ONE-WAY RESERVATION SCHEME USING OPTICAL CODE PROCESSING FOR FAST DATA TRANSFER IN WDM NETWORKS

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Abstract OBS (Optical Burst Switching), in which wavelengths are reserved on a demand basis is one way to effectively use WDM networks. To reduce overhead time, high-speed processing of the signaling message at each hop is imperative. However, conventional electronic processing is not fast enough and will eventually become a bottleneck as the bit rate of data links increase. To reduce the overhead time in OBS networks, we propose an OC-TAG (Optical Code based Tell-And-Go) protocol for transmitting variable length burst without buffering, and fast burst transfers over WDM networks. Optical-code-based processing is introduced for handling the out-of-band control packets. Through computer simulation, we show the effect of introducing our protocol.

Keywords: Optical Code, Optical Burst Switching, Wavelength Division Multiplexing, Tell-and-Go, Just Enough Time

1. INTRODUCTION

The exponential growth of Internet traffic is driving the demand for photonic network using WDM (Wavelength Division Multiplexing). WDM technology makes it possible to offer high-speed data transfer. One way to effectively use WDM networks is to use OBS (Optical Burst Switching), in which are allocated on a demand basis [1, 2, 3]. When a burst transfer request arises at a source node, a wavelength is dynamically assigned between the source and destination nodes, and the burst is transferred using the assigned wavelength. The burst corresponds to an upper–layer protocol data unit, such as a file or block, in the case of a file transfer. The wavelength is immediately released when the data transfer is completed.

OBS proivides data transparency and eliminates buffering. In OBS, there are two schemes for burst transfer: *one-way reservation* [1, 2, 3] and *two-way reservation* scheme [4, 5]. In the former, the source node does not have to wait for an acknowledgment of wavelength reservation from the network; in the latter, it does have to wait for the acknowledgment until wavelength reservation is completed. With the one-way reservation scheme, in-band or out-of-band control signals are transmitted ahead of the burst to reserve the optical switches along the path. With the two-way scheme, the wavelength assignment time, including the propagation delay between the source and destination, is a key issue in achieving the high throughput needed to enjoy the large bandwidth provided by WDM technology. The main advantage of the one-way scheme is that the round-trip propagation delay between the source and destination nodes is eliminated. While this makes it possible to use the large bandwidth provided by WDM technology, the source nodes cannot know before transmitting the data whether the requests will be blocked along the path.

A common thread to the OBS is quick setup of optical path for data transmission by the reduction in time needed for pre-coordination. We previously investigated an OC-based architecture for setting up a light-path between source and destination nodes using two-way reservation [5]. In this paper, we consider the elimination of the round-trip waiting time before data transmission by using optical code processing [6].

The one-way reservation scheme also has overhead time, which depends on the number of hops the burst traverses. It is the protocol processing time, including the time for routing control signals, for assigning wavelengths, and for unexpected delays due to the high load of control signals. A key to reducing this overhead time is the high-speed processing of the signalling messages at each hop. Slow processing is a particu-

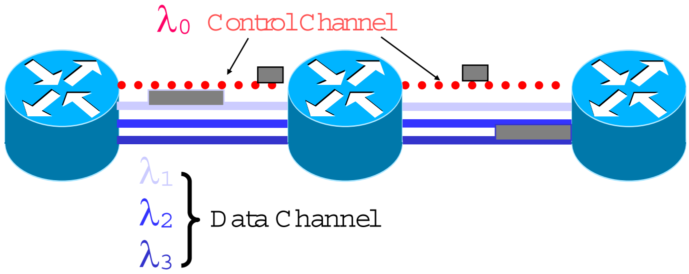


Figure 1 An OBS network

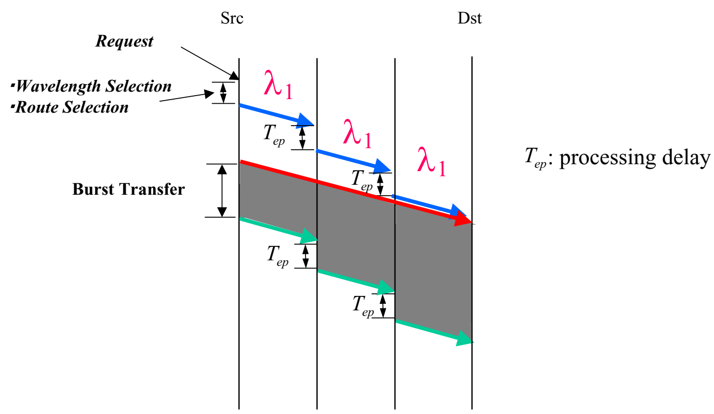
lar problem for relatively short-distance transmissions and/or short data lengths. Conventional electronic processing is not fast enough and will eventually become a bottleneck as the bit rate of data links increases. To reduce overhead time in OBS networks, we propose an OC-TAG (Optical Code based Tell-And-Go) protocol that supports variable–length bursts without buffering, resulting in fast burst transfer over WDM networks. Optical–code–based processing is described for signaling messages in the optical domain.

In Section 2, we briefly describe the one-way reservation scheme. We then present our protocol and its enabling architecture in Section 3. In Section 4, we present numerical results demonstrating its efficiency. In Section 5, we conclude with a brief summary and a look at future work.

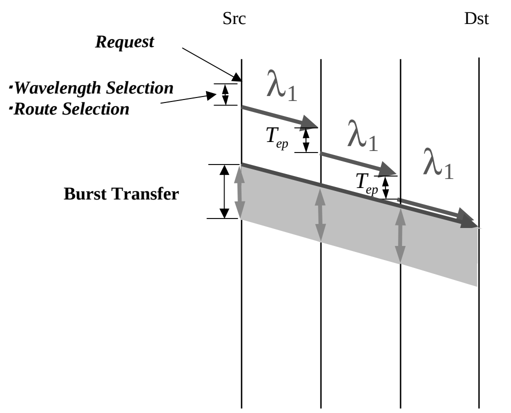
2. OPTICAL BURST SWITCHING USING ONE–WAY RESERVATION PROTOCOL

In this section, we describe the conventional one-way reservation protocol for OBS networks. The characteristics and variants of burst switching schemes are discussed in detail elsewhere [1]. We will next describe the basic concepts of OBS and why we focused on the use of optical code for OBS.

As shown in Fig. 1, each node in an OBS network has a cross-connect switch (OXC) to cut–through the incoming wavelength channel to the outgoing wavelength channel. Each node also has the functionality needed to control the switch. The nodes are connected via WDM links. A data burst is transmitted all-optically over the network, whereas the corresponding control packet is handled in the electronic domain by O/E/O conversion. The electronic packet entering to the network is first buffered, and then assembled into a burst at the edge of the network. It is then assembled into a burst, in which all the packets have the same destination address, or the same class of services. The bursts



(a) Tell-And-Go



(b) Just-Enough-Time protocol

Figure 2 Illustrative example of one-way reservation schemes (successful case).

are transmitted over the network using one of the available wavelength channels. The destination node of the burst disassembles the burst into packets and provides the packets to the upper layer.

Many burst transfer protocols have been developed. They include *Reserve-fixed-duration* (RFD) [1] and *'Tell-And-Go (TAG)'*-based wavelength reservation [3]. In both, an out-of-band signaling message (or control packet) travels ahead of the data burst to reserve the OXCs needed to route the data. The source node transmits a control packet,

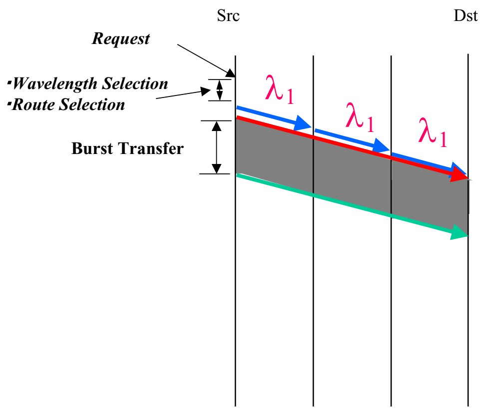


Figure 3 Our OC-based Tell-and-Go protocol (successful case)

which is followed by the burst after offset time T. The need to buffer the burst at intermediate nodes is eliminated if

$$T = \sum_{h=1}^{H} p_h, \tag{1}$$

where H is the number of hops along the pre–specified route and p_h is the processing delay at the h-th node. By setting T accordingly above, fiber delay lines (FDLs) are not necessary at each intermediate node to delay the burst while the control packet is being processed.

The difference between RFD and TAG reservation is that the RFD uses the burst duration information specified in the control packet. Due to the electronic processing delay at each node, void space is created ahead of a data burst (see Fig. 2). In TAG, the wavelength is released after the source node transmits a release signal (which means that the burst duration is unlimited if a limit is not set in the protocol specifications). Thus, the other bursts cannot make use of the void space because the intermediate node do not know when the previous burst will end. This means that the previous burst in TAG implicitly reserves the void space. On the other hand, RFD reserves the wavelength based on the burst duration time specified by the control packet. Hence, the other bursts can make use of the void space since the finishing time of the next burst is calculated from the arrival time, offset time, and burst duration, which are specified in the control packet.

Using the information about burst duration and electronic processing at each intermediate node, RFD potentially maximizes bandwidth usage. However, the disadvantage of RFD is in its inherent necessity of pre-specified burst duration. Practically, the length of a data burst is limited because the field length in the control packet is also limited. Furthermore and more importantly, the time at which a data burst arrives is delayed due to the electronic processing at intermediate nodes. We propose an OC–based burst transfer protocol that supports variable–length bursts without buffering. The void space, caused by allowing variable–length bursts, is eliminated to some extent by using OC processing in the optical domain (Fig. 3).

Note that JET (Just-Enough-Time) [1], which is categorized as RFD, allows *Delayed Reservation* (DR) to enhance the degree of bandwidth utilization. DR works as follows. If the requested wavelength is not available, the contending bursts are delayed by using FDLs until the wavelength becomes available. DR can increase the effectiveness of the available FDLs if we use an appropriate scheduling algorithm that uses information about burst duration. In this paper, we consider neither contention resolution using FDLs nor the wavelength conversion within the OBS network, where data bursts encounter propagation delays of FDL and wavelength conversion delays. An objective of this paper is to clarify the effect of introducing optical code processing on the delay of end-to-end data transfer.

3. OC-TAG: FAST DATA TRANSFER PROTOCOL

3.1. OPTICAL READ/WRITE OF SIGNALING MESSAGE

In OC-TAG, an optical control packet carries the signaling message from the source to the destination. Mapping the information in the message onto an optical code enables ultrafast reading and writing of the message in the optical domain. The reading and writing operations can be done using optical correlation and encoding, respectively. By taking the correlation between the incoming code and the template codes in parallel, a distinction of auto- and cross-correlation tells whether the code is matched or unmatched. The processing speed of optical correlation and encoding is only limited by the velocity of light in the passive optical devices [6]. Each optical code is a sequence of optical pulses packed into a bit duration, so-called chip pulses, and the chip itself is a short pulse. The number of available optical codes increases as the number of chip pulses (i.e., the code length) increases. For example, bipolar optical codes are illustrated in Fig. 4, in which the phase of optical carrier of individual chip pulse takes two states of either 0 or π, representing binary value of 1 or -1, respectively. The optical correlator is structured with an optical decoder, a time-gate, and optical thresholder. The

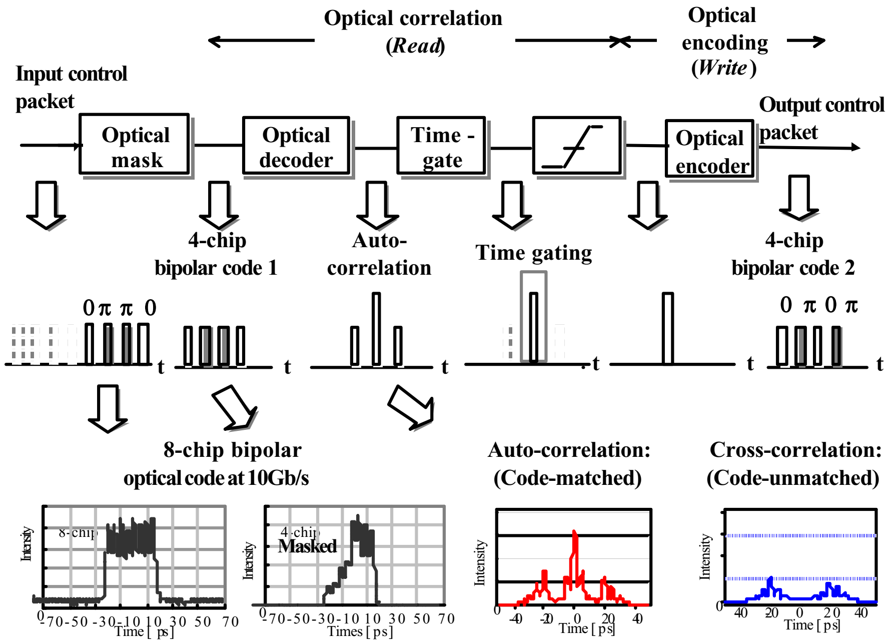


Figure 4 Optical correlation (read) and encoding (write)

block diagram is schematically illustrated in Fig. 4. The optical mask, if necessary, is placed in front of the optical decoder to extract an optical code among a series of codes. Note that the optical encoder and optical decoder are the same optical device. It is a passive optical device such as an optical tapped delay-line waveguide or a fiber Bragg grating. As shown by the graphs at the bottom of Fig. 4, the feasibilities of the optical correlation and encoding have been experimentally demonstrated at 10 Gbps with 8–chip–long codes [6]. The bit rate can be increased up to hundreds of Gbps.

3.2. OC-TAG PROTOCOL

Our OC-TAG protocol waits Δ after sending a RESERVE signal, where Δ is the time to configure the OXCs at the intermediate nodes, and it does not include any electronic processing delay at the intermediate node. Importantly, Δ is independent of the hop-count because control packets need not wait for the completion of OXC configuration. Our protocol is described below. Note that the optical code processing is introduce for the processing of a control packet at intermediate node, and operations, such as wavelength selection or the signal (control packet) generation, at source and destination nodes are performed in an electronic domain.

Source node operation

- If a burst transfer request is received from a source node, the usage conditions of the link wavelengths connected to the source node are checked, and the empty wavelengths are recognized as candidate wavelengths. One wavelength is randomly selected from the candidates. The wavelength is then written into the RESERVE signal, and the signal is sent to the next node. After the RESERVE signal is sent, the source node waits for Δ and then transmits the data burst.
- If an ACK signal from the destination node is received, the source node knows the request is admitted and transfer the data burst.
- If a NACK signal is received, the source node knows the request is blocked.
- When the data burst ends, the wavelength used to transmit it is written into the RELEASE signal, which is then sent to the destination node telling it to release the reserved wavelength.

Intermediate node operation

- If a RESERVE signal is received, a set of the reserved wavelength written to the RESERVE signal and empty wavelengths in the next link is taken.
- If a NACK signal or an ACK signal is received, it is sent to the next node without change.
- If a RELEASE signal is received, the wavelength reserved in the next link are released, and the RELEASE signal is send to the next node.

Based on the wavelength written to the RESERVE or RELEASE signal, the OXC must be configured. The configuration is performed by a electronical signal (See our architecture in Sec. 3.4 for details). Therefore O/E conversion to the information of wavelength is necessary and processing delay of the O/E conversion is also included in Δ. The control packets itself proceeds by the velocity of light in the passive optical devices.

Destination node operation

- If a RESERVE signal is received, the set of reserved wavelengths in the signal are checked. If the set is empty, a NACK signal is sent to the source node. If the set is not empty, an ACK signal is sent to the source node. Note that these operations are performed in the electronic domain.

3.3. CONTROL PACKET FORMAT

A control packet consists of three fields; signal information, routing information, and wavelength information. All are optically encoded at the source node and then transmitted over a network of a out-of-band channel. Each intermediate node handles control packets in the optical domain.

The first field in a control packet is used to distinguish the type of signal. The OC-TAG protocol requires four types: RESERVE, RELEASE, ACK, and NACK. RESERVE (or RELEASE) signal tells each intermediate node which wavelength to reserve (or release). The concerned wavelength is written into the wavelength information field. Since our OC-TAG supports four types of signals, we need a three-chip pulse to distinguish them. The OC codes for each signal are

$$OC_{s1} \text{ (RESERVE): } [0, 0, \pi]$$

$$OC_{s2} \text{ (RELEASE): } [\pi, 0, \pi]$$

$$OC_{s3} \text{ (ACK) : } [0, \pi, 0]$$

$$OC_{s4} \text{ (NACK): } [\pi, 0, 0] .$$

The routing information is used for routing the control packet. The basic concepts of routing using optical code is described in [7]. We assume that the routes of the control packets are pre-determined, i.e., the OC-label of outgoing packet is assigned in advance.

The wavelength information is used to determine which wavelength should be reserved or released. In our OC-TAG protocol, since the wavelength to be reserved is determined at the source node, we need information for a limited number of wavelengths. However, as described in the next subsection, our node architecture internally broadcasts the wavelength information filed and then matches current wavelength usage. Thus, we include the information for all wavelengths in the control packet. The OC codes representing whether each wavelength is available or not are as follows.

$$OC_{\lambda_1}^{ON}: [0, 0, 0, \pi]$$

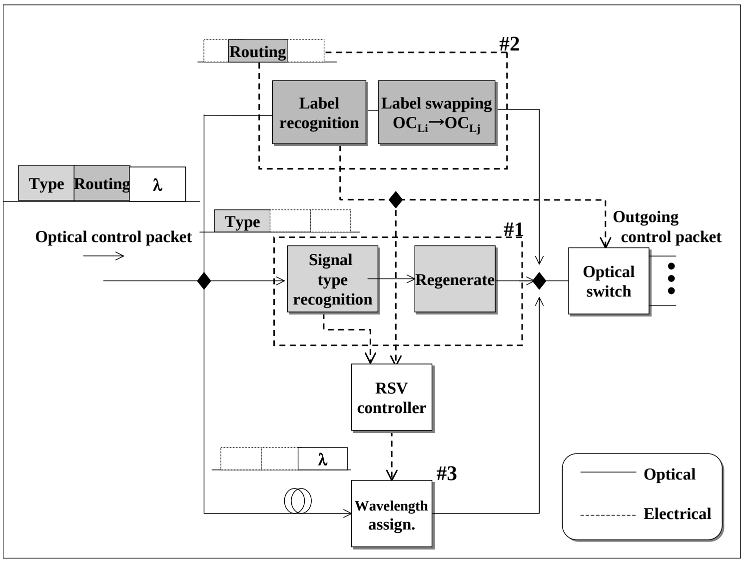


Figure 5 Architecture of optical processor

$OC^{ON}_{\lambda_2}$: $[0, 0, \pi, 0]$

$OC^{ON}_{\lambda_3}$: $[0, \pi, 0, 0]$

$OC^{ON}_{\lambda_4}$: $[\pi, 0, 0, 0]$

$OC^{ON}_{\lambda_5}$: $[\pi, \pi, \pi, \pi]$

That is, the number of chip pulses necessary for the wavelength information filed equals $W - 1$, where W represents the number of available wavelengths on the fibers.

3.4. OPTICAL PROCESSOR FOR ULTRAFAST OPTICAL PATH SETUP

As shown in Fig. 5 the architecture of an optical processor has three processing units; signal–type recognition (#1), control packet routing(#2), and wavelength assignment (#3). Their optical implementations are shown in Fig. 6. Note that three different families of optical codes have to be prepared. Recognition of the signal type works as follows.

1. Extract the corresponding optical code from the control packet by using an optical mask and split it.

Table 1 Parameters used in simulations

Wavelength capacity	C	10 (Gbps)
Guard band	G	0.001 (msec)
Link propagation delay	D	0.01 (msec)

2. Perform optical correlation and again generate the matched optical code where only one output appears from the correlator.
3. Insert the output code into the control packet. The result of optical correlation is used to configure the OXC.

Control packet routing is based on OC-MPLS [7]. It works as follows.

1. Extract the corresponding optical code from the control packet.
2. Perform optical correlation and generate a new optical code where only one output appears from the correlator.
3. Insert the output code into the control packet.

The implementation for the wavelength assignment is slightly modified by introducing as many switches as there are wavelengths. It works as follows.

1. Update the available wavelengths by setting switch SW_i 'ON' if λ_i is available and 'OFF' if it is not.
2. Extract the corresponding optical code from the control packet by using an optical mask and split it.
3. Perform optical correlation and combine all the output optical signals.
4. Insert the output optical code into the control packet if a code is obtained.

4. EVALUATION AND DISCUSSION

We evaluate our OC-TAG protocol by comparing its performance to that of a conventional one-way reservation algorithm. JET without delayed reservation is used for comparison. We use four–node tandem network for the network model. Burst transfer requests originated in all node pairs. The shortest path is used as the preassigned route for each request. The arrivals of burst transfer requests at each node pair are assumed to be governed by a Poisson process with parameter e. The

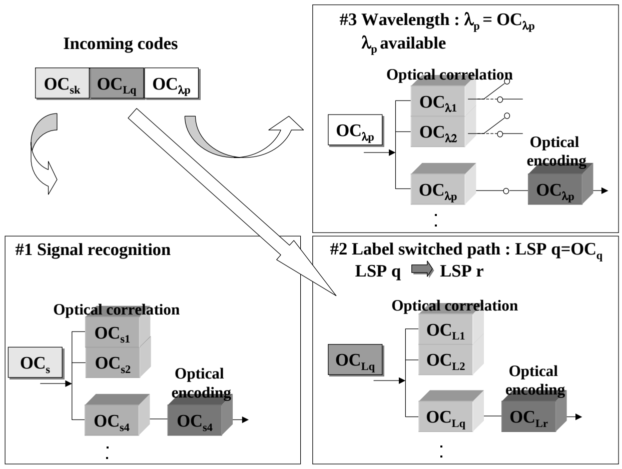


Figure 6 Optical implementation of signal–type recognition, control packet routing, and wavelength assignment

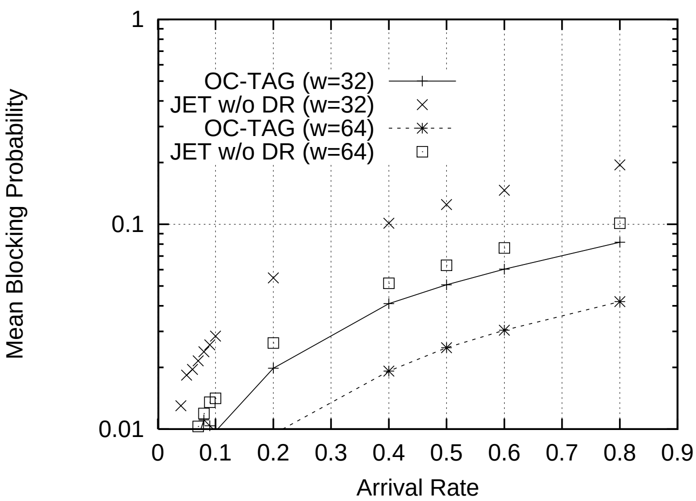


Figure 7 Blocking probability dependent on the arrival rate: p_c=1.0, u_a = 1.0

data transfer time for each request is assumed to be exponentially distributed with mean μ. The arrival rate of the transfer requests and the mean transfer time of the bursts are identically set to $e = e_a$ (burst/ms) and $\mu = 1.0$ (ms), respectively. We assume no retransmission even when a burst transfer request is rejected. In JET, the processing delay at each node is set to p_c (ms). We set Δ, the time to configure the OXC, to 1.0

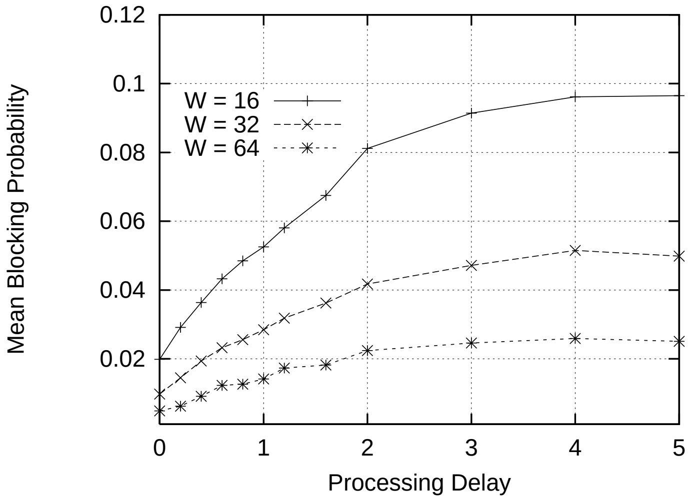


Figure 8 Effect of processing delay: $e_a = 0.1$, $u_a = 1.0$

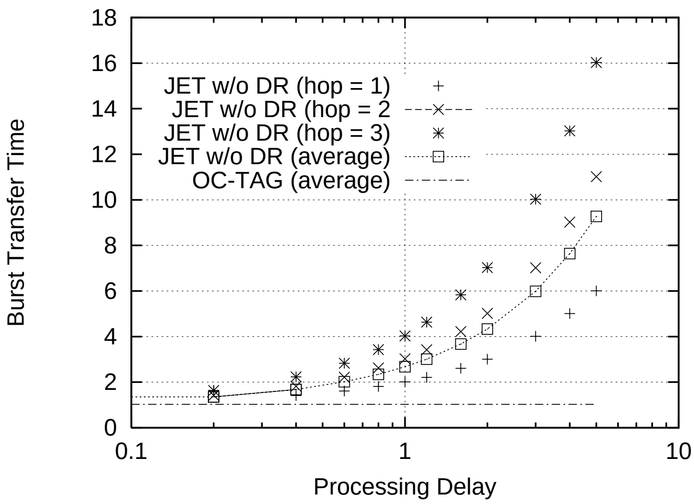


Figure 9 Burst transfer time dependent on the processing delay: $W = 32$, e_a=0.1, $u_a = 1.0$

(ms). Note that both JET and our OC-TAG protocol incur the OXC configuration time. The other parameters are summarized in Table 1.

The dependence of the average blocking probability on the arrival rate of the burst transfer requests is shown in Fig. 7 for 32 and 64 wavelengths per link. The results of the JET protocol with no delayed reservation is labeled as "JET w/o DR". The blocking probability is reduced by up to 50% by using optical code processing.

Fig. 8 shows the effect of processing delays at intermediate nodes for 16, 32, 64 wavelengths. The point at which the processing delay equals 0.0 (ms) corresponds to the OC-TAG protocol. The figure shows that our OC-TAG protocol always has a lower mean blocking probability. The larger the processing delay at the nodes, the larger the blocking probability.

More importantly, our protocol reduces the burst transfer delay dramatically. Fig. 9 shows the burst transfer time, defined as the time from when the burst transfer request arrives at the source node to when the RESERVE signal is received by the destination node. As expected, the time with our protocol is the shortest. That is, the OC-TAG protocol provides very fast data trasfer. One of the characterisics of OC-TAG is that the end-to-end delay is almost the same regardless of the number of hops, while with JET, the delay varis with the number of hops, if propagation delays on each link are excluded.

5. CONCLUDING REMARKS

We have described an OC-TAG protocol based on the tell-and-go protocol. It enables transmission of variable-length bursts with no buffering. The results of four node tandem network showed that it reduces the blocking probability, compared to that of the Just–Enough–Time protocol without delayed reservation. Since our protocol eliminates both the round-trip time and the electronic processing delay in an OBS network, a fast burst transfer is achieved. Our future work is to combine the OC-TAG protocol with contention resolution facilities using wavelength conversion or fiber delay lines.

Acknowledgements

This work was supported in part by the Telecommunications Advancement Organization of Japan (TAO), and by a Grant-in-Aid for Scientific Research (A) 14208027 from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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