit is strongly influenced by the bits that preceded it [29].

Recently, [30] proposed Reed-Solomon (RS) code based FEC mechanism to provide protection in a OBS network wherein bits in multiple bursts are encoded to create a redundant burst (of RS codes), and all these bursts are transmitted on multiple paths in order to provide protection against links failures in the core network. The FEC burst loss recovery scheme in [30] has limited scope since it is only applicable to traffic that need transmission of multiple bursts. Also, in order to implement this FEC mechanism, all these group of bursts have to sent on several (possibly disjoint) paths across the network. Transmitting burst on multiple paths causes severe problems at the receiver in terms of buffering delay so as to reorder, decode, and verify these bursts.

In this paper, we propose a FEC-based loss recovery mechanism for an OBS network with burst segmentation support. As discussed before, segmentation drops only the overlapping packets of a burst in contention to minimize packet loss. In our scheme, FEC codes (or redundant packets) can be placed along with every burst so that the receiver can recover from selective packet loss of each burst in the forward direction. Note that without segmentation, there is no benefit of adding redundant FEC codes into a burst. In general, RS codes are represented by $(T, T - X)$, where T-byte data consists of $(T - X)$-byte original data and X-byte redundant code [31]. The $(T, T-X)$ RS code can recover up to X-byte loss. Let T' is the burst length (in bytes) at the destination after possible segmentations in the OBS core. In scenario depicted in Fig. 3(a), final burst length given by, $T' < T - X$, results in a packet loss of $T - X - T'$ bytes. While in scenario depicted in Fig. 3(b), final burst length given by, $T' \geq T - X$, results in zero packet loss.

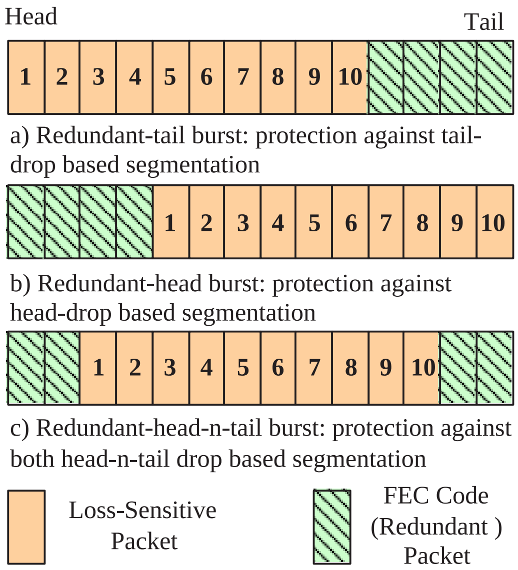

Fig. 4. Different burst assembly options using FEC, based on the segmentation technique incorporated in the OBS core.

If the type of segmentation [7] implemented by the OBS core is known in advance, we can place the code packets at specific positions inside a burst as shown Fig. 4. Fig. 4 illustrates the specific locations of a burst that are more susceptible to loss for each flavor of burst segmentation implemented in the core. For instance, if in a (n, k) RS code with $n = 14$ and $k = 10$, we could place the four redundant FEC code packets toward the tail of the burst, as shown in Fig. 4(a), if a strict tail-dropping segmentation is implemented in the OBS core. Similarly, Fig. 4(b) and Fig. 4(b) depict the scenarios of a strict head-dropping and a head-n-tail-dropping is implemented in the OBS core. In the general case, segmentation can be performed on the tail, the head, or both, and no specific burst assembly mechanism would do better than the other.

IV. ANALYTICAL LOSS MODEL

In this section, we develop an analytical model for evaluating the packet loss probabilities using forward error correction in an OBS network that supports a strict tail-dropping segmentation. Note that the loss model can be easily extended to other types of burst segmentation. We assume that bursts arrive in to the network according to a Poisson process with rate λ^{sd} bursts per second for each source-destination pair (s, d). We assume fixed shortest path routing, negligible switch reconfiguration time, and no buffer support at core nodes. We also assume that all bursts have the same offset time. This implies that the BHP of the original burst always arrives before the BHP of the contending burst (refer Fig. 2). We also assume that traffic on each link is independent. We assume that the length of each burst is fixed and that each burst is constituted of original data packets and redundant FEC code packets.

We begin by defining the following notation:

- λ_l^{sd}: arrival rate of bursts to link l, on the path between source s and destination d.
- $\lambda_l = \sum_{sd} \lambda_l^{sd}$: arrival rate of bursts to link l, due to all source-destination pairs sd.
- r_{sd}: route from source s to destination d.

The load placed on a link l by traffic going from source s to destination d depends on whether link l is on the path to destination d. If link l is on the path to d, then, the load applied to link l by sd traffic is simply λ^{sd}. Thus,

$$\begin{aligned} \lambda_l^{sd} &= \lambda^{sd} && \text{if } l \in r_{sd} \\ &= 0 && \text{if } l \notin r_{sd}. \end{aligned} \tag{1}$$

Also, the total (new) burst arrival into the network, λ, is given by:

$$\lambda = \sum_s \sum_d \lambda^{sd}. \tag{2}$$

We calculate the packet loss probability by finding the distribution of the burst length at the destination and comparing the mean burst length at the destination and the amount of redundant FEC codes to the mean burst length at the source. Let the initial cumulative distribution function of the burst length (including the FEC codes) be $G_{l_0^{sd}}(t)$, where l_0^{sd} is the zeroth hop link between source s to destination d, and the cumulative distribution function of the burst after h hops be $G_{l_h^{sd}}(t)$ for the bursts transmitted from source s to destination d. Let $F_{l_h^{sd}}(t)$ be the cumulative distribution function for the arrival time of the next burst on the h^{th}-hop link l between source-destination pair sd.

$$F_{l_h^{sd}}(t) = 1 - e^{-\lambda_{l_h^{sd}} t}, \tag{3}$$

where $\lambda_{l_h^{sd}}$ is the arrival rate of all bursts on the h^{th}-hop link on the path between the source s and destination d, l_h^{sd}.

The burst length will be reduced if another burst arrives while the original burst is being transmitted; thus, the probability that the burst length is less than or equal to t after the first hop is equal to the probability that the initial burst length is less than or equal to t or that the next burst arrives in time less than or equal to t. Therefore,

$$\begin{aligned} G_{l_1^{sd}}(t) &= 1 - (1 - G_{l_0^{sd}}(t))(1 - F_{l_1^{sd}}(t)) \\ &= 1 - (1 - G_{l_0^{sd}}(t)) e^{-\lambda_{l_1^{sd}} t}. \end{aligned} \tag{4}$$

Similarly, let $G_2(t)$ be the cumulative distribution function of the burst after the second hop.

$$\begin{aligned} G_{l_2^{sd}}(t) &= 1 - (1 - G_{l_1^{sd}}(t))(1 - F_{l_2^{sd}}(t)) \\ &= 1 - (1 - G_{l_0^{sd}}(t)) e^{-(\lambda_{l_1^{sd}} + \lambda_{l_2^{sd}}) t}. \end{aligned} \tag{5}$$

In general,

$$\begin{aligned} G_{l_h^{sd}}(t) &= 1 - (1 - G_{l_{h-1}^{sd}}(t))(e^{-\lambda_{l_h^{sd}}}) \\ &= 1 - (1 - G_{l_0^{sd}}(t)) e^{-\left(\sum_{i=1}^{h} \lambda_{l_i^{sd}}\right) t}. \end{aligned} \tag{6}$$

We now find the expected length after h hops and compare with the expected length at the source node to obtain the expected loss that a particular burst will experience. Let $L_{l_h^{sd}}$ be the expected length of the burst at the h^{th}-hop.

If we have fixed-sized bursts of length, $\frac{1}{\mu} = T$, the initial distribution of the burst length,

$$\begin{aligned} G_{l_0^{sd}}(t) &= Pr(T \leq t) \\ &= 1 \text{ if } t \geq T \\ & \quad\; 0 \text{ if } t < T. \end{aligned} \tag{7}$$

Substituting Eq. 7 into Eq. 6 and taking the expected value, we obtain:

$$L_{l_h^{sd}} = \frac{1 - e^{-\sum_{i=1}^{h} \lambda_{l_i^{sd}} T}}{\sum_{i=1}^{h} \lambda_{l_i^{sd}}}. \tag{8}$$

Let X be the expected length of the FEC codes placed in the burst at the source. We now find the expected length after H hops, where H is the total number of hops between s and d, and we compare with the expected length at the source node to obtain the expected loss that a particular burst will experience. Let $Loss_{sd}$ be the expected length of the burst lost per burst for a burst traveling from s to d.

$$\begin{aligned} Loss_{sd} = \; & T - X - L_{l_H^{sd}} && \text{if } (L_{l_H^{sd}} < T - X) \\ & 0 && \text{otherwise.} \end{aligned} \tag{9}$$

Note that the packet loss is proportional to the length of the route and the length of the burst. The packet loss probability of bursts, P_{loss}^{sd}, is given by:

$$\begin{aligned} P_{loss}^{sd} &= \frac{E[Length\ Lost]}{E[Initial\ Length]} \\ &= \frac{Loss_{sd}}{(T - X)}. \end{aligned} \tag{10}$$

We can then find the average packet loss probability of bursts for the system by finding the individual loss probability for each source-destination pair, and taking the weighted average of the loss probabilities:

$$P_{loss} = \sum_s \sum_d \frac{\lambda^{sd}}{\lambda} P_{loss}^{sd}. \tag{11}$$

Also, a more accurate model may be obtained by taking into account the link correlation effect.

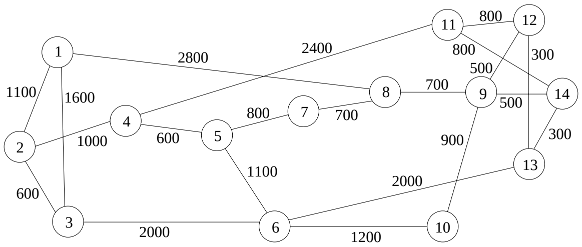

Fig. 5. NSF network topology (distance in km).

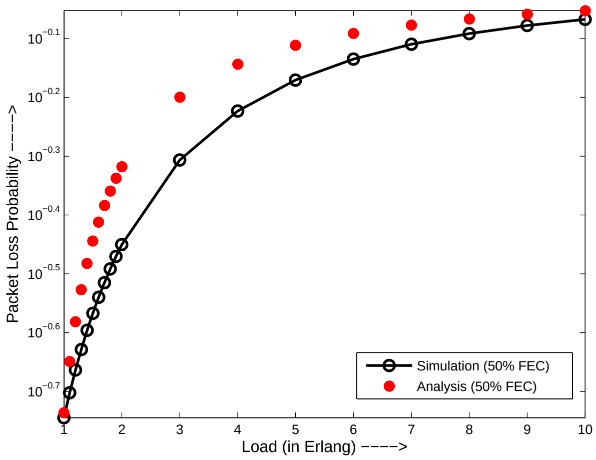

Fig. 6. Packet loss probability vs. load for simulation and analytical results.

V. NUMERICAL RESULTS

A. *Analytical Results*

In this section, we verify the analytical loss model for an OBS-based NSF network shown in Fig. 5. We assume that the number of wavelengths on each link is 1 and the transmission rate is 10 Gb/s. There are data traffic flows traversing through eight source-destination node pairs: (1,11), (3,11), (2,9), (3,9), (1,13), (2,10), (4,12), and (7,13). Burst arrivals follow a Poisson process and are uniformly distributed among the eight flows. Each burst generated has a fixed length of 100 packets and each packet is 1250 bytes long. We analyze the FEC loss recovery mechanism with 50% redundant code packets. Fig. 6 shows that the packet loss probability over the OBS network obtained by the analytical model and simulation. We observe that the simulation results match with the analytical results.

B. *Simulation Results*

In this section, we develop a network-wide simulation model in order to evaluate the performance of loss minimization and loss recovery mechanisms. We compare the performance of the FEC loss recovery scheme, the burst retransmission scheme, the segmentation scheme, and a baseline scheme that drops the entire burst on a contention. We simulate on the NSF network as shown in Fig. 5. The number of wavelengths on each link is 8 and the transmission rate on each wavelength is 10 Gb/s. We assume that all core nodes are bufferless (no FDLs) and have full-wavelength conversion capability. We also assume that the queueing delay is $0.1\ ms$ for the FEC scheme, the segmentation scheme, and the baseline scheme. The data traffic simulated traverse through eight ingress-egress node pairs: (1,11), (3,11), (2,9), (3,9), (1,13), (2,10), (4,12), and (7,13). Burst arrivals follow a Poisson process and are uniformly distributed among the eight flows. Each burst generated has a fixed length of 100 packets and each packet is 1250 bytes long. The load value in each plot is the original input traffic load in to the entire network in Erlang.

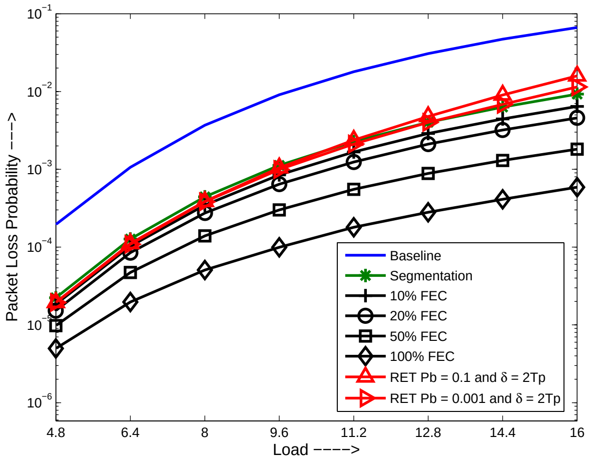

Fig. 7. Packet loss probability vs.load.

Figure 7 plots the average packet loss probability versus load for the OBS network with different loss minimization and loss recovery mechanisms. We simulate the FEC loss recovery mechanism with 10%, 20%, 50%, and 100% redundant code packets. In the burst retransmission scheme (RET), we set the delay constraint to be $2T_p$ and the different retransmission buffer blocking probability, p_b, to be 0.1 and 0.001. Note that $2T_p$ is the round-trip propagation delay between the source and the destination and p_b is the probability of a incoming burst being blocked at the ingress retransmission buffer. We observe that with higher redundancy, the packet loss probability of the FEC scheme reduces. We also observe that the FEC schemes performs better than all the other schemes, especially at high loads.

Figure 8 plots the average packet delay versus load for the OBS network with the different loss minimization and loss recovery mechanisms. We observe that the retransmission scheme has the highest average packet delay. This is due to the fact that the delay incurred in the FEC scheme includes only one-way propagation delay and data transmission delay, but the retransmission scheme incurs an additional retransmission delay. Also,

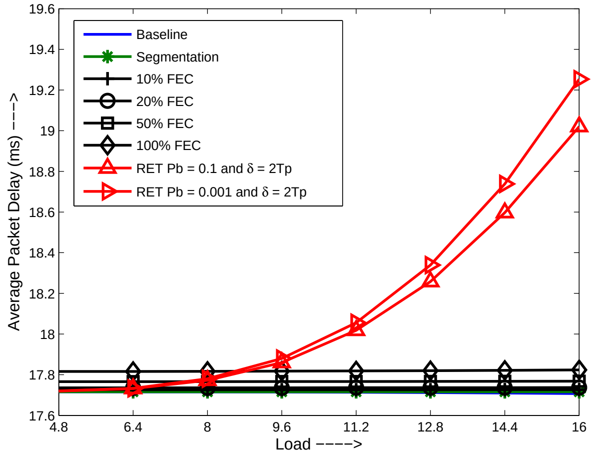

Fig. 8. Average packet delay vs. load.

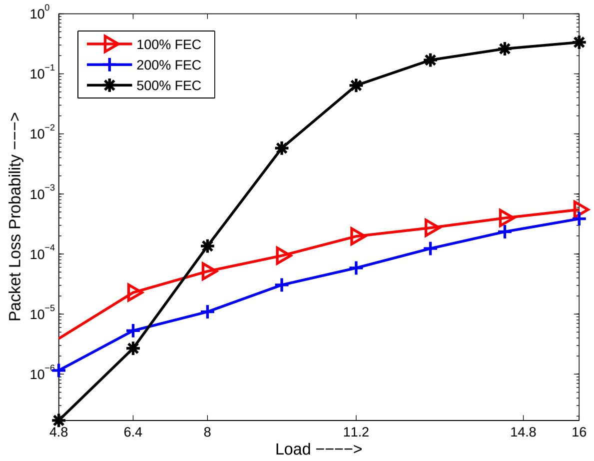

Fig. 9. Packet loss probability vs. load with very high redundant FEC code packets.

the FEC scheme with higher redundancy values results in higher packet delay, since higher redundancy generates larger-sized bursts resulting in higher data transmission delay.

However, the performance of the FEC loss recovery mechanism degrades at higher values of redundancy. Fig. 7 plots the average packet loss probability versus load for the OBS network using the FEC loss recovery mechanism with 100%, 200%, and 500% redundancy. We notice that at the highest load of 16 Erlang, the packet loss probability of the FEC scheme with 200% redundancy is similar to that of the FEC scheme with 100% redundancy. This is because the available network resource reduces with higher redundancy, and the gain due to redundancy reduces. We also observe that at loads higher than 7 Erlang, the performance of the FEC scheme with 500% redundancy degrades dramatically since the size of a burst increases significantly with higher values of redundancy leading to high loss at OBS edge nodes.

VI. CONCLUSION

In this paper, we presented a comprehensive framework for implementing a reliable OBS network using loss minimization and loss recovery mechanisms. The different proactive and reactive mechanisms are introduced and evaluated. We also compared the performance of the FEC mechanism with burst retransmission using the NSF network. Our simulation results show that FEC loss recovery mechanism significantly reduce the packet loss without any additional delay as compared to any other known OBS loss recovery mechanism. We developed an analytical loss model for the FEC loss recovery mechanism and we also verified its correctness through discrete-event simulations.

In this paper, we limit our study to static FEC, wherein the ratio of the data packets to the code packets is fixed. We intend to extend the static FEC mechanism to a dynamic feedback-based FEC mechanism such that the coding ratio of different traffic streams is dynamically adjusted based on the experienced loss (and load) along the path so as to add the optimal redundancy to each burst. Another area future work is to evaluate the effect of FEC schemes on different TCP flavors so as to achieve better performance in high bandwidth-delay optical networks.

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