
Eric Jonsson School of Engineering and Computer Science

4-2003

Destination-Initiated Wavelength-Weighted Reservation Protocol in WDM Rings

Sudhakar Pitchumani, *et al.*

For more information about this item go to: <http://libtreasures.utdallas.edu/xmlui/handle/10735.1/2663>

**Destination-Initiated Wavelength-Weighted
Reservation Protocol in WDM Rings**

Sudhakar Pitchumani, Isabella Cerutti and Andrea Fumagalli

Technical Report UTD/EE-04/2003
April 2003

Destination-Initiated Wavelength-Weighted Reservation Protocol in WDM Rings

Sudhakar Pitchumani, Isabella Cerutti, and Andrea Fumagalli

OpNeAR lab.

The University of Texas at Dallas

Richardson, TX

Email: {sudha,isabella,andrea}@utdallas.edu

Abstract

In networks that require dynamic assignment of wavelengths, it is known that destination initiated reservation protocols lower the blocking probability — caused by unavailable wavelengths or convergence problems of the network status information —, when compared to source initiated reservation protocols [1]. Choosing the wavelength using weights based on past performance may further lower such blocking probability, when compared to random selection strategies [2].

This paper presents a Destination initiated Weighted-Wavelength Reservation DW²R protocol that improves the performance of destination initiated reservation protocol and does not require any additional signaling messages. Wavelength weights are computed based on past blocking probabilities and stored at the source.

A meticulous simulation study carried out on ring networks reveals for the first time a number of interesting properties of the proposed DW²R protocol: a reduced (backward) blocking probability when compared to other reservation protocols, a good scalability in the number of ring nodes (links) and in the number of wavelengths, and a contained performance degradation due to an increase of either the ring signaling latency or the frequency of traffic changes.

I. INTRODUCTION

One of the advantages of Wavelength Division Multiplexing (WDM) networks is the possibility to establish multiple optical connections — referred to as lightpaths — upon the user's request, by reserving one or more wavelengths along the path between the lightpath terminal nodes. In order to dynamically establish lightpaths, fast and reliable signaling protocols are necessary for discovering the available resources and for reserving the wavelengths¹, that are selected to support the end-to-end lightpath traffic.

In distributed network architectures, two resource reservation schemes are commonly considered for such purposes [1]: Destination-initiated Wavelength Reservation (DWR) and Source-initiated Wavelength Reservation (SWR). In both protocols, upon arrival of a lightpath request, a control packet propagates forward from the lightpath source to the lightpath destination along the predefined path. Then, the destination selects a wavelength and informs of such choice to the other nodes along the path by sending a backward control packet. However, while in DWR the chosen wavelength is reserved during the backward control packet propagation phase (backward phase, for short), in SWR all the available (not used) wavelengths are reserved during the forward control packet propagation phase (forward phase, for short). The ones that are not selected by the destination are then freed during the backward phase.

It has been shown [1] that the DWR ability of reserving only the necessary resources (when available) to support the lightpath requests provides a reduction of the probability that a lightpath request can not be satisfied, called *blocking probability*, with respect to the SWR protocol. The superior performance of the DWR protocol has encouraged a number of researchers to further improve this basic protocol. Their objective is to reduce the overall blocking probability, by lowering the blocking probability in the forward phase — called *forward blocking probability* — caused by insufficient available resources and/or by lowering the blocking probability in the backward phase — called *backward blocking probability* — caused by inaccurate (outdated) network status information. Variations of the DWR protocol include the possibility to increase the number of trials to establish a connection (*DWR-with retries*) [3] and to vary the number of wavelengths to be probed (called *aggressiveness*) [4].

An open question, affecting the blocking probability, concerns the strategy adopted for choosing the optimal wavelength to support a given lightpath request. Indeed the lightpath destination has the responsibility to select a wavelength among the available ones. Various strategies may be applied to optimize the wavelength selection in order to reduce the overall blocking probability. The work published in [3] demonstrates that using a random strategy for the wavelength selection, i.e., random selection of a wavelength among those available, provides an overall blocking probability lower than the one obtained by using the first-fit strategy. More recently, weight-based wavelength selection heuristics have been proposed for burst-switched networks [5] and have been successfully extended to circuit switched WDM networks [2]. The results in [2] show that by applying a weight-based wavelength selection strategy to the DWR protocol, the overall blocking probability can be further lowered in arbitrary (mesh) topologies. In the weight-based strategy proposed in [2], weights are assigned to the wavelengths,

¹In this paper it is assumed that a lightpath is using a single wavelength, without any intermediate wavelength conversion.

proportionally to the probability that in the past a given wavelength was successfully used to support lightpaths between a given node pair. Such weights are used to rank the wavelengths: the highest weight wavelength, among the available wavelengths, is then selected by the destination. The information required for the calculation of the weights is stored at the lightpath destination. Additional control messages are thus required to update the weights stored at the destination about the successfully established (incoming) lightpaths.

In this paper, the authors propose and study a Destination initiated Weighted-Wavelength Reservation (DW²R) protocol that does not require additional signaling messages, besides those already required by the conventional DWR protocol with random wavelength selection. This is made possible by storing the weights related information at the lightpath source. The DW²R protocol is tested in bi-directional ring networks, with shortest path routing, where it is expected to yield significant gains due to the minimal network connectivity of such topology.

The overall blocking probability, the forward and backward blocking probabilities obtained by both the DW²R and the DWR protocol with wavelength random selection are derived and compared. For the first time it is shown that the use of a weight-based wavelength selection scheme yields a tangible reduction of the backward blocking probability, that in turns reduces the overall blocking probability. The paper also shows that the performance improvement achieved by the weight-based wavelength selection scheme in ring topology is appreciable.

The simulation results presented in the paper quantify the following advantages of the DW²R protocol, that are not offered by the DWR protocol with wavelength random selection.

- The DW²R protocol scales well with the network size: as the number of nodes (links) of the ring grows, the DW²R protocol reduces the amount of resource (wavelength) contention, providing lower backward blocking probability, when compared to DWR.
- It improves performance under light and medium load: the backward blocking probability is predominant over the forward blocking probability at light and medium load. These are also the traffic conditions under which the DW²R protocol is superior than DWR.
- It is relatively immune to growing signaling latency: as the control packet propagation time increases, e.g., due to congestion, the blocking probability of the DW²R protocol is only marginally affected.
- It is adaptive to growing frequency of traffic changes: as lightpaths are set up and torn down more frequently, i.e., migration toward more dynamic traffic patterns, the blocking probability of the DW²R protocol is only marginally affected.
- It scales well with the number of wavelengths: when the number of wavelengths in the ring increases, the DW²R protocol better exploits the augmented resources.

II. DW²R SCHEME

This section describes in details the weight calculation and the signaling protocol for DW²R scheme when the database of the weights is maintained at the source node.

A. Weight Calculation

Weight calculation requires information of each wavelength for every node. Different techniques can then be applied to evaluate the weight.

In this paper the weight calculation strategy proposed in [6] is applied to estimate the wavelength weights. In this case, the information required to calculate the weights are:

- S_d^w , the number of successfully established lightpaths using wavelength w for a given destination node d , and
- T_d^w , the number of (successful or unsuccessful) trials to establish a lightpath using wavelength w to a destination node d .

The weight assigned to wavelength w for destination node d , P_d^w , can be calculated as:

$$P_d^w = \frac{S_d^w}{T_d^w}. \quad (1)$$

Weights are updated in the following way. Initially, the weights of all the wavelengths for every destination node are set to zero. If a lightpath to node d is successfully established using wavelength w , the weight is increased as follows:

$$P_d^w = \frac{S_d^w + 1}{T_d^w + 1}. \quad (2)$$

If a lightpath to node d cannot be established using wavelength w , the weight is decreased as follows:

$$P_d^w = \frac{S_d^w}{T_d^w + 1}. \quad (3)$$

The following section will explain in detail the signaling messages required to update the database and to exchange weight information.

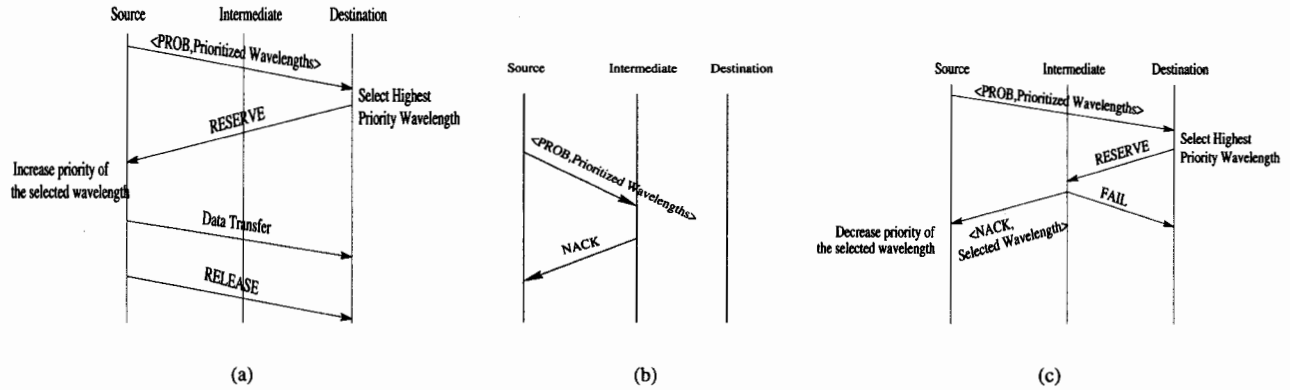


Fig. 1. Signaling protocol: 1(a) successful wavelength reservation, 1(b) forward blocking, and 1(c) backward blocking

B. Signaling Protocol

DW²R signaling scheme is based on DWR protocol [1]. When the database storing the information required to calculate the weights (see Section II-A) is maintained at the source node, the signaling protocol of DW²R is the same of DWR protocol and will be briefly presented here.

Figure 1 shows the different control packets involved in DW²R.

Initially, the source node routes a PROB packet containing, in the payload, the weight value of each wavelength for that destination. The weight values of these wavelengths to the destination are copied from the weight database maintained by the source. The wavelengths, that are not available in the outgoing link, are assigned a negative value as weight to distinguish them from the other available wavelengths. When an intermediate node receives the PROB packet, it determines the outgoing link the PROB packet should be sent on, by checking the routing table. Then, the set of available wavelengths on such outgoing link is intersected with the available wavelengths (indicated by the non-negative weight value) in the PROB packet. Again, the weights of all the non-available wavelengths are set to a negative value and a new PROB packet is formed and sent out. Upon receiving the PROB packet, the destination node picks the highest weight wavelength available in the set and sends out a RESERVE packet back to the source. The RESERVE packet follows the same path in the backward direction up to the source and reserves the highest weight wavelength. When the source node receives the RESERVE packet, it updates the database by increasing the weight of the reserved wavelength for such destination node, according to the weight update rule presented in Equation 2. The sequence of packets, resulting in a successful reservation, is illustrated in Figure 1(a).

Figure 1(b) and Figure 1(c) show the cases of unsuccessful reservation. Figure 1(b) illustrates the forward blocking case in which PROB packet propagation is blocked at an intermediate node, due to lack of available resources, i.e., the intersection of available wavelengths is null. In this case, the intermediate node sends an NACK to the source node. Since no resources are available, the weights of wavelengths are not updated.

Figure 1(c) illustrates the backward blocking case in which the RESERVE packet propagation is blocked in an intermediate node, because another lightpath started to use the selected wavelength after the passage of the PROB packet in such intermediate node. The intermediate node sends a FAIL packet to the destination node and a NACK packet to the source node. The FAIL packet releases all the resources that have been reserved, while NACK packet informs the source node of the failed trial on the selected wavelength. Upon receiving the NACK packet, the source node decreases the weight of the selected wavelength for such destination node, according to the weight update rule in Equation 3.

When the database is maintained at the destination (see [2] for a complete overview of the signaling protocol), an additional control packet (called SUCCESS) should be sent by the source to the destination. In this way, the destination node will be able to increase the weight of a selected wavelength upon receiving a SUCCESS packet.

Next section provides performance evaluation of the DW²R scheme in the case of source-maintained databases.

III. PERFORMANCE EVALUATION

This section presents the simulation results of DW²R scheme on bi-directional ring topologies.

The results have been generated assuming that lightpath requests arrive in the network as a Poisson process with a rate of λ requests per second, and that lightpath holding times are exponentially distributed with an average holding time of $\frac{1}{\mu}$ seconds. Lightpaths and also control packets are routed along the shortest path (in number of links) between the terminal nodes. A separate control channel is used to transmit control packets. At least 10^6 lightpath requests are generated during each simulation run. The traffic load is defined as $\frac{\lambda}{\mu}$.

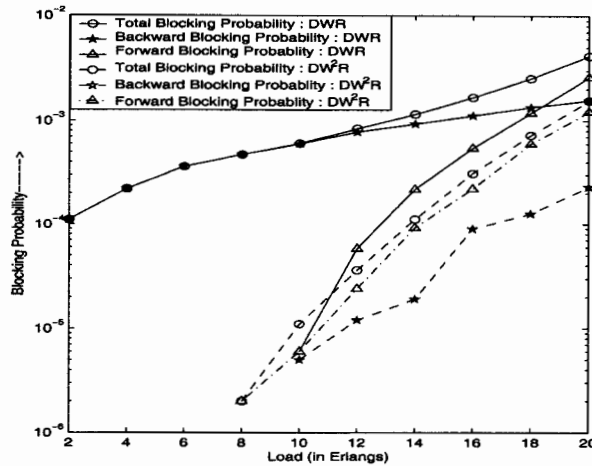


Fig. 2. Blocking probability vs. load

Unless otherwise explicitly specified, the following parameters are assumed:

- number of nodes in the ring: 25;
- number of wavelengths (channels) on each link: 10;
- average arrival rate of lightpath requests: $\lambda = 20/s$;
- average lightpath holding time, $\frac{1}{\mu} = 1s$;
- propagation time on each link: $250 \mu s$; and
- packet processing time in the node: $1 \mu s$.

DW²R performance is evaluated in terms of backward, forward, and overall blocking probabilities (i.e., sum of forward and backward blocking probabilities) and it is compared against the performance of DWR protocol using a random strategy for selecting the wavelengths. The effects of the following network parameters:

- 1) traffic load,
- 2) network size,
- 3) arrival rate of lightpaths,
- 4) propagation time, and
- 5) number of wavelengths on a link

on the blocking probabilities are evaluated next.

A. Effect of the Traffic Load

Figure 2 shows the backward, forward, and overall blocking probabilities as a function of the network load for a 5 node ring, using DW²R and DWR schemes. Network load is varied by changing the arrival rate of lightpath requests and by keeping constant the average lightpath holding time.

In DWR, for light traffic load, it is evident that the main contribution to the overall blocking is the backward blocking probability, due to outdated wavelength state information collected by the PROB control packet. However, when using DW²R scheme, backward blocking probability increases only slightly, thanks to the DW²R "learning" process, i.e., the ability to memorize the "best" wavelength for successful lightpath establishment.

For higher traffic loads, DW²R is still performing better than DWR. However, the improvement is reduced, since lightpaths are blocked primarily because of insufficient resources, leading to high forward and overall blocking probabilities in both DWR and DW²R schemes.

B. Effect of Network Size

Figure 3 presents the blocking probabilities for DWR and DW²R as a function of network size.

As the number of nodes in the ring increases, the average lightpath length is longer, thus increasing the possibility of contention of resources among lightpaths. Thus, both the backward and forward blocking probabilities tend to increase in DWR as well as DW²R. However, the increased rate of the backward blocking probability in DW²R is lower than that of DWR, leading to an appreciable difference in the overall blocking probabilities up to 50% in a 25 node ring. These clearly document the high scalability of DW²R scheme for increasing network size.

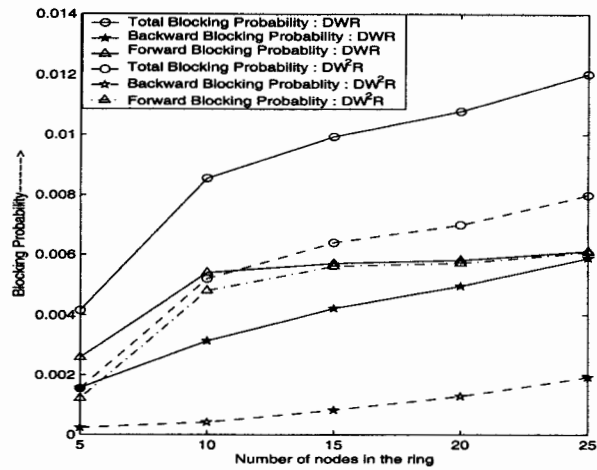


Fig. 3. Blocking probability vs. network size

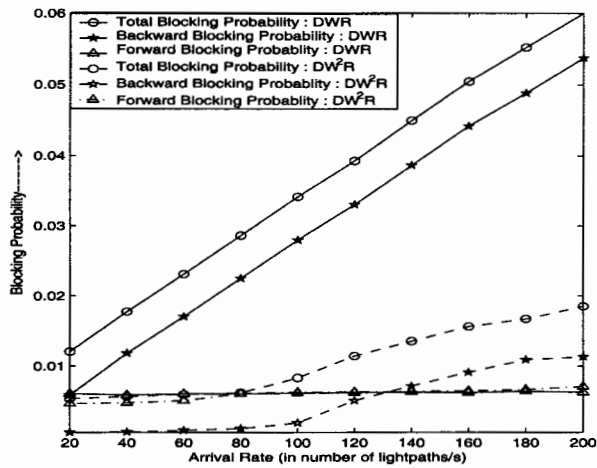


Fig. 4. Blocking probability vs. arrival rate

C. Effect of the Traffic Fluctuation

Figure 4 shows the blocking probabilities for DWR and DW²R in a 25 node ring, for increasing arrival rates and under a given network load. The traffic fluctuations are simulated by varying λ and μ , to keep the network load constant. As the arrival rate increases while the network load is constant, the wavelength state changes rapidly making the information outdated. Thus the plot documents the effects of incorrect information on the backward blocking probability (and then also on the overall blocking probability).

The increase of blocking probabilities is more contained in DW²R with respect to DWR. As already demonstrated, DW²R is able to reduce at minimum the backward blocking probability, which is the dominant factor of the overall blocking probability in case of rapid traffic fluctuations.

Another interesting observation concerns the slight decrease in the forward blocking probability as the arrival rate increases. In agreement with [7], it is possible to speculate that, as the backward blocking increases, the resources occupied by the blocked lightpaths are released and hence the effective load decreases, leading to a decrease of the blocking due to insufficient resources, i.e., forward blocking probability.

D. Effect of Propagation Time

Figure 5 represents the blocking probabilities for varying values of propagation delay on each link for DWR and DW²R schemes.

As the packet propagation time increases, the time required for a control packet to travel augments consequently, yielding to a longer latency to gather information about wavelength availability in the forward direction. Thus, the wavelength state information, collected in the PROB packet and used by the destination node to make the selection, may result already outdated

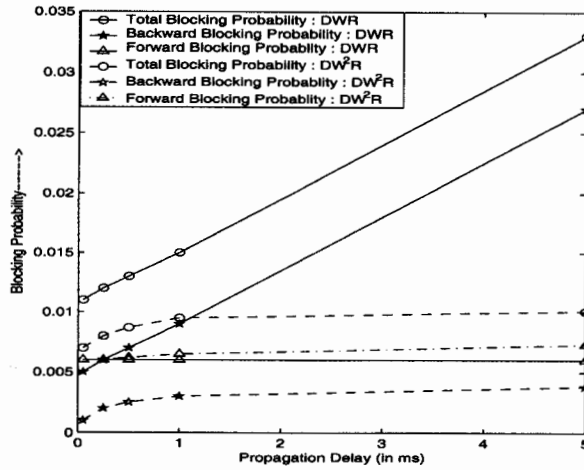


Fig. 5. Blocking probability vs. propagation delay

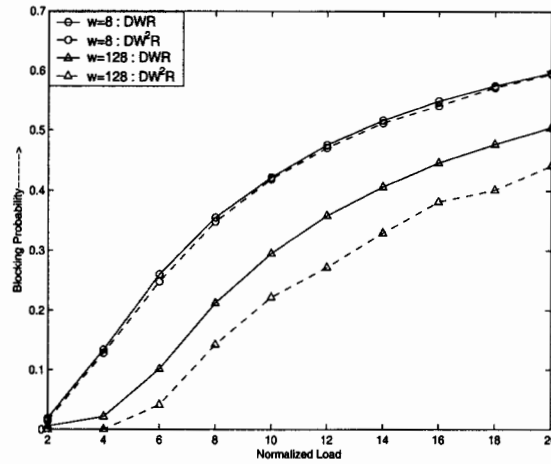


Fig. 6. Blocking probability vs. normalized load

when the PROB packet reaches the destination node. The probability that the destination selects a wavelength no-longer available is higher, leading to an increased backward blocking in DWR, as mentioned also in [1].

DW²R is less affected by the devastating effects of outdated information. The blocking probabilities do not increase as much as in DWR, thanks to DW²R ability of learning which wavelengths are more favorably used by the different lightpath requests.

Notice that even in this case there is a slight decrease in the forward blocking in DWR. The phenomenon can be justified as in the case of rapid traffic fluctuations.

E. Effect of Number of Wavelengths

Figure 6 presents the overall blocking probabilities as a function of normalized traffic load², when the number of allocated wavelengths varies (8 and 128 in the plot).

As the number of wavelengths increases, DW²R outperforms DWR by a significant margin. This high scalability with the number of wavelengths is due to the capacity of DW²R to better segregate the wavelengths between the different source-destination pairs. Hence the probability of contention for the same wavelength by different lightpath requests, i.e., backward blocking probability, can be significantly reduced.

IV. SUMMARY

This paper presented a Destination initiated Weighted-Wavelength Reservation DW²R protocol, that does not require any additional signaling messages, besides those already required by conventional destination-initiated wavelength reservation protocols, e.g., with random or first-fit wavelength selection.

²Traffic load is normalized by the number of wavelengths.

The first comprehensive study of the DW²R protocol performance — in the form of blocking probability — was presented for ring networks. Several anticipated advantages of the proposed reservation protocol were thus confirmed and quantified. First, it was found that the blocking probability reduction due to the DW²R protocol is significant in ring networks. The blocking probability of the DW²R protocol is only marginally affected by increasing network signaling latency and increasing frequency of traffic pattern changes. The proposed protocol scales well in the number of ring nodes (links) and the number of wavelengths.

To the authors' best knowledge, this is the first study that demonstrates how wavelength selection based on past performance helps reduce the backward blocking probability that is caused by outdated network status information in distributed network architectures.

REFERENCES

- [1] Y. Mei and C. Qiao, "Efficient Distributed Control Protocols for WDM All-Optical Networks," in *Proc. International Conference on Computer Communications and Networks*, 1997, pp. 150–159.
- [2] X. Wang, L. Pong, H. Morikawa, and T. Aoyama, "Dynamic Lightpath establishment using prioritized wavelength assignment," in *Proc. IEICE General Conference*, Sep 2002, pp. B–10–30.
- [3] D. Saha, "An Efficient Wavelength Reservation Protocol for Lightpath Establishment in All-Optical Networks(AONs)," in *Proc. GLOBECOM 2000*, vol. 2, 2000, pp. 1264–1268.
- [4] G. Manimaran, H. Rahul, and C.S.R. Murthy, "A new distributed route selection approach for channel establishment in real-time networks," in *IEEE/ACM Trans. Networking*, vol. 7, no. 5, Oct 1999, pp. 698–709.
- [5] X. Wang, H. Morikawa, and T. Aoyama, "Priority-based wavelength assignment algorithm for burst switched photonic networks," in *Proc. OFC*, Mar 2002, pp. 765–767.
- [6] Y. Akaiwa and H. Andoh, "Channel segregation—a self-organized dynamic channel allocation method: application to TDMA/FDMA microcellular system," *IEEE Journal on Selected Areas in Communication*, vol. 11, 1993.
- [7] Jason P. Jue and Gaoxi Xiao, "Analysis of blocking probability for connection management schemes in optical networks," in *Proc. Globecom*, vol. 9, 2001, pp. 1546–1550.