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Distributed lightpath establishment techniques using Multi-wavelength Reservation Protocols in WDM optical networks

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ABSTRACT

Distributed lightpath establishment in WDM optical networks involves, apart from routing, two important steps, namely wavelength selection and wavelength reservation. In uni-wavelength reservation protocols, often multiple connection requests unknowingly compete for the same wavelength, even when other free wavelengths are available, resulting in a collision. Attempting multiple wavelengths for reservation in that case improves the probability of successful reservation as exhibited in Destination Initiated Multi-Wavelength Reservation Protocol (DIMRP). So we extend the concept of multi-wavelength reservation to Split Reservation Protocol (SRP) next and then to Markov-based Split Reservation Protocol (MSRP) and find that performance is improved considerably for them too. Initially, we discuss three multi-wavelength schemes separately and compare performance of these protocols with related uni-wavelength protocols in their own category. Then we undertake a comparative study among the three proposed multi-wavelength protocols to find that multi-wavelength MSRP performs the best.

1. Introduction

In distributed WDM optical networks [1–8] having no wavelength conversion facility [9], usually a dedicated lightpath is first established between the *source–destination* pair, before the actual data transfer starts. A continuous path, having the same wavelength reserved in all the hops of the path, is called a lightpath. Currently, to deal with the growth of optical networks and to make room for a dynamic allocation of lightpaths, distributed schemes have been proposed and are being standardized in the framework of Generalized Multi-Protocol Label Switching (GMPLS) [10]. In GMPLS, the physical wavelengths on each link are represented by generalized labels, and lightpaths are established using the resource reservation protocol with traffic engineering extensions (RSVP-TE) [11–12].

In this work, we have used the network without any wavelength converter. So, first of all a lightpath is to be established between *source* and *destination*, and then, that may be used to transfer data. An example is given below to explain lightpath.

Here a network with 5 nodes is taken, as shown in Fig. 1. In this example, for a request Q_1 (say) node 1 is *source* and node 5 is *destination*. A route R (say) between nodes 1 and 5 is: {(1–3), (3–4), (4–5)}. Lightpath establishment means hop by hop reservation of any one wavelength, throughout the route, between *source* and *destination*. In this example, a wavelength w_3 is reserved for all the hops of the route. So a lightpath in the route R (shown in figure with dotted line) using w_3 is established.

Lightpath establishment in a distributed system involves three basic steps [1]: (i) routing [16], (ii) wavelength selection and (iii) wavelength reservation. The RSVP-TE protocol is responsible for provisioning the requested lightpaths. Here, we have not dealt with routing, rather concentrated on steps (ii) and (iii). To exemplify our cases, we have considered fixed shortest path routing. However, the distributed lightpath establishment protocols discussed here in terms of (ii) and (iii) are independent of step (i) i.e., they may use other routing methods also.

Lightpath is first established and then used for transmission. After completion of data transfer, the lightpath is torn by releasing the wavelength used in the lightpath.

During lightpath establishment, requests may be blocked due to the unavailability of a common wavelength on all the links of a route. Again, unavailability of wavelength may occur due to scarcity of resource or resource contention. This resource contention is caused by the concurrent attempts by two or more requests to reserve the same wavelength on a common link. Initially, to handle this issue, three basic reservation protocols, were suggested: (i) Source Initiated Reservation Protocol (SIRP) [1] – also called Forward Reservation Protocol (FRP) [2], (ii) Destination Initiated Reservation Protocol (DIRP) [13] – also known as Backward Reservation Protocol (BRP) [2], and (iii) Intermediate Node Initiated Reservation Protocol (INIRP) [14]. It is also reported [8] that

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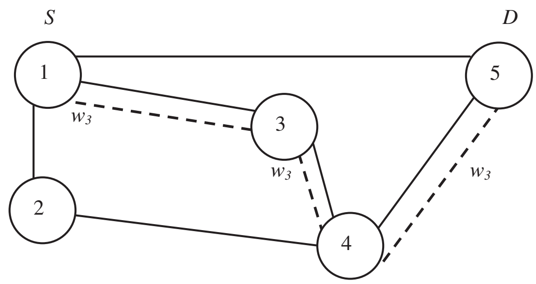

Fig. 1. Lightpath establishment.

INIRP performs better than SIRP and DIRP. In Fig. 1, for request Q_1, if reservation is initiated from node 1, i.e., from *source*, the scheme is SIRP and for DIRP, initiation of reservation should be from node 5, i.e., from *destination*. For INIRP, some intermediate node, i.e., node 3 or node 4 may initiate reservation of wavelength.

Basically resource contention occurs due to lack of updated information regarding availability of wavelength. So, in distributed networks, periodical information flooding or exchange of information among neighboring nodes is done to reduce resource contention. However, due to propagation delay, information about wavelength availability is difficult to be guaranteed at any particular place and time in a large distributed system such as a WDM network. So we cannot totally exclude wavelength collision. Collision of wavelength occurs when two or more requests try to reserve the same wavelength. In Fig. 1, if there be a request Q_2 (say), having a route R_2 (say) between node 2 (*source*) and node 5 (*destination*) as: {(2–4), (4–5)}, and if Q_2 selects the same wavelength (as that of Q_1), i.e., w_3, then the two requests Q_1 and Q_2 will face wavelength collision in their common link (4–5).

To handle the resource contention, wavelength selection process can too play a very important role for distribution of wavelengths (a critical resource) and hence blocking of requests. The basic target of wavelength selection process is to select disjoint sets of wavelengths by concurrent requests for a common link. Though different methods are used for selection of wavelength for reservation, two familiar methods are: *random-fit* and *first-fit* [9]. In *random-fit*, a wavelength is selected randomly from the available pool of wavelengths. In *first-fit*, all wavelengths are indexed in an order, and the wavelength having the lowest index is selected from the available set of wavelengths for reservation. In another method, wavelength selection is done using *label prioritization* [15,21], where the priorities of wavelengths are set depending on their duration of stay in the pool. Accordingly, Giorgetti et al. proposed two schemes [10]:- *suggested label* (SL) and *suggested vector* (SV). Both schemes keep track of potential contentions using an additional bit in the control messages, sent in the forward direction, for contention detection. The SV scheme additionally keeps record of the previously suggested labels. Thus, the *destination* node is provided with an indication of potential contentions, which helps identification of the wavelength to be preferably reserved. It is reported that the proposed label preference schemes are effective in reducing the blocking probability (denoted by '*bp*' in this paper) in *backward path*, without affecting the *bp* in *forward path*, under a variety of network loads. Another important selection method uses *Markov model* first showcased as Markov based Backward Reservation Protocol (MBRP) in [17]. MBRP is discussed in Section 2.

After selection of wavelength, attempts are made for reservation of wavelength(s) throughout the route. An important aspect for wavelength reservation is the number of wavelengths attempted for reservation. The number of wavelengths attempted to be reserved concurrently, is denoted by *aggressiveness* (denoted by '*b*' in this paper)) [2]. Usually, the reservation protocols [5,14,15–19] are least aggressive, i.e., they attempt only one wavelength at a time for reservation (i.e., $b = 1$). We call them uni-wavelength reservation techniques. On the contrary, multi-wavelength reservation schemes, discussed in this work, attempt to reserve multiple wavelengths simultaneously (i.e., $b > 1$). In Fig. 1, for Q_1, if three wavelengths, w_3, w_5 and w_6 (say) are attempted for reservation simultaneously, then that becomes an example of multi-wavelength approach. Multi-wavelength reservation schemes increase the probability of successful reservation of at least one wavelength throughout the route. But the disadvantage is that they always thrive for *over reservation*. If pre-reservation of wavelength(s) is done for longer duration, i.e. much before the actual use of them, that phenomenon is called *over reservation*. Thus multi wavelength reservation may be good for the request under consideration, but it may reduce the probability of successful reservation for the other contemporary requests. Thus, *b* is required to be managed carefully; otherwise the current request may reserve excessive resource (wavelength) for itself thereby causing scarcity of resource for other requests. Hence, the value of *b* is to be optimized to achieve the effectiveness of multi wavelength reservation.

In order to demonstrate the efficacy of multi-wavelength approach, previously we applied this concept of using optimized *b* to DIRP, and the scheme was reported as Destination Initiated Multi-wavelength Reservation Protocol (DIMRP) [13]. In DIMRP, *b* wavelengths (where $b > 1$), are attempted for reservation (subject to availability), and thereby *bp* is reduced.

In this work, we have proposed the use of multi-wavelength approach on two other protocols: (i) Split Reservation Protocol (SRP) [18] and (ii) Markov-based Split Reservation Protocol (MSRP) [19]. The proposed protocols are named as SRP with multi-wavelength (SRPM) and Multi-wavelength MSRP (MMSRP) [20] respectively. In SRPM, splitting may take place depending on some network parameters during probing [2]. If splitting takes place, two reservation packets are initiated in both forward and backward directions simultaneously. Among them, forward reservation packet attempts to reserve *b* wavelengths to implement *aggressiveness*. If backward reservation packet fails at some intermediate node, it releases the reserved wavelength and retries with another wavelength from the available set. In MMSRP, an ordered set of wavelengths is obtained using probabilistic method and the set is continuously updated during probing in the *forward path* before first splitting. If the current wavelength being attempted for reservation is found unavailable, then it uses the top candidate from the ordered set for further splitting.

We have simulated all the above three aggressive schemes and compared their performances.

The paper is organized as follows. Section 2 describes the related reservation protocols and their limitations. Variables and control packets used in different schemes are described in Section 3. Multi-wavelength reservation schemes, DIMRP, SRPM and MMSRP are discussed in Section 4. Section 5 deals with comparison of the protocols and finally, Section 6 concludes the work.

2. Related works

In SIRPs [2], reservation of wavelength is initiated from *source*, much before the wavelength is actually used for data transmission. This increases the *reservation duration* (the duration for which wavelength is reserved prior to actual data transfer). If *reservation duration* is more, wavelength is reserved for a longer period of time, which in effect causes *over reservation*. Due to *over reservation* other concurrent requests may not get enough free wavelengths, and hence, overall blocking increases.

To reduce *over reservation*, DIRPs were proposed [2], where reservation is initiated from *destination* after successful probing from