Efficient and Scalable Design of Protected Working Capacity Envelope

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Outline

1. Problem definition and motivation
    - Protected Working Capacity Envelope
    - Problem statement
    - Motivation
2. Design of PWCE using p-cycles
    - Literature review
    - Proposed solution method
3. Performance results
    - Evaluation metrics
    - Performance evaluation

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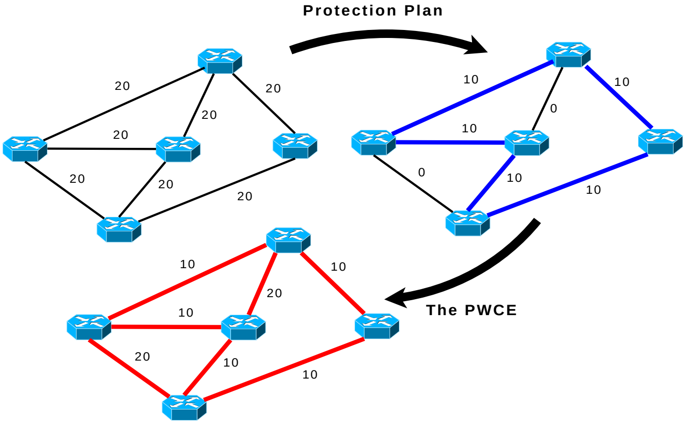
Protected Working Capacity Envelope(PWCE)

The PWCE is a new design approach of survivable WDM networks (Grover 2004), it is characterized by:

- The protection plan is designed ahead of the working plan, i.e., the protection capacity is deployed before any working capacity or failure in the network.
- The deployed protection capacity creates an implicitly protected capacity called the The Protected Working Capacity Envelope.

p-cycle-based PWCE

- An example of a design of resilient WDM network based on p-cycle-PWCE



Advantages

- Network operation is largely simplified: Provisioned working capacity within the PWCE is implicitly protected.
- Provisioning is less depend on network state information (routing databases ...), thus results in a more consistent and coherent scheme.
- The integrity of backup paths is guaranteed as an active monitoring and tuning of signal parameters can be actively performed.

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The design problem

The associated PWCE design problem can be defined as follows:

- **Input**
  - A network/link spare capacity budget.
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- **Objective**
  - PWCE of maximum size.
  - Shaped PWCE to suit a certain potential traffic forecast.

Motivation

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- Integer Linear Programming based solutions have been proposed for it, but unfortunately they are not scalable and/or not efficient.

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However,

- Mathematical modeling is not unique for a given problem
- Optimization techniques for large scale mathematical models have not been used yet
- Column generation techniques, in which optimization is performed without having to enumerate all the variables a priori are very efficient optimization tools in large scale systems

Literature review

- The classical design methods are based on a two-step approach: an explicit enumeration of all/most promising *p*-cycle followed by an ILP optimization method.
  - A method that explicitly enumerates -(brute strength)- all the *p*-cycles is time and effort consuming, and results in a huge optimization model thus, not scalable.
  - A method that performs a selective enumeration (e.g., SLA, Expand, Grow) [Grover et all 2004] may have the advantage of scalability, but does not guarantee an optimal solution.

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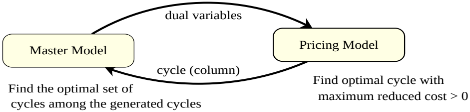
A column generation based PWCE design approach

- The whole design problem is divided into two sub-problem: master and pricing problems which are executed sequentially.
  - The pricing problem generates dynamically relevant *p*-cycles (this is not a complete enumeration).
  - The master problem optimizes the generated p-cycles.



Master Model

Pricing Model

dual variables

cycle (column)

Find the optimal set of cycles among the generated cycles

Find optimal cycle with maximum reduced cost > 0

- The process is iterated until all the potential *p*-cycle are generated.

Master Problem

Objective

$$\max \quad \sum_{s \in S} u_s w_s,$$

where u_s is the shaping factor.

Parameters

$$a_s^c = \begin{cases} 2 & \text{if } s \text{ is a straddling-cycle span in } p\text{-cycle } c \\ 1 & \text{if } s \text{ is an on-cycle span in } p\text{-cycle } c \\ 0 & \text{otherwise,} \end{cases}$$

$$b_s^c = \begin{cases} 1 & \text{if } s \text{ is an on-cycle span in } p\text{-cycle } c \\ 0 & \text{otherwise.} \end{cases}$$

Master Problem

- Actually, this is a restricted master problem, it grows as new *p*-cycles are added by the pricing problem.
- Variables are w_s (number of protected channel on s) and z^c(number of copies of *p*-cycle c).
- The constraints of the master problem are:

$$\begin{aligned}
\sum_{c\in C} a_s^c z^c \quad - \quad w_s &\geq 0 && s \in S && (1)\\
\sum_{c\in C} b_s^c z^c \quad + \quad w_s &\leq w_s^{max} && s \in S && (2)\\
w_s &\geq w_s^{\min} && s \in S && (3)\\
w_s, z^c \in \mathbb{Z}^+ & && && (4)
\end{aligned}$$

Pricing problem

Objective

$$\max \left(\sum_{s \in S} a_s^c t_s^1 - \sum_{s \in S} b_s^c t_s^2 \right),$$

Variables

$$x_s^o = \begin{cases} 1 & \text{if } s \text{ is an on-cycle span in } p\text{-cycle } c \\ 0 & \text{otherwise,} \end{cases}$$

$$x_s^s = \begin{cases} 1 & \text{if } s \text{ is a straddling-cycle span in } p\text{-cycle } c \\ 0 & \text{otherwise,} \end{cases}$$

$$\max \left(\sum_{s \in S} \overbrace{(x_s^o + 2x_s^s)}^{a_s^c} t_s^1 - \sum_{s \in S} \overbrace{x_s^o}^{b_s^c} t_s^2 \right),$$

Pricing problem

Feed the master problem with new relevant *p*-cycle.

$$\sum_{s \in \mathcal{E}(v)} x_s^o \leq 2 \qquad v \in V \tag{5}$$

$$\sum_{s' \in \mathcal{E}(v): s' \neq s} x_{s'}^o \geq x_s^o \qquad v \in V, s \in \mathcal{E}(v) \tag{6}$$

$$4x_s^s \leq \sum_{v \in \mathcal{V}(s)} \sum_{s' \in \mathcal{E}(v)} x_{s'}^o \qquad s \in S \tag{7}$$

$$\sum_{s \in \mathcal{E}(N)} x_s^o \geq x_{s'}^s \qquad N \subset V, s' \in \mathcal{E}(N) \tag{8}$$

$$x_s^o, x_s^s \in \{0, 1\}. \tag{9}$$

Evaluation metrics

Classical evaluation metrics (redundancy, computing time) we have considered two other metrics

$$\text{Protection gap ratio} = \frac{\sum_{s \in S} \text{unprotected capacity on } s}{\text{overall protected capacity}}$$

$$\text{Protection overhead ratio} = \frac{\sum_{s \in S} \text{protection overhead on } s}{\text{overall protection capacity}}$$

$$\text{Protection overhead} =$$
$$\text{supposed protected capacity} - \text{the protected capacity.}$$

NSF Network

NSF Network (12 nodes, 21 links), S-ILP(SLA), E-ILP(Extend), G-ILP(Grow), B-ILP(Brute strength), CG(Column generation)

Table: all the spans have the same spare capacity budget - NSF Network

	NSF				
	S-ILP	E-ILP	G-ILP	B-ILP	CG
# of potential *p*-cycles	18	31	88	138	3
Computing time (sec.)	0.02	0.03	0.04	0.7	0.03
# of selected *p*-cycles	7	5	12	1	1
Average *p*-cycle size	7.9	10	9.2	14	14
Working capacity	840	880	994	1120	1120
Spare capacity	740	668	658	560	560
Redundancy	88%	76%	67%	50%	50%
Protection gap ratio	12%	15%	2.9%	0%	0%
Protection overhead ratio	12%	0.3%	5.5%	0%	0%

COST239 Network

COST239 Network (11 nodes, 26 links)

Table: all the spans have the same spare capacity budget - COST239 Network

	COST239				
	S-ILP	E-ILP	G-ILP	B-ILP	CG
# of potential *p*-cycles	26	97	763	3517	3
Computing time (sec.)	0.02	0.08	0.42	21.5	0.03
# of selected *p*-cycles	19	25	19	1	1
Average *p*-cycles size	4.5	6.1	6.95	11	11
Working capacity	1120	1292	1472	1640	1640
Spare capacity	858	788	608	440	440
Redundancy	76%	61%	41.3%	26.8%	26.8%
Protection gap ratio	9.2%	0%	0%	0%	0%
Protection overhead ratio	15.4%	1.3%	5.3%	0%	0%

USA network

USA Network (28 nodes, 45 links)

Table: all the spans have the same spare capacity budget - USA Network

	USA				
	S-ILP	E-ILP	G-ILP	B-ILP	CG
# of potential *p*-cycles	35	96	1017	7314	3
Computing time (sec.)	0.03	0.05	0.64	190	0.2
# of selected *p*-cycles	19	17	18	1	1
Average *p*-cycles size	6.7	8.36	12.38	28	28
Working capacity	1916	2045	2308	2480	2480
Spare capacity	1604	1501	1264	1120	1120
Redundancy	83.7%	73.4%	54.8%	45%	45%
Protection gap ratio	4.2%	2.7%	1.3%	0%	0%
Protection overhead ratio	11.3%	8.8%	9.5%	0%	0%

Capacity efficiency

Table: optimality gap of S-ILP, E-ILP and G-ILP

	S-ILP	E-ILP	G-ILP
NSF	62%	41.3%	25.4%
COST239	73.8%	35.5%	19.8%
USA	54.2%	39.9%	20.6%

Larger networks

France network (43 nodes, 71 links) Brazil (27 nodes, 68 links)

Table: all the spans have the same spare capacity budget - larger networks

	France			Brazil		
	G-ILP	B-ILP	CG	G-ILP	B-ILP	CG
# of potential *p*-cycles	2263	-	2	4613	-	2
Computing time (sec)	4.15	-	0.6	45.5	-	6.6
# of selected *p*-cycles	44	-	1	51	-	1
Average *p*-cycles size	16	-	43	11	-	27
Working capacity	3625	-	3960	3961	-	4520
Spare capacity	2011	-	1720	1627	-	1080
Redundancy	55.5%	-	43%	41%	-	23%
Protection gap ratio	1.21%	-	0%	0.3%	-	0%
Protection overhead ratio	4.3%	-	0%	10.1%	-	0%

Restricted spare capacity budget

Table: spans with different spare capacity budgets

	COST239					
	[40-80]			[60-80]		
	G-ILP	B-ILP	CG	G-ILP	B-ILP	CG
# of potential *p*-cycles	763	3517	7	763	3517	14
Computing time (sec)	1256	1846	8.4	1722	128	21.55
# of selected *p*-cycles	17	7	6	19	4	6
Average *p*-cycles size	6.5	7.43	8.67	6.84	8	8.33
Working capacity	1010	1056	1056	1303	1429	1429
Spare capacity	442	390	384	550	426	426
Redundancy	44%	37%	36.3%	43%	30%	30%
Protection gap ratio	0%	0.5%	1.2%	0.3%	0.1%	0.1%
Protection overhead ratio	18%	64%	55.7%	13%	28%	22%

Questions

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