Effect of Geographical Distribution of Failed Links on Survivability Improvement in Translucent Elastic Optical Network Employing Shared Protection with Fallback

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Abstract: We show that the geographical distribution of simultaneously failed links influences survivability improvement only slightly when employing shared protection with fallback (SP-FB) in translucent elastic optical networks. Results show that SP-FB is useful during disasters.

OCIS codes: (060.4257) Networks, network survivability; (060.4257) Networks, protection and restoration

1. Introduction

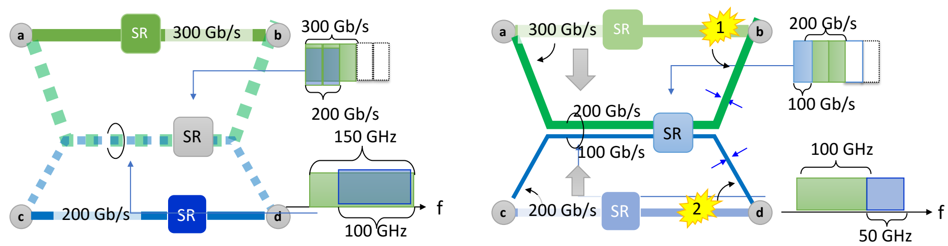
Shared protection in current wavelength division multiplexing (WDM) networks ensures 100% recovery from an arbitrary single link failure in a network while conserving the backup network resources such as spectrum in a link and/or regenerators on the common route by sharing them among link-disjoint working paths. However, the benefits from conserving the backup resources in conventional shared protection come at the sacrifice of survivability in the case of double link failures. These failures occur when working paths that mutually share their backup resources are simultaneously cut at, for example, geographically uncorrelated links or adjacent links during a catastrophic disaster. In such situations, only a part of the working paths can survive. In order to address this problem, a novel protection scheme for translucent elastic optical networks (EONs), which is referred to as shared protection with fallback (SP-FB), was proposed [1]. Here, a translucent EON is an EON [2, 3] employing optical-to-electrical-to optical regenerators to increase the network size beyond the optical reach of an optical channel.

As one key enabler in this scheme, a new type of regenerator called a sliceable regenerator (SR) [4, 5] was employed where an SR comprises an array of spectrum-selective sub-regenerators acting as a virtualized regeneration resource pool. Another key enabler was a routing and spectrum/sub-regenerator assignment (RS/SRA) algorithm for the network planning state of SR-based translucent EONs with shared protection and a fallback operation for the network restoration state. If the connection survivability (CS) is defined as the ratio of the number of recovered demands to the number of affected demands expressed as a percentage, the CS for the conventional shared protection scheme becomes 100% for a single link failure but it decreases to 50% for a double link failure. The idea behind SP-FB is that by taking advantage of sliceable transponders [4, 5] and SRs, the CS will be significantly increased through mutual concessions in the bandwidth of the affected demands. Specifically, by reducing the bit rates of transponders and allocating reduced numbers of backup sub-regenerator units (SRUs) in an SR and backup frequency slot units (FSUs) in a link to the backup paths, almost all the affected demands are expected to be restored. This operation is referred to as fallback operation.

In [1], CS was evaluated for double link failures occurring at two randomly chosen links and fallback operation was confirmed to provide the survivability of 97% while conserving 8~28% of the resources in terms of working, backup spectral, and regeneration resources compared to dedicated 1 + 1 protection, at the expense of a reduced bandwidth for each demand. However, in a catastrophic disaster, failed links are most likely geographically close to each other and more than two links may be cut simultaneously. In this paper, we investigate how geographical distribution of failed links and the number of simultaneously cut links affect the extent of survivability improvement when employing SP-FB in translucent EONs.

2. RS/SRA Algorithm and Fallback Operation

Figure 1(a) shows how the RS/SRA algorithm calculates the backup routes and shares resources among disjoint working paths in a translucent EON employing SRs. Here, we assume two demands $D1 = (a,\ b,\ 300\ Gb/s)$ and $D2 = (c,\ d,\ 200\ Gb/s)$. The required numbers of 100-Gb/s SRUs for demands with 200 Gb/s and 300 Gb/s are assumed to 2 and 3, and the required numbers of 50 GHz-slot FSUs for Nyquist WDM superchannels are assumed to 2 and 3, respectively. Thanks to the elastic frequency slot and sub-regenerator allocation capabilities in a translucent EON, the necessary number of both the SRUs of the shared backup SR and FSUs at the shared link can be reduced from 5



(a) Shared protection

(b) Fallback operation

Fig. 1. Shared protection with failback in a translucent EON.

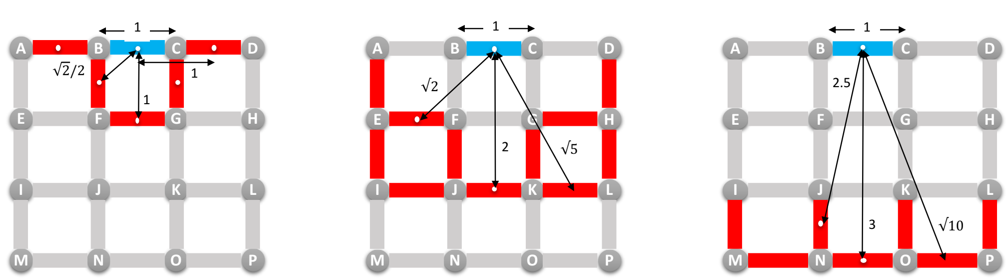
(Dedicated Protection) to 3. Figure 1(b) shows how the fallback operation increases the CS through mutual concessions in the bandwidth of the affected demands. By reducing the bit rates of the transponders for demands *D1* and *D2* down to 200 Gb/s and 100 Gb/s, respectively, and allocating reduced spectral and regeneration resources to the backup paths, we can recover all the affected demands, resulting in a 100% CS.

The definition of the RS/SRA problem for a set of static traffic demands in a SR-based translucent EON employing shared protection and the heuristic to address the RS/SRA problem used in this paper are described in [1] in detail. The objectives of the heuristic are to find a working path and its backup path for each demand that is identified by the route, the spectrum to be used in each link on the route, and the sub-regenerators in an SR at each node on the route through which the superchannel is regenerated. Achieving these will minimize the total numbers of SRUs and FSUs while adhering to the constraints below.

- Along the optical path, the length of each transparent segment must not exceed optical reach L.
- Along each transparent segment of the optical path, FSUs must be contiguous to each other, must be the same for each link on the transparent segment, and must not overlap with those of other optical paths.
- All sub-channels within the superchannel for the optical path must be regenerated using the same SR.
- Working path w and its backup path b must be link- and node-disjoint.
- An SRU and FSU cannot be shared between w_i and w_j; w_i and b_j; or w_j and b_i.

In order to investigate the dependency of geographical distribution of failed links on the CS for shared protection with and without fallback, we simultaneously cut two links, (l_i, l_j), in the network and then create demand sets $\boldsymbol{D}_i$ and $\boldsymbol{D}_j$ that comprise demands affected by the cuts at links l_i and l_j, respectively. Any demand in $\boldsymbol{D}_i$ or $\boldsymbol{D}_j$ whose working path includes two cut links, whose working and backup paths are simultaneously cut, or whose backup path does not share any resources with any of the backup paths for other demands in $\boldsymbol{D}_i$ or $\boldsymbol{D}_j$ is deleted and not subject to the CS evaluation. For switch-over without fallback, we compare the numbers of demands in $\boldsymbol{D}_i$ and $\boldsymbol{D}_j$ and select the demand set that has a larger number of demands. On the other hand, for switch-over with fallback, we order demand set $\boldsymbol{D}_i \cup \boldsymbol{D}_j$ in ascending order of the requested capacity to be served first. For simplicity, we allocate resources that guarantee the minimum 100-Gb/s bandwidth uniformly to all backup paths. The CS evaluation is conducted for any pair of links, (l_i, l_j), in the network where link pairs are categorized into *near, middle*, and *far* in terms of the distance between link centers, D_{lc}. In the case of a 4×4 mesh network model with a uniform distance between adjacent nodes, link pairs are categorized into *near* links ($D_{lc} \leq 1$), *middle* links ($1 < D_{lc} \leq \sqrt{5}$), and *far* links ($\sqrt{5} < D_{lc}$) as shown in Fig. 2.

A similar evaluation is conducted for triple link failures in three links, (l_i, l_j, l_k), in the network and associated demand sets, $\boldsymbol{D}_i$, $\boldsymbol{D}_j$, and $\boldsymbol{D}_k$ that comprise demands affected by the cuts at links l_i, $l_j$and l_k, respectively. In this evaluation, any demand in $\boldsymbol{D}_i$, $\boldsymbol{D}_j$, or $\boldsymbol{D}_k$ whose working path includes three cut links, whose working and backup

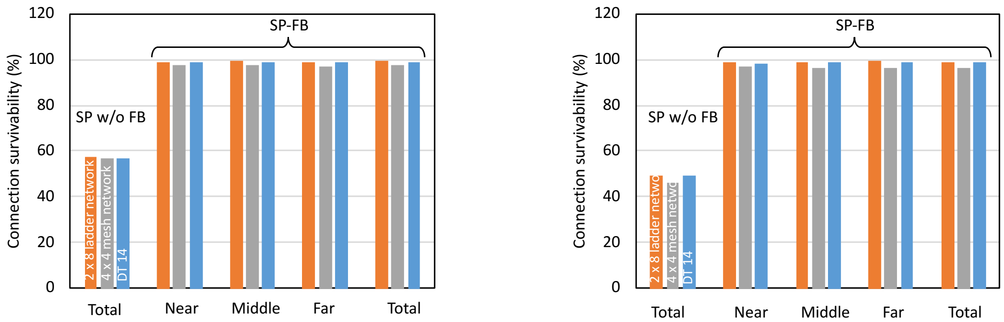


(a) Near links

(b) Middle links

(c) Far links

Fig. 2. Examples of link-center distance categorization in 4 x 4 mesh network model with a uniform distance between adjacent nodes.



(a) Double simultaneous link failures (b) Triple simultaneous link failures

Fig. 3. Connection survivability of three network models.

paths are simultaneously cut, or whose backup path does not share any resources with any of the backup paths for other demands in $\boldsymbol{D}_i$, $\boldsymbol{D}_j$, or $\boldsymbol{D}_k$ is deleted and not subject to the CS evaluation. In this case, sets of three failed links are categorized into *near* links (D_{lc} of any pair among the three links is less than 1), *far* links (D_{lc} of any pair among the three links is greater than $\sqrt{5}$, and *middle* links (the rest of the sets of the three links).

3. Simulation Results

The CS with and without fallback operation for double and triple simultaneous link failures is investigated for 2×8 ladder and 4×4 mesh network models. A real-world network model, Germany network model DE14 (14 nodes, 23 bi-directional links with the longest link of 353 km and shortest link of 37 km), is also considered. A link center position for a link in DE14 is defined as the middle point of a straight line between adjacent sites. The traffic demand for each node pair is chosen uniformly from 100 Gb/s, 200 Gb/s, 300 Gb/s, and 400 Gb/s. The results are averaged over 100 randomly generated traffic demand sets. Figure 3(a) shows the average CS for double link failures for shared protection with and without fallback. The optical reach (OR) is set to 3 for the 2×8 ladder and 4×4 mesh network models and 700 km for DE14, respectively. Regardless of the link center distance and the network topology (mesh, ladder, DE14), shared protection with fallback achieves a very high CS of greater than 97% while that without fallback provides a much lower CS of approximately 58%. We conducted the same simulations by changing the OR and obtained similar results.

Figure 3(b) shows that the average CS in the case of triple link failures with fallback is very high at greater than 97% regardless of the link center distance and the network topology meaning that SP-FB is also effective under more serious failure conditions. In the case of triple link failures without fallback, the average CS decreases below 50% because the cases where every two pairs fail among the three demands share backup resources resulting in only one demand that can be restored.

Conclusion

We showed that the geographical distribution of failed links exerts little influence on survivability improvement when employing SP-FB in translucent EONs. The results confirm that SP-FB is very useful both for double and triple simultaneous link failures among adjacent links that may occur in the case of a catastrophic disaster where ensuring connectivity would be the first priority.

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References

[1] M. Jinno, T. Takagi, and Y. Uemura, "Enhanced survivability of translucent elastic optical network employing shared protection with fallback," Optical Fiber Communication Conference, Th3K. 1 (2017).

[2] M. Jinno, H. Takara, B. Kozicki, Y. Tsukishima, Y. Sone, and S. Matsuoka, "Spectrum-efficient and scalable elastic optical path network: Architecture, benefits, and enabling technologies," IEEE Commun. Mag., 47, I66-73 (2009).

[3] M. Jinno, B. Kozicki, H. Takara, A. Watanabe, Y. Sone, T. Tanaka, and A. Hirano, "Distance-adaptive spectrum resource allocation in Spectrum-Sliced Elastic Optical Path Network (SLICE)," IEEE Commun. Mag., 48, 138-145 (2010)

[4] M. Jinno, H. Takara, K. Yonenaga, and A. Hirano, "Virtualization in optical networks from network level to hardware level," Journal of Optical Communications and Networking 5, A46-A56 (2013).

[5] M. Jinno, "Elastic optical networking: Roles and benefits in beyond 100-Gb/s era," Journal of Lightwave Technology 35 (5), 1116-1124, (2017).