A New Heuristic for Disjoint Path Selection Under SRLG Constraints

Jiangyong Sun, Qingfu Zhang, Gaoxi Xiao and Edward Tsang

Abstract: This paper proposes a novel heuristic for disjoint path selection with SRLG constraints. The proposed heuristic can be regarded as an extension of the conventional k-shortest path algorithm. There are several algorithmic parameters in our algorithm. The experimental design technique is used to choose these parameters. Experimental results show that our heuristic is better than the best-known algorithm proposed by Oki et al. in terms of solution quality.

***Index Terms*— Shared-Risk-Link-Group, disjoint path selection, uniform design**

I. Introduction

Wavelength-division multiplexing (WDM) technology allows a single fiber to transmit several signals simultaneously. It is generally believed that the new generation Internet will be mainly based on WDM technology for fulfilling the fast increasing demands of transmission capacities [4]. A link cut or node failure could cause huge damage to customers. Hence, WDM network providers have to consider the network survivability under a link or node failure. A natural way to enhance the survivability of an optical WDM network is to set disjoint paths between source-destination pairs with connection requests. A number of algorithms have been proposed [1] for finding as many as possible link/node-disjoint paths between source and destination pairs. However, most of these algorithms did not consider Shared-Risk-Link-Group (SRLG) constraints. In practice, some fibers may be put into the same cable, or duct. Destructive natural events, such as earthquakes, could break a duct and cause all the fibers in this duct fail. All fibers bundled in the same cable or duct belong to the same SRLG. For example, figure 1 gives an illustration of a network with SRLG constraints. In this figure, links $L(s,4)$, $L(s,5)$ and $L(s,6)$ are bundled in the same duct. They belong to the same SRLG. Obviously, a network survivable to a single link failure is not necessarily survivable in the scenarios of SRLG constraints. Moreover, SRLG constraint makes the maximum disjoint path problem, which is NP-hard, much more complicated [3]. Recently, the path-protection routing problem of WDM mesh networks with SRLG constraints has attracted a lot of attentions [6]. However, research in network protection under SRLG constraints is still in its very infancy.

Oki et al. have proposed the weighted-SRLG (WSRLG) scheme for finding disjoint paths with SRLG constraints [5].

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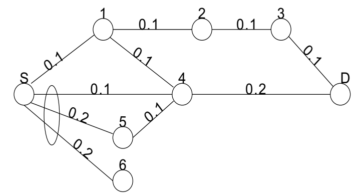

Fig. 1. A network with SRLG, where $L(s,4)$, $L(s,5)$ and $L(s,6)$ belong to the same SRLG.

In their WSRLG scheme, the costs of the links in a given network are adjusted according to the SRLG constraints in order to find more disjoint paths.

In this paper, we modify the WSRLG scheme and propose a novel heuristic for finding node disjoint paths[1] with SRLG constraints. The proposed heuristic is based on experimental design techniques. For this reason, we call it the WSRLG scheme with experimental design (WSRLG/ED). There are several algorithmic parameters in the WSRLG/ED scheme. The uniform experimental design technique [2] is used to choose these parameters. Experimental results show that the WSRLG/ED scheme outperforms the WSRLG scheme.

II. Algorithm

A. Terminology

To make readers easy to follow, we adopt most of the notations used in [5].

- G : number of SRLGs in a network;
- $M(g)$: number of members in SRLG g;
- s : source node;
- d : destination node;
- $C(i,j)$: original cost of link $L(i,j)$;
- C_{comp} : augmented cost of link $L(i,j)$ used in algorithms;
- $SRLG(i,j,g)$: SRLG information, where

$$SRLG(i,j,g) = \begin{cases} 1, & \text{if } L(i,j) \text{ belongs to SRLG } g, \\ 0, & \text{otherwise;} \end{cases}$$

- α : weight factor for SRLG used in the algorithms;
- $D_{req}(s,d)$: required number of disjoint paths between nodes s and d;
- $C_{path}(s,d)$: sum of original costs of all disjoint paths between nodes s and d;
- $K(s,d)$: number of obtained disjoint paths between nodes s and d.

[1]We consider node disjoint paths in this paper as Oki et al. did in [5].

- N : number of points in a uniform array.

B. K-Shortest Path Algorithm

The conventional K-shortest path algorithm based on link cost $C_{comp}(i,j)$ can be described as follows.

Step 0 Set $k=1$.

Step 1 Search the k-th shortest path between the nodes s and d by the shortest path algorithm (such as Dijkstra's algorithm) based on link cost $C_{comp}(i,j)$. If such a path is found, go to Step 2. Otherwise, set $K(s,d)=k-1$ and stop the algorithm.

Step 2 For $g=1$ to G, prune all the links in SRLG g if the $k-$th shortest path has a link in SRLG g. Delete all the nodes apart from s and d in the $k-$th shortest path.

Step 3 Set $k=k+1$ and go to Step 1.

Setting $C_{comp}(i,j)=C(i,j)$, we can directly apply the K-shortest path algorithm for finding disjoint paths between s and d. As shown in [5], however, its performance could be very poor.

C. The WSRLG scheme

The WSRLS scheme, proposed by Oki et al., aims to find at least $D_{req}(s,d)$ disjoint paths with low original link costs. It applies the $K-$shortest path algorithm based on augmented link costs. $C_{comp}(i,j)$ in the WSRLG scheme is set as follows:

$$C^{\alpha}_{comp}(i,j)=\frac{1-\alpha}{C^{\max}}C(i,j)+\frac{\alpha}{S^{\max}}\max\{S(i,j),1\} \quad (1)$$

where

$$S(i,j)=\sum_{g=1}^{G}M(g)SRLG(i,j,g), \quad (2)$$

$$S^{\max}=\max_{i.j}S(i,j), \quad (3)$$

and

$$C^{\max}=\max_{i,j}C(i,j). \quad (4)$$

The smallest α is searched by using a binary search in order to minimize the original costs of disjoint paths. ε is used to determine when the algorithm stops. The WSRLG scheme can be described as follows:

Step 0 Set $\alpha_{max}=1$, $\alpha_{min}=0$.

Step 1 Set $\alpha:=\frac{\alpha_{min}+\alpha_{max}}{2}$.

Step 2 Apply the K-shortest path algorithm based on augmented link cost $C^{\alpha}_{comp}(i,j)$ to the network and obtain $K(s,d)$ disjoint paths from s to d.

Step 3 If $K(s,d)<D_{req}(s,d)$, set $\alpha_{min}=\alpha$. Otherwise, set $\alpha_{max}=\alpha$;

Step 4 If $\alpha_{max}-\alpha_{min}>\varepsilon$, goto Step 1. Otherwise, stop the algorithm and return a set of disjoint paths in which $K(s,d)-D_{req}(s,d)$ is the smallest value. If there are more than one such path sets, choose the one with the smallest value of $C_{path}(s,d)$ as the solution.

In the WSRLG scheme, $SRLG(i,j,g)$, the SRLG factor for $L(i,j)$ contributes to the augmented link cost $C^{\alpha}_{comp}(i,j)$. Hence, the algorithm tends to avoid the links with many SRLGs. However, the setting of the SRLG term $S(i,j)$ in (2) is not always helpful for finding more disjoint paths. Take the network shown in figure 1 as an example, the K-shortest path algorithm based on the original links costs can find two SRLG disjoint paths, namely, $s\rightarrow 1\rightarrow 2\rightarrow 3\rightarrow d$ and $s\rightarrow 4\rightarrow d$. While using the augmented cost C^{α}_{comp} with $\alpha=1$ can find only one path, i.e, $s\rightarrow 1\rightarrow 2\rightarrow 3\rightarrow d$. In this paper, we suggest that several different SRLG terms should be tried for searching SRLG disjoint paths. We use uniform design technique [2] for setting different SRLG terms.

D. Uniform Design

In many scientific and engineering areas, one often needs to select a small set of experimental points that are uniformly scattered on the unit hypercube $[0,1]^G$. Uniform design technique provides a series of uniform arrays for this purpose [2]. A uniform array, denoted by $U_N(N^G)$, is an $N\times G$ matrix with each column being a permutation of $\{1,2,\ldots,N\}$. The following is an example of uniform array:

$$U_9(9^6)=\begin{bmatrix} 1 & 2 & 4 & 5 & 7 & 8\\ 2 & 4 & 8 & 1 & 5 & 7\\ 3 & 6 & 3 & 6 & 3 & 6\\ 4 & 8 & 7 & 2 & 1 & 5\\ 5 & 1 & 2 & 7 & 8 & 4\\ 6 & 3 & 6 & 3 & 6 & 3\\ 7 & 5 & 1 & 8 & 4 & 2\\ 8 & 7 & 5 & 4 & 2 & 1\\ 9 & 9 & 9 & 9 & 9 & 9 \end{bmatrix}$$

Given a uniform array $U_N(N^G)=(u_{ij})$, let

$$x_{ij}=\frac{u_{ij}-0.5}{G},$$

for $i=1,2,\cdots,N$ and $j=1,2,\cdots,G$. Then $X_N(N^G)=(x_{ij})$ is a uniform array on the unit hypercube $[0,1]^G$. Each row $x^i=(x_{i1},x_{i2},\cdots,x_{iG})$ of $X_N(N^G)$ is a point in $[0,1]^G$. It has been proved that these points $x^1,x^2,\cdots,x^N$ scatter more uniformly than N randomly generated points in $[0,1]^G$ [2]. There are several algorithms for generating design arrays. Many uniform design arrays can be found from $www.math.hkbu.edu.hk/UniformDesign$.

E. The WSRLG/ED scheme

Let $X_N(N^G)=(x_{ij})$ be a uniform array on $[0,1]^G$, $S^{\ell}(i,j)$, a SRLG term used in the WSRLG/ED scheme can be set as follows:

$$S^{\ell}(i,j)=\sum_{g=1}^{G}x_{\ell g}M(g)SRLG(i,j,g) \quad (5)$$

for $\ell=1,2,\cdots,N$. In the above setting, the penalty from each SRLG g is weighted by $x_{\ell g}$. Since $x^1,x^2,\cdots,x^N$ are uniformly distributed, the penalties $S^1(i,j),S^2(i,j),\cdots,S^N(i,j)$ will be good representatives of all the possible penalties. The WSRLG/ED scheme applies the WSRLG scheme N times by using each SRLG term defined in (5). The outline of the WSRLG/ED scheme is given as follows:

Step 1 For $\ell = 1, \cdots, N$, do:

Step 1.1 Set

$$C^{\alpha,\ell}_{comp}(i,j) = \frac{1-\alpha}{C^{max}} C(i,j) + \frac{\alpha}{S^{\max}} \max\{S^{\ell}(i,j), 1\},$$

Step 1.2 Use the WSRLG scheme based on the $C^{\alpha,\ell}_{comp}$ and obtain a path set.

Step 2 Choose a path set with the largest $K(s,d)$ from the N path sets. If more than one set have the largest $K(s,d)$, return the one with the smallest value of $C_{path}(s,d)$.

III. Experimental Results

We compare the WSRLG/ED scheme with the WSRLG scheme on a suite of test networks. The test network configurations here are almost the same as these in [5][2].

- The number of the nodes n is set to 20;
- The average node degree D is set to 6, 8 or 10.
- The number of SRLGs G is set to 6.
- The average number of links in SRLGs is $\sum_{k=1}^{G} M(k) = m$;
- $SRLG(i,j,g)$ is set randomly under the constraint that $\sum_i \sum_j SRLG(i,j,g) = M(g)$ for $g = 1, \cdots, G$.
- The original link cost $C(i,j)$ is set randomly between 0 and 1.

The number of the test networks for each configuration is set to 100. The uniform array $X_{20}(20^6)$ is used in the experiment.

Since $(1, 1, \cdots .1) \in X_{20}(20^6)$, one of SRLG terms used in the WSRLG/ED scheme is the same as one in used the WSRLG scheme. Therefore, the WSRLG/ED scheme can find at least the same number of disjoint paths as the WSRLG scheme does for all three configurations.

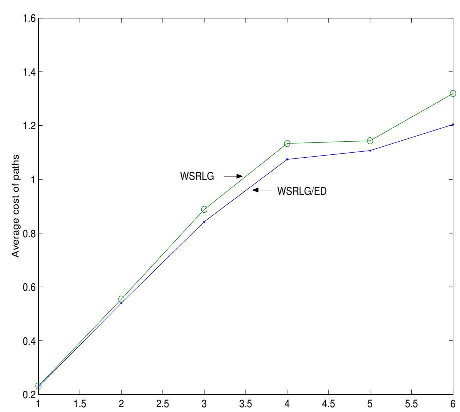

Fig. 2. Comparison of average cost of paths found (D=6, n=20, $m = 14$, $G = 6$).

[2]The only difference is that we test two more configurations with $D = 8$ and 10.

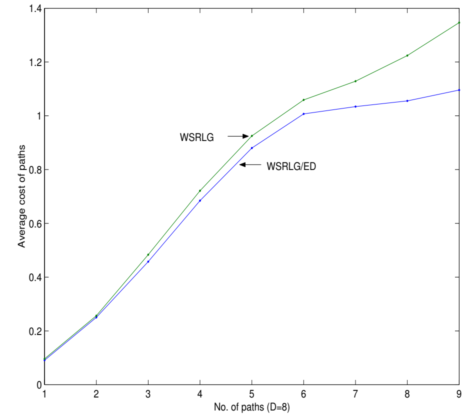

Fig. 3. Comparison of average cost of paths found(D=8, n=20, $m = 14$, $G = 6$).

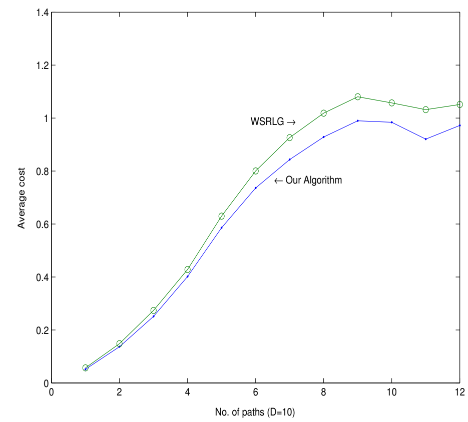

Fig. 4. Comparison of average cost of paths found (D=10, n=20, $m = 14$, $G = 6$).

IV. Conclusion

Combining uniform design technique with the WSRLG scheme, we proposed the WSRLG/ED for finding node disjoint path in a communication network under SRLG constraints. We compared the WSRLG/ED scheme with the WSRLG scheme on randomly generated test networks. The results show that the WSRLG/ED scheme can find shorter paths.

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