A novel look-ahead collision-free optical burst transmission scheme

Seoung-Young Lee¹, Young-Tae Han²a) and Hong-Shik Park¹

¹ The Dept. of Information and Communications, Korea Advanced Institute of Science and Technology (KAIST)
Daejeon, S. Korea

² The Dept. of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST)
Daejeon, S. Korea

a) han0tae@gmail.com

Abstract: This paper presents a novel collision-less optical burst transmission scheme, namely, look-ahead optical burst transmission (LAOBT) for WDM ring networks. In the LAOBT, bursts are generated and inserted into burst streams by utilizing the void intervals of incoming bursts (IBs) in advance. The void size is estimated by splitting optical power into two paths, delaying one of the signals at the fiber delay line (FDL) and calculating IBs’ residual time from the splitter to the optical cross-connect (OXC). The performance evaluation results show that our proposed scheme increases link utilization without significant increment of end-to-end delay and signaling overhead.

Keywords: collision-less, optical burst transmission, WDM ring networks, void interval.

Classification: Fiber-optic communication

References


1 Introduction

Optical burst switching (OBS) has become one of the promising technologies for future optical networks because OBS can accommodate high bandwidth consuming services such as video on demand (VoD) and Internet Protocol television (IPTV), and it has inherited advantages from both circuit switching and packet switching technologies \[2\]. In OBS, several packets are assembled into a data burst (DB) and the DB is transmitted by cut-through burst switching in all optical domains after a burst control packet (BCP) is transmitted through a separated wavelength. As a result, queuing delay and overhead of processing time can be reduced compared to conventional packet switching technologies \[1\].

Though OBS has many advantages, it has an inevitable burst contention problem due to its one-way reservation (ACK-less) mechanism \[2\] and wastes network resources due to a dedicated channel for signaling. Much attention has been given to the burst contention problem especially in OBS ring networks using the out-band signaling scheme for BCP. The authors in \[3\] solved the contention issue in WDM ring networks by adopting a token-passing scheme, but the end-to-end (E2E) delay was highly redundant. Recently, the beforehand resource reservation (BRR) using the time division multiplexing (TDM) scheme has been proposed \[4\], but it still has an issue regarding poor link utilization.

To resolve poor utilization issues in OBS WDM ring networks, this paper proposes a look-ahead optical burst transmission (LAOBT) scheme for collision avoidance by inserting generated bursts (GBs) within the void interval which is the size between incoming bursts (IBs). After that, we propose the appropriate scheduling mechanism for the LAOBT to maximize link utilization and mitigate delay increment caused by the FDL, and evaluate the system performance in the aspect of delay and link utilization.

2 A new look-ahead optical burst transmission scheme

In this section, we present the node structure of the proposed the LAOBT and how the LAOBT increases link utilization with delay compensation for the slightly increased E2E delay caused by the FDL. Fig. 1 shows the node structure of the LAOBT in a unidirectional WDM metro ring network. In LAOBT, instead of using the control channel, which is commonly used in conventional OBS protocols \[1\], the burst control information is embedded in the header of the burst and transferred simultaneously through data channels.

Before we describe the LAOBT operation mechanism, we distinguish bursts as generated bursts (GBs), incoming bursts (IBs), transit bursts (TBs), and arriving bursts (ABs). A GB denotes a burst generated at the current node, and an IB denotes a burst that is incoming from the previous nodes. Additionally, IBs are classified as TBs, which pass through the current node, and ABs, whose destinations are the current node.

To insert GBs without any contention within the anticipated void between incoming bursts, the control logic determines the appropriate void size. When
Fig. 1. Node structure of look-ahead optical burst transmission (LAOBT).

an incoming burst arrives at the splitter, the optical signal is split into two. One \( (\text{Sig}_A) \) is used at the control logic and the other \( (\text{Sig}_B) \) is delayed by the FDL and then dropped/bypassed by the OXC according to the types of IB (i.e., TB or AB). If the control logic detects the arriving burst using \( \text{Sig}_A \) in advance, it calculates the burst’s remaining time to the OXC for each wavelength while \( \text{Sig}_B \) is being delayed in the FDL. In Fig. 1, \( TB_0 \) means the closest TB to the OXC, and \( RT_{0i} \) is the \( TB_0 \)’s remaining time to the OXC for the \( i \)th wavelength. If the \( TB_0 \) locates at the outside of the splitter, the maximum void size is same as \( D_F \), the fixed time delay by the FDL. Whereas, if the \( TB_0 \) locates inside the FDL, the void size is determined as the \( RT_{0i} \).

Because our insertion-based burst generation scheme uses the FDL to anticipate the void size, the FDL induces E2E delay at each node. To mitigate increased E2E delay, we adopt two scheduling schemes for selecting the transmission queue and channels. First, for generating the bursts, we consider the longest queue (LQ) scheme, in which the queue having the largest amount of packets is selected, because the packet waiting time among the queues can be kept small and fair, and the void size can be utilized maximally compared to the round robin scheme. Second, for the channel selection scheme, we choose the Max Void First (MVF) scheduling scheme because a larger void can accommodate more packets. In the MVF scheduling scheme, the largest void size \( (L_{VD}) \) is chosen among selected void lengths for each wavelength and limited by \( D_F \) as in Eq. (1)

\[
L_{VD} = \min \left[ D_F, \max \left[ RT_{0i}, RT_{1i}, ..., RT_{NWi} \right] \right],
\]

where \( N_W \) is the number of wavelengths.

3 Performance evaluation

In this section, we evaluate the average packet waiting time at the TX node by comparing numerical analysis and simulation results with our own simulator implemented by the C-programming language. Also, we compare the
proposed scheme with the BRR statistical TDM (BRR_STDM) scheme [4] in terms of the E2E packet delay, the queue delay, and link throughput.

To analyze the packet’s waiting time at the TX node, we modify the bursts’ behavior as shown in low part of Fig. 2. As TBs cut through the current node, we assume that the TBs preempt the exclusive wavelengths and the GBs is only allowed to use residual bandwidth to transmit bursts. As a result, the number of available channels for the GB, $W_{GB}$, is given by

$$W_{GB} = (1 - \rho_{TB}) \cdot N_W,$$

(2)

where $\rho_{TB}$ is the normalized traffic load corresponding to the TBs. Then, we define the normalized traffic load by $W_{GB}$ for the GB, $\rho_{GB}^M$, as follows.

$$\rho_{GB}^M = \frac{N_W}{W_{GB}} \cdot \rho_{GB},$$

(3)

where $\rho_{GB}$ is the original traffic load corresponding to the GBs.

In the optical burst transmission system, the delay consists of the packet assemble time, the burst waiting time for an available channel, and the burst transmission time. First, to obtain the packet assemble time, $T_A$, which is the time needed to aggregate waiting packets into a burst, we assume that the packets are virtually grouped into a burst as shown at the TX queue in Fig. 2 and the packet arrivals follow the Poisson process. Because the 1st packet in a burst is assembled immediately, it does not have assemble time delay. So we only investigate the delay for the 2nd and the following packets. By applying these assumptions, $T_A$ can be approximately obtained by multiplying the packet’s waiting time before assembling and the existence probability of each packet in a burst, and finally summing waiting times of each packet, as appeared in the 2nd term inside the parentheses in Eq. (4).
The 1st term in the parentheses is added to calculate assemble time when the mean number of packets in a burst is not an integer value.

$$T_A = \left( \frac{\left( N_{pk}^B - \left\lceil N_{pk}^B \right\rceil \right)}{N_B^pk} \cdot \left( N_{pk}^B - 1 \right) + \frac{1}{N_B^pk} \cdot \sum_{k=1}^{\left\lceil N_{pk}^B \right\rceil} \left( k - 1 \right) \right) \cdot \bar{t}_{IA}, \quad (4)$$

where $\bar{t}_{IA}$ is the mean packet inter-arrival time to the edge node and $N_B^pk$ is the average number of packets contained in a burst.

Second, by applying the number of wavelengths and traffic load acquired by Eq. (2) and Eq. (3) to the M/M/c queuing model [6] for bursts, we can obtain the average waiting time of the GB, $T_Q$, which is the summation of burst waiting time and burst transmission time, as following Eq. (5).

$$T_Q = \frac{\bar{h} \cdot N_B^pk}{W_{GB} \cdot P_{GB}^M}, \quad (5)$$

where $\bar{h}$ is the mean burst length.

The total delay at the TX node, $T_{tot}$, which is the summation of $T_A$ and $T_Q$, is verified by comparing with simulation results when the number of wavelength is 16. As shown in Fig. 3 (a), the delay of the simulation is little higher than the analysis at the high load. The reason of the increased delay is that the wavelengths are not ideally separated as shown in Fig. 2, so GBs should skip the current void when void size is not larger than burst’s length. Thus, even though the minor discrepancy between analysis and simulation exists, we conclude that $T_{tot}$ is verified for the LAOBT delay calculation.

Next, our scheme is compared with the previous work (BRR_STDM [4]). The WDM metro ring network is considered as the simulation topology in which the number of nodes is four and the incoming traffic from access networks is assumed to be evenly distributed to each node. In the BRR_STDM, a signaling channel is added to the four data channels, but in the LAOBT only four data channels are used. The incoming traffic from access networks at each WDM node ranges from 0.01 Gbps to 19.5 Gbps. We assume that the link capacity (40 Gbps) of the WDM ring is fully utilized by the merged traffic from the access networks and previous nodes when the incoming traffic reaches 20 Gbps. As a traffic model, we choose self-similar traffic rather than Poisson traffic because, when the range of the shape parameter ($F$) is $1 < F < 2.0$, the traffic behaves like Ethernet traffic.

The evaluation result in Fig. 3 (b) shows E2E delay. At low input traffic load, the E2E delay of the LAOBT is slightly larger than that of the BRR_STDM because the FDL size of the LAOBT is longer than that of the BRR_STDM. The LAOBT, however, has smaller queuing delay as shown in Fig. 3 (c). So, the delay increment of the LAOBT is less affected by input traffic especially in heavy traffic load compared to that of the BRR_STDM. This delay enhancement stems from the insertion-based burst generation scheduling described in Section 2. Fig. 3 (d) shows the relation between the offered traffic and the throughput at a link. We observe that the throughput of the LAOBT is always higher than that of the BRR_STDM.
4 Conclusion

We have proposed a look-ahead optical burst transmission (LAOBT) scheme for a WDM metro ring network using a FDL. Even though the LAOBT sacrifices E2E delay due to the FDL, this delay increment is compensated by minimizing the burst generation time at the TX queue. Thus, the delay increment by the FDL is negligible. The LAOBT also achieves performance enhancement in regarding to link utilization by utilizing the residual bandwidth of the TB’s and sending control and data information via a same channel.

Acknowledgments

This research was supported by the Ministry of Knowledge Economy (MKE), Korea, under the Information Technology Research Center (ITRC) support program supervised by the National IT Promotion Agency (NIPA)(NIPA-2011-(C1090-1111-0013)).