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代替経路選択に基づく分散光パス設定方式の評価

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あらまし　各ノードが自律的に光パスを設定する分散環境を対象とした光パス設定に関する研究では、ネットワーク内の各リンクにおける波長利用状況を収集し、収集した波長利用情報に基づいて光パスの経路および波長を選択するための様々なアルゴリズムが提案されてきた。しかし分散環境では情報配布での伝搬遅延や情報の交換間隔の影響により劣化した情報を各ノードが経路選択に利用するため、ネットワーク全体の情報を正確に知ることができると仮定した場合よりも棄却率が上昇する。一方、代替経路選択アルゴリズムではパス設定要求が棄却された場合に代替経路を選択できるため、劣化した情報によって不適切な経路を選択するために発生する性能の劣化が小さくなると考えられる。情報の劣化を考慮にいれたアルゴリズムによって性能の良い経路選択を実現できる可能性がある。そこで本稿では、劣化した情報が経路選択におよぼす影響を明らかにするため複数の代替経路選択アルゴリズムについて、パス設定が完了するまでの平均時間を評価する。評価の結果、パス設定要求が到着した際に 1 本目の経路を最短ホップ数の経路とし、2 本目以降を低負荷の経路を選択するアルゴリズムは配布されたリンク利用情報の劣化による性能への影響が小さく、また他のアルゴリズムより良い性能を示すことを明らかにした。

キーワード　分散光パスネットワーク、代替経路選択、適応型経路選択、リンク利用情報

Alternate Routing Algorithms for Distributed Lightpath Establishment in WDM networks

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Abstract　Previous studies on routing and wavelength assignment algorithms assumed that the global link state information is obtained without delays. However, in distributed lightpath establishment, sender nodes need an adaptive routing algorithm to achieve less probability of request blocking. On the other hand, with alternate routing algorithm, the sender node selects next route if path establishment fails. In consequence, the performance degradation because of worse route selection is expected smaller than adaptive routing algorithm. And an adaptive alternate routing algorithm where the delayed link state information is considered to perform better. In this paper, we evaluate the average path setup time for routing algorithms to clarify the effect of delayed link state information. The simulation results show that an adaptive routing algorithm (least loaded algorithm) is affected by the delayed link state information. And a new routing algorithm (FAR with 1SP and LL) performs better than other routing algorithms, and the effect of delayed link state information is small.

Key words　distributed lightpath network, alternate routing, adaptive routing, delayed link state information

1. Introduction

Wavelength division multiplexing (WDM) is used to multiplex wavelength channels on a single fiber, and it enables high–capacity parallel transmission. One way to use the WDM technology is to establish wavelength channels (called *lightpath*) on demand basis. That is, when a data transfer request arrives at the sender node, one wavelength is reserved along the route between the sender and receiver nodes [1], [2]. After the data have been transferred using the lightpath, the wavelength is released immediately. However, because several lightpaths cannot share a wavelength on a fiber, a method is needed to control the process of lightpath establishment in lightpath networks.

There are two approaches to establishing lightpaths: a centralized approach, in which a special node sets up and tears down lightpaths, and a distributed approach, in which each node can set up and tear down lightpaths. In the distributed approach, because nodes do not know whether the other nodes are trying to reserve wavelengths, a conflict may occur. To minimizing the probability of such conflicts in distributed lightpath establishment, the sender node must select the appropriate route and wavelength for a lightpath. To select the appropriate route, the nodes should know the state of wavelength use in the network to find out which route is appropriate. A number of routing algorithms to solve this problem have been proposed for distributed lightpath establishment [1]～[4].

Each node must have precise information about the use of wavelength resources so that the routing algorithm finds the best route. In a distributed network, however, each node knows only the state of the adjacent link, so the nodes must exchange link state information to select an appropriate route efficiently. There are two types of link state information exchange, one is frequent exchange (nodes distribute the link state information immediately if the states of wavelength use change), and the other is infrequent exchange (nodes distribute the link state information periodically or when the states change over a threshold). In case nodes periodically exchange the information, the amount of exchange information data is greatly smaller than frequent exchange. But the blocking probability may increase because of the discrepancy between the current status of wavelength use and the exchanged link state information [1]. Even the nodes exchange link state information every time if the link state changes, propagation delays prevent this information from arriving at all the nodes at the same time, which affects on the route and wavelength selection at the sender node.

Many routing algorithms have been studied for lightpath network. [3], [5], [6]. Mainly, two algorithms have previously been proposed for routing of lightpath: adaptive routing and alternate routing. In adaptive routing algorithms, a sender node at which lightpath setup request arrives evaluates all available routes in a network, according to the current status of wavelengths use, and selects the one that will provide the best route for lightpath. In alternate routing algorithm, each node has a route–list in which a set of pre–defined routes is described. The routes in the list is ordered by e.g., hop–counts, and the sender node selects a route from the list. If lightpath setup on the selected route fails, the sender node trys the next route.

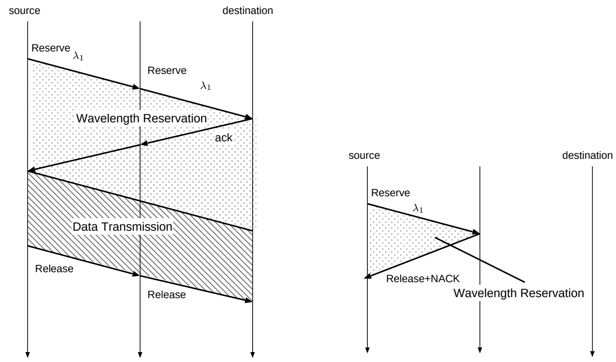
Adaptive routing shows better performance than the alternate routing ([7]), however, it requires additional overhead to calculate appropriate route from link state information. Alternate routing requires less computational complexity than adaptive routing since a set of routes is pre–defined and no route calculation is performed when the lightpath setup request arrives at sender nodes. However, a discrepancy between the current status of wavelength use and the exchanged link state information has not been considered in these studies. The discrepancy make sender nodes to select "worse" route, which lead to the blocking on that route. The performance of lightpath setup is worse than the performance when the link state information is collected without delay. In this case, the adaptive routing algorithm may not perform well due to the necessity of collecting precise link state information. Alternate routing algorithm may be enough for the route selection of lightpaths in distributed environments.

In this paper, based on this observation, we describe reservation protocols on a point of collecting information about available wavelengths. And then we discuss routing algorthims for reducing the selecting "worse" lightpaths with delayed link state information and better performance. And finally we evaluate the routing algorithms on simulation environment.

This paper is organized as follows. In Section 2., the existing routing and wavelength selection methods and wavelength reservation protocols are explained. In Section 3., we investigate how the frequency of link state information exchange affects the blocking probability by using computer simulation. Our conclusion is presented in Section 4..

2. Wavelength reservation protocols and alternate routing

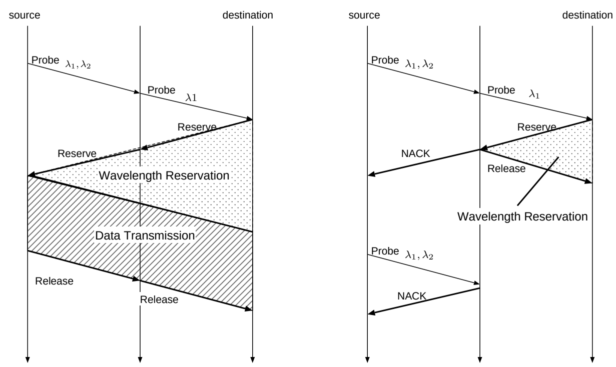
One of the important issues for routing in distributed networks is the interval between link state information exchanges. If nodes exchange the link state information on every time the link status changes, huge amount of information spread in the network and frequent calculation of routing table makes the CPU of nodes higher. To reduce these processing overheads, a method is needed to enable less frequent link state exchange using less detailed link state information. Furthermore, because the forward reservation protocol needs to select a route as well as a wavelength at the sender node, the link state information should include information about the use of each wavelength on each link. We can use the number of available wavelengths as link state information; however, the sender node may select the wrong wavelength because of this less–detailed link state information, and the blocking probability will increase. In contrast, the backward reservation protocol selects only the route at



(a) A successful case of a lightpath establishment

(b) A failure case of a lightpath establishment

Figure 1　Forward reservation protocol



(a) A successful case of lightpath establishment

(b) A failure case of lightpath establishment

Figure 2　Backward reservation protocol

the sender node. In this case, information about the number of available wavelengths on each link is enough for the route selection. We therefore consider the backward reservation protocol in this paper. In following sections, we will explain the backward reservation protocol in detail, and two route selection scheme; adaptive routing and alternate routing.

2. 1　Backward reservation protocol

When a lightpath request arrives at the sender node, the sender node selects only the route for the lightpath. Next, the sender node generates a PROBE signal containing a set of available wavelengths on the next link, and transmits it to the receiver node. When an intermediate node receives the PROBE signal, it intersects the sets of available wavelengths on the next link and contained in the PROBE signal, and write in the PROBE signal.

After updating the PROBE signal, the node transmits the signal to the next node. The set of wavelengths in the PROBE signal contains available wavelengths on the route when the PROBE signal arrives at the receiver node. The receiver node selects a wavelength from the available wavelengths in the PROBE signal, and transmits a RESERVE signal to reserve the wavelength on the route. Upon receiving the RESERVE signal at the sender node, the sender node acknowledges that the lightpath establishment has been successfully completed, and starts transferring the data. After the data have been transferred, the reserved wavelength is released via a RELEASE signal. Figure 2(a) shows a case of successful wavelength reservation. There are two cases when a request for wavelength reservation can be rejected with the backward reservation protocol (Fig. 2(b)); one is when during the available wavelengths are being probed (a PROBE sequence), and the other is when the wavelength has already been reserved (a RESERVE sequence).

Rejection on receiving a PROBE sequence occurs when the set intersected by the intermediate node is empty. In this case, there are no available wavelengths on the route, and the intermediate node sends a NACK signal to the sender node. Rejection upon the receipt of a RESERVE sequence occurs when wavelength reservation conflicts with the establishment of another lightpath. When the wavelength reservation fails, a NACK signal is transmitted to the sender node, and a RELEASE signal is transmitted from the intermediate node to the receiver node to release the reserved wavelength.

2. 2　Adaptive Routing

With adaptive routing, sender nodes dynamically select a route to the receiver node when a lightpath setup request arrives. The route selection depends on both the connectivity of each adjacent nodes and the wavelength use of each link. The advantage of this algorithm is that the sender node evaluates all available routes in a network, which is expected to be a less blocking. The disadvantage of this algorithm is that the discrepancy between the current status of wavelength use and the exchanged link state information much affects on the blocking performance. In this algorithm, it is necessary to achieve good performance on selecting proper route that current link state information can be used.

In this paper, we use a least loaded routing algorithm, where the sender node selects a route that has the minimum number of reserved wavelengths on the route. Note that the least loaded routing algorithm requires on the number of reserved wavelength in each link as the link state information.

2. 3　Alternate routing

There are two types of alternate routing; fixed–alternate routing and adaptive–alternate routing [8], [9]. With fixed–alternate routing, each node has a route–list for set of pre–determined routes. This list contains an ordered list of routes to each destination node, and the routes are not changed dynamically. When lightpath setup request arrives at the sender node, the node selects a route (primary route) according to the order of the list. If the lightpath cannot be established along the primary route, the sender node then selects the next route. This operation continues until all of route in the list is examined. An advantage of the fixed–alternate routing is that since the list is determined in advance, there is no calculation of the route before the lightpath is setup. Furthermore, even if some links are fails,

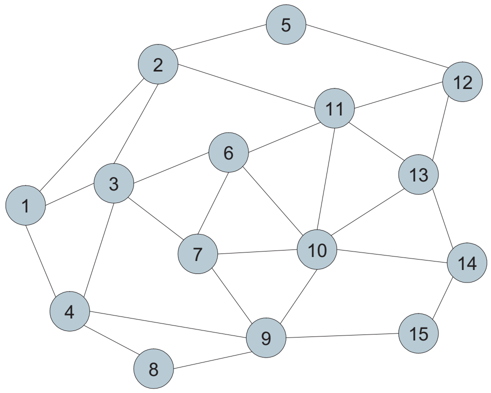


Figure 3 Random network model

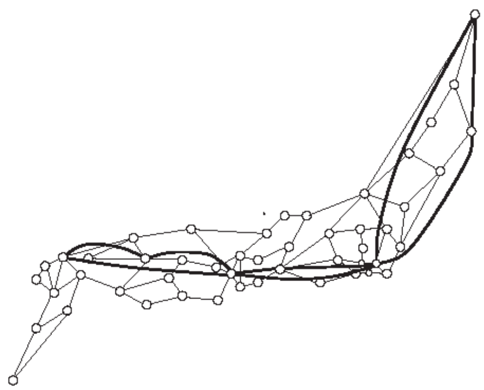


Figure 4 The Japan backbone network

the sender node can easily select other routes. In adaptive routing, the sender node must calculate another route to avoid the failed link.

With the adaptive–alternate routing, each node also has the route list, but the order of routes is changed dynamically according to the wavelength use in the network. This is a hybrid approach of adaptive routing and fixed–alternate routing to load balancing on the wavelength use while providing less computational complexity for the routing. If the sender node knows congestion on links based on the link state information exchange, the sender node set the order to make the network load–balanced. If the lightpath setup along the route fails, the sender node selects another route by considering the route would be less loaded. In adaptive routing, the order of the routes can be changed by the sender node, so we consider that the performance degradation because of the delayed information can be small using the adaptive routing with appropriate routing algorithm.

3. Performance evaluation

In this section, we evaluate the above mentioned routing algorithms in the distributed environments by the computer simulation. The lightpath setup delay, which is defined as the time from when the lightpath setup request at the sender node to when the lightpath is successfully established, is evaluated in this simulation.

3.1 Simulation Model

Figures 3–4 show two network topologies used in our performance evaluation. In Fig. 3, random network which is consisted of 15 nodes and 28 duplex links is presented. The average number of minimum hop–counts between node pairs is 2.50, and mean propagation delay of each link was set by multiplying the length of each of link in Fig. 3 by scale factor α. Figure 4 shows the Japan backbone network, which consists of 49 nodes and 91 duplex links. In this network, the average numbers of minimum hop–counts is 6.06, and mean propagation delay is 0.59 ms.

We perform the simulations on computer with the following parameters.

- Requests arriving at each node follow with the Poisson arrival with mean P. And the arrival rate to each node pair is even.
- The service time of a lightpath has an exponential distribution with mean $1/\mu$.
- The number of multiplexed channels on each optical fiber is $W + 1$. One channel is used as a control channel on which the nodes exchange control signals and link state information. Other W channels are used for lightpath establishment.
- The link state information is updated at T intervals.

We assume that there is no processing delay in the routing, wavelength selection, and wavelength reservation processes at each node. Every control signals is delayed on the effect of link propagation delay. The signals are not affected by neither node processing delay nor queuing delay.

3.2 Route and wavelength selection algorithms

Next, we evaluate the performance in adaptive routing and alternate routing. We use the backward reservation protocol to select available wavelength on the route. And to select a route for the lightpath, we use k–shortest path algorithm ([10]). In adaptive routing, the best route in the k–shortest paths is selected by the sender node. In alternate routing, the sender nodes decide the order of route selection from the k–shortest paths. If the lightpath setup fails k–times, the sender node re-decides the order of route selection from the k–shortest paths. Table 1 summarizes routing algorithms which we use in our simulation.

Table 1 Routing Algorithms

Algortihm name	Routing Type	Brief summary
Shortest Path	Fixed	minimum hop count
FAR	Alternate	By the order of hop count
Least Loaded	Adaptive	The least loaded route is selected
FAR with LL	Adaptive Alternate	By the order of load
FAR with 1SP and LL	Adaptive Alternate	The primary route is shortest, the others are by the order of load.

In shortest path (SP) algorithm, the sender node selects a shortest path which has minimum hop counts, repeatedly. In FAR(: Fixed Alternate Routing), the sender node only selects route from the pre–defined route–list. Each node selects the route from the route–list in ascending sequence (with regards to the number of hop–counts).

In least loaded algorithm, the sender node selects a least loaded according to the collected link state information which is dynamically updated. This algorithm balances the number of reserved wavelengths on the links, therefore, the blocking probability is small in highly–loaded networks.

The “FAR with LL” is the fixed alternate routing algorithm with adaptive (least loaded) selection. The sender node selects a route in the order of less loaded route from the candidate routes. This algorithm also balances the number of reserved wavelengths on the links. In least–loaded algorithm, the delayed link state information degrades the performance because of wrong route selection is repeatedly. But in this algorithm, the sender node can select the other routes from the candidate routes, so the performance degradation of delayed link state information is expected small.

We finally introduce our new algorithm: FAR with 1SP and LL algorithms. In this algorithm, the sender node selects the less loaded route from the candidate routes the same as FAR with LL algorithm, except that the primary route is fixed to the shortest path. FAR with 1SP and LL algorithm has the advantages of Shortest Path and FAR with LL. By this algorithm, the primary route selection achieves smaller consumption of wavelength resources, and next route selection achieves load–balancing. And according to the primary route is fixed, the performance degradation from delayed link state information is expected small.

3.3 Numerical Results

Figs. 5–8, we show the average setup time of lightpath requests for different alternate routing algorithms with the backward reservation protocol. The x–axis is the arrival rate, and the y–axis is the average path setup time of a lightpath request. Both x–axis and y–axis are linear scale. “Global” means that the sender nodes can use the global link state information without any propagation delay, which is an ideal case. Here, “T=0” means that the link state information is exchanged immediately after there has been a change in the link state, “T=15sec”means that the link state information is exchanged every 15 seconds.

Fig. 5 shows that the average path setup time of the algorithms in random network topology (Fig. 3). It is observed that the average path setup time by Shortest Path, FAR with 1 SP, and Least–Loaded Global is shorter than that by Least–Loaded and FAR with LL algorithm when the arrival rate is small. As the arrival rate of lightpath setup requests increases, the path setup time by Shortest Path algorithm gets longer than that by other algorithms. This is because that when the arrival rate is low and the number of hop–counts of established lightpath is small, more available wavelengths are left in network than those of the case when least–loaded route is selected.

Fig. 6 shows the performance comparison of the algorithms with dynamic link state information and periodic link state information. It is observed that the performance degradation is small because of the delayed link state information. There are three reasons in this result. First, PROBE signals collect the information of available wavelengths on the route, so the affect of delay is only routing. Second, as the lightpath is established by the alternative routes with

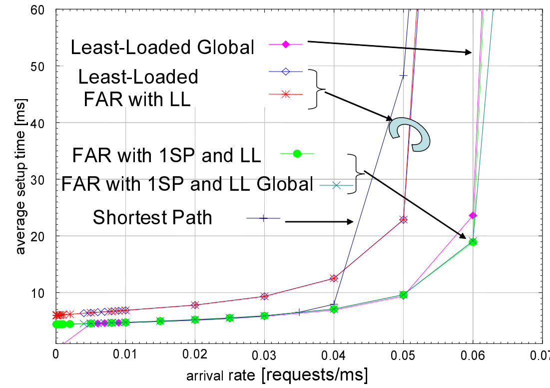


Figure 5 The average path setup time in random network with dynamic link use information: $W = 8$, $1/\mu$ = 1.0ms, the average of link propagation delay 0.1 ms

small number of retry, appropriate route is selected soon because the number of alternative routes is small. Third, in least loaded routing algorithm, it is assumed that the delayed link state information prevents the sender nodes from selecting an appropriate route selection. However this result shows the affect of delayed link state information is small. This is because this topology is small (mean hop distance of node pair is 2.2), the sender nodes can collect the neighbored link state information, so the value of load on the routes is approximately close to current network state.

In Fig. 7–8 shows the results of same comparison of the routing algorithms in the Japan backbone network topology. According to these results, the difference of performance with each algorithm shows same trend. The FAR with 1SP with LL performs better than the other algorithms do. And in Fig. 8 doesn’t shows the characteristics as in Fig. 6; Least loaded algorithm degrades because of imprecise information, and the other algorithm degrades little. This is because that the topology of the Japan backbone topology has more links and nodes, the wavelength resources frequently changes. So the block in PROBE sequence occurs frequently when the sender node has imprecise link state information. On the other hand, the sender node which can select alternate route, the imprecise link state information degrades little.

4. Conclusion

We investigated the effect of the frequency of link state information exchange on the blocking probability on the both forward and backward reservation protocols. We evaluated them in three network topologies; random mesh network, realistic mesh network, and 3–node tandem network. The simulation results show that when the backward reservation protocol is used, the routing can be done with less frequent link state information exchange using less detailed information than the forward reservation protocol is used. And next we evaluated the alternate routing algorithms on the point of delayed link state information. The result shows that when the primary route is fixed to a shortest path and the other routes are

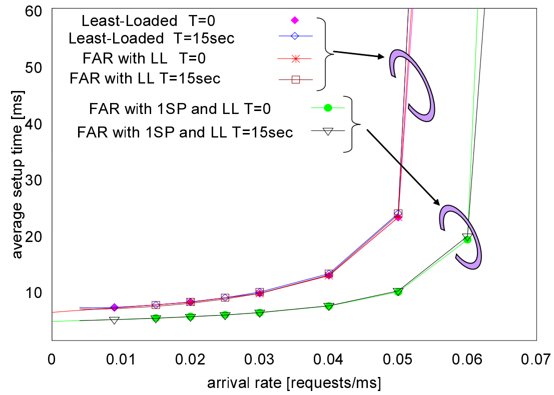


Figure 6 The average path setup time in random network with periodic link use information: $W = 8$, $1/\mu$ = 1.0ms, the average of link propagation delay 0.1 ms

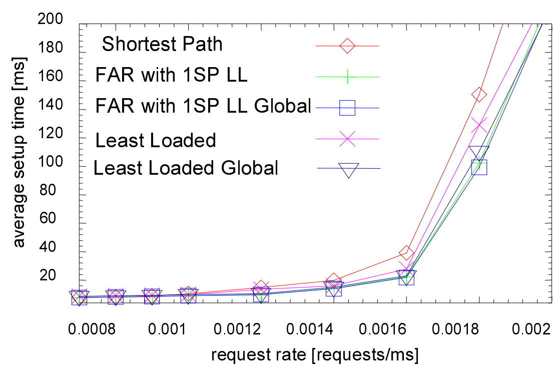


Figure 7 The average path setup time in random network with dynamic link use information: $W = 8$, $1/\mu$ = 1.0ms, in the Japan backbone network

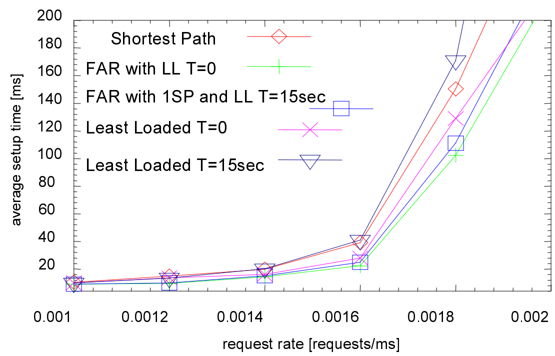


Figure 8 The average path setup time in random network with periodic link use information: $W = 8$, $1/\mu$ = 1.0ms, in the Japan backbone network

the order of less loaded performs as same average lightpath establishment time as the least loaded algorithm with global link state information. And large topology makes the least loaded algorithm degrades because of imprecise link state information, and the other alternate routing algorithms degrades less.

We are implementing these signaling methods in Linux to evaluate in realistic model to elucidate these performance evaluations with realistic condition.

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