A Markov selection Split Reservation Protocol for WDM Optical Networks without Wavelength Conversion

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I. INTRODUCTION

In wavelength division multiplexed (WDM) [1]-[9] optical networks, when a connection request arrives at a source node, a dedicated path is first established (routing), and then a free wavelength is assigned to all the links in the route. Such an all-optical path throughout the route is commonly referred as lightpath [1]-[3]. Our work is restricted to wavelength assignment (WA) part only which is independent of routing [5],[6]. We have not considered any wavelength converters in the network.

WA process involves two basic steps: a) selection of a free wavelength from a set of available wavelengths and b) reservation of the selected wavelength throughout the route. Different methods are used for selection of a free wavelength. Two common methods are: random-fit and first-fit [5]. In random-fit, a wavelength is selected randomly from the available pool of wavelengths. In first-fit, the wavelength having the lowest index is selected. Another method, proposed recently, uses label prioritization [10], where the priorities of wavelengths are set depending on the duration of stay in the pool. Another method guesses the availability of wavelengths in advance for each request separately. Thus, other concurrent requests can exclude the already guessed wavelengths and consider the rest. In this work, we employ this strategy using Markov model to select a wavelength to be reserved [7].

TABLE 1: Reservation protocols

<table>
<thead>
<tr>
<th>Selection Reservation</th>
<th>Random</th>
<th>Markov</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalized threshold=0</td>
<td>FRP</td>
<td>MFRP</td>
</tr>
<tr>
<td>Normalized threshold=0.5</td>
<td>SRP</td>
<td>MSRP</td>
</tr>
<tr>
<td>Normalized threshold=1</td>
<td>BRP</td>
<td>MBRP</td>
</tr>
</tbody>
</table>

F: Forward; S: Split; B: Backward; M: Markov; R: Reservation

Note-Normalized threshold is represented by x in the following sections.

Depending on the selection methods and reservation schemes of wavelengths, various reservation protocols (RPs) have been suggested from time to time [3]-[9]. TABLE 1 summarizes a classification of some of these protocols. We already know that, in terms of blocking probability (bp), backward RP (BRP) performs better than forward RP (FRP) [2]. The normalized threshold (denoted by x in this work) selects the position for initiation of reservation dynamically. The parameter x may be applied on total hop count or on the distance between source and destination of a route. For 0<x<1, the reservation is initiated from source and for x=1, the reservation is initiated from destination. For 0<x<1, the reservation may be initiated from any intermediate node. A Split RP (SRP) [11] can use either hop count or distance for selecting the optimal splitting point. When it uses distance, we denote it by SRP* in order to differentiate it from SRP which uses hop count. We have implemented both SRP* and SRP and found their performances to be very close to each other. Initiation of reservation from intermediate nodes may be either static (e.g., Intermediate node Initiated RP (IIRP)) or dynamic (e.g., SRP).
It is reported that SRP[11] performs better than both BRP and IIRP. However, in normal SRP, selection of wavelength is random. So there is a scope to improve the scheme by guessing the wavelength to be selected for reservation in advance using Markov model. This motivates us to try Markov-selection SRPs (MSRP) in this work. We have implemented both MSRP (uses hop count) and MSRP* (uses distance) and similar to SRP, found them to be very close to each other in terms of performances. So, without any loss of generality, we discuss only MSRP* here. Among other schemes, a notable one is a strategy to select a wavelength for reservation using Markov model on BRP (MBRP) [7] which outperforms normal BRP considerably. In another similar protocol, known as Destination Initiated Multiple wavelength RP (DIMRP) [9], BRP is modified to reserve multiple numbers of wavelengths. It is reported that DIMRP also performs better than BRP [9]. So we compare MSRP* with SRP, DIMRP and MBRP in this paper.

We have used the following terms. Source and destination indicate source node and destination node respectively. PROB, RES, REL, ACK and NACK are all control packets used in a designated route to probe and collect the availability of wavelengths, to reserve wavelength(s), to release wavelength(s), to acknowledge the acceptability of a connection request and to acknowledge the rejection of a connection request respectively. The paper is organized as follows. MSRP* and its necessary background are described in Section III. Comparative simulation results are presented in Section IV. Section V concludes the paper.

II. DESCRIPTION OF MSRP*

When a request comes, the source initiates a PROB [2] towards destination (Figure 1). PROB includes the following fields: source id, destination id, route-path, probe-map, connection id and prev-guess-index, where route-path is the ordered list of nodes on the selected route and probe-map is an array indicating the availability/unavailability of each wavelength in the route. For now, we assume that prev-guess-index stores the guessed wavelength. While the PROB moves towards destination, each node performs three major tasks: (i) detects the interfering connection requests, (ii) selects a guessed wavelength for the request and (iii) initiates splitting (dynamic splitting) if necessary. Dynamic splitting is discussed in section III. Detection of interfering connection requests and selection of guessed wavelength are discussed below.

![Figure 1. Timing diagram of MSRP* (for successful case)](image)

A. Detection of interfering connection requests

Each node creates a table called node-table (Table II). A node-table records all connection requests passing through the node. Each record contains source-id, destination-id, connection-id, pre-hop-id, next-hop-id, arrival time and guessed-wavelength. When a connection request arrives at a node, it is called current request. All other ongoing requests that arrived earlier at that node are called under process requests. Those under-process requests who have identical pre-hop-id or next-hop-id as that of next-hop-id of the current request are called interfering requests. All the interfering requests have already guessed some wavelengths, and the node-table keeps those as guessed wavelengths. The duration of a record in a node-table is bounded by source-destination round trip time of the concerned connection request.

B. Selection of a guessed wavelength

Each node broadcasts its adjoining link usage information at every T seconds. This is stored in link-status table which contains link-id and bit map representing status of usage of all wavelengths of the link. A ‘0’ is placed in the bit map when the corresponding wavelength is not free and a ‘1’ otherwise. So each node comes to know about the wavelength allocation on all links in the network at times 0T, 1T, ..., sT, ..., where s is a natural number. However, this information is not necessarily correct at an arbitrary time between sT and (s+1)T. To overcome this uncertainty, a prediction is required to select wavelength. To take the probabilistic method of selection, we have used C-T Markov chain [7] in this work, where each state is represented by the number of wavelengths used in a link. If a state is k that means k wavelengths are used. Total number of states is (N+1), where N is the number of wavelengths per link. Another parameter of the Markov chain is the transition rate between states. Transition of a state k may be to either state (k+1) or state (k-1). Transition time of state k is the time interval between entry and exit of the state k. Transitions can happen multiple times in a monitoring period. The number of transitions (for state k: k to k+1 and k to k-1) per unit time is called the transition rate. Markov parameters are broadcast at every T” seconds and stored in markov-table at all nodes. Here, we have considered T” to be much longer compared to T so that the Markov chain remains stable. After receiving a PROB, a node first updates the probe-map field of PROB by marking those wavelengths as busy (if any), which are (i) guessed by interfering requests or (ii) being used by other requests for transmission. Then, for each free wavelength (if any), the node uses the markov-table to find the maximum probability of getting a wavelength free throughout the path [7]. That wavelength is selected as guessed wavelength. Henceforth, wavelength(s) and average arrival rate of

<table>
<thead>
<tr>
<th>source-id</th>
<th>destination-id</th>
<th>connection-id</th>
<th>pre-hop-id</th>
<th>next-hop-id</th>
<th>arrival time</th>
<th>guessed-wavelength</th>
</tr>
</thead>
</table>

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connection request(s) will be represented as \( w_l \) and \( c_r \), respectively.

III. DYNAMIC SPLITTING

MSRP* adaptively splits a probe attempt into two concurrent (upstream and downstream) reservation attempts at some intermediate nodes selected dynamically. For a connection request, splitting may occur if both the following conditions are satisfied: (i) PROB has traversed a pre-selected distance \((x \times d)\) of a route, where \( d \) is the total distance of the route, \( x \) is a positive fraction \((0 < x < 1)\) and (ii) the guessed \( w_l \) selected earlier is not available at a forward link of a node. We have studied the effect of \( x \) on bp for various network conditions and found that optimum values of \( x \) normally varies from 0.3 to 0.6 depending on the crisis of resources as \( c_r \) and \( w_l \) vary. One such representative result for \( w_l = 50 \) and \( c_r = 50 \) is shown in Figure 2. However, the value of \( x \) may be considered as 0.5 for a moderate to high crisis situation. As shown in TABLE I, for \( x = 1 \), the reservation scheme becomes simple BRP or DIRP [3], and, for \( x = 0 \), it is simple FRP or SRP [3] provided the second condition of splitting mentioned above is not considered. If \( d \) is expressed in number of hops and \( x = 0.5 \), the protocol becomes SRP provided the selection process of \( w_l \) is random.

At the source, \( \text{prev-guess-index} \) field is initialized to the \( w_l \) guessed at that node. During the process of propagation of PROB at the subsequent nodes of a route, a node checks the availability of already guessed \( w_l \) (stored in \( \text{prev-guess-index} \)) in the forward link. If it is not available, a new \( w_l \) is guessed and \( \text{prev-guess-index} \) is updated to the new guessed \( w_l \). Then the node checks the conditions of splitting as mentioned above. If the conditions of splitting are satisfied, it splits; otherwise the PROB propagates to the next node.

If splitting does not occur and the PROB successfully reaches the destination, the destination converts PROB into RES. RES includes the fields: connection id and selected \( w_l \). The \( w_l \) of \( \text{prev-guess-index} \) field is assigned to selected \( w_l \). Destination initiates reservation by sending RES towards source. Standard BRP is used for reserving the \( w_l \). The intermediate nodes, on receiving this RES, lock the selected \( w_l \) as busy and delete the record in the \( \text{node-table} \) of this connection request. However, at any point, if the selected \( w_l \) becomes unavailable, RES is converted to REL which moves towards destination and releases the \( w_l \) in the links reserved so far. A NACK, generated from the point of failure, proceeds towards source releasing the \( w_l \) reserved so far by forward as well as backward RES and the request is blocked. If backward RES is stuck before it reaches the source, it is converted to REL and a NACK is also generated. The REL moves towards destination releasing the \( w_l \) reserved by both forward and backward RES. The NACK moves towards source deleting the entries of this request in \( \text{node-tables} \) of the path. A pseudo code for MSRP* showing the movement of a connection request is given below.

\[
\begin{align*}
\text{Begin} & \\
& \text{calculate } d = \text{distance between source and destination.} \\
& \text{for the first node (i.e., node1) } \\
& \quad \text{find the set of free } w_l W_i \text{ on link } j=1 \text{ excluding the } w_l i \text{ currently used by other requests ii) guessed by earlier requests (using } \text{node-table of node}; \\
& \quad \text{if } W_i \text{ is empty, block the request and exit; } \\
& \quad \text{else, guess a } w_l \lambda_{si} \text{ from } W_i \text{ using link-status table or markov-table as the case may be; } \text{prev-guess-index} = \lambda_{si}; \text{ update node-table; move to the next node; } \\
& \text{end for} \\
& \text{while node; (1< i < n) : n is number of nodes of the route } \\
& \quad \text{find the set of free } w_l W_i \text{ on link } j=i \text{ excluding the } w_l i \text{ locked by the node and ii) guessed by earlier requests (using } \text{node-table of node}; \\
& \quad \text{if } \text{prev-guess-index} \in W_i \\
& \quad \quad \text{update node-table; } i=i+1; \text{ move to the next node; } \\
& \quad \quad \text{else guess a } w_l \lambda_{si} \text{ from } W_i \text{ using link-status table or markov-table; } \text{prev-guess-index} = \lambda_{si}; \text{ update node-table; } \\
& \quad \quad \quad \text{if total distance traveled } \geq d.x, \text{ split and exit; } \\
& \quad \quad \quad \text{else } i=i+1; \text{ move to the next node; } \\
& \text{end while} \\
& \text{End}
\end{align*}
\]
We assume that there are \( N \) indexed \( \lambda_0, \ldots, \lambda_{N-1} \) on each fiber. In the protocol, \( \lambda \) availability is checked during probing and actual availability is used during reservation. Thus, uncertainty prevails until reservation is done. This uncertain period is represented by \( \text{vulnerable period} (t^v(j)) \) and is measured by the duration from the moment when the information regarding availability of \( \lambda \) of a link is collected (during probe) and the moment when actual reservation is done on that link. When splitting occurs, reservation of a selected \( \lambda \) starts towards both source and destination simultaneously from the \( sp \). Thus, splitting reduces the vulnerable period as explained below.

If vulnerable period from a link \( j \) is denoted as \( t^v(j) \), then

\[
\begin{align*}
\text{for MBRP,} & \quad t^v(j) = 2(d - d_j)t_p, \\
\text{for MSRP*,} & \quad t^v(j) = 2(d - d_j - (1-x)d)t_p, \text{ when link } j \text{ is before } sp. \\
\text{= 0, when link } j \text{ is at or beyond } sp. 
\end{align*}
\]

where \( d \) is the distance of the whole route and \( d_j \) is the distance between the source and downstream node of the link \( j \) (Figure 3), \( t_p \) is the propagation delay per unit distance, \( x \) is the ratio of the distance from the source to the \( sp \) and \( d \).

From the above expressions, we find that \( t^v(j) \) for MSRP* is less than that of MBRP which improves the performance of MSRP*. In expression (2), if \( x=0 \), i.e. reservation is initiated at source then link \( j \) must be beyond \( sp \) and \( t^v(j) \) is 0. This is the case of FRP. If \( x=0.5 \) and if we assume (for the sake of simplicity) that there is a node at \( 0.5d \) from source, then the scheme becomes SRP and the value of \( t^v(j) \) is \( 2(d / 2 - d_j) t_p \) which is less than \( t^v(j) \) of MBRP.

\[
\begin{align*}
\text{source} & \quad j^\text{th link} & \quad sp & \quad \text{destination} \\
\quad \downarrow & \quad \downarrow & \quad \rightarrow & \quad \downarrow \\
\quad d_j & \quad x.d & \quad (1-x)d & \quad d \\
\end{align*}
\]

\text{Figure 3. Diagram for vulnerable period}

\[
\begin{align*}
\text{If vulnerable period from a link } j \text{ is denoted as } t^v(j), \text{ then} \\
\text{for MBRP,} & \quad t^v(j) = 2(d - d_j)t_p \quad (1) \\
\text{for MSRP*,} & \quad t^v(j) = 2(d - d_j - (1-x)d)t_p, \text{ when link } j \text{ is before } sp. \quad (2) \\
\text{= 0, when link } j \text{ is at or beyond } sp. \quad (3)
\end{align*}
\]

IV. SIMULATION RESULTS

To evaluate MSRP* and compare it with other protocols, we have used networks of 40 nodes with two topologies. One is mesh with 46 links and the other is dual core ring. Routing in mesh network is fixed shortest path. Signaling is considered as out-band. Connection requests arrive following Poisson’s distribution and connection holding times are exponentially distributed. Simulation model is event driven with negligible processing delay at the nodes. The source and destination of a connection are chosen uniformly at random. We have considered the propagation delay for all control packets including the network broadcast packets. A key performance metric in lightpath establishment schemes is \( bp \). So we have studied the effect of variation of \( \lambda \) and \( cr \) on \( bp \) exhaustively for both mesh and ring networks. Also we have compared the average number of control packets used and average setup time for all the protocols. It is observed that average setup time does not vary significantly compared to other protocols. So the results of average setup time are not presented here. It is also observed that relative performance of MSRP*, in general remains same both in mesh and ring networks. Due to limitation of space, the results presented here are for mesh network only except a representative result of ring network which is shown in Figure 7.

We define \( T_{\text{ratio}} \) as the ratio of \( T' \) to \( T \). First we have studied the effect of \( T_{\text{ratio}} \) on \( bp \) for different values of \( cr \) to select an optimal value of \( T_{\text{ratio}} \). For instance, Figure 4 shows that for \( cr=75 \) and \( \lambda=75 \), \( bp \) is minimum when \( T_{\text{ratio}} \approx 300 \). So, in the subsequent results, we fix \( T_{\text{ratio}} \) at 300. Next, we have studied the effect of \( \lambda \) on \( bp \) for different values of \( cr \). One such result is shown in Figure 5 (for \( cr=75 \)). We find that MSRP* always performs better than SRP*, DIMRP and MBRP(retry is not used in any protocols to keep parity in comparisons). Also as \( \lambda \) increases, \( bp \) of all the schemes decreases and tends to saturate for higher values of \( \lambda \). Next we have studied the effect of \( cr \) on \( bp \) for different values of \( \lambda \). It is observed, in general, that MSRP* performs better than other
protocols. However for low values of cr, the deviations in bp among the protocols are minimum. One such representative result is shown in Figure 6 for wl=75. Figure 7 shows the result for ring network using same parameters. We observe from Figure 6 that i) MSRP* performs always better than all other schemes, ii) for moderate values of cr (60-80) MSRP* performs best. This happens because, in this region of cr, the crisis of getting a wl is moderate which leads maximum number of splitting cases to success. In fact, in this critical situation, MSRP* offers maximum advantage over other protocols. Similarly, We observe from Figure 7 that MSRP* performs always better than all other schemes.

![Figure 6. Variation of bp with cr for wl =75.](image1)

![Figure 7. Variation of bp with cr for wl =75 for ring network.](image2)

Due to better wl guessing, MSRP* needs less splitting than what SRP* needs, and so the average control packets used by MSRP* is more compared to that of MBRP (the difference is restricted to 10% only) but less than SRP*(Figure 8). We have considered PROB, RES, REL, ACK and NACK as control packets for all the protocols presented here. The usage of control packets in DIMRP increases rapidly with increase of cr due to REL packets used for higher number of unsuccessful attempts to release the wl.

V. CONCLUSION

This work shows that the combination of Markov based guessing (to anticipate the probability to get a wl successfully) and adaptive splitting (to minimize bp) entails an effective reservation technique for WDM networks. Our proposed new approach MSRP* performs better than the current best protocols both for mesh and ring network. Though MSRP* uses more control packets as compared to MBRP, given its reduced blocking probability (without any degradation in setup time), MSRP* is a better performer especially in the applications where blocking probability is of prime importance.

MFRP, one of the protocols shown in TABLE I is not yet studied. Also, there is scope of further study in selection of guessed wl using Markov model. For example, instead of selecting the wl with highest probability, the same may be selected randomly from top three candidates.

REFERENCES