

An Intelligent Destination Initiated Reservation Protocol for Wavelength Management in WDM Optical Networks

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Abstract— This paper proposes a new destination initiated (i.e., backward) reservation protocol for lightpath establishment in wavelength division multiplexed (WDM) optical networks. This protocol, named Intelligent Backward Reservation Protocol (iBRP), initially attempts a quick forward reservation using a definite wavelength selected intelligently, failing which it becomes standard BRP. If the initial direct attempt succeeds, BRP is not invoked at all, making iBRP very quick sometimes. The small pre-emptive forward reservation in iBRP provides enhanced efficiency and low setup time (at the cost of slight increase in overall control overhead on average), compared to standard BRP. Simulation analyses of iBRP along with typical variations of BRP and FRP reveal the marginally better performance of iBRP than others even at very high load.

Keywords— WDM, Optical Networks, Reservation Protocols, Wavelength Management, Simulation.

I. INTRODUCTION

In wavelength division multiplexed (WDM), wavelength-routed optical networks [1]-[2], each connection request, prior to be admitted, requires a wavelength path (or, connection) to be established from source to destination. This wavelength path is called lightpath [2]-[4], which uses a single wavelength throughout the path (known as wavelength continuity constraint). A lightpath eliminates the need for buffering and opto-electronic conversions at intermediate nodes [3]. Distributed reservation protocols [4]-[9], under the condition of rapidly changing availability of resources in a dynamic WDM network, should correctly and efficiently reserve necessary and available wavelengths during lightpath (i.e., connection) set-up and again release those resources when they are no longer needed. This wavelength reservation is normally accomplished with the help of a few control packets exchanged between the source-destination pair, prior to the start of data transfer.

Distributed wavelength reservation is controlled by either forward reservation protocols (FRPs) [7],[8], or backward reservation protocols (BRPs) [9],[10]. Forward (backward) reservation protocol is also known as source- (destination-) initiated protocol because the source (destination) node

begins the actual reservation process. In both types of protocols, the source node sends out the first control packet towards the destination node either to reserve (in case of FRP) or to probe (in case of BRP) the available wavelengths enroute [10]. The destination node selects one of the reserved (or potential) wavelengths in case of FRP (or BRP) and issues the second control packet back to the source node to release the unselected wavelengths (or to reserve the selected wavelength) in case of FRP (or BRP) [10].

To improve the performance of BRPs, retry mechanism [9] is introduced wherein multiple wavelengths are tried one after another until success is achieved or the wavelength pool is exhausted. But there is no specific rule for selecting these wavelengths and in most of the cases they are chosen randomly (in a memory-less fashion) [11]-[12]. While investigating this selection process, we have found that once we apply the following kind of stateful (i.e., memory-based) selection, performance improves. If the destination node keeps the recent usage history of wavelengths in the memory and based on that picks up the wavelength, which has been made free very recently after being used by the same source-destination pair, the chance of success increases. This finding motivated us to select the ‘most recently released wavelength’ at the destination in BRPs. Next, going one more step ahead, we argue that since this knowledge about the most recently released wavelength is also available with the source node too, the source node itself can take a chance by directly beginning the reservation process using that particular wavelength in the forward direction instead of waiting for the destination node to do that in backward reservation. If this selective forward reservation fails, standard BRP may be followed next. We call this unique combination of FRP and BRP, where BRP is pressed into action on demand following an intelligent FRP, a new protocol known as intelligent BRP (iBRP).

The above concept is based on the *Principle of Locality*, which states there exists often a high correlation between recent referring history and near future referring patterns. This principle is used in operating systems (OSs) for page swapping – most policies try to predict the future behavior on the basis of past behavior. We are using this principle of locality in selecting the wavelength for a source-destination pair.

The rest of this paper is organized as follows. In Section II, we briefly discuss the background of FRPs and BRPs. In Section III, we present the proposed protocol and discuss its relevant properties. In Section IV, we give a detailed performance comparison of the proposed protocol with respect to standard FRPs and BRPs. Section V concludes this paper.

II. BACKGROUND ON FRP AND BRP

In order to understand the new protocol, we need to have a background on reservation protocols in some details. This is provided in this section. For all the protocols, we assume that the routing decision has been taken a priori and it is known for each source-destination pair.

A. Forward Reservation Protocol

In forward reservation technique, the source node sends a reservation (RESV) packet to the destination node along the decided route, once a connection request has arrived. Each node along the path processes the RESV packet and temporarily locks one or more appropriate wavelengths on the next link for the connection. If no suitable wavelength is found on the next link at an intermediate node, the node sends a failure (FAIL) packet back to the source. FAIL packet unlocks all the wavelengths reserved thus far on the previous link(s). Otherwise, at the destination, one of the wavelengths available in the RESV packet is picked up, and a confirmation (CONF) packet in this regard is sent back from destination to source. On its way back to the source, the CONF packet permanently locks the selected wavelength and unlocks the other wavelengths at the intermediate nodes. There are many variations of FRP [7]-[10] which are discussed below:

Exhaustive: All available wavelengths in all hops in the selected path are blindly reserved by RESV.

Selective All: All available wavelengths are not blindly reserved; only those wavelengths are reserved, which are already reserved in the previous hop by RESV.

Selective N: Similar to Selective All but there is an upper limit (say, N) on the number of wave-lengths that can be reserved in any hop. Details can be found in [6].

Selective N with Intermediate Unlocking (SNWIU): Similar to Selective N but wavelengths unavailable on a hop are immediately unlocked on the previous hops. This increases the protocol efficiency but with an extra control overhead. Details can be found in [7],[8]. While discussing comparative results in this paper, we shall talk about S3WIU, where $N=3$.

B. Backward Reservation Protocol

In BRP, a source node sends a probe (PROB) packet, instead of a RESV packet, to the destination. This PROB packet only gathers the wavelength usage information along the path and does not lock any wavelength. Upon receiving the PROB packet, the destination node decides the wavelength to reserve and sends back a RESV packet, which now locks the wavelength (if it is still available) along the reverse path towards the source node. This is shown in the

upper part of Figure 1. If the wavelength is not found available at some intermediate node in the reverse path, the node generates a FAIL packet to the destination and a NACK packet to the source. The FAIL packet releases the wavelengths locked so far, and the NACK packet informs the source about the reservation failure [9]-[12].

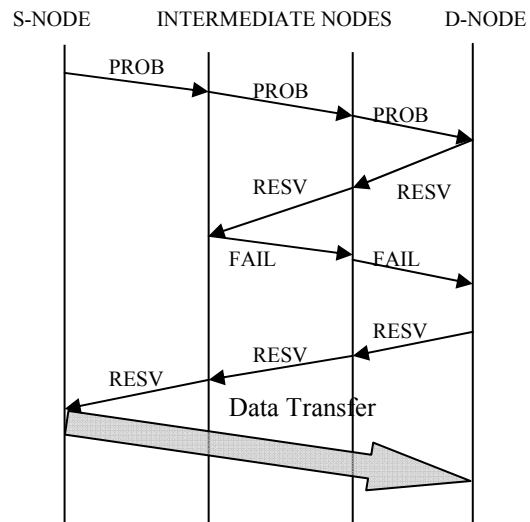


Figure 1. Backward Reservation with Retries (BRP-Tn)

The main drawback of BRPs is that two contemporary connections, sharing one or more common links, can accidentally select the same wavelength to reserve by RESV, because both of them have found the wavelength available by their respective PROB packets. So one of them will be blocked, though other wavelength(s) may be available for the connection. Hence, there will be an unnecessary blocking which is not logically tolerable. To avoid this problem, the following enhancement [9] of BRPs, known as *BRP with reTries (BRP-T)*, is used.

Intuitively, if a connection is blocked accidentally, it should get another chance to start afresh with a new wavelength from the wavelength pool created at the destination. So, when a failure is reported back to the destination by the FAIL packet, it selects another wavelength from the available pool, and a retry is made to find out whether the second wavelength is still available. This is shown in Figure 1. If this attempt fails too, another retry can be made provided a third wavelength is available in the PROB packet. The more the number of retries, the less the chance of blocking, and, hence, the better the performance. But retries will obviously introduce some extra delay in set-up time. So usually a maximum of (say) n attempts, including the first try and following $(n-1)$ retries, are made and correspondingly the protocol is called BRP-Tn.

III. PROPOSED PROTOCOL

As discussed in Section I, iBRP uses the principle of locality and predicts the future behavior of wavelengths regarding their availability, on the basis of their most recent past behavior. In

BRP, we select a wavelength randomly out of the available wavelengths. But, in iBRP, we select a wavelength based on the previous behaviour of the wavelengths. Following the 'most recently used' technique of paging in operating system theory, we employ here the concept of 'most recently released wavelength' and select it. Each node maintains a wavelength record which stores the wavelength indices (say numbers) that were used previously for various destinations with this node as source. So, if there are 20 nodes in a network, each node maintains 19 such wavelength numbers (as there are a maximum of 19 possible destinations from this source).

The protocol is as follows. If a connection request arrives at a source, the source node looks for the wavelength to be used for the destination in its record (stored in memory). If no wavelength is available in the memory, the source node implements the normal BRP-Tn and attempts to establish a lightpath. But, at the time of releasing this wavelength after the service time is over, the source node makes a note of this wavelength to be used for the particular destination in its memory for future use. Now let us consider the case when a connection request arrives at the source and source has the information of previously released wavelength for the destination. Now, the source, without probing and reserving as in case of BRP, directly tries to reserve the particular wavelength, which is stored in the memory for the particular destination, using FRP. If the reservation is successful (Figure 2), the destination sends a CONF packet to the source and lightpath is established.

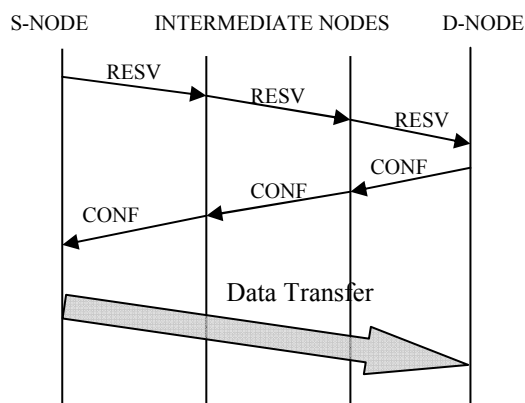


Figure 2. Reservation successful using the wavelength stored (most recently released wavelength) in iBRP-T3

But, if the reservation is unsuccessful, i.e. the particular wavelength cannot be reserved on all the links, the intermediate node sends the NACK-I packet to the source to indicate that this intelligent FRP has failed (i.e., the wavelength has been put to use by some other connection having overlapped lightpath). The source node then reverts back to normal BRP-Tn and carries out probing followed by reservation, if successful. While releasing the wavelength, it stores in the memory the wavelength used (Figure 3).

But, it may so happen that even after trying to establish a lightpath by implementing normal BRP-Tn, a wavelength cannot be reserved. In such cases, the intermediate node sends the usual NACK packet (but not NACK-I packet) informing the source that lightpath establishment has failed. This part follows BRP-Tn exactly.

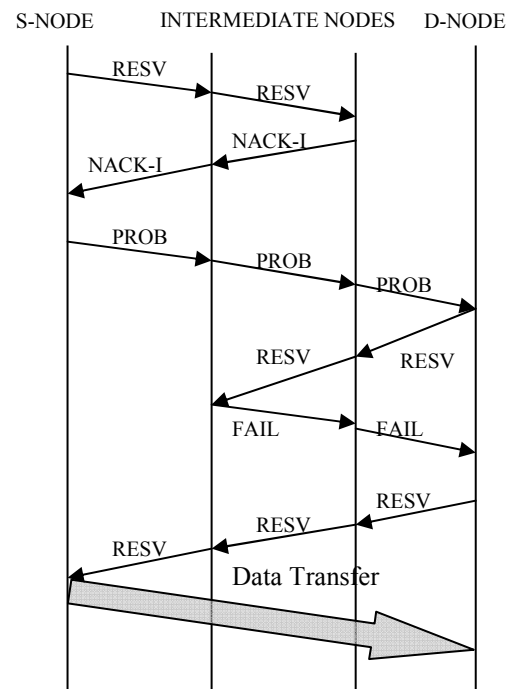


Figure 3. Lightpath establishment fails in the first attempt using the wavelength in the memory but is successful at second attempt in iBRP-T3

Thus, iBRP is actually equal to (FRP+BRP-Tn) where FRP is not an arbitrary one, but an intelligent one. We shall see in the next section that this small overloading of BRP-Tn with FRP yields good results even under high load.

IV. RESULTS AND DISCUSSION

We have tested the afore-mentioned protocol in a simulation environment. Networks of arbitrary mesh topology are generated randomly with varying number of nodes and links. The number of wavelengths per fibre is assumed to be identical for all links in a network. Propagation delay over a link is assumed to be proportional to the length of the link, and processing delay at intermediate nodes is ignored.

In our simulation, we have considered the complete data transfer event spanning three phases. The arrival of connection (call) requests follow Poisson distribution i.e., call inter-arrival time follows exponential distribution. Call holding time (i.e., connection duration) is assumed to follow exponential distribution. If two requests arrive at the same time, they are processed in random order. Routing algorithm uses shortest path and is static in nature, i.e., all the possible paths from a node are calculated in advance and are kept in its local database

table. When two or more wavelengths are available for assignment, random selection is done at the destination.

We have varied the arrival rate (denoted by LAMBDA here) from 50 (light traffic condition) to 500 (heavy traffic condition) requests per second in a representative network with 20 nodes and 152 links with 10 wavelengths per link ($W=10$). Connection requests are assumed to have a mean service rate of 0.0032 second.

We use the following notations in presenting the simulation results.

PE: Protocol Efficiency: It is defined as the ratio of successful connection establishment attempts to total connection attempts that the network is tested with in an observation period.

ACP: Average no. of Control Packets (ratio of total number of control packets in the network to the total number of requests that are tested with the network).

ST: Set-up Time of a request (difference between the time a request starts sending data and the time the request entered the network).

AST: Average Set-up Time (ratio of sum of STs of all the requests in the network to the total number of requests that are tested with the network).

iBRP-Tn: Intelligent Backward Reservation Protocol with 'n' retries.

Success%: Percentage of connection requests which resulted in successful reservation, when 'Most Recently Released Wavelength' is used, out of total connection requests.

Table 1. P.E., AST and ACP of BRP-T1

LAMBDA(/sec)	P.E.	AST (mSec)	ACP
50	78.83	0.17769	2.42
100	67.27	0.14897	2.65
150	59.55	0.13010	2.81
200	53.17	0.11520	2.94
250	48.37	0.10374	3.03
300	44.50	0.09491	3.11
350	41.23	0.08752	3.18
400	38.68	0.08169	3.23
450	35.93	0.07559	3.28
500	33.87	0.0709	3.32

Table 2. P.E., AST and ACP of BRP-T2

LAMBDA(/sec)	P.E.	AST (mSec)	ACP
50	95.72	0.23337	2.54
100	89.85	0.22306	2.93
150	84.51	0.21096	3.20
200	79.55	0.19938	3.44
250	74.75	0.18686	3.64
300	70.87	0.17782	3.81
350	66.53	0.16655	3.96
400	63.17	0.15786	4.09
450	60.07	0.14998	4.21
500	57.18	0.14279	4.31

Table 3. P.E., AST and ACP of BRP-T3

LAMBDA(/sec)	P.E.	AST (mSec)	ACP
50	99.19	0.24975	2.58
100	96.54	0.25278	3.03
150	93.29	0.24969	3.37
200	89.71	0.24306	3.69
250	86.17	0.23542	3.94
300	82.73	0.22784	4.16
350	79.17	0.21933	4.37
400	75.73	0.21062	4.56
450	72.33	0.20172	4.72
500	69.07	0.19303	4.86

From the above three tables we note that PE of BRP-Tn increases with increase in retries. AST and ACP also increase with increase in retries. Next, we present the results of iBRP-T1, iBRP-T2 and iBRP-T3:

Table 4. P.E., AST and ACP of iBRP-T1

LAMBDA	P.E.	AST	ACP	Success%
50	86.50	0.17587	2.64	42
100	76.53	0.15850	3.07	33
150	68.86	0.14242	3.34	29
200	62.37	0.12863	3.55	25
250	57.64	0.11807	3.69	23
300	53.61	0.10947	3.81	20
350	50.15	0.10222	3.92	20
400	46.97	0.09523	4.01	18
450	43.87	0.08871	4.10	17
500	41.91	0.08426	4.15	16

From Table 4, we observe that PE decreases with increase in Lambda. Also the 'Success %' decreases with the increase in Lambda. On comparing this table with Table 1, we find that, for any Lambda value, PE of iBRP-T1 is greater than that of BRP-T1 and AST of iBRP-T1 is less than that of BRP-T1. But ACP of iBRP-T1 is slightly greater than that of BRP-T1.

Table 5. P.E., AST and ACP of iBRP-T2

LAMBDA	P.E.	AST	ACP	Success%
50	97.31	0.21246	2.67	44
100	92.89	0.21297	3.17	36
150	88.27	0.20575	3.51	33
200	83.81	0.19699	3.79	30
250	79.59	0.18722	4.01	28
300	75.61	0.17845	4.21	26
350	71.59	0.16768	4.37	25
400	68.41	0.16042	4.52	23
450	65.33	0.153	4.66	22
500	62.74	0.14636	4.75	21

Tables 5 and 6 also follow the same trend as that of BRP-T2 and BRP-T3. For any lambda value, PEs of iBRP-T2 and iBRP-T3 are greater than those of BRP-T2 and BRP-T3 and

ASTs of iBRP-T2 and iBRP-T3 are less than BRP-T2 and BRP-T3 respectively.

In [10], it is proved that S3WIU variation of FRP and BRP-T3 variation of BRP are the best protocols in terms of efficiency. So, in this work, we compare iBRP with these variations of FRP and BRP and analyze the results.

Table 6. P.E., AST and ACP of iBRP-T3

LAMBDA	P.E.	AST	ACP	Success%
50	99.53	0.22258	2.67	44
100	97.67	0.23394	3.21	37
150	95.02	0.23428	3.58	34
200	91.87	0.23076	3.90	31
250	88.33	0.22447	4.20	29
300	84.98	0.21741	4.41	28
350	81.73	0.20886	4.60	27
400	78.56	0.20159	4.79	25
450	75.17	0.19298	4.95	24
500	72.08	0.18512	5.11	23

Next we present the graphical comparison of PEs of iBRP-T3, BRP-T3 and S3WIU in Figure 4.

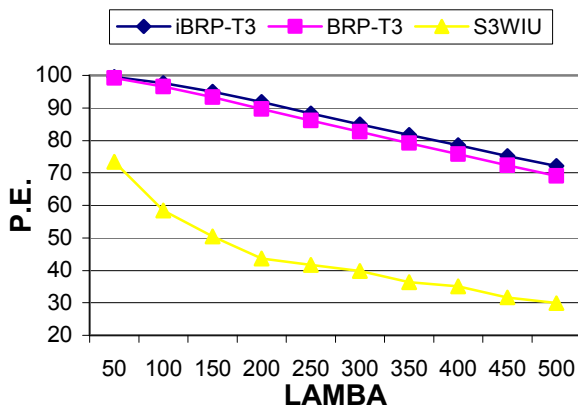


Figure 4. Comparison of PE of iBRP-T3, BRP-T3 and S3WIU

We observe from Figure 4 that, for any value of LAMBDA, iBRP-T3 is performing better than BRP-T3 and S3WIU. PE of iBRP-T3 is better than that of BRP-T3 even at a very high lambda value (as high as 500). The reason for high PE in iBRP-T3 compared to BRP-T3 is due to the fact that we are not probing and reserving any wavelengths in many cases but directly reserving the most recently released wavelength, thus decreasing the setup time and reducing the blocking probability.

From Figure 5, we observe that AST of iBRP-T3 is less than BRP-T3 while AST of S3WIU is the least. The reason for low AST of iBRP-T3 when compared to BRP-T3 is due to the fact that we are directly trying to reserve the 'most recently released wavelength' with out probing and reserving in most of the cases.

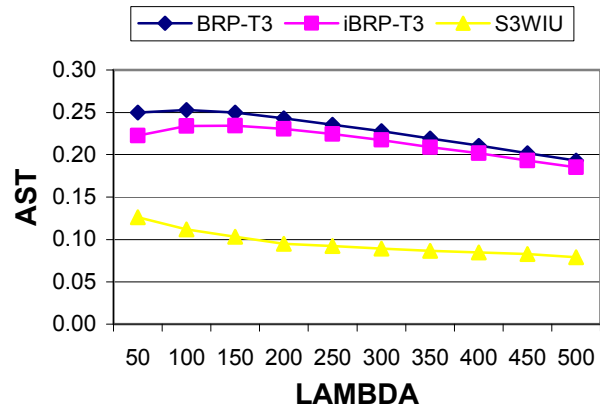


Figure 5. Comparison of AST of iBRP-T3, BRP-T3 and S3WIU

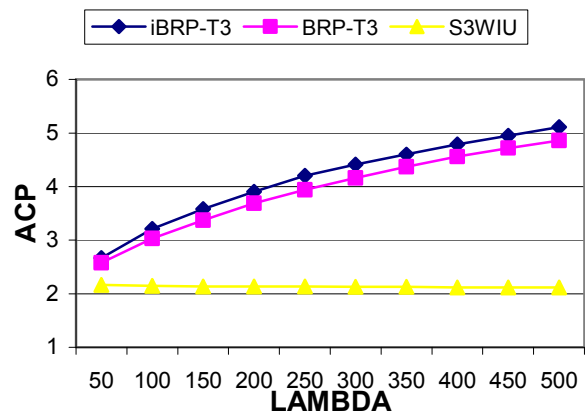


Figure 6. Comparison of ACP of iBRP-T3, BRP-T3 and S3WIU

From Figure 6, we observe that ACP of iBRP-T3 is slightly higher than ACP of BRP-T3. The reason is due the fact that since we are directly trying to reserve a wavelength based on past behavior, if this reservation fails, we will have to generate a NACK-I packet – thus a total of two control packets (RESV, NACK-I) are generated in excess of normal packets, if the wavelength reservation fails at the first attempt. AST of S3WIU is the least when compared to the other two protocols.

Similar trend of PE, ACP and AST follows when BRP-T1 and BRP-T2 are compared with iBRP-T1 and iBRP-T2, respectively.

V. CONCLUSIONS

In this work, we have introduced an intelligent Backward Reservation Protocol, called iBRP, and analyzed it. Simulation results show higher protocol performance of iBRP in comparison with existing variations of both BRP and FRP. At the same time, average setup time of iBRP is less than existing variations of BRP. But the control overhead of this protocol is slightly higher than BRP variations. Therefore, if set-up delay

is tolerable, then iBRP-T3 should be the choice of network designers, particularly under heavy traffic load condition.

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