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Resource Reservation Techniques in WDM Optical Networks: A Comprehensive Survey

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Abstract— **In WDM optical networks, wavelength is the critical resource for efficient communication of traffic. Hence, suitable protocols are required to allocate and use the wavelengths efficiently. We have studied the protocols already developed and reported in literature, for such networks, and considering the historical development, we have outlined some generalized classification for them. We have also provided comparison of their**

is implemented and reported as *Intermediate node* Initiated Reservation Protocol (IIRP) [29],[30].

Reservation Protocols (RP)

$x=0$
Source Initiated (SIRP)

$x=1$
Destination Initiated (DIRP)

$1>x>0$
Intermediate Node Initiated (INIRP)

Static

Dynamic

Fig.2: Classification of reservation protocols depending on initiation of reservation.

In dynamic INIRP, the nodes, from where the initiation of reservation takes place, are not predefined, rather decided *backward path* and releases all the wavelengths except the selected wavelength in the *backward path*. After receiving the ACK, *source* initiates data transmission.

During reservation, if RES fails at any node, i.e., none of the *b* wavelengths remains available in the *next link* (defined as the link, which connects the *present node* and the *next node*) and *reserve_set* becomes empty, the request is blocked. RES is then converted to NACK, which moves back to *source* and carries the information regarding the wavelength(s) to be released. The nodes on the *backward path* releases the wavelength(s) reserved so far, using the information in NACK.

The timing diagrams of the above scheme for successful and failed cases are shown in Fig.4 and Fig.5, respectively. In Fig. 5, *fp* represents the point of failure. In the subsequent figures also *fp* is used to indicate point of failure.

Source *Destination*

RES

ACK

Source *Destination*

PROB

RES

fp

NACK

REL

Fig.7: Reservation failure in DIRP

On the way to *source*, if reservation attempt of any node fails to reserve the selected wavelength, a NACK is generated and sent towards *source*. The request is blocked if no retry is attempted. In that case, one REL is also generated and sent towards *destination*, so that the nodes present on its way can release the wavelength(s) reserved so far. Fig.7 represents the timing diagram for this case of failure.

Source *Destination*

PROB

RES

REL

RES

Data Transmission + REL

Fig.8: Case of success after one retry in DIRP

In DIRP with retry, for similar situation (if RES fails), RES is converted to REL, which returns to the *destination*, releasing the wavelength reserved so far. *Destination* then sends a fresh RES (retry) towards the *source*, selecting another wavelength from the *prob_set*. This may be repeated for a number of retries till a retry becomes successful, or, until all possible retries are exhausted. If all the retries fail, a NACK is generated and sent to the *source*. A case of success using one retry is shown in Fig.8.

A request may be blocked in DIRP, either in *forward path* (i.e., during probing) or in *backward path* (i.e., during reservation. In such cases, REL is used to release the reserved

Reservation), AFD (Aggressive Forward Dropping), and CFD (Conservative Forward Dropping). Similarly DIRP schemes are named as ABD (Aggressive Backward Dropping), CBD

Source *Destination*

PROB

PROB

RES(p)

RES(k)

Data Transmission + REL

Fig.14: Case of success in DIMRP

Source *Destination*

PROB

fp RES(k)

NACK RES(p)

REL

sTJ(y)J749to1 Tf8.5749 0 TD-29342 Tc0 Tw3

Fig.15: Case of failure during reservation in DIMRP

It may be noted that *aggressiveness* (*b*

performance [Fig. 18]. In Fig.18, t represents the time interval after which updated link state information are available.

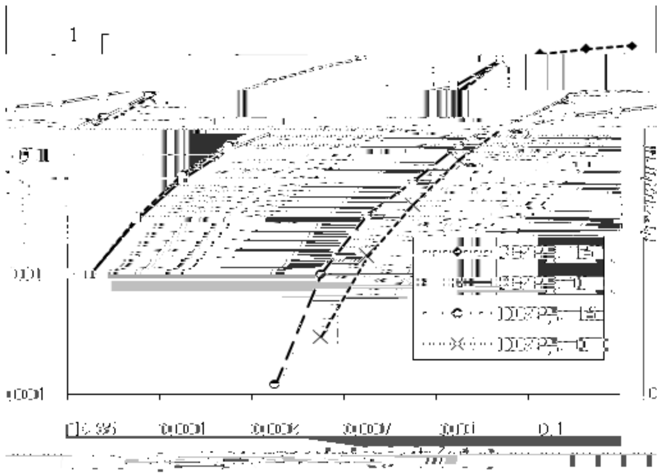


Fig.18: Effect of frequency of exchange of link state information on throughput

F. DIRP using Markov model

To increase the probability of getting the selected wavelength reserved, the concept of broadcasts is used in [7]. The model used by them is reported as *Markov model* and we refer the scheme as MBRP (reported as MBR). In their work, following two types of broadcasts are used: (i) Each node broadcasts its adjoining link usage information at every T seconds. This link usage information is stored at every node. (ii) Link usage information as broadcast above, is not necessarily correct at an arbitrary time between sT and $(s+1)T$. To overcome this uncertainty, a prediction is suggested to select wavelength during these intervals. To take the *probabilistic* method of selection, a C-T Markov chain is used in this work. The required parameters are broadcast at every T' seconds and stored in a table referred as *markov_table* at all nodes. So essentially *markov_table* contains the information of rate of change of states of the wavelength usage for all the wavelengths in all the links. T' is considered to be much longer compared to T. If value of T' is lower than a certain level, it is vulnerable to oscillation which may ultimately lead to poor performance.

In MBRP, When a request comes, the *source* initiates a PROB towards *destination*. While the PROB moves towards *destination*, each node performs two major tasks: (i) detects the *interfering requests* and (ii) selects a *guessed wavelength* for the request.

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* of that node 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.

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*.

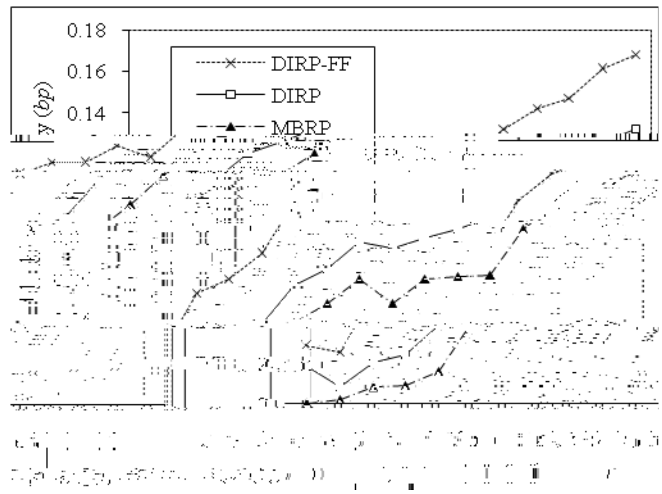


Fig 19: Performance of MBRP over DIMRP and SRP

Using simulated results, they informed that MBRP works best in a small-scale network (Fig. 19). In such networks, the average hop number of a lightpath is small. Backbone networks usually satisfy this topology condition. The performance of MBRP will not improve as the number of wavelength per fiber increases. This is a shortcoming of MBRP compared to DIRP, which uses random selection method (reported as RND) and DIRP-FF, which uses first fit selection method (reported as FFP). However, if the number of wavelengths per fiber is relatively small, then the use of MBRP to decrease reservation confliction is more effective than the use of other algorithms, DIRP and DIRP-FF. They have r oher r oher r .n89 TwfD.4 Tc.(t)6.5(h)-4. 83t5(h)-4yhhmdreco *destination*) as well, thereby reducing the *vulnerable period* and hence reducing the uncertainty of reservation due to *outdated information*. This concept is termed as splitting. However, arbitrary splitting invites certain degree of *over reservation*. Considering this aspect, the position of splitting is to be optimised in order to reduce the effect of *over reservation*. Moreover, decision of splitting is to be taken adaptively to improve the probability of successful reservation in the subsequent links of the route. This is implemented in dynamic INIRP and is reported as SRP [37] and is discussed in Subsection G.1.

If the probability of successful reservation of wavelengths throughout the route can be anticipated using some method, then the decision to select a particular wavelength becomes simple. One such selection method is Markov based selection [7], [10]. The protocol using Markov based selection method with the concept of split embedded in it, is reported as MSRP and is discussed in Subsection G.2.

MSRP is further improved, as reported in [20],[38], using the concept of piggybacking to update link status information in a better way. This scheme is named as Fast Markov based Split Reservation Protocol (FMSRP). FMSRP is presented in Subsection G.3.

MSRP is also improved using multiple splitting [39] and the scheme is reported in Subsection 6.4.

G.1 INIRP using splitting

SRP uses concept of conditional splitting, and both way reservation. In SRP, PROB is split into two reservation both RES_FWD (from the node where failure takes place to *sp*) and RES_BKD (from *sp* to *source*). After receiving the NACK_REL at *source*, the request is blocked.

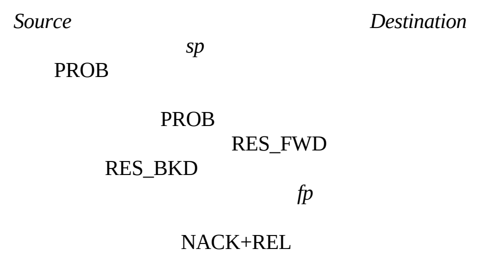
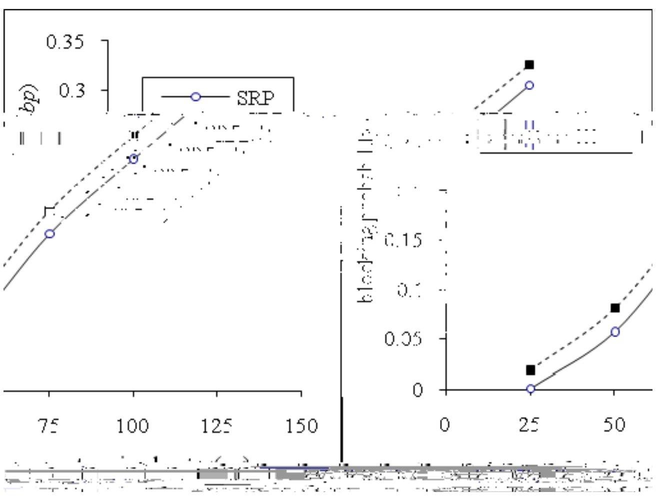


Fig.21: Failure of RES_FWD in SRP

The simulation results (Fig.22) show that SRP outperforms IIRP with respect to *bp*, and *average control overhead*. It is reported that though SRP may have more *average latency*, but considering the betterment in *bp* and *average control overhead* used, the protocol can be considered as better performer.



information is received. A new technique, called fast updating system is implemented in FMSRP. In this protocol, two schemes are used for exchange of information: (i) regular broadcast scheme (usual periodic update) and (ii) *piggy_update* scheme. In *piggy_update* scheme, all control packets used otherwise are *piggy_backed* with link usage information of the links, through which the control packets travel. Under this scheme, the nodes update the link usage information while control packets pass through the nodes. Thus, *piggy_update* scheme may allow longer interval of regular broadcasts (*T*

However if RES_BKD fails at some *intermediate node* due to non-availability of ঠ2, then it attempts for further splitting. Then the node at *fp*, selects the next candidate (say ঠ3) of *future-guess-wavelengths* carried by RES_BKD, for the second splitting. If conditions of splitting are satisfied, second splitting takes place and the RES_BKD again splits into two new RES packets, if ঠ3 is available. These new RES packets are RES_FWD and RES_BKD and they function like previously generated RES packets after the first splitting. These RES packets now attempt to reserve ঠ3 both in forward and backward direction as well as release all the previously reserved wavelengths. If both RES_FWD and RES_BKD are successful, then data transmission starts after receiving the acknowledgement from *destination*. However if any of the RES packets is stuck at some *intermediate node*, the connection request is blocked and packet is converted into NACK which moves towards *source* and another REL_FWD is generated from that point of failure which moves towards *destination* and releases the wavelengths reserved so far by both RES_FWD and RES_BKD. Again if RES_FWD fails, it is converted into REL-BKD which moves towards *source* and releases the wavelengths reserved so far and also acts as a NACK.

Source *sp*$_2$ *sp*$_1$ *Destination*

PROB

RES_FWD

RES_BKD

RES_BKD

RES_FWD+REL

ACK

Data Transmission

Fig. 25: Case of success in MMSRP.

A timing diagram of MMSRP is presented here. Fig.25 shows a case of success. Sp$_1$ and Sp$_2$ used in the figures indicate the two splitting points (nodes) where the first and second splitting respectively occur in a connection request.

The proposed scheme MMSRP is compared with MSRP and MBRP. One representative result for *wl*= 500 is shown in Fig. 26. From the figure, in general it is found that for all the protocols, *bp* increases with increase in *cr*. However MMSRP performs distinctly better than other two. Also it can be observed from the Fig. 26 that with the increment of *cr* the relative performance of MMSRP also improves. This happens because, as *cr* increases, crisis also increases and even after splitting, the rate of failure cases increases. Since MSRP uses splitting only once, it cannot utilize the other wavelengths even if they are free. In contrast MMSRP takes the advantage in such cases, and tries to utilize those free wavelengths, through the process of further splitting.

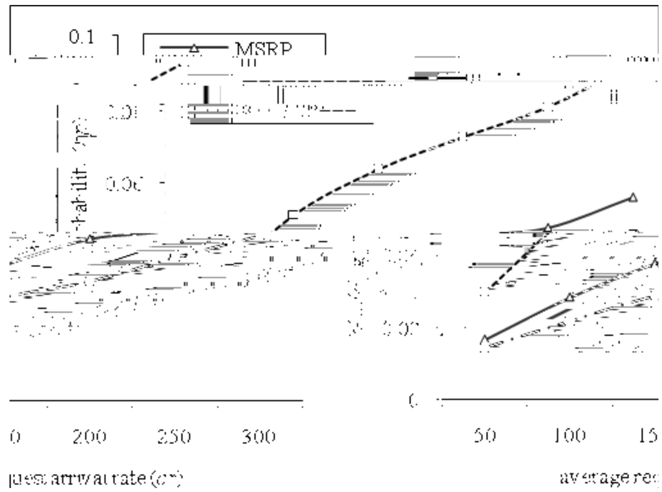


Fig. 26: Variation of *bp* with *cr* for *wl* =500

Variation of *average latency* with *dey onavelika coaeoplikat f(u)5.ast MM* ideally to improve throughput, both *reservation duration* and *vulnerable period* are to be minimized. But these two parameters are interlinked and hence both cannot be reduced simultaneously. Hence, optimization is needed and different protocols are developed having moderate *reservation duration* and *vulnerable period*.

Assuming time required to travel the distance between *source* and *destination* as *d/*s (where *d* is the distance between *source* and *destination* and *s* is the transmission speed), we can compute approximate *able pe* implementation, and hence may be applied on other protocols also.

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Table-3 : Comparison of characteristics of all important protocols

schemes	Ref. no.	Initiation of reservation	Wavelength selection method	(n=total no. of wavelengths per fiber)