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波長ルーチングネットワークにおける オンデマンド型高速光パス設定方式の評価

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あらまし　WDM を利用した通信形態のひとつにコネクション設定要求が到着すると同時に波長を予約し，通信を行うオンデマンド型波長ルーチングネットワークが考えられている．このようにオンデマンドで光パスが設定される波長ルーチングネットワークでは光パス設定遅延時間が通信に大きく影響を与える．光パス設定遅延時間とは要求が発生してから光パスが設定されるまでの遅延時間を意味し，伝搬遅延時間と光パス設定試行回数によって決定される．本研究では光パス設定遅延時間の短縮を目的とし，波長予約がブロックされた場合でも高速にリトライを試みる光パス設定手法の提案を行う．計算機シミュレーションの結果から，光パスが設定されるまで無制限にリトライを繰り返すモデルにおいて，提案方式は従来より高速に光パス設定を行うことが可能であることがわかった．また，より現実的な評価としてリトライ可能回数に制限を設けたモデルで棄却率に関しての評価も行った．その結果，提案方式が棄却率においても優れていることが明らかとなった．
キーワード　WDM ネットワーク, 光パス, コネクション設定遅延時間，棄却率，リトライ可能回数

Fast Wavelength Reservation Method for Distributed Lightpath Setup in WDM Networks

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Abstract　A promising approach to the effective utilization of wavelength division multiplexed networks is to transfer the data on an on-demand basis using fast wavelength reservation. The data can then be transferred using the assigned wavelength channel. However, if wavelength reservation fails, the lightpath setup delay, which is defined as the time from when the data–transfer request arises at the source node to when the lightpath between the source–destination pair is successfully established, is seriously affected since retrials of the wavelength reservation are in turn delayed by propagation delays. In this paper, we propose a new wavelength reservation method to reduce the lightpath setup delay. The computer simulation results show that our method can setup the lightpath faster than the conventional method. Furthermore, to evaluate our proposal more clearly, we limit the number of retrials and evaluate the blocking probability that lightpath cannot be established. From the computer simulation, our proposal shows better blocking probability regardless of the number of retrials.
Key words　WDM network, lightpath, lightpath setup delay, blocking probability, retrial

1. Introduction

The improvement of wavelength division multiplexing (WDM) technology enlarges bandwidth and enables optical networks to support the increasing Internet traffic. At the same time, optical systems utilizing Optical Closs–Connects (OXCs) or Optical Add–Drop Multiplexer (OADM) have emerged. These systems enable the data transfer to be performed entirely in optical domain. Without these facilities, optical networks can be opaque networks which need optical–electronic–optical (O-E-O) conversion or regeneration at every intermediate node. The main drawback of such networks is the high cost of the additional O-E-O converters at the intermediate nodes. Moreover, the data transmission will be delayed by the processing speed of the converters. Therefore, the networks utilizing the all-optical systems have been brought to great attention. Our focused wavelength–routed WDM network is one of these all-optical networks. Employing OXCs in WDM networks, we can establish all optical connections or *lightpath* [1], between the source and the destination node. The lightpath is configured by reserving a wavelengths in each fiber links along the source–destination path. The lightpath enables the data transfer to be high speed and low cost communication since the absence of the expensive O-E-O converters. On the other hand, bursty nature of the Internet traffic reduces the bandwidth utilization even if we can perform all optical communication. It is a big research topic in all-optical WDM networks.

A promising approach to the effective utilization of WDM networks is to transfer the data on an on-demand basis. That is, when a data request arises at a source node, a wavelength is dynamically reserved between the source and destination nodes, and a wavelength channel is configured. After the data transmission using the lightpath, the lightpath is immediately torn down (i.e., the wavelength is released). These dynamic lightpath setup or tear down will be adapted for the bursty nature of the Internet traffic and utilize the bandwidth efficiently.

Two methods have previously been proposed to set up the lightpath in a distributed manner [2]. In both methods, the lightpaths are established by exchanging control packets between the source and the destination node. The actual reservation of the link resources is performed while the control packet is traveling from either the source node to the destination node (i.e., forward direction), or from the destination node to the source node (i.e., backward direction). There have been several studies on reservation schemes aimed at reducing the blocking probability for lightpath requests [2–6]. However, a more important measure for these reservation models is the lightpath setup delay, which is defined as the time from when the lightpath request arrives at the source node to when a lightpath is successfully configured between the source and the destination node. When the wavelength reservation is blocked at the intermediate node, the retrial is required to transfer the data successfully. If it is difficult to establish a lightpath, the reservation must be retried repeatedly. Consequently, the lightpath setup delay is increased by such retrials due to the link propagation delay along the source–destination path. Thus, it is important to improve the lightpath setup delay when we assume the retrial.

In this paper, we present a novel wavelength reservation method which aims to reduce the lightpath setup delay. More specifically, by integrating two existing reservation method, our method reserve a wavelength in both forward and backward direction, while existing reservation methods reserve a wavelength in either forward or backward direction.

The rest of the paper is organized as follows. Section 2 outlines wavelength–routed networks and related work, Section 3 presents our proposed method, Section 4 presents some simulation results, and Section 5 includes a brief summary.

2. Related works

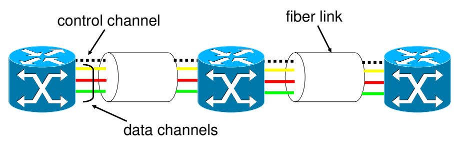


Fig. 1 Wavelength routed network

First, we explain the outline of our concerning wavelength–routed network. A model of the wavelength–routed network is shown in Fig. 1. The network consists of optical cross–connects (OXCs) and optical fibers. Each fiber carries a certain set of wavelengths. Among the set, one wavelength carries control packets and the other wavelenghts are used for data transfer. The control packet controls set–up and / or tear–down of lightpaths. In a wavelength–routed network, conventional lightpath setup methods are mainly categorized into two reservation scheme: *Forward reservation* and *Backward reservation*. In the forward reservation, the source node sends a reservation packet (RESV) immediately when the lightpath request arises. The reservation packet reserves a wavelength from the source node to the destination node. Since the source node does not know the wavelength availability information, there is no guarantee that the wavelength will be available in each link along the path. On the other hand, in the backward reservation, the source node sends a probe packet (PROBE) toward the destination node. Only the information on usage of the wavelengths is collected along the forward path, and the wavelength reservation is not made at this time. Each intermediate node on the forward path only removes the wavelengths from the list if those wavelengths are currently used. Based on the information of the PROBE packet, the destination node determines a wavelength for reservation, and then send the RESV packet toward the source node. We illustrate the above–mentioned behaviors of the forward and the backward reservation scheme in Fig. 2 and 3. Note that, in this paper, we do not consider wavelength conversion facilities. That is, a lightpath uses the same wavelength along the path, which is known as the wavelength continuity constraint [7].

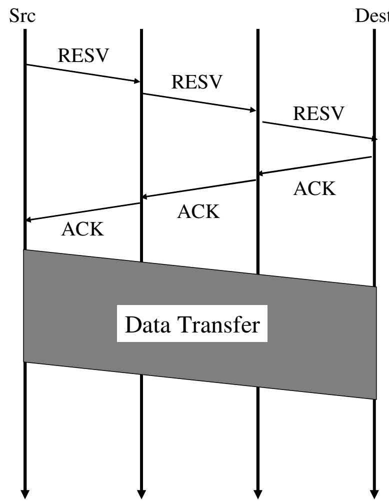


Fig. 2 Forward reservation

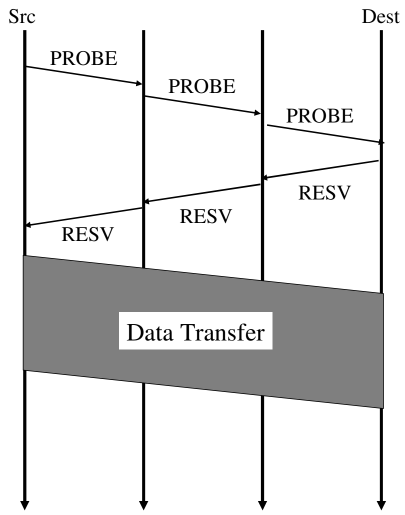


Fig. 3 Backward resesrvation

3. Our proposal

In both conventional reservation methods, there is only one trial for lightpath establishment while a round–trip propagation time. We therefore, propose a new lightpath setup method by integrating the forward reservation scheme and the backward reservation scheme, which tries to establish a lightpath twice in a round–trip propagation time. Fig. 4 and 5 illustrate our proposed scheme. In the proposed scheme, when the lightpath setup request arises at the source node, the source node sends a PROBE packet toward the destination node like the backward reservation. Defferent from the backward reservation, when the destination node receives a PROBE packet, it sends toward the source node not only a RESV packet (or NACK packet) but also a PROBE packet. The PROBE packet collects the wavelength usage information from the destination node to the source node, the source node selects a wavelength based on the information. This retrial case is illustrated in Fig. 5. The main characteristics of proposed scheme is that edge nodes exchange a PROBE packet at the all times. Now, we explain details of our proposed reservation scheme.

(1) Behavior of the source node

- (S1) When the data transfer request comes from a terminal, the source node creates a PROBE packet and sends it toward the destination node.
- (S2) When a RESV (or ACK) packet arrives, the source node informs a terminal about completion of the lightpath establishment.
- (S3) When a NACK packet arrives, the source node sends a RESV packet and a PROBE packet (A NACK packet has been accompanied by a PROBE packet always.). This is the case of the reservation failure in backward direction and this behavior is originality of our proposition. In addition, if the reservation has been blocked halfway, the source node must send also a release packet (RLS).
- (S4) When the data transfer finishes, the source node sends a RLS packet to tear-down the lightpath.

(2) Behavior of the intermediate node(s)

- (I1) When an intermediate node receives a PROBE packet, it calculates the intersection between the probed wavelength group and the wavelength group which is available in the next link.
- (I2) When a RESV or a RLS packet arrives, an intermediate node reserves or releases the wavelength respectively.
- (I3) An ACK and a NACK packet are forwarded to the next node with no processing.

（3） Behavior of the destination node

(D1) Basically, the behavior of the destination node is similar to that of the source node. When a PROBE packet arrives, the destination node sends a RESV packet and a PROBE packet simultaneously.

(D2) When a NACK packet arrives, the destination node sends a RESV packet, a PROBE packet and a RLS packet simultaneously. this is similar to (S3).

(D3) When a RESV packet arrives, the destination node sends an ACK packet toward the source node to notify that the lightpath is established.

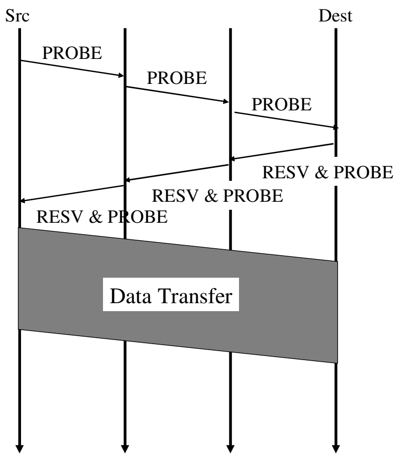


Fig. 4 Proposed scheme (successful case)

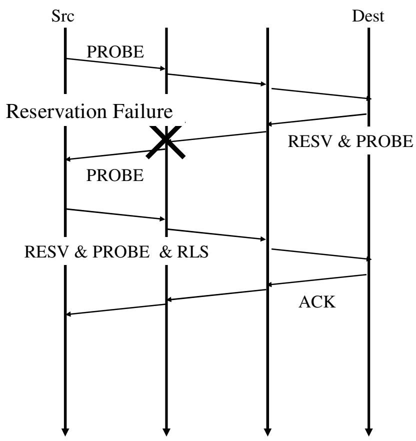


Fig. 5 Proposed scheme (retrial case)

4. Simulation results

4.1 Simulation Model

To evaluate the performance of our proposed scheme, we compare it with the backward reservation scheme through the computer simulation. We use the random network as a simulation topology. Fig. 6 shows the topolory which has 15 nodes. The other brief simulation parameters are shown as follow.

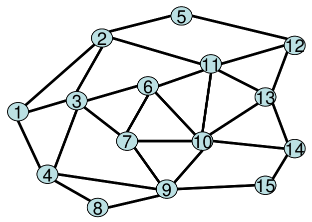


Fig. 6 Random Network

– The number of wavelengths on each link is set to 32.

– Each link has the random propagation delay with mean 1.77 [ms].

– Data transfer requests arrive according to Poisson process, and lightpaths are held during connection holding time that is assumed to be exponentially distributed with mean $1/\mu$ [ms].

4.2 Evaluation of the Lightpath Setup Delay

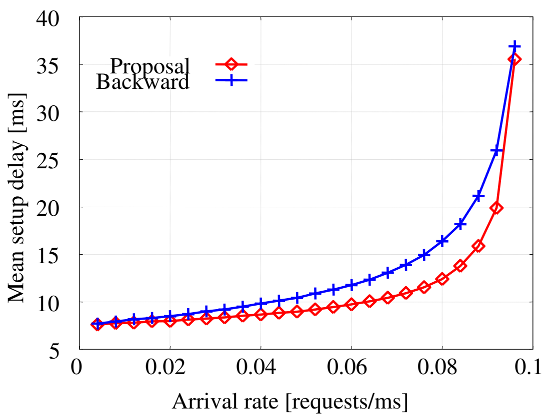
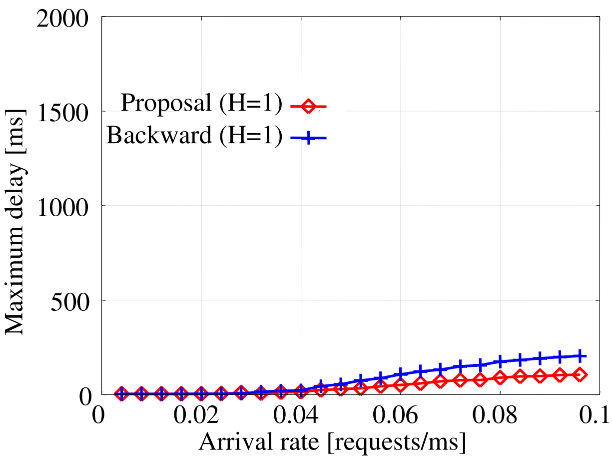
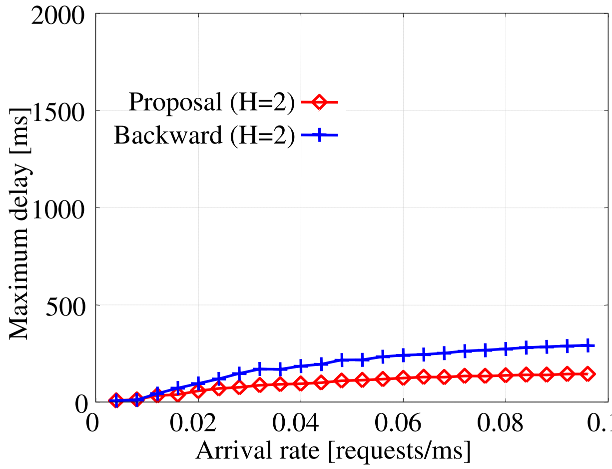


Fig. 7 Lightpath setup delay ($1/\mu$=100ms)

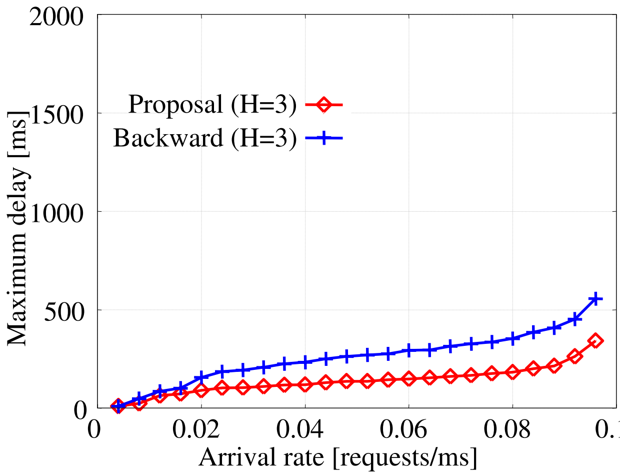
In Fig. 7 and Fig. 8, we present the mean setup delay dependent on the arrival rate of the connection request. Fig. 7 and Fig. 8 are the results when the average connection holding time $1/\mu$ is set to 100 [ms], 10 [ms], respectively. we observe that our proposed scheme shows better performance than the backward reservation at the almost all range, except for the arrival rate > 0.04 in Fig. 8. The reason why the proposed scheme is inferior to the backward reservation is the resource over–consumption. When it is hard to reserve a wavelength throughout the entire path, the RESV packet is blocked at the intermediate node. In this case, the network resource (i.e. wavelength) is wasted because some finite time is required to release the wavelength, and other node–pairs



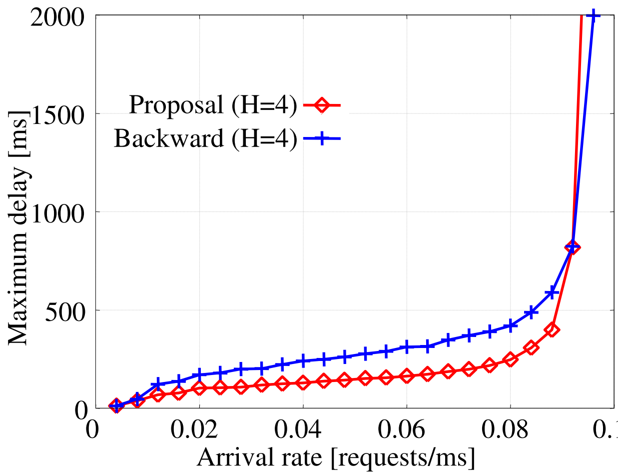
(a) Result of 1–hop connection



(b) Result of 2–hop connection



(c) Result of 3–hop connection



(d) Result of 4–hop connection

Fig. 9 Maximum setup delay

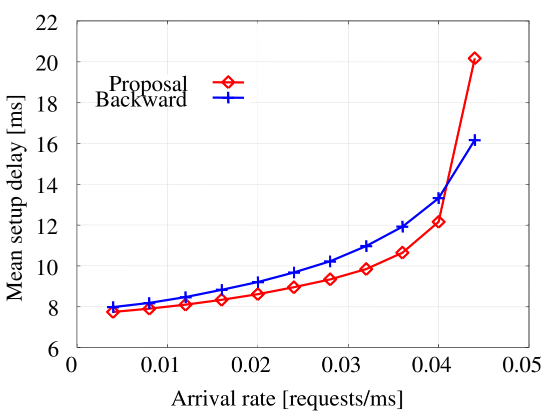


Fig. 8 Lightpath setup delay ($1/\mu$=10ms)

can't use the wavelength until it is released. As the feature of our proposal, the reservation is performed in both direction. This means that the proposed method may waste more network resources and consequently the lightpath setup delay increases.

4. 3 Variation of the Lightpath Setup Delay

In the wavelength–routed networks, it is desired to establish the lightpath with small variation of the setup delay. If the wavelength reservation method has large variation, we cannot achieve stable data transmission. Therefore, it is important to take care of the variation of lightpath setup delay. In this subsection, we employ the maximum setup delay as an index of the delay variation. We set the connection holding time: $1/\mu$=100 [ms], and we evaluate the maximum setup delay about each number of hop–count. Fig. 9(a)–9(d) show these results. In the Fig. 9(a)–9(c), the proposed method shows better performance than the backward reservation. The maximum delay of the proposed method is about half value of that of the backward reservation. On the other hand, in Fig. 9(d), the maximum delay of the proposed method is saturated more quickly than that of the backward reservation. The reason is the same as what I mentioned in the previous section. Due to the wavelength continuity constraint, the more links a RESV packet travels, the more difficult the lightpath establishment becomes. As a result, the result of our proposal in Fig. 9(d) becomes saturated at smaller arrival rate than the backward reservation.

4.4 Evaluation of the Blocking Probability

In the previous subsection, we assume the reservation retrial is performed until a lightpath is successfully established.

However, in more realistic case, the lightpath request should be blocked if much retrials occur. Otherwise, the network is congested and saturated by unsuccessful RESV packets. In this subsection, we present the blocking probability that the lightpath cannot be established after N_R trials. Fig. 10 and Fig. 11 indicate the results of $N_R = 10$ and $N_R = 20$ respectively. Since our proposed method tries a reservation two times in each trial (, while conventional method try a reservation once), it shows better blocking probability in both figures.

5. Summary

In this paper, we presented a new lightpath setup method that reserves a wavelength in both forward and backward directions. The main objective of our method is to reduce the lightpath setup delay. By integrating conventional two methods, our proposed method performs the lightpath establishment twice in a round–trip time, while the conventional method performs only once in a round–trip time. The simulation results indicate that the proposed method can reduce not only the mean setup delay but also the maximum setup delay. In addition, we evaluated the blocking probability under the condition that the reservation retrial limited based on the pre-specified number of retrials. From the simulation results, our proposal shows better blocking probability regardless of N_R. Our future work is to develop a numerical analysis about the lightpath setup delay.

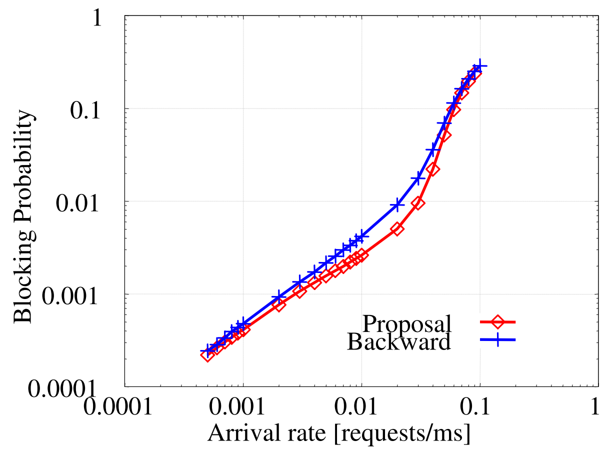


Fig. 10 Blocking probability (N_R=10)

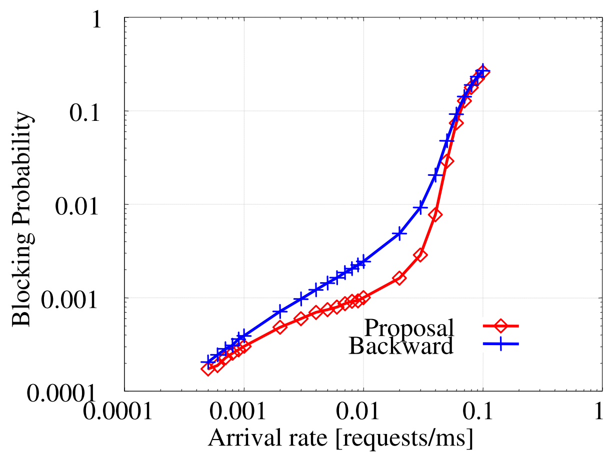


Fig. 11 Blocking probability (N_R=20)

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