Shared Protection ILP Formulation

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I. ILP Formulation

In this section, we develop ILP formulations for the RWA problem under shared path protection.

A. notations

The following are given as input to the problem.

- N: the set of nodes in the network. The nodes are numbered from 1 through $|N|$.
- E: the set of links in the network. The links are numbered from 1 through $|E|$.
- e: the link in the network, every link is bidirectional.
- $con(e_i, e_j)$: takes on value 1 if edge e_1 is connected with edge e_2,($e_1 < e_2$);0 otherwise.
- W: wavelengths available on each link. The wavelength are numbered from 1 through $|W|$, and the same number of wavelengths are available on all links.
- In(v): The set of links connected with node v,$v \in N$.
- R: set of request LSPs in the traffic-demand matrix.
- s(l): the source node of the lth LSP, $l \in R$.
- d(l): the destination node of the lth LSP,$l \in R$.
- Pw_l: the working path of the LSP l. Each path is composed of some concatenated links in the network.
- Pp_l: the protection path of the LSP l. Each path is composed of some concatenated links in the network.
- α: the cost weight for the converters, and the cost weight for the number of wavelength is $1-\alpha$.

The following are the variables used in the ILP formulations.

- $x_e^{l,\lambda}$: takes on the value 1 if wavelength λ on link e is used by the working path of LSP l; 0 otherwise.
- $y_e^{l,\lambda}$: takes on the value 1 if wavelength λ on link e is used by the protection path of LSP l; 0 otherwise.
- c_e^{λ}: takes on the value 1 if wavelength λ on the link e used by some LSP;0 otherwise.
- WC_{e_1,e_2}^{λ}: takes on the value 1 if wavelength λ on link e_1 is converted to other wavelength on link e_2; 0 otherwise.
- θ: number of wavelength converters used in the network.
- γ: number of wavelength links used in the network.

B. formulations

objective: Minimize the total number of wavelength links and number of wavelength converters used in the network.
Cost function:

$$\alpha\theta + (1-\alpha)\gamma \tag{1}$$

subject to:

every LSP using one wavelength of each link along the working path

$$\sum_{\lambda \in W} x_e^{l,\lambda} = 1, \forall l \in R, \forall e \in Pw_l \tag{2}$$

every LSP using one wavelength of each link along the protection path

$$\sum_{\lambda \in W} y_e^{l,\lambda} = 1, \forall l \in R, \forall e \in Pp_l \tag{3}$$

the wavelength of the link could be used by at most one LSP's working path

$$\sum_{l \in R} x_e^{l,\lambda} \le 1, \forall e \in E, \forall \lambda \in W \tag{4}$$

protection path of the LSP can not use the wavelength used by working path of any other LSP

$$x_e^{l_1,\lambda} + y_e^{l_2,\lambda} \leq 1, \forall l_1 \in R, \forall l_2 \in R, l_1 \neq l_2, \forall e \in E, \forall \lambda \in W \tag{5}$$

working paths of LSPs whose protection paths share some links should be link disjoint

$$\begin{aligned} &\sum_{\lambda \in W} x_{e_1}^{l_1,\lambda} + \sum_{\lambda \in W} x_{e_1}^{l_2,\lambda} + y_{e_2}^{l_1,\lambda_1} + y_{e_2}^{l_2,\lambda_1} \leq 3, \\ &\forall l_1 \in R, \forall l_2 \in R, \forall e_1 \in E, \forall e_2 \in E, l_1 \neq l_2, e_1 \neq e_2 \end{aligned} \tag{6}$$

wavelength usage constraint

$$c_e^{\lambda} \geq \sum_{l \in R} x_e^{\lambda}, \forall \lambda \in W, \forall e \in E \tag{7}$$

$$c_e^{\lambda} \geq y_e^{l,\lambda}, \forall l \in R, \forall \lambda \in W, \forall e \in Pp(l) \tag{8}$$

converter usage constraint

$$\begin{aligned} &WC_{e_1,e_2}^{\lambda_1} \geq x_{e_1}^{l,\lambda_1} + x_{e_2}^{l,\lambda_2} - 1, \\ &\forall l \in R, \forall e_1 \in Pw(l), \forall e_2 \in Pw(l), con(e_1, e_2) = 1, \\ &\lambda_1 \in W, \lambda_2 \in W, \lambda_1 \neq \lambda_2 \end{aligned} \tag{9}$$

$$\begin{aligned} &WC_{e_1,e_2}^{\lambda_1} \geq y_{e_1}^{l,\lambda_1} + y_{e_2}^{l,\lambda_2} - 1, \\ &\forall l \in R, \forall e_1 \in Pp(l), \forall e_2 \in Pp(l), con(e_1, e_2) = 1, \\ &\lambda_1 \in W, \lambda_2 \in W, \lambda_1 \neq \lambda_2 \end{aligned} \tag{10}$$

in the source and destination, the wavelength of the working path and protection path could be different by using wavelength converters

$$WC_{e_1,e_2}^{\lambda_1} \geq x_{e_1}^{l,\lambda_1} + y_{e_2}^{l,\lambda_2} - 1, \forall l \in R, \forall \lambda_1 \in W, \forall \lambda_2 \in W, \lambda_1 \neq \lambda_2, \forall e_1 \in In(v), \forall e_2 \in In(v), v \in \{s(l), d(l)\}, e_1 \neq e_2 \tag{11}$$

calculation of number of converters used in the network

$$\theta \geq 2 \times \sum_{\lambda \in W} \sum_{e_1 \in E} \sum_{e_2 \in E} WC_{e_1,e_2}^{\lambda} \tag{12}$$

calculation of the usage of wavelength links

$$\gamma \geq 2 \times \sum_{\lambda \in W} \sum_{e \in E} c_e^{\lambda} \tag{13}$$