社団法人　電子情報通信学会
THE INSTITUTE OF ELECTRONICS,
INFORMATION AND COMMUNICATION ENGINEERS

信学技報
TECHNICAL REPORT OF IEICE.

光符合処理に基づく高速バースト転送手法の検討

荒川　伸一[†]　　村田　正幸[††]　　北山　研一[†††]

[†] 大阪大学大学院 経済学研究科　〒 560–0043 大阪府豊中市待兼山町 1–7
[††] 大阪大学 サイバーメディアセンター　〒 560–0043 大阪府豊中市待兼山町 1–30
[†††] 大阪大学大学院 工学研究科　〒 560–8531 大阪府吹田市山田丘 2–1
E-mail: †arakawa@econ.osaka-u.ac.jp, ††murata@cmc.osaka-u.ac.jp, †††kitayama@comm.eng.osaka-u.ac.jp

あらまし　WDM 技術を適用したデータ通信方式として、データ発生時に高速に波長を割り当て、データ転送を行う方式が考えられる。本稿では、波長割当時のオーバーヘッドを極限まで減らすことを目的として、光符合処理を利用したバースト転送方式を提案する。提案方式では、ネットワーク内部にバーストを一時保存するためのバッファ領域は不要であり、また、無限長のバーストの転送が可能となる。計算機シミュレーションによって提案方式の有効性を示している。その結果、光符合処理によって高速にバースト転送が可能となることがわかった。

キーワード　光符合、バースト交換、波長分割多重、Tell-And-Go、Just Enough Time

One-way Reservation Scheme using Optical Code Processing for Fast Data Transfer in WDM Networks

Shin'ichi ARAKAWA[†], Masayuki MURATA[††], and Ken-ichi KITAYAMA[†††]

[†] Graduate School of Economics, Osaka University
Mathikaneyama 1–7, Toyonaka, Osaka, 560–0043 Japan
[††] Cybermedia Center, Osaka University
Mathikaneyama 1–30, Toyonaka, Osaka, 560–0043 Japan
[†††] Graduate School of Engineering, Osaka University
Yamadaoka 2–1, Suita, Osaka, 565–0871 Japan
E-mail: †arakawa@econ.osaka-u.ac.jp, ††murata@cmc.osaka-u.ac.jp, †††kitayama@comm.eng.osaka-u.ac.jp

Abstract　For effectively utilizing the WDM network, OBS (Optical Burst Switching) where the wavelengths are reserved on demand basis is considered. To reduce the overhead time, the high-speed processing of the signaling message at each hop is imperative. However, conventional electronic processing are not fast enough and will eventually become a bottleneck as the bit rate of data link goes higher. In this paper, to reduce the overhead time in OBS network, we propose an OC-TAG (Optical Code based Tell-And-Go) protocol for variable length of burst with no buffering, and fast burst transfer over the WDM network. The optical-code based processing is introduced for handling the out-of-band control packet. Through computer simulations, we show the effect of introducing our protocol.

Key words　Optical Code, Optical Burst Switching, Wavelength Division Multiplexing, Tell-and-Go, Just Enough Time

1. Introduction

An exponential growth of the Internet traffic has led to demand for introducing photonic network using WDM (Wavelength Division Multiplexing). It is possible to offer a high-speed data transfer capability by employing a WDM technology. For effectively utilizing the WDM network, OBS (Optical Burst Switching) where the wavelengths are reserved on demand basis is considered [1–3]. In such a network, when the burst transfer request arises at the source node, the wavelength is dynamically assigned between source and destination nodes, and the burst is transferred using the assigned wavelength. Here, the burst corresponds to the upper–layer protocol data unit such as the file or block in the case of file transfer. The wavelength is immediately released when the data transfer is successfully finished.

OBS has advantages in data transparency as well as elimination of buffering. In OBS, there are mainly two schemes for burst transfer; *one-way reservation* scheme [1–3], where the source node does not have to wait for the acknowledgment of wavelength reservation from the network, and *two-way reservation* scheme [4,5], where the sender has to wait for the acknowledgment until wavelength reservation is completed in the network. The one-way reservation transmits in-band or out-of-band control signals ahead of the burst to reserve the optical switch along the path (see Section 2 below). In the two-way reservation scheme, the wavelength assignment time, including the propagation delay between the source and destination, becomes a key issue to achieve a high throughput so that the large bandwidth provided by the WDM technology can be enjoyed. On the other hand, the advantage of the one-way reservation is that a round-trip propagation delay between source and destination nodes is eliminated. This is useful for the large bandwidth provided by the WDM technology, but the source nodes cannot know whether they will be blocked in the path, before transmitting the data.

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

An one-way reservation also has the overhead time dependent on the number of hop-counts that the burst traverses. It is a protocol processing time such as the routing of control signals, wavelength assignments, or unexpected delay due to the high load of control signals. To reduce the overhead time in the one-way reservation scheme, the high-speed processing of the signaling message at each hop is imperative. Slow processing particularly becomes tangible for relatively short-distance transmission and/or short data length. However, conventional electronic processing is not fast enough and will eventually become a bottleneck as the bit rate of data link becomes larger. In this paper, to reduce the overhead time in OBS network, we propose an OC-TAG (Optical Code based Tell-And-Go) protocol. Our method allows variable length bursts without buffering, and hence fast burst transfer over the WDM network. The optical-code based processing is introduced for signaling messages in an optical domain.

The rest of the paper is organized as follows. In Section 2, we present a brief description of one-way reservation scheme. We then present our protocols and its enabling architecture in Section 3. In Section 4, we give some numerical results and show the efficiency of our proposed protocol. In Section 5, we conclude our paper.

2. Optical Burst Switched Network using Electronic Processing

In this section, we review the conventional one-way reservation protocol for OBS networks. Note that the characteristics and variants of burst switching schemes have deeply been discussed in [1]. We will next describe the basic concepts of OBS and our motivation of OC-based one in this section.

An OBS network is illustrated in Fig. 1. Each node has a cross-connect switch (OXC) to cut-through the incoming wavelength channel to the outgoing wavelength channel, and has functionality to control the cross-connect switch. Each node is connected via WDM links. In the OBS network, the data burst is transmitted all-optically over the OBS network, whereas the control packet is handled in an electronic domain via O/E/O conversion. At the edge of the network, the electronic packet coming to the network is first buffered, and then assembled into a burst, in which all the packets have the same destination address, or the same class of services. The bursts are transmitted over the OBS 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.

In past, many burst transfer protocols have been studied. Those include *Reserve-fixed-duration* (RFD) [1] and *'Tell-And-Go'*-based wavelength reservation (TAG) [3]. In either protocol, an out-of-band signaling message (or control packet) travels ahead of the data burst to reserve the OXC to route the data. A source node transmits a control packet, which is followed by a burst after a offset time T. To eliminate buffering the data burst at intermediate nodes, we should have a relation

$$T = \sum_{h=1}^{H} p_h \qquad (1)$$

where H is the number of hop-counts along the pre-specified route and p_h is the processing delay spent at h-th node. By setting T as above, no fiber delay lines (FDLs) are necessary at each intermediate node to delay the burst while the control packet is being processed.

The difference between RFD and TAG is that the RFD utilizes the

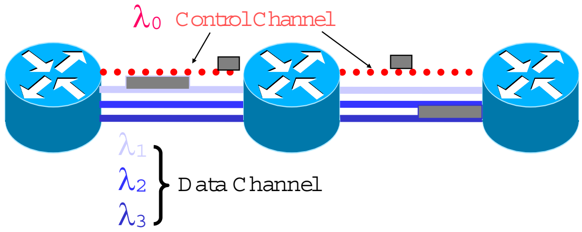
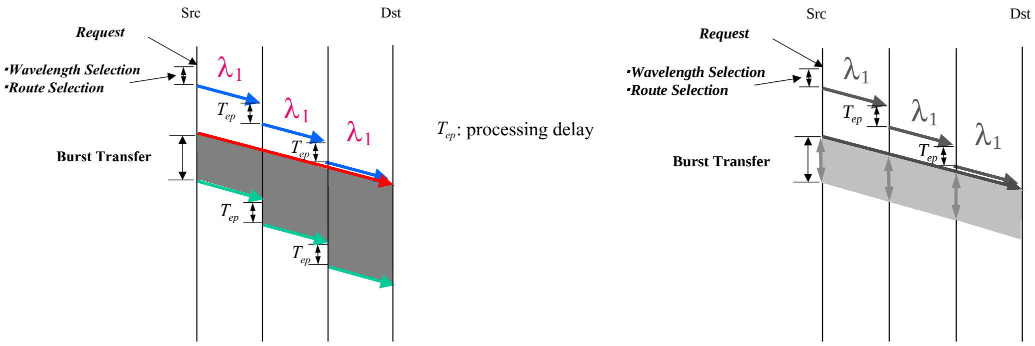


Fig. 1 Our OC-based Tell-and-Go protocol (successful case)



(a) Tell-And-Go

(b) Just-Enough-Time protocol

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

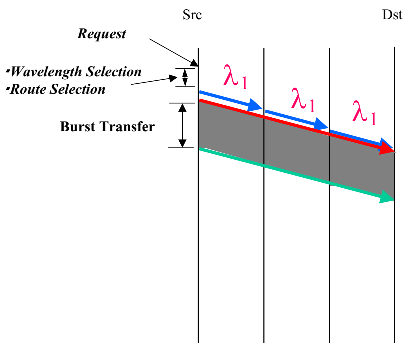


Fig. 3 Our OC-based Tell-and-Go Protocol (Successful case)

information of burst duration specified by 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 sender node transmits a release signal (which means that the burst duration is unlimited if the limit is not posed in protocol specification). Thus, the other bursts cannot fill in the void space because the intermediate node cannot know when the latter burst will end. It means that the former 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 fill in the void space since the finishing time of the later burst is calculated from the arrival time, offset time, and burst duration, which are specified within the control packet.

Using the information of 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 data burst is limited since a field length in the control packet is also limited. Furthermore and more importantly, the time at which data burst arrives is delayed due to the electronic processing at intermediate nodes. In this paper, we propose OC-based burst transfer protocol, which allows variable-length bursts without buffering. The void space, caused by allowing variable-length of bursts, is also eliminated to the extent by utilizing OC processing in an optical domain (Fig. 3).

Note that JET (Just-Enough-Time) [1], which is categorized in RFD, considers *Delayed Reservation* (DR) to enhance the degree of bandwidth utilization. DR works as follows. If the requested bandwidth is not available, the contended bursts are delayed by using the FDLs until the bandwidth becomes available. DR can increase the effectiveness of the available FDLs by an appropriate scheduling algorithm that utilizes information on the duration of burst. In this paper, we do not consider a contention resolution using FDLs

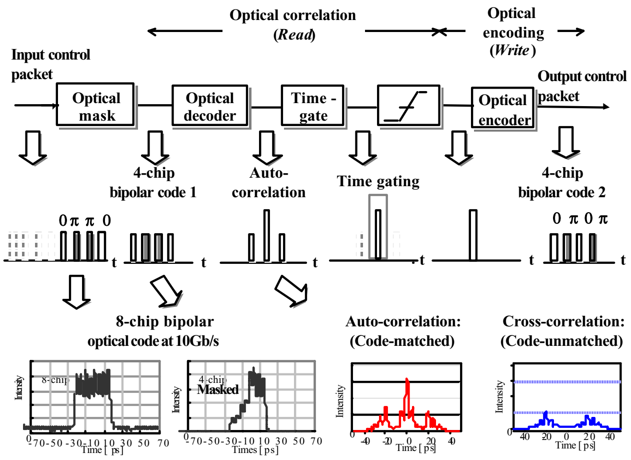


Fig. 4 Optical correlation (read) and encoding (write)

as well as the wavelength conversion within the OBS network.

3. OC-TAG: Fast Data Transfer Protocol

3.1 Optical read/write of signaling message

In OC-TAG, optical control packet carries the signaling message from the source to destination. Mapping the information of the message onto optical codes allows ultrafast read/write of the message in optical domain. The read and write operations can be done by 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. Unique to the optical correlation and encoding is that the processing speed is only limited by the velocity of light in the passive optical devices [6]. The 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 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 the optical decoder are the same optical device. It is a passive optical device such as optical tapped delay-line waveguide or fiber Bragg grating. As shown in the insets of Fig. 4, the feasibilities of the optical correlation and encoding have been experimentally demonstrated at 10 Gb/s with 8-chip long codes [6]. The bit rate can be increased up to hundreds of Gb/s.

3.2 OC-TAG Protocol

Our OC-TAG protocol is described as follows. Note that our OC-TAG waits Δ after sending the RESERVE signal, where Δ is a time to configure the OXC at intermediate nodes, and do not include any electronic processing delay. Importantly, Δ is independent from hop-counts.

Source node operation

- If a burst transfer request is received from a terminal, the usage conditions of the link wavelengths connected to the send node are checked, and the empty wavelengths are recognized as the candidate wavelengths. One wavelength is randomly selected from the candidate wavelengths. Then the RESERVE signal is written as the reserved wavelength, and sent to the next node. After the RESERVE signal is sent, the send node waits for Δ, and then transmits the data burst.
- If the ACK signal from the destination node is received, the terminal is known to have been completed.
- If the NACK signal receives, the terminal knows the burst transfer fails.
- If the data burst ends, the reserved wavelength is sent to the destination node and the RELEASE signal written by the reserved wavelength is sent to the destination node.

Intermediate node operation

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

Destination node operation

- If the RESERVE signal is received, the reserved wavelengths in the RESERVE signal are checked. If the set is empty, the NACK signal is sent to the send node. If the set is not empty, the ACK signal is send to the send node. Note that the ACK and NACK signals are generated in an electronic domain.

3.3 Control Packet Format

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

A first field in the control packet is used to distinguish the type of signals. The OC-TAG protocol requires four types of signals: RESERVE, RELEASE, ACK, and NACK. RESERVE (or RELEASE) signal tells each intermediate node at which wavelength should be reserved (or released). The concerned wavelength is written in the filed of wavelength information. Since our OC-TAG needs four types of signals, we need three-chip pulse to distinguish it. OC-codes for each signal are as follows.

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

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

OC_{s3} (ACK) : [0, π, 0]

OC_{s4} (NACK): [π, 0, 0]

The routing information is used for routing control packets. The basic concepts of a routing method utilizing optical code is described in [7]. We assume that routes of control packets are predetermined and outgoing OC-label is assigned in advance.

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

$OC^{ON}_{\lambda_1}$: [0, 0, 0, π]

$OC^{ON}_{\lambda_2}$: [0, 0, π, 0]

$OC^{ON}_{\lambda_3}$: [0, π, 0, 0]

$OC^{ON}_{\lambda_4}$: [π, 0, 0, 0]

$OC^{ON}_{\lambda_5}$: [π, π, π, π]

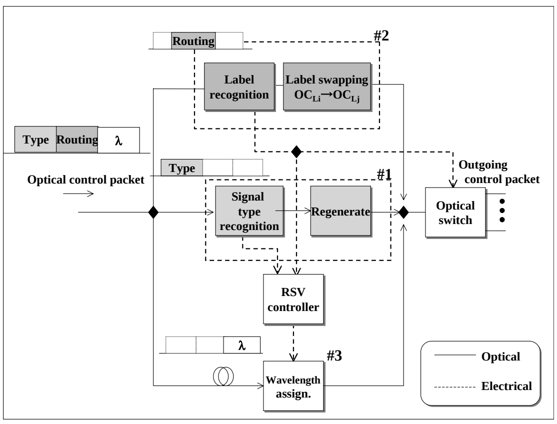


Fig. 5 Architecture of optical processor

3.4 Optical processor for ultrafast optical path setup

In Fig. 5 the architecture of an optical processor is shown. Three processing units are involved; signal recognition (#1), routing of control packet (#2), and the wavelength assignment (#3). Each optical implementation are shown in Fig. 6. Note that the three different families of optical codes have to be prepared. First, the recognition of signal type is as follows;

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

Secondly, the routing is based upon OC-MPLS [7]. The operation mechanism is the following;

1. Extract the corresponding optical code from the entire 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.

Finally, the optical implementation for the wavelength assignment is slightly modified by introducing switches as many as total wavelengths. The operation mechanism is the following;

1. Update the available wavelengths by setting switch (SW_i) 'ON' if λ_i is available and 'OFF' if it is unavailable.
2. Extract the corresponding optical code out of the entire control packet by using optically 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 the output is obtained.

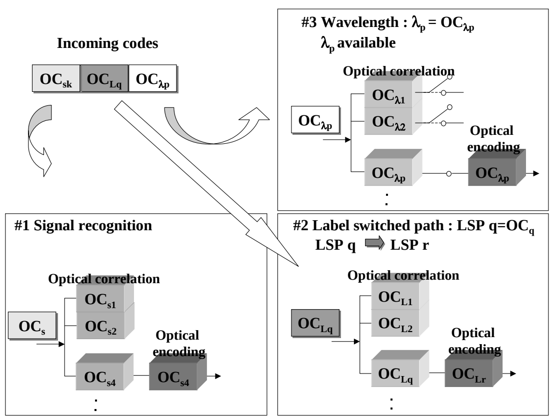


Fig. 6 Optical implementation of signaling recognition, routing, and wavelength assignment

4. Performance Results and Discussions

In this section, we evaluate our OC-TAG by comparing the conventional one-way reservation algorithm. JET with no delayed reservation is selected for comparison. 4-node tandem network is used for the network model. The burst transfer requests arise in all

Table. 1 Parameters used in the simulations

Capacity of wavelength	C	10 (Gbps)
Guard-band	G	0.001 (msec)
Link propagation delay	D	0.01 (msec)

of the node-pairs. The shortest path is used as a 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 data transfer time for each request is assumed to be exponentially distributed with mean μ. In this paper, the arrival rate of burst transfer requests and the mean transfer length of the bursts are identically set to $e = e_a$ (burst/ms) and $\mu = 1.0$ (ms), respectively. We assume no retransmission even when the burst transfer request is rejected. In the conventional JET, the processing delay at node is set at p_c (ms). In this paper, we set Δ, which is the time to configure the OXC, to be 1.0 (ms). Note that both conventional JET and our OC-TAG incur the configuration time of OXC. The other parameters are summarized in the Table 1.

Results are shown in Fig. 7 where the average blocking probability dependent on the arrival rate of the burst transfer requests are shown. In this simulation, we change the number of wavelength per link to 32 or 64. The results of the JET protocol with no delayed reservation is labeled as "JET w/o DR". From this figure, we can observe that the blocking probability reduces upto 50% by introducing the optical code processing.

Figure 8 shows the effect of processing delays at intermediate nodes. In the figure, three cases of different number of wavelengths (16, 32, 64) are shown. The point at which the processing delay equals to 0.0 (ms) corresponds to the OC-TAG protocol. As we observe from the figure, our OC-TAG protocol is always better than the JET protocol. Larger the processing delay at nodes, the blocking probability become large.

More important is that our method can reduce the burst transfer delay dramatically. In Fig. 9, the burst transfer time, which is defined as the time from when the burst transfer request arrives at the source node to when the RESERVE signal is successfully received by the destination node, is shown. As expected, the results of our OC-TAG protocol is smaller than the other protocol, that is, OC-TAG protocol can achieve a very fast data trasfer.

5. Concluding Remarks

In this paper, we have proposed OC-TAG protocol based on the Tell-And-Go protocol. Our protocol allows variable-length of bursts with no buffering. The results of 4-node tandem network shows that the blocking probability slightly improves, compared to the Just-Enough-Time protocol with no delayed reservation. However, since our protocol eliminate both round-trip time and electronic processing delay overhead times in the OBS network, a faster burst transfer is achieved. Our future work is to combine the OC-TAG protocol with contention resolution facilities utilizing the wavelength conversion or fiber delay lines.

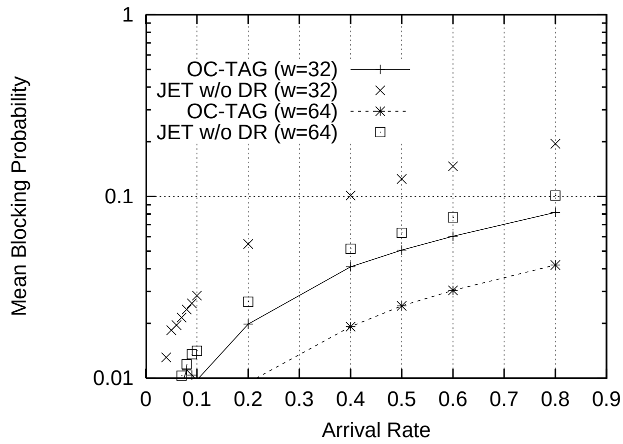


Fig. 7 Blocking probability dependent on the arrival rate: p_c=1.0, u_a = 1.0

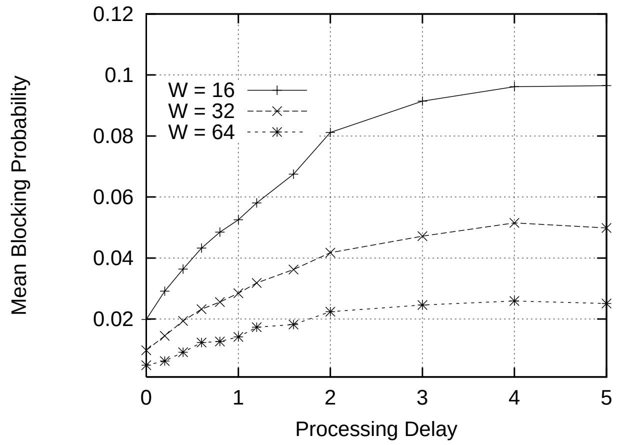


Fig. 8 Effect of Processing Delay: e_a = 0.1, u_a = 1.0

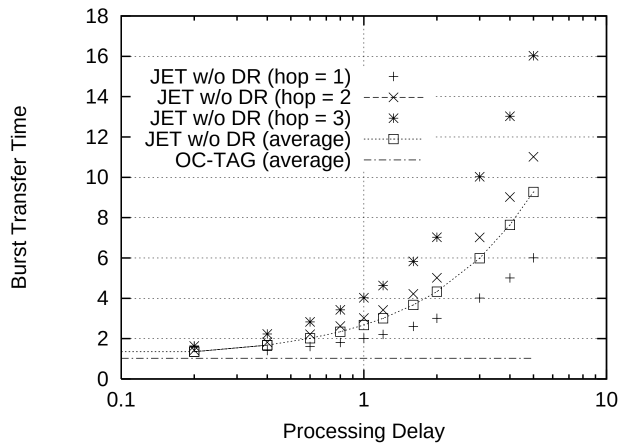


Fig. 9 Burst Transfer Time dependent on the processing delay: W = 32, e_a=0.1, u_a = 1.0

Acknowledgement

This work was supported in part by the Telecommunications Advanced Organization of Japan (TAO), and the Ministry of Education, Science and Culture, Grant-in-Aid for (A)(1), 14208027, 2002.

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, Jan. 1999.

[2] J. Y. Wei and R. I. McFarland, “Just-in-time signaling for WDM optical burst switching networks,” *Journal of Lightwave Technology*, vol. 18, pp. 2019–2037, Dec. 2000.

[3] J. S. Turner, “Terabit burst switching,” *Journal of High Speed Networks*, vol. 8, pp. 3–16, Jan. 1999.

[4] X. Yuan, R. Gupta, and R. Melhem, “Distributed control in optical WDM networks,” in *IEEE Conference on Military Communications*, Oct 1996.

[5] S. Arakawa, I. Ogushi, M. Murata, and K. Kitayama, “A study on architecture using optical code processing for fast path setup in generalized MPLS network,” *IEICE Technical Report* (PNI2002-06), Apr 2002. (in japanese).

[6] K. Kitayama, N. Wada, and H. Sotobayashi, “Architectural considerations of photonic IP router based upon optical code correlation,” *Journal of Lightwave Technology*, vol. 18, pp. 1834–1844, Dec. 2000.

[7] M. Murata and K. Kitayama, “A perspective on photonic multiprotocol label switching,” *IEEE Network Magazine*, vol. 15, pp. 56–63, July/August 2001.