Signaling-based path-segment protection in mesh optical networks

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Path protections have become increasingly important for current mesh optical networks because fast restorations in generalized multiprotocol label switching (GMPLS) networks are uncertain. However, setting up additional disjoint paths to protect connections leads to more path setup blocking and signaling collisions. We analyze signaling collisions, path blocking and blocking probability, as well as calculate node-to-node blocking probabilities. A signaling-based path-segment protection (PSP) is proposed, which integrates segment protections and path protections as well as enhances the performance of path protections and ring protections. The setup of PSP connections causes less blocking probability than the setup of path protection connections in the simulations.

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Recently, with the emergence of new protection and restoration methods, mesh topologies have gradually replaced ring topologies, especially in optical transport networks (OTNs)[1], automatically switched optical networks (ASONs)[2], generalized multiprotocol label switching (GMPLS) protocol networks[3,4], and packet transport networks (PTNs)[5]. However, fast restoration methods currently face some challenges in China. The first challenge is that recoveries depend on the network capacity for restoration. It is also not confirmed whether paths can be recovered or not[6]. The second challenge is that the restoration time is not guaranteed. The third challenge is that restorations are not transparent to users[7−9].

Path protections that protect working paths have the performance of 50 ms recovery and confirmed recovery in mesh networks. However, compared with fast restorations, they have high signaling blocking probabilities in path setups. Most companies provide planning systems, such as Ciena's modeling and planning software (MPS), which can plan capacities for working paths and backup paths in order to improve the recovery performance and avoid signaling collisions and path blocking. Recently, p-cycle protections have been applied to wavelength-division multiplexing (WDM) networks and PTNs; however, algorithms for p-cycle protections require a large amount of computing[10]. Shen *et al.* proposed the pre-computed path-segment protection (PSP) based on p-cycle, which also required complex computing and was not suitable for signaling optical networks[11]. This current study proposes a new method, called signaling-based PSP (S-PSP), which extends path protections to PSPs for signaling optical networks.

Since GMPLS-based mesh networks are distributed control systems, signaling collisions and path blocking exist in connection setups and restorations. The following gives the analysis of signaling collisions and path blocking.

Network elements in ASONs are homogeneous. They have the same algorithm for path calculation, such as shortest path first (SPF) and constrained SPF (CSPF)[12], as well as the same method for collision handling. The homogeneous activities simplify the element design, but they lead to more signaling collisions than dissimilar activities. Capacity sharing and path sharing collisions widely occur in ASONs, GMPLS networks, and multiprotocol latel switching (MPLS) networks.

In the present study, we use the blocking probability as the performance indicator for the collision analysis. The blocking probability has the value ([0, 1]), which shows the blocking level for the network. We give the evaluation of network blocking probability on a connection setup sample.

Suppose there is a connection setup sample S_i, in which n connections want to be setup within the duration T_i, and m connections fail to be setup after the duration, then the network blocking probability $P(S_i)$ for this sample is

$$P(S_i) = m/n. \quad (1)$$

Recently, many distributed control policies have been used to reduce blocking probabilities, especially in fast restorations for ASONs and GMPLS networks.

Figure 1 gives the collision analysis on control policies, where samples (loads from 50 to 350) are evaluated on our platform, ASON emulation and modeling system (AEMS). The control policies selected for simulation are first fit (FF) amd last fit (LF), as well as random for long distance connection (LDC) and short distance connection (SDC)[13−15]. Although control policies can reduce the blocking probabilities, e.g., the FF–random SDC, the blocking probabilities become more serious when the load increases.

The capacity utilization is improved with the increase of fast restoration connections (FRCs) in mesh networks. However, the increase of recovery blocking probability (RBP) reduced the restoration performance of these

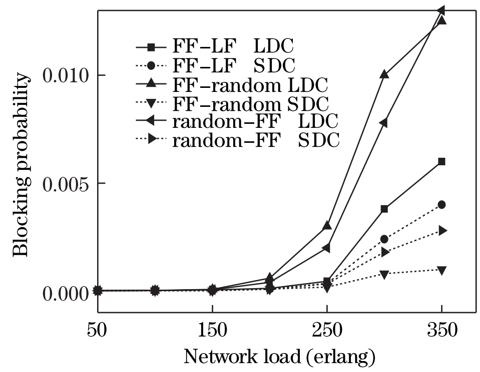

Fig. 1. Collision analysis on control policies (data from our tests and evaluations).

FRCs. Therefore, researchers proposed path protection connections (PPCs) in mesh networks to avoid recovery blocking[16]. Since PPCs require additional disjoined protection paths, they have the higher initial setup blocking probability (ISBP) than FRCs.

Generally, connection paths are optimized in order to increase the capacity utilization; however, distributed control optical networks, such as ASON and GMPLS, cannot optimize connection paths globally. Therefore, paths may be blocked (i.e., path blocking) because of the capacity limitation or inappropriate path calculation methods.

Figure 2 illustrates the path blocking caused by the SPF algorithm. Since PPC needs two disjoint paths, namely, the working path and the protection path, the path blocking either occurs in the working path setup or in the protection path setup. Once the working path has been established, sometimes, we cannot find its disjoint protection path. For example, the working path (a $\longleftrightarrow$ b $\longleftrightarrow$ c $\longleftrightarrow$ d) in Fig. 2(a) is the shortest path according to the SPF algorithm, but we cannot find its disjoint protection path.

PPCs need new path calculation algorithms for setup because the path blocking is caused by the SPF algorithm. Figure 2(b) illustrates the right algorithm for PPCs, which does not use the SPF algorithm. The working path (a $\longleftrightarrow$ b $\longleftrightarrow$ f $\longleftrightarrow$ d) (the weight is 1+2+2=5) has a larger weight than the working path above (the weight is 1+1+1=3), but the connection has the disjoint protection path (a $\longleftrightarrow$ e $\longleftrightarrow$ c $\longleftrightarrow$ d) and has no path blocking.

The signaling blocking is caused by signaling collisions and path blocking, but we still do not know non-blocking probabilities. For example, in setting up a path from node a to node d in Fig. 2(b), we are concerned with the non-blocking probability between them. The following gives a model to calculate the non-blocking probability.

There are many reasons for the signaling blocking; of these, node-to-node non-blocking probabilities are very important but are not yet fully understood. These probabilities denote the possibility of establishing a connection, which is related to the node-to-node capacity, path length, etc. In addition, it can be pre-calculated according to the link evaluation.

Suppose the non-blocking probability of link (x_1,x_2) is $p_\mathrm{l}(x_1, x_2)$. For example, $p_\mathrm{l}(a, b)$=0.8 in Fig. 3(a). Let $p_\mathrm{p}(x_1, x_2, \cdots, x_n)$ denote the non-blocking probability of

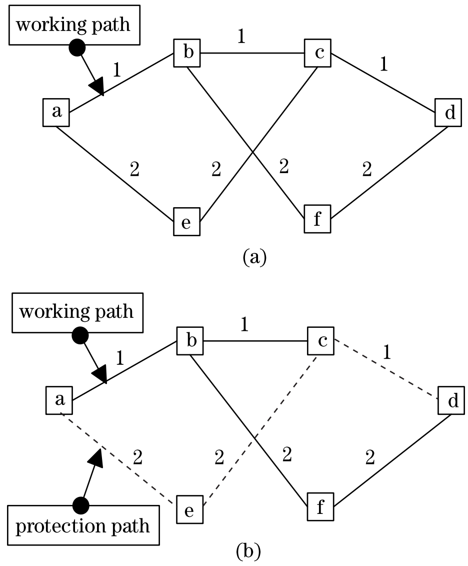

Fig. 2. Signaling blocking caused by the SPF algorithm.

path $(x_1, x_2, \cdots, x_n)$ and $p_n(x_1, x_n)$ denote the non-blocking probability of node-to-node (x_1, x_n).

In this case, $p_\mathrm{l}(x_1, x_2)$ is a value between 0 and 1. We evaluate it according to the link capacity, the network scope, node capacity, etc.

The path non-blocking probability depends on link non-blocking probabilities and can be calculated as

$$p_\mathrm{p}(x_1, x_2, \cdots, x_n) = p_\mathrm{l}(x_1, x_2)p_\mathrm{l}(x_2, x_3)\cdots p_\mathrm{l}(x_{n-1}, x_n). \tag{2}$$

The node-to-node non-blocking probability $p_n(x_1, x_n)$ depends on the protection and restoration of the path. If the working path requires a protection path, the node-to-node non-blocking probability would go down.

(1) When the working path does not need any protection, the node-to-node non-blocking probability $p_\mathrm{n}(\mathrm{a}, \mathrm{c})$ in Fig. 3(b) can be calculated as

$$\begin{aligned} &p_\mathrm{n}(\mathrm{a}, \mathrm{c}) = p_\mathrm{l}(\mathrm{a}, \mathrm{b})p_\mathrm{l}(\mathrm{b}, \mathrm{c}) + p_\mathrm{l}(\mathrm{a}, \mathrm{e})p_\mathrm{l}(\mathrm{e}, \mathrm{c}) \\ &-p_\mathrm{l}(\mathrm{a}, \mathrm{b})p_\mathrm{l}(\mathrm{b}, \mathrm{c})p_\mathrm{l}(\mathrm{a}, \mathrm{e})p_\mathrm{l}(\mathrm{e}, \mathrm{c}) \\ &= 0.8 \times 0.8 + 0.5 \times 0.5 - 0.8 \times 0.8 \times 0.5 \times 0.5 = 0.7476. \end{aligned} \tag{3}$$

(2) When the working path needs a protection path, the node-to-node non-blocking probability $p_\mathrm{n}(\mathrm{a}, \mathrm{c})$ in Fig. 3(b) can be calculated as

$$\begin{aligned} &p_\mathrm{n}(\mathrm{a}, \mathrm{c}) = p_\mathrm{l}(\mathrm{a}, \mathrm{b})p_\mathrm{l}(\mathrm{b}, \mathrm{c})p_\mathrm{l}(\mathrm{a}, \mathrm{e})p_\mathrm{l}(\mathrm{e}, \mathrm{c}) \\ &= 0.8 \times 0.8 \times 0.5 \times 0.5 = 0.16. \end{aligned} \tag{4}$$

Comparing case (1) with case (2), the protection for working path leads to a lower non-blocking probability.

The change of path calculation methods is a big challenge, because equipment needs standardized algorithms to follow ITU Telecommunication Standardization sector (ITU-T) or Internet Engineering Task Force (IETF). Moreover, the signaling blocking is complicated, because nodes cannot foresee the capacity deployment, signaling calls, collision handlings, and path calculations no matter how often the open SPF routing protocol broadcasts link state advertisements (LSAs). Therefore, PPC needs an extension, which can reduce the blocking probability.

S-PSP is a method to reduce blocking probabilities.

Figure 4 illustrates the S-PSP.

(1) The working path is calculated by the SPF algorithm, so that path (a $\longleftrightarrow$ b $\longleftrightarrow$ c $\longleftrightarrow$ d) is calculated as the working path.

(2) Since there is no disjoint protection path for the working path above (path protection required), we set up two path segments, one is (a $\longleftrightarrow$ e $\longleftrightarrow$ c) and the other is (b $\longleftrightarrow$ f $\longleftrightarrow$ d) to protect the working path (a $\longleftrightarrow$ b $\longleftrightarrow$ c $\longleftrightarrow$ d).

Since step (2) above avoids the path blocking, S-PSP reduces the blocking probability for connection setup. S-PSP does not need two end-to-end disjoint paths, yet the protection is still powerful. For example, the PSP in Fig. 5 protects the working path, once links (b $\longleftrightarrow$ c) and (c $\longleftrightarrow$ e) both fail. Thus, S-PSP can enhance or weaken the protection by adding or reducing path segments.

S-PSP reduces blocking probabilities and enhances the protection performance, while its advantages are more notable in the mixed protection. Recently, ASONs support ring and mesh topologies, but path protections are not suitable for mixed topologies and ring topologies.

Figure 6 illustrates the mixed protections, where the working path passes through two mesh topologies and a ring topology. Since the ring topology does not need any path protection, the path protection is not suitable for the working path (s $\longleftrightarrow$ b $\longleftrightarrow$ c $\longleftrightarrow$ d $\longleftrightarrow$ e $\longleftrightarrow$ f $\longleftrightarrow$ g $\longleftrightarrow$ t). We preset two path segments, namely, (s $\longleftrightarrow$ a $\longleftrightarrow$ c) and (g $\longleftrightarrow$ j $\longleftrightarrow$ t), in the mesh topology to protect the working path. Hence, the mixed protection improves the protection performance and reduces blocking probabilities.

Most optical networks, such as ASONs, are pre-planned by the China Information Technology Consulting and Designing Institute, before network deployment. The planning and design tools, such as vitual path identifier (VPI) planning systems[17], are widely used in China. In the current study, we used ASON planning (ASONP), which is a software developed by us for planning and designing ASONs.

Capacity planning is a well-known planning method, which appends the capacity of the optimized paths. For example, if the traffic model is 50 end-to-end connections, ASONP finds the best path for each working path

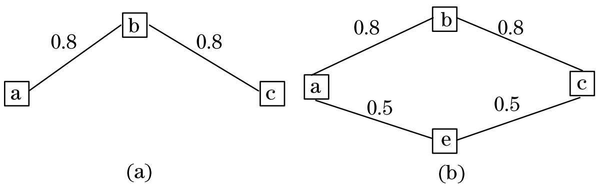

Fig. 3. Node-to-node non-blocking probabilities.

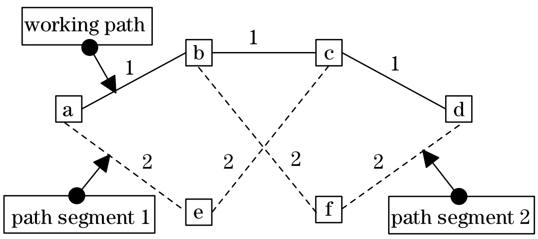

Fig. 4. S-PSP.

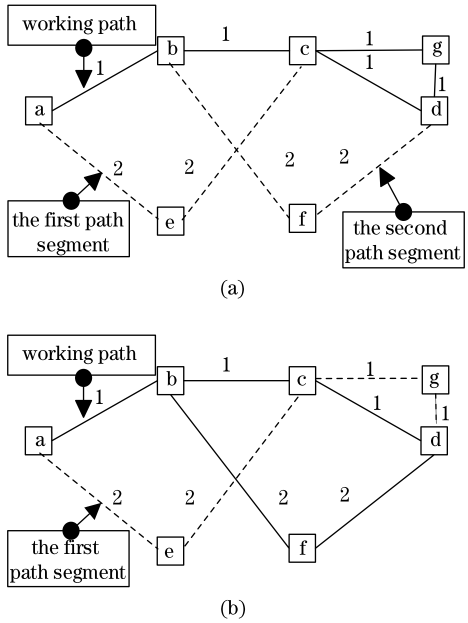

Fig. 5. Disjoined path segments.

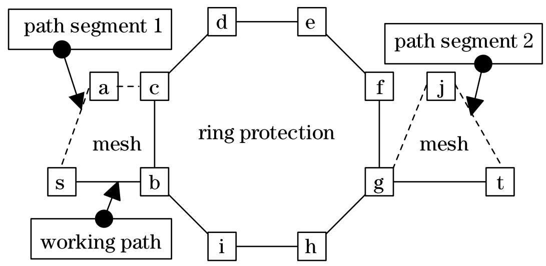

Fig. 6. Mixed protections.

and appends the corresponding capacity of the working paths. However, this appends the capacity more than what the working path requires. For example, the tool appends a 10-Gb link for a single STM-4 (622.08 Mb/s) path because the network uses the multiplex technology.

ASONP finds the capacity and network for connections, and calculates the total network capacity for PPCs, PSP connections (PSPCs), and ring-protection connections (RPCs). PSPCs have two kinds of disjoined path segments, namely, the node disjoint path segment and the link disjoint path segment. Figure 5(a) shows two node disjoined path segments, and Fig. 5(b) shows one link disjoined in the path segment. The node disjoined path segment protects the node and prevents link failures for the working path, whereas the link disjoined path segment only protects the link failure for the working path.

Figure 7 gives the evaluation of the capacity planning result, where PSPC uses node disjoined path segments to protect the working path. Node disjoined path segments for PSPC require more capacity than link disjoined path segments and the path protection.

ASONP plans the capacity and network for connections, but it has no distributed simulation, e.g., the signaling call, collision, and path blocking. We have established a distributed simulation platform for ASONs and AEMS, which includes 20 servers, a management server, and a measurement server. AEMS provides interfaces for protocol test, performance measurement, and

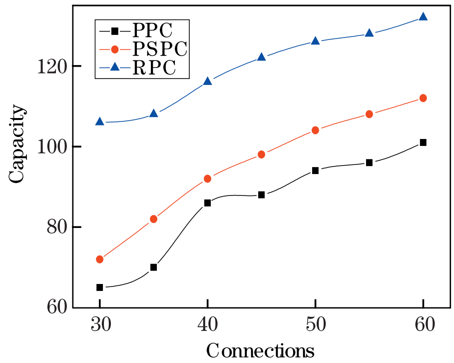

Fig. 7. Capacity utilization analysis.

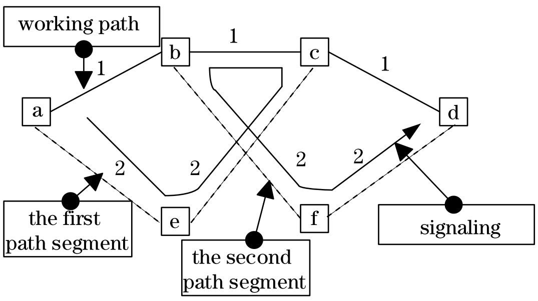

Fig. 8. Signaling call for path segment setup.

network analysis. The following gives the method for PSPC analysis.

It is necessary to design a new signaling for the PSPC setup, but path segments may not be connected. We designed a scheme, which can connect each path segments and setup path segments in a signaling call. The scheme is illustrated in Fig. 8, where node a wants to setup path segments for the working path.

(1) Node a calculates the first path segment and passes the signaling to node c.

(2) Node c calculates the second path segment, but fails to find the second path segment. Node c wants to connect all path segments, so it passes the signaling back to its neighbor (node b).

(3) Node b finds the second path segment and passes the signaling to node d. Finally, path segments are setup in one signaling call.

The signaling collision and path blocking are measured by AEMS because PPCs, PSPCs, and RPCs use the signaling to setup. We tested 7 samples (n=30, 35, 40, 45, 50, 55, and 60), in which AEMS measured each m value after each duration. Figure 9(a) gives the result, where PSPC setup always has less blocking probability than PPC. This is significant in parallel restorations of high capacity networks.

Figure 9(b) shows the path blocking and signaling collision for PSPC. The signaling collision and path blocking rose with increased connections in the sample, but path blocking showed more sensitivity to the number of connections.

In conclusion, path protections have become increasingly important for current mesh signaling optical networks. Thus, the development of path protections is crucial for guaranteed services. S-PSP extends path protection, gives a method for enhancing the protection performance, and reduces blocking probabilities. Moreover, S-PSP requires simple computing compared with

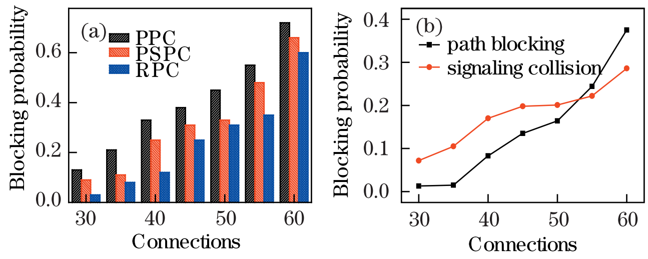

Fig. 9. (a) Blocking probability and (b) path blocking and signaling collision for PSPC.

p-cycle protections and p-cycle-based non-signaling path segment protections. Although the use of S-PSP may increase the protection capacity compared with the use of path protections in our proposal, the increased protection capacity for PSPC improves survivability. Such survivability may be enhanced or weakened depending on path segments and capacity. In future work, we intend to evaluate the shared node S-PSP, which requires less protection capacity than the path protection.

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