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WDM ネットワークにおける光符号処理を用いた高速データ転送アーキテクチャの提案

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あらまし　光バースト交換ネットワークにおいて、光パス設定のための制御信号の処理を光領域で行なうことによりノードの処理遅延を大幅に削減し、高速に光パスを設定する方式が考えられている。しかし、ネットワーク内で競合が発生すると再送が必要となり、リンクの伝播遅延の影響が大きくなる。本稿では高速光パス設定手法のデータ転送性能の向上を目的として、ファイバ遅延線を用いた競合回避アーキテクチャを提案する。提案アーキテクチャの有効性を示すため、データ転送要求が発生してからデータ転送開始までに必要となる時間の評価を行っている。その結果、提案アーキテクチャを適用することにより競合が回避され、データ転送をさらに高速化できることが明らかになった。
キーワード　光バースト交換ネットワーク、光符号、高速光パス設定、ファイバ遅延線、再送

High Speed Data Transfer Protocol using Optical Code Processing in WDM Networks

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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. 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. However, the optical–code based processing is not enough for the faster data transfer since if the data transfer request is blocked, a round–trip propagation delay is necessary to retransmit the data transfer request. In order to reduce the retransmission, a contention resolution facility utilizing fiber delay lines is introduced for each node. Through computer simulations, we show the effect of introducing our architectures.
Key words　OBS, Optical Code, Fast data transfer, Fiber delay line, Retransmission

1. Introduction

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.

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 [4]. This OC-based architecture enables fast lightpath establishment. However *two-way reservation* scheme [4, 5] has an inevitable performance limit caused by two-way propagation delay (round-trip time), hence in this paper, we apply the OC-based architecture to *one-way reservation* scheme [1–3] for fast data transfer.

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. However, conventional electronic processing is not fast enough and will eventually become a bottleneck as the bit rate of data link becomes larger. Therefore, to reduce the overhead time in OBS network, we propose an OC-TAG (Optical Code based Tell-And-Go) protocol [6]. Our method allows variable length bursts without buffering, and hence fast burst transfer over the WDM network can be established. The optical-code based processing is introduced for signaling messages in an optical domain [4].

However, the optical–code based processing is not enough for the faster data transfer since if the data transfer request is blocked, a round–trip propagation delay is necessary to retransmit the data transfer request. In order to reduce the retransmission, a contention resolution facility utilizing fiber delay lines is introduced for each node. Through computer simulation, the data transfer delay which is defined as the time from when the burst transfer request arrives at the source node to when the data is successfully received by the destination node, is evaluated. And we show that it can be dramatically improved through our method. 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 present the contention resolution scheme using FDL architectures and show the efficiency of our architecture. Finally, we conclude our paper in Section 5.

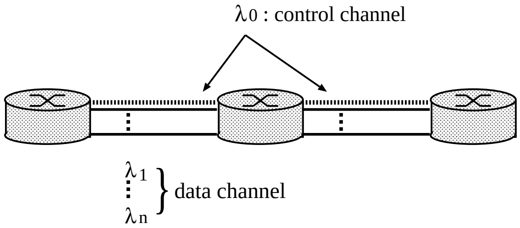

Figure 1 An OBS Network

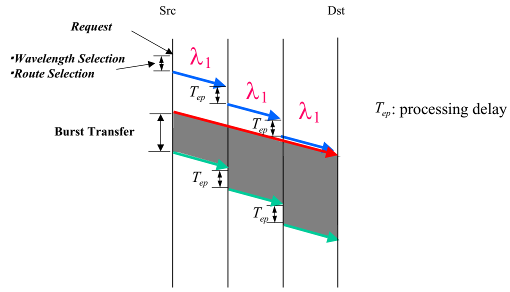

Figure 2 Tell–And–GO protocol

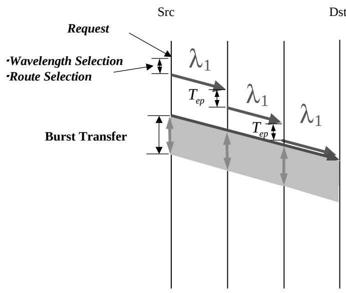

Figure 3 Just–Enough–Time protocol

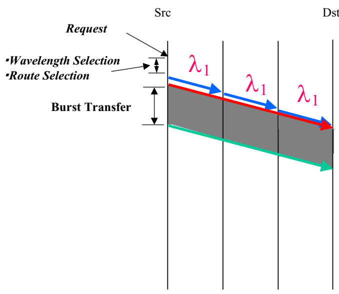

Figure 4 Our OC-based Tell-and-Go protocol

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 then describe our motivation of OC-based OBS architecture.

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 *Just-Enough-Time* (JET) method [1] and *'Tell-And-Go'*(TAG)-based wavelength reservation method [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 [7].

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

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 JET and TAG is that the JET utilizes the 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, 3). 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, JET 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, JET potentially maximizes bandwidth usage. However, the disadvantage of JET 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. Therefore 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. 4).

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 [8]. 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 [6], 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 [6]. 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. The feasibilities of the optical correlation and encoding have been experimentally demonstrated at 10 Gb/s with 8-chip long codes [8]. 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 because control packets need not wait for the completion of OXC configuration.

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 wavelength is written into the RESERVE signal, and the signal is 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 wavelength used to transmit the burst is written into the RELEASE signal. Then, the RELEASE signal is sent to the destination node in order to release the reserved wavelength.

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.

The routing information is used for routing control packets. The basic concepts of a routing method utilizing optical code is described in [9]. 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 of node internally broadcasts the wavelength information, and matches the current wavelength usage. Thus, we prepare the information of all wavelengths in the control packet. That is, the number of chip pulse necessary for the field of wavelength information equals to $W - 1$, where W represents the number of available wavelengths on fibers.

3.4 Optical processor for ultrafast optical path setup

In Fig. 5 the architecture of an optical processor is shown. Three

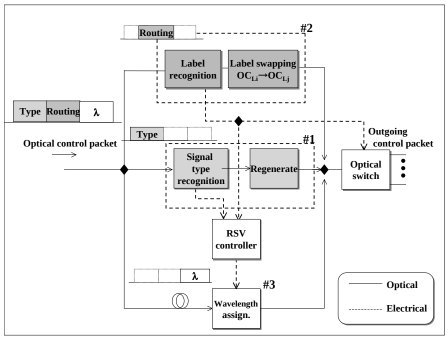

Figure 5 Architecture of optical processor

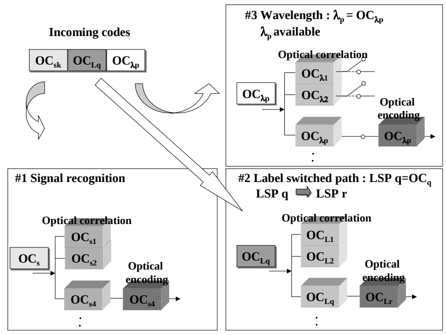

Figure 6 Optical implementation of signaling recognition, routing, and wavelength assignment

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 [9]. 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;

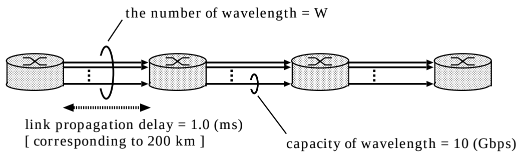

Figure 7 Network model

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.

3.5 Performance of OC–TAG

The advantage of our OC–TAG against the electronic control plane is shown in [6]. However, a retransmission when the burst transfer request is rejected is not considered in that paper. In this subsection, we present the results of OC–TAG protocol with retransmission and show that the mean transfer delay is much depends on the configuration time of OXCs.

Fig.7 shows the network model which we used in this simulation and some parameters. Burst transfer requests arise in all node-pairs. The arrivals of burst transfer requests at each node pair are assumed to be governed by a Poisson process. Burst length is assumed to be exponentially distributed with mean 1.0 (ms). We set Δ, which is the time to configure the OXC, to be 1.0 (ms). The number of wavelength per link, W is set to 32. Figure 8 shows the mean data transfer delay for our OC–TAG, which is dependent on the arrival rate. The mean data transfer delay is defined as the time from when the data transfer request arrives at the source node to when the data is successfully received by the destination node. Here three cases for the OXC configuration time are presented. We can see that as the OXC configuration time increases, the mean data transfer delay rapidly increases. Especially, data transfer delay shows a sharp curve when Δ = 10 (ms). This is because source node need to wait for Δ after RESERVE signal is sent, which means that the OXC is reserved during Δ.

4. Contention Resolution Scheme using Fiber Delay Line

4.1 Structure of FDL architecture

When contention occurs inside the OBS network, the source node needs to retransmit the burst. However, as mentioned in the previous section, the retransmission of the data transfer request depends on both round–trip propagation delay and processing delay at the edge nodes. In addition, the configuration time for the OXC is also

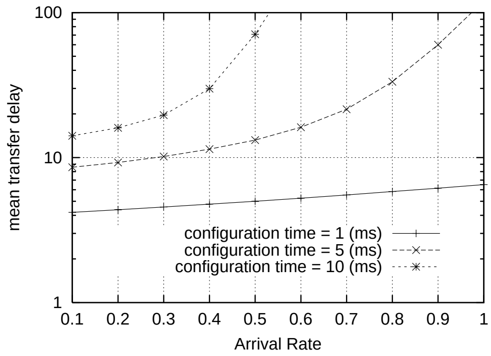

Figure 8 Difference in mean data transfer using different OXC configuration times

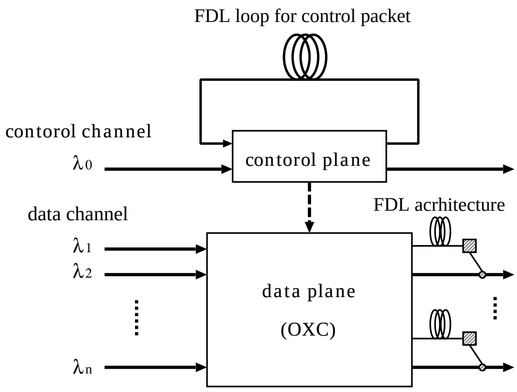

Figure 9 OXC with FDL architectures

an important factor in increasing burst transfer delay. We need some contention resolution mechanisms inside the OBS network for fast data transfer. One possible approach is FDL (Fiber–Delay–Line) buffering in the optical domain [10]. Due to the lack of optical RAM memory, the FDL has been used for buffering purposes in the optical packet switches. However, since FDL only provides fixed delay, a rather complicated packet scheduling is necessary at each node, which leads to performance degradation of the optical switch. It is especially true in OBS because the length of offset time in OBS is directly affected by the scheduling time at the intermediate nodes. Furthermore, since the unit length of burst is much larger than that of packet, the capacity of FDL buffer in OBS should be limited in order to avoid the complicated management of the FDL buffer.

Keeping those facts in mind, we propose a simple contention resolution architecture using FDL that only provides a retrial of the contended data request and therefore no scheduling is necessary. Our FDL architecture is different from FDL buffers in that it does not need scheduling or buffering. Since FDL only provides a fixed delay to bursts, our architecture can be designed much simpler than architecture using FDL buffers. Figure 9 has an architectural model of a node with FDL. It has a feed-back loop for the control plane and additional ouput ports that have FDL for the data plane. These FDLs for the data plane are prepared for every output line and can be shared by each wavelength. A contention resolution scheme using these architectures is described as follows.

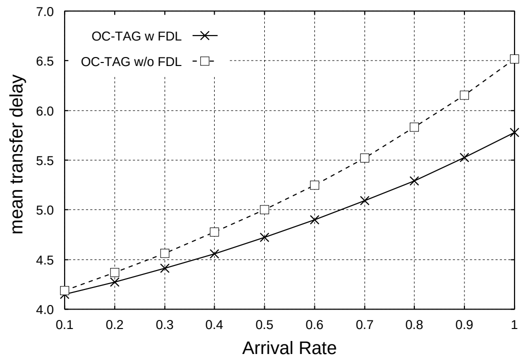

Figure 10 Effect of FDL architectures

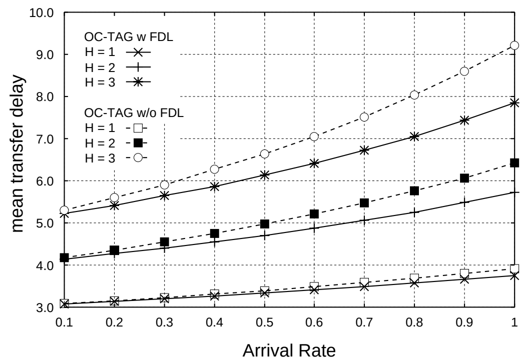

Figure 11 Effect of FDL architectures per hop

If a RESERVE signal cannot make a reservation in an OXC, it is sent to the FDL loop temporarily. This FDL loop provides a fixed delay and another chance of making a reservation to a RESERVE signal. A RESERVE signal in the FDL loop will return to an OXC and attempt to reserve a wavelength. If this RESERVE signal again fails to reserve, it is discarded. However, in comparison to OC–TAG without FDL architectures, there is a stronger possibility of making a reservation in OC–TAG with FDL architectures. Burst transfer is done using an optical path in the OC–TAG protocol. Since this optical path is set up through a RESERVE signal, an interval between a RESERVE signal and burst, i.e., OXC configuration time, must be maintained. Therefore, a burst will also be sent to the FDL architecture, when a RESERVE signal is sent to the FDL loop.

4.2 Performance results

We evaluate our FDL architecture by comparing it with the normal OC–TAG, i.e., an OC–TAG without FDL architectures. We use OPNET Modeler 9.0 [11] in this simulation. Here, we set the link propagation delay, $D = 1.0$ (ms) and OXC configuration time, $\Delta = 1.0$ (ms). The other parameters are the same as in Section 3. In this simulation, we assumed retransmission when the burst transfer request was rejected.

The results in Fig.10 indicate that the mean burst transfer delay which is dependent on the arrival rate. If a burst transfer is blocked, then the burst has to wait for a NACK signal, and needs retransmission. This results in delayed burst transfer. We can observe from the figure that FDL architectures reduce the required time to transmit a burst. In other words, FDL architectures reduce the number of retransmissions and enable fast data transfer. Moreover, by comparing the data of each H which is the number of the hop-counts in Fig.11, we can see that our FDL architecture is more effective in a long hop than in a short one. The more intermediate nodes a burst passes through, the more difficult burst transfer becomes. Our FDL architecture improves burst loss probability per hop. Consequently its effect is larger in long hops.

5. Concluding Remarks

In this paper, We evaluate the data transfer delay of our OC–TAG protocol. If a data transfer request is blocked, a round–trip propagation delay is necessary to retransmit the data transfer request. In order for more faster data transfer, we have introduced a contention resolution facilities utilizing fiber delay lines. Through the computer simulation, we show that our FDL architectures are effective in fast data transfer. Our future work is to combine another contention resolution facilities, such as wavelength conversion.

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