

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 l th LSP, $l \in R$.
- $d(l)$: the destination node of the l th 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:

$$\alpha\theta + (1 - \alpha)\gamma \quad (1)$$

subject to:

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

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

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

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

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

$$\sum_{l \in R} x_e^{l,\lambda} \leq 1, \forall e \in E, \forall \lambda \in W \quad (4)$$

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

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

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

$$\sum_{\lambda \in W} x_{e_1}^{l_1, \lambda} + \sum_{\lambda \in W} x_{e_2}^{l_2, \lambda} + y_{e_2}^{l_1, \lambda_1} + y_{e_2}^{l_2, \lambda_1} \leq 3, \\ \forall l_1 \in R, \forall l_2 \in R, \forall e_1 \in E, \forall e_2 \in E, l_1 \neq l_2, e_1 \neq e_2 \quad (6)$$

wavelength usage constraint

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

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

converter usage constraint

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

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

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

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

calculation of number of converters used in the network

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

calculation of the usage of wavelength links

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