2012 International Conference on Information and Computer Networks (ICICN 2012)
IPCSIT vol. 27 (2012) © (2012) IACSIT Press, Singapore

A wavelength protection algorithm based-on wavelength utilization ratio in DWDM Optical Networks

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Abstract. In virtue of the high capacity of optical networks, a little failure of the network would result in a great loss of the traffic, hence a well-performed protection strategy is of great importance. Several protection strategies have been proposed during the past few years, such as link protection and differentiated path-shared protection. A wavelength protection algorithm for the optical wavelength is presented in this paper. Compared with the previous works, this method achieves better protection effect for the wavelength than the algorithms proposed ever before, and this algorithm provides a higher wavelength utilization ratio and lower wavelength blocking probability.

Keywords: Optical networks, Protection strategy, Wavelength protection algorithm, Utilization ratio, blocking probability.

1. Introduction

With the developing of communications technologies, the request for wider networks bandwidth is rapidly presented. Dense Wavelength-Division Multiplexing (DWDM) is emerging as the dominant technology for next-generation optical networks[1], for it can greatly expand the inherent capacity of optical fibers[2].In the DWDM system, each fiber has several (for example N) available wavelength channels, A wavelength failure in fiber link is shown in Figure 1. If a wavelength fails, a lot of business may be blocked. Therefore, wavelength protection plays an important role of DWDM optical networks.

There are several techniques that have been proposed in literature to realize survivable optical network. Various authors have investigated the link failure problem and presented the algorithms that is called complete path-shared protection (CPSP) and differentiated path-shared protection (DPSP). The basic idea of CPSP is to assign one working path and two link-disjoint backup paths to each connection request. In the worse case, if the working path traverses a failed link and the first backup path traverses another failed link, the second backup path also can be available to transmit the traffic. Furthermore the DPSP, which utilizes the idea of differentiated reliable protection, can dynamically establish the connection according to the requirements of users, and thus, it can save significant resources and reduce the blocking probability.

However, in actual networks the fiber links may under go correlated failures because they may share some common physical resources, which results in a high blocking probability of CPSP and DPSP. Moreover, they do not utilize the wavelength resources in the failed link, so they have a low wavelength resource utilization ratio. And thus, this paper presented an algorithm named wavelength utilization ratio based wavelength protection algorithm (WUR-WP) in single fiber link, which has a better wavelength resource utilization ratio and a lower wavelength blocking probability than the previous works.

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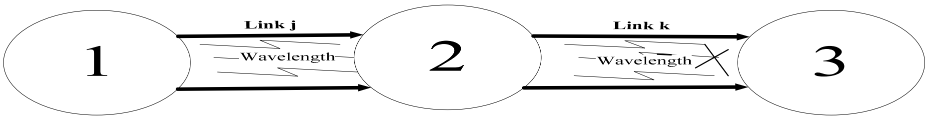


Fig.1: Wavelength failure

This paper is organized as follows. In section 2, we briefly expound the problem to be solved. In section 3, the construction of the protection algorithm is proposed and the simulation results together with the analysis of the algorithm is presented in section 4. Finally, we conclude in section 5.

2. problem statement

A network for a given survivable meshed DWDM optical network can be expressed as $G(V, E, W)$ [3], where V is the set of optical nodes, E is a set of bidirectional links in which each link is made up by a pair unidirectional fibers with opposite direction, and W is the set of available wavelengths per fiber link. The expressions $|N|$, $|E|$, and $|W|$ denote the numbers of all the nodes, links, and wavelengths in the network, respectively. The algorithm assumes that connection requests arrive at the network dynamically, but just one request at a time. And each wavelength channel can bear only one connection requirement at a time either. The algorithm also supposes that each node has the capacity of optical-electronic-optical (OEO) wavelength conversion and wavelength-routing switching[4]. The Dijkstra's algorithm, a classical minimal-cost path algorithm, is applied for the computation of the routes.

Next, this paper introduces some notations and assumptions used in the algorithm[5]. In this paper a bidirectional fiber link between a node pair in G is denoted as l, $l \in E$, and $cost_l$ expresses its cost. The cost of a link is dynamically changed along with the state of the transmission business of the network, such as working wavelengths, free wavelengths, reserved wavelengths, paths' reliabilities. WW_l, FW_l, PW_l represents the number of working wavelengths, free wavelengths, protecting wavelengths on link l, respectively[6].

In DWDM optical networks, there are three kinds of main constraints related to wavelengths: wavelength continuity constraint (WCC), distinct wavelength assignment constraint (DWAC), and non wavelength continuity constraint (NWCC) [7]. In WCC, the wavelength of the links between the nodes of the selected route must be the same. For DWAC, the assigned wavelength on the fibers of randomly chosen two light-paths must not be the same. And in NWCC, different wavelengths can be used on the links between the nodes of the selected route, but the nodes should have he capability of wavelength conversion. Wavelength conversion is the ability to convert the data which is presented by a certain wavelength to a different one. Eliminating the wavelength conversion ability of a switching node would significantly reduce the cost of the network[8]. However, it also may reduce network efficiency, because more wavelengths might be used in the transmission. For such a reason, the algorithm requires that the nodes adjacent to the protected link have the capacity of optical wavelength conversion in this paper, and as a result, the NWCC strategy is adopted[9,10].

Two wavelength assignment strategies are used in our wavelength assignment algorithm and wavelength protection algorithm. One is the Most-Used (MU) strategy, and another one is the Least-Used (LU) strategy. In the MU strategy, the wavelength that is used by most of the links in the network is firstly tried, and then the wavelength with the second-highest number of connections, this procedure is not ended until the available wavelength is found. This strategy attempts to provide maximum wavelength reuse in the network and leave the maximum wavelengths underutilized for the future connection requirement. On the contrary, the LU strategy selects the wavelength which is the least used on links in the network, and it attempts to spread the load evenly across all wavelengths. The LU strategy is the opposite of the MU strategy in that it attempts to select the least-used wavelength in the network[11].

In this paper, the Most-Used (MU) Strategy is used for searching for working wavelength, and the Least-Used (LU) Strategy is selected to search for protecting wavelength（PW）. A protecting wavelength can be a free wavelength or a least-used protecting wavelength, and the most-used working (MWW) wavelength with high wavelength utilization ratio is protected by the free wavelength or least-used protecting wavelength with the smallest wavelength utilization ratio when the MWW fails.

3. Proposed Algorithm

Most of the previous works investigate the failure of single-link, which is dominant case in the DWDM optical networks. Hence this paper adopts the same protection setting. And then the proposed algorithm named Wavelength Utilization Ratio based Wavelength Protection algorithm (WUR-WP) will be illustrated. In the proposed algorithm, the wavelength with high wavelength utilization ratio is preferentially protected. The wavelength utilization ratio of the i-th wavelength of a link can be expressed as

$$U_i = \frac{m}{n}$$

where *m* is the number of times that wavelength *i* is occupied in unit time period, and *n* is the number of times that the total business are transported in the fault fiber link in unit time period.

According to the case of transmission businesses, the endpoint of a link calculates the wavelength utilization ratio of each wavelength, and stores the results in an array *w*[ ]. When a wavelength, for example wavelength *p*, fails, the algorithm searches for a new free wavelength. If there are some free wavelengths, it chooses the one with the smallest wavelength utilization ratio to replace the failed one. Else, the algorithm selects a busy wavelength with the minimum utilization ratio, say wavelength *q*, in the array *w*[ ]: if $w[p]>w[q]$, replace the failed one by wavelength *q*, else, terminate the algorithm and it means that the protection is failed. The procedures of the WUR-WP algorithm are presented as follows.

Step 1. Fault detection: the fault is defined as the wavelength failure in the link *k*, and the fault will be fixed on wavelength *i*.

Step 2. Calculate all the wavelengths' utilization ratio in the failing optical link.

Step 3. Store all the results in an array *w*[ ] (the same calculation results, including free wavelengths' are reserved according to the calculation orders).

Step 4. Protect the fault working wavelength (FWW):

(i) Search for available free wavelength firstly, if there is any, then use it to replace the FWW. Else, go to (ii).

(ii) Extract the fault wavelength's utilization ratio $w[p]$ in the array *w*[ ], then seek the protecting wavelength with the smallest wavelength utilization ratio in *w*[ ] of descending order, assumed to be $w[q]$.

(iii) Judge whether $w[p]>w[q]$? If the inequality holds, use the protecting wavelength (PW) with the smallest wavelength utilization ratio $w[q]$ to replace the FWW. Else, the protection algorithm fails.

This algorithm introduces the conception of wavelength utilization ratio, which is a Real-time protection strategy. It adopts the Seizing Protection Mechanism (that is, it could occupy the wavelength with small wavelength utilization ratio when the network is competing for resources) and the resources are shared in the whole network, which ensures the maximum protection of the working wavelength with high wavelength utilization ratio. Besides, it also improves the transmission reliability of the key wavelengths, which is suitable for the transmission of the significant businesses. The flow chart of our proposed algorithm is presented in Figure 2.

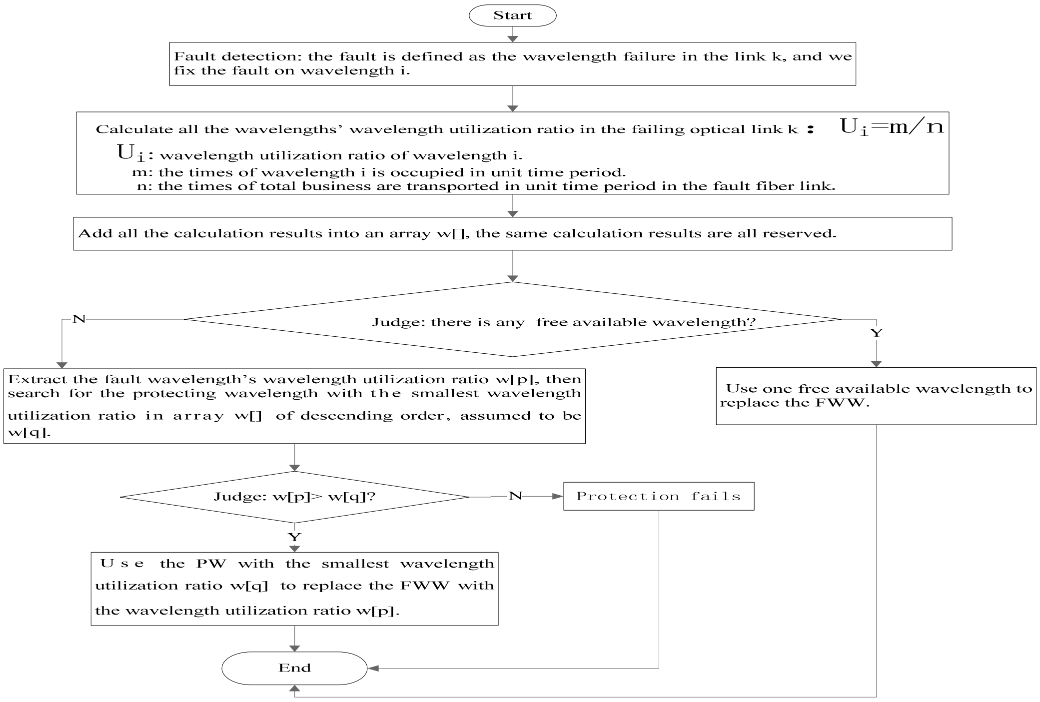
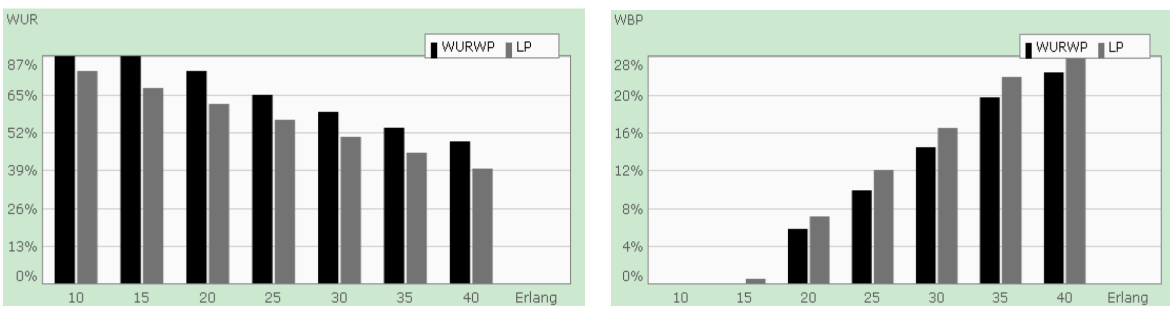


Fig.2 : The flow chart of the WUR-WP algorithm

4. Simulation Results and Analysis

The algorithm assumes that the connection requests arrival according to an independent Poisson process, and the holding time of each connection is a negative exponentially distributed with rate μ. Then, the network load is Erlang business with large capacity. The algorithm assumes that $|W|=16$ in each bidirectional fiber and each required bandwidth is a wavelength granularity. Additionally, all nodes are assumed to have wavelength conversion capacities (OEO). The test network is shown as Fig.2(c), where each node pair is interconnected by a bidirectional fiber link. The Dijkstra's shortest path algorithm is used to find the path from source to destination. In addition, this paper requires the nodes adjacent to the protected link have the capacity of optical wavelength conversion, so it adopts the NWCC strategy. Afterwards, the Most-Used (MU) Strategy is used to search for working wavelength (WW), and the Least-Used (LU) Strategy is used to search for protecting wavelength.

This paper compares WUR-WP with the previous Link Protection (LP) on the performances of Wavelength Utilization Ratio (WUR) and Wavelength Blocking Probability (WBP). The simulation results are shown in Figure 3, where the horizontal level presents the network traffic density in Erlang and the vertical level presents the different standards (WUR and WBP) separately.



(a) Wavelength Utilization Ratio (WUR) (b) Wavelength Blocking Probability (WBP)

Fig.3 : Performance of WUR-WP and LP with different standards

From the first figure, it can be found out that WUR-WP has higher wavelength utilization ratio than LP. There are two reasons for this: (1) The WUR-WP algorithm protects against the wavelength fault, which can guarantee precision of protection. However, the LP algorithm protects against the link fault, when the working wavelength has failed, it searches for another normal link to transport business alternatively, but the WUR-WP algorithm searches for another available wavelength in the fault link, and more wavelength resources will be saved; (2) The WUR-WP algorithm adopts sharing resources protection mechanism, and thus more free wavelength resources and sharing protecting wavelengths can be used by the subsequent requests. So the wavelength utilization ratio will be higher than LP.

From the second figure, it can be found out that the WUR-WP has lower wavelength blocking probability than LP. The reason for this is that, the WUR-WP adopts the real time protection strategy, which can improve the efficiency of recovery and reduce the wavelength blocking probability.

It can be noticed that the cost of the WUR-WP is higher than LP's. The reason is that all nodes are required to have wavelength conversion capacities in the WUR-WP, which the LP does not require, so LP can reduce the network costs significantly. In addition, the WUR-WP adopts the priority protection model, so that it can provides a maximum wavelength protection of high utilization ratio.

In summary, it can be concluded that the proposed WUR-WP can obtain better performances in wavelength utilization ratio and blocking probability than the previous LP. However, the network cost of WUR-WP is higher than LP.

5. Conclusion

In this paper, a new algorithm to protect against wavelength failures in DWDM optical networks is presented. This work adopts the priority protection model and the sharing resources protection mechanism (that is, the network can occupy the wavelength with low utilization ratio when the network is competing for resources), so it ensures a maximum wavelength protection of high utilization ratio, and also it improves transmission reliability about the important business and significant wavelength. Besides, it is applicable to the important business with large-capacity transmission. This algorithm provides a lower level of network wavelength congestion. At the same time, it is a real-time protection strategy, so it can improve the efficiency of recovery. The simulation results show that, compared to previous LP, WUR-WP can provide a higher wavelength utilization ratio and lower wavelength blocking probability.

6. Acknowlegment

This work was supported by the National Natural Science Foundation Project of China No. 60872047 and the supported by "the Fundamental Research Funds for the Central Universities" (FRF-TP-09-015A).

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