OSNR-aware lightpath provisioning in distributed optical network

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Received September 29, 2010; accepted December 17, 2010; posted online April 22, 2011

An optical signal-to-noise ratio (OSNR) aware lightpath provisioning mechanism (OSNR-LPM) is proposed for distributed optical networks. This OSNR-LPM takes the OSNR value of the lightwave along the lightpath into consideration when establishing the lightpath for the connection request using resource reservation protocol-traffic engineering (RSVP-TE). Moreover, the OSNR-LPM makes full advantages of the OSNR monitoring function in each node and assigns the lightwave by judging the OSNR value carried by the signaling message in order to guarantee the reliable establishment of the lightpath in the data plane. The simulation results show that the OSNR-LPM outperforms other lightpath assignment mechanisms in terms of real blocking probability in the data plane.

OCIS codes: 060.4250, 060.4264, 060.4510.

doi: 10.3788/COL201109.050605.

In distributed optical networks, efficient lightpath provisioning poses a great challenge to routing and wavelength assignment schemes. This type of optical network must take bandwidth availability and wavelength continuity constraints into account. The simplification of the node to avoid complex routing modules and the provision of effective lightwave assignments have both posed a major challenge to distributed optical networks.

In the lightwave resource assignment aspect, several mechanisms have been developed such as source-initiated reservation[1], destination-initiated reservation[1], first fit (FF)[1], random fit (RF)[1], contention detection (CD)[2], collision-aware first fit (CAFF)[3], circular wavelength-list (CWL)[4], and wavelength pre-assignment collision schedule (WPCS)[5], among others. However, these schemes mainly focus on bandwidth availability. In fact, the optical signal-to-noise ratio (OSNR) is also a crucial factor in lightpath provisioning. More and more new optics technologies are being developed to improve the performance of optical networks[6,7]. One of the challenges in distributed all-optical networks is the accumulation of the OSNR as the optical signal transport along the lightpath, especially in a large-scale transport network. The OSNR can be attributed to a number of reasons, one of which is the optical amplifier. However, current studies only focus on the lightwave availability and collision from the control plane aspect. Thanks to the development of OSNR monitoring technologies[8,9], the system can be informed about the OSNR of the lightpath.

Under the wavelength continuity constraint, the aim of wavelength assignment is not only to optimize network resource utilization but also to select a wavelength in order to avoid collision and guarantee the reliable OSNR of the lightwave. The goal is to make sure the lightpath can be set up successively in the data plane. Otherwise, the lightpath cannot be established in the data plane although the signaling procedure is successive in the control plane, which is called "false success". In fact, false success in the control plane actually occurs at times. This is because the lightpath is not provided and established successively in the data plane due to the low OSNR value, even though the signaling procedure is successively completed in the control plane with resource reservation protocol-traffic engineering (RSVP-TE).

Therefore, in this letter, we take the factor of OSNR into consideration in lightwave provision and correspondingly propose an OSNR-aware lightpath provisioning mechanism (OSNR-LPM) that guarantees the smooth establishment of the lightpath and the avoidance of false success. A software testbed of wavelength-routed optical networks is designed and the performance of different assignment schemes is analyzed. The simulation results show that the OSNR-LPM can address false success in terms of blocking probability.

In previous studies, various wavelength provision schemes have been developed, including source initiated reservation (SIR) and destination-initiated reservation (DIR). DIR can be expanded as FF, RF, CD, CAFF, and CWL, among others.

1) SIR: a reservation request PATH message is sent from the source to the destination, reserving one or more wavelengths along the route. One of the reserved wavelength channels is selected by the destination node, and a RESV confirmation is sent back to the source informing it of the selected wavelength.

2) DIR: a reservation PATH message is forwarded from the source to the destination, collecting the wavelength availability information along the route. An available wavelength is then selected, and a RESV message is sent back to the source node to reserve the selected wavelength. Based on DIR, FF/RF is developed in which the destination node selects the first or random wavelength in the available wavelength set in order to reserve and send a reservation request back to the source node. CD is also developed from DIR, which detects the possible resource potential collisions in the forward detection phase by adding a CD bit in the control message; the destination chooses the wavelength selection strategy (FF or RF) accordingly. Moreover, CAFF can assign a weight

to each wavelength of the network links so that the destination can select a wavelength according to the weight collected in the forward detection phase. In addition, in CWL, the intermediate node forecasts which wavelength is selected by the incoming PATH message. The result is then communicated to the subsequent PATH messages passinging through the node. Due to this communication of wavelength information, the connection requests that pass through the same link can consistently select different wavelengths.

WPCS has been proposed by Hua *et al.*[5] By preassigning the wavelength and scheduling the potential collision in the forward detection phase, the WPCS can alleviate the potential collision to a low extent[5].

In the OSNR monitoring aspect, various OSNR monitoring methods have been reported as OSNR monitoring is one of the essential optical performance monitoring functions in wavelength division-multiplexing (WDM) systems. The use of OSNR monitoring technologies makes the network aware of the OSNR of the lightpath.

In this letter, an OSNR-LPM is proposed on the basis of WPCS, which takes OSNR aware into account when establishing layered service provider (LSP). In the new mechanism, the data and the control planes are both considered when allocating the wavelength for the connection request. Compared with other schemes, the proposed OSNR-LPM makes full advantages of the OSNR monitoring technologies of the data plane, in which the PATH message carries the OSNR information of each node along the path at the forward detection phase of signaling. By judging the OSNR value to assign the wavelength for the connection request, the control plane can avoid potential false success when establishing LSP.

For implication, we assume that erbium-doped fiber amplifiers (EDFAs) are widely used among networks and that all nodes in the network are equipped with all-optical based wavelength convertors. Both the wavelength convertor and the EDFA result in the degradation of the optical signal.

The approach used to calculate the OSNR of EDFAs has been well established, and it has played an important role in the design of optical networks for years because EDFAs are widely used in optical networks[10,11]. If the OSNR of an optical signal is infinite at the input of EDFA, the OSNR at the output is given as[10]

$$\mathrm{OSNR}_{\mathrm{EDFA}}=\frac{P_{\mathrm{in}}\mathrm{g}G}{2gn_{\mathrm{sp}}\cdot h\cdot v\cdot B_{\mathrm{o}}}, \quad (1)$$

where P_{in} is the signal power at the input of the EDFA, G is the gain of the EDFA, n_{sp} is the population inversion parameter, h is Plank's constant, v is the optical frequency, and B_{o} is the optical bandwidth that measures the OSNR.

For an optical link consisting of multiple EDFAs and wavelength convertors, the link OSNR of the link can be obtained by using the values of all EDFAs and wavelength convertors:

$$\mathrm{OSNR}_{\mathrm{link}} = \frac{1}{\sum\limits_{i=1}^{N}(1/\mathrm{OSNR}_{\mathrm{EDFA},i})+\sum\limits_{j=1}^{M}(1/\mathrm{OSNR}_{\mathrm{CONV},j})}, \quad (2)$$

where N is the number of EDFAs comprising the optical link, M is that of wavelength convertors, and $\mathrm{OSNR}_{\mathrm{CONV},j}$ is the OSNR value of wavelength convertor j.

Therefore, the total OSNR is estimated by using the monitored link OSNRs of all links comprising a lightpath:

$$\mathrm{OSNR}_{\mathrm{total}} = \frac{1}{1/\mathrm{OSNR}_{\mathrm{init}}+\sum\limits_{k=1}^{K}(1/\mathrm{OSNR}_{\mathrm{link},k})}, \quad (3)$$

where $\mathrm{OSNR}_{\mathrm{init}}$ is the initial OSNR value of the optical signal at the ingress node, $\mathrm{OSNR}_{\mathrm{link},k}$ is the link OSNR of link k, and K is the number of optical links comprising the lightpath.

Currently, various OSNR monitoring functions are integrated into transport plane devices[6,7]. The collection of OSNR information or values is convenient for the control plane.

In the proposed OSNR-LPM, OSNR values are added into the database of the control plane, which is designed to receive OSNR monitoring parameters from the date plane. Additionally, a sub-type-length-value (sub-TLV), which records the OSNR values of each node along the LSP, is added into the PATH message. When the PATH message reaches a pair of neighboring nodes, it first checks the lightwave availability. Then it judges whether the LSP can be established successively according to the OSNR value of the available lightwaves, which is stored in the database. If both constraints are satisfied, the lightwave is selected and assigned to the connection request. If the value of the OSNR of the available lightwave fails to meet the requirement, the lightwave fails even though there are available wavelengths.

The procedure of OSNR-LPM is described as follows.

Step 1: The PATH message is received by the node from its upstream node, which carries the OSNR value of all nodes the PATH message goes through.

Step 2: This node searches the available wavelength for the connection request.

Step 3: The OSNR monitoring module checks the OSNR values of all available wavelengths according to the OSNR constraint and excludes those wavelengths that cannot meet the requirement of OSNR.

Step 4: If there are eligible wavelengths, a wavelength is pre-allocated to the connection request.

Step 5: The OSNR value of the pre-allocated wavelength is added into the PATH message which is sent to the next node.

Step 6: A RESV message is generated and sent by the terminal node which reserves a wavelength that satisfies both requirement of availability and OSNR for the connection request.

Step 7: If there is no eligible wavelength, a RESV message is generated and sent to the source node from the destination node, and the connection request is denied.

In order to evaluate the performance of the proposed mechanisms of OSNR-LPM and demonstrate the validity of the analytical conclusion, a simulation platform testbed is constructed, which consists of 14 interconnected nodes and 21 bi-direction fiber-links with 2 fibers in each fiber-link, with each fiber containing 40-

wavelength links. We assume that there are 8 EDFAs in each fiber link. Further, a network management server and a C^{++} built event-driven program as the client, as well as the generalized multi-protocol label switching (GMPLS) protocol software, are implied in each node. The National Science Foundation (NSF) net topology was adopted in this simulation.

The following six mechanisms are studied in the simulation: FR, FF, WPCS, OSNR-LPM, CD, and CWL. The comparison is made by observing and studying three major performance types: blocking probability without the OSNR factor, real blocking probability with the OSNR factor, and the average setup time of connections.

The real blocking probability without the OSNR factor is shown in Fig. 1. The real blocking probability here refers to the blocking probability of the data plan and not only that of the control plane. In Fig. 1, RF has a slightly lower blocking probability than FF, and so do WPCS and OSNR-LPM. WPCS/OSNR-LPM has a lower blocking probability than FF/RF, and WPCS/OSNR-LPM outperforms FF/RF.

Figure 1 shows that WPCS/OSNR-LPM performs better than the other schemes, and OSNR-LPM still keeps the advantage of WPCS. In CD schemes, a CD bit is used to distinguish potential collisions. In different wavelength selection strategies, different CD bits are used. However, there is only one CD bit, which means that at least two connections have the same wavelength selection strategy in three or more collisions. Therefore, the CD failed to solve the more than two connections, whereas WPCS and OSNR-LPM can solve the same direction collision of more connections by wavelength pre-assignment and

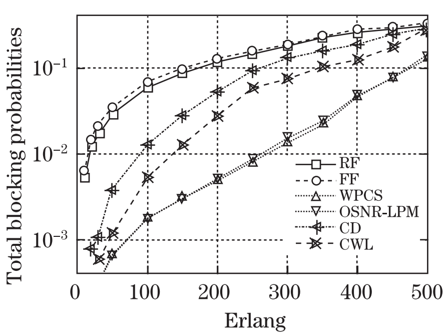

Fig. 1. Real blocking probability without the OSNR factor.

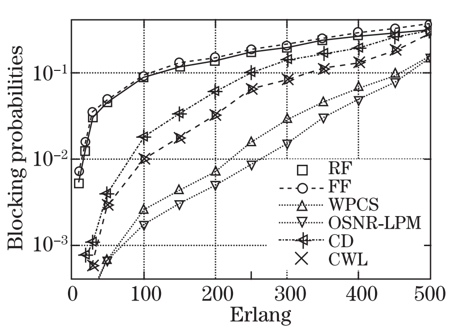

Fig. 2. Real blocking probability with the OSNR factor (threshold is 5 dB).

schedule, and it can also address opposite direction collision (ODC). Therefore, OSNR-LPM performs better than CD in blocking probability. In addition, we can see that OSNR-LPM performs better than CWL. In the wavelength assignment method, CWL is similar to WPCS/OSNR-LPM, but CWL fails to solve ODC.

The real blocking probability with the OSNR factor is shown in Fig. 2 (OSNR threshold is 5 dB) and Fig. 3 (OSNR threshold is 19 dB). From Fig. 2, when the OSNR factor is added into the simulation circumstance, the result is a little different from that of Fig. 1. OSNR-LPM obviously outperforms the other schemes in terms of blocking probability from the aspect of the transport plane because false success occurs in other schemes, and their total OSRN cannot meet the requirement.

By comparing Fig. 3 with Figs. 1 and 2, the values of all schemes increase to some degree under the OSNR constraint, especially RF and FF. In Fig. 2, if we only consider the effect of EDFAs or if the threshold is too low (e.g., 5 dB), the simulation result of blocking probability with OSNR is not so obvious because 5 dB is too low to show the effect of the OSNR constraint. As Fig. 3 shows, when the effect of EDFAs and wavelength convertors are both added into the simulation, and the threshold rises increases (threshold is 19 dB), the result is much more obvious.

The average time of the connection setup is shown in Fig. 4. This simulation aims to compare approximatively the set-up time of various schemes. We take the delay time, time of routing calculation, and process time of signaling message into consideration. The delay time is 2 ms, the routing calculation time is 10 ms, and the process time is varied according to the complexity of the schemes. Connection requests are set to be poisson distribution with $\lambda = \{1, 2, \cdots, 10\}$ per minute, and their holding time follows exponential distribution with an average value of one minute. As the result shows, the values of six schemes increase slightly as the traffic increases. The values of FF and RF are nearly the same as each other, and so are WPCS and OSNR-LPM. The value of the connection setup of CD is a bit higher than that of FF/RF because CD is a bit more complex than FF/RF. The average time of the connection setup of CWL is a bit higher than that of WPCS/OSNR-LPM because CWL uses a circular list, and WPCS/OSNR-LPM uses a much easier fixed length array. The average time of the connection setup of WPCS/OSNR-LPM/CWL is longer than that of FF/RF/CD. WPCS/ OSNR-LPM/CWL assigns the wavelength in the forward and backward phases, so

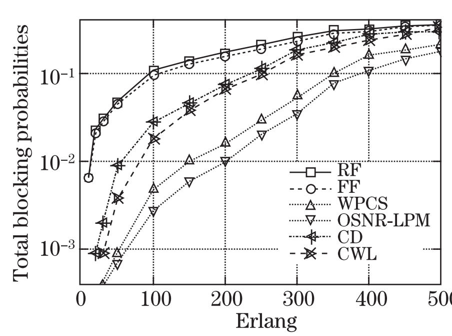

Fig. 3. Real blocking probability with the OSNR factor (threshold is 19 dB).

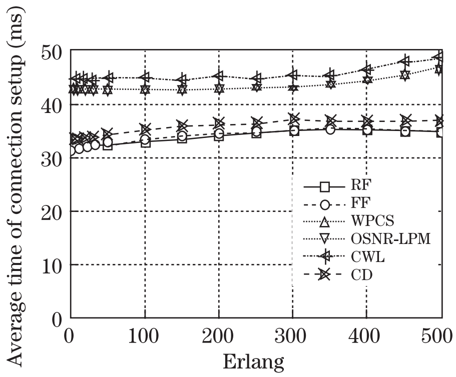

Fig. 4. Average time of the connection setup.

the increased process complexity in WPCS/OSNR-LPM/CWL consumes extra time, which is the unavoidable cost of the lower blocking probability of the new mechanism.

In conclusion, an OSNR-LPM is proposed to guarantee the smooth establishment of the lightpath and the avoidance of false success when establishing the lightpath in the data plane. A test-bed of wavelength-routed optical network is designed, and the performance of different assignment schemes is analyzed. The simulation results show the optimal performance of the proposed mechanism in terms of real blocking probability of the light path establishment.

This work was supported in part by the National "863" Program of China (Nos. 2009AA01z255 and 2009AA01A345), the National "973" Program of China (No. 2007CB310705), the National Natural Science Foundation of China (No. 60932004), and the Specialized Research Fund for the Doctoral Program of Higher Education of China (No. 200800130001).

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