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K-dimensional protection structure (KDPS) for multi-link failure in data center optical networks

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ABSTRACT

Currently, data center has become one of the most important application resources. Meanwhile, there is huge amount of data streams within a data center or among different data centers, which requires the transmission channel with high bandwidth and good reliability. Optical networks become the essential solution for the data center interconnection. Especially for intra data center networks, there are too many links for a limited number of nodes, which make the network so complex and vulnerable. A K-dimensional protection structure (KDPS) is proposed against multi-link failure in data center optical networks, and 3DPS is mainly introduced and analyzed in the paper. Two greedy algorithms are proposed to construct KDPS in static and dynamic optical networks respectively. Numerical results show that 3DPS can be constructed with more difficulty in dynamic optical networks, and the greedy algorithm can find the 3DPS much easier under three-link failures than under dual-link failures.

1. Introduction

In order to meet the rigid requirement of Internet users, and reduce the cost and energy consumption, data centers are being deployed widely. Typically, a data center contains tens of thousands of identical servers into one or more clusters which consist of multiple racks [1]. Huge amount of data streams flow in the data center and among different data centers. Then high bandwidth channel is necessary for the data transmission. Fiber is considered as the best candidate of the transmission media data center networks.

Within a data center, servers are interconnected with each other through massive identical switching equipment, and the interconnections can be achieved in different topologies, such as torus, hypercube, fat-tree and flattened butterfly [2–6]. These topologies are so complex that all kinds of failures may appear at any time. Especially multi-failure may occur and not easy to be found and recovered, which will result in tremendous traffic loss without effective survivable schemes.

Survivability modeling and analysis of multi-link failures have become an important issue currently. The classical protection and recovery techniques, such as 1 + 1, 1:1, P-Cycle [7–11], have disadvantage in dealing with the new trends, and one of the main reasons is that they cannot provide an effective protection for concurrent multi-failure survivability. This paper mainly focuses on the survivability against multi-failure in data center networks. A K-dimensional protection structure (KDPS) is designed.

The rest of the paper is organized as follows. Section 2 proposes the K-dimensional protection structure (KDPS), and three-dimensional protection structure (3DPS) is introduced in Section 3. Section 4 gives the performance analysis of 3DPS. Two greedy algorithms are proposed to construct KDPS in static and dynamic optical networks respectively in Section 5. Finally, Section 6 concludes the paper.

2. K-dimensional protection structure (KDPS)

In order to overcome the problem of multi-failure, K-dimensional protection structure (KDPS) is proposed in the paper, which must be k-regular and k-connected, and contain k internally link-disjoint paths between any two nodes. When $k-1$ failures occur in the network then each failed link can find one unaffected recovery path at least to resume the interrupted traffics.

We can also find that p-cycle is 2-regular and 2-connected structure and it can only handle single link failure. The resources relationship between working capacity and spare capacity on p-cycle structure is 1:1:2 (working capacity on on-cycle link:spare capacity on on-cycle link:working capacity on straddling link). As presented in Fig. 1, the failure may occur on on-cycle link or straddling link. We assume the working capacity on on-cycle link is one unit. Then the spare capacity on on-cycle link must be at least

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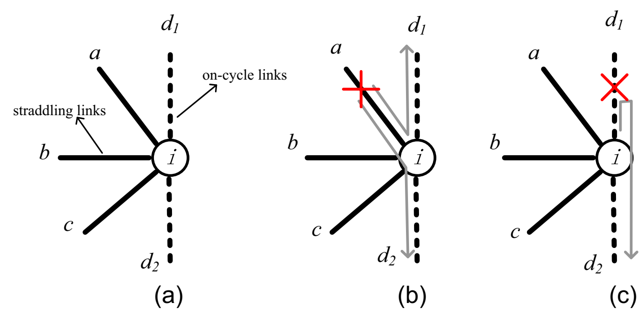

Fig. 1. Node model of p-cycle.

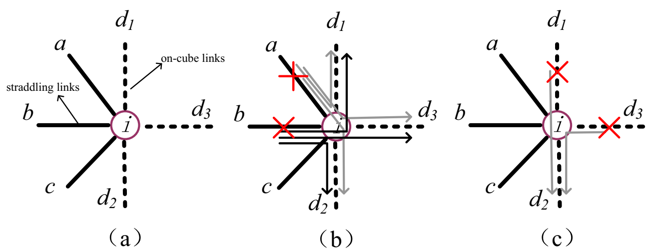

Fig. 2. Node model of cube structures.

one unit because the working capacity on failed on-cycle link can resume the traffic on another on-cycle link depicted in Fig. 1(c). And the working capacity on straddling link can be two units because there are two on-cycle links can be used to resume the working traffic on failed straddling link depicted in Fig. 1(b).

The resources relationship between working capacity and spare capacity on *k*-regular and *k*-edge-connected protection structure is 1:*m*:*m* + 1 (working capacity on the link of *k*-regular and *k*-edge-connected structure: spare capacity on the link of *k*-regular and *k*-edge-connected structure: working capacity on straddling link). As presented in Fig. 2(c), the failures may occur on both links of *k*-regular and *k*-edge-connected structure. We assume the working capacity on the link of *k*-regular and *k*-edge-connected structure is one unit. When m failures both occur on links of *k*-regular and *k*-edge-connected structure, then the spare capacity on each link of *k*-regular and *k*-edge-connected structure must be at least m unit because the total working capacity on m failed link can resume the traffic on the remaining link of *k*-regular and *k*-edge-connected structure depicted in Fig. 2(c). When *m-1* failures occur on links of *k*-regular and *k*-edge-connected structure and a remaining failure occur on straddling link, there is one useful link of *k*-regular and *k*-edge-connected structure that can be used to resume the working traffic depicted in Fig. 2(b). The spare capacity on the useful link of *k*-regular and *k*-edge-connected structure is m units and there is also one unit spare capacity on other links to protect the one unit working capacity on this useful link, so the total spare capacity can be used to resume the working capacity on straddling link are *m* + 1 units.

3. Three-dimension protection structure (3DPS)

One kind of KDPS is introduced in this section, where *k* is 3. As presented in Fig. 3(a), the optical network based on wavelength-division multiplexing (WDM) contains 12 physical links and 8 nodes. We assume the working capacity in each link only consumes one wavelength.

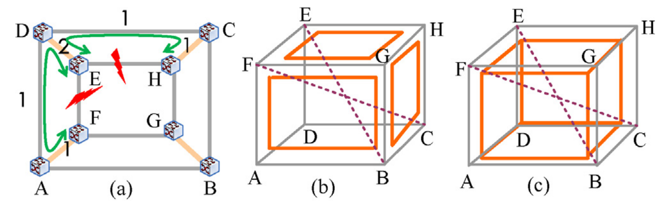

Fig. 3. 3DPS and p-cycles protection structures.

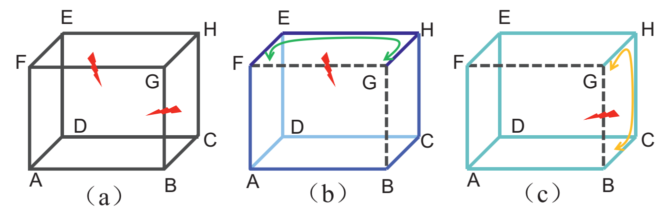

Fig. 4. Protection paths for on-structure links.

3.1. Working procedure

Initially, there are no spare wavelengths in each physical link. Dual-link failures are generated randomly according to uniform distributions. We apply Dijkstra's algorithm to calculate the recovery paths. Then we reserve spare wavelengths along the recovery paths as presented in Fig. 3(a). Finally, we obtain a lower bound on spare capacity requirement for full recovery against random dual-link failures. The needed spare capacity in each link must consume two wavelengths for the lower bound. We construct pre-configured protection structure using these spare wavelengths.

3.2. Implementation example

The physical topology presented in Fig. 3(a) can be modeled as 3DPS. First, we construct six p-cycles (each p-cycle only consume one wavelength) which are located in the six sides of the cube as presented in Fig. 3(b). When dual-link failures occur in the network then each failed link can at least find one unaffected recovery path provided by p-cycle to resume interrupted traffics. In order to support 100% recovery against random dual-link failures, the straddling links (E-B, F-C... if exist) cannot be used for normal working traffics until we construct additional p-cycles which can protect these links. But the spare capacity required to construct additional p-cycles will increase the lower bound. Second, considering a novel protection scheme based on 3DPS we construct two 3DPS instead of six p-cycles presented in Fig. 3(c). Each physical link (also called on-structure links) is located in two 3DPS and each 3DPS is still connected under random dual-link failures so that two failed links can each use one of the two 3DPS to resume the interrupted traffics. The two 3DPS are blue cube and green cube presented in Figs. 4(b, c) and 5(b, c). The pre-configured cross-connect structure at each node is a three-dimensional connection where the traffic coming from any direction can switch to other two directions.

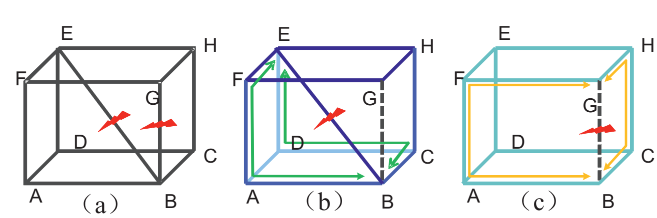

Fig. 5. Two 3DPS.