Optimizing p-Cycles Selection with MOEAs approach to protect WDM Optical Networks

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ABSTRACT

With the enormous breadth of potential bandwidth provided by WDM optical networks, the study of prevention and protection against failures becomes critical. The protection based on p-Cycles is a novel approach, based on optimal pre-configured cycles of protection to provide speed and efficient recovery. This paper proposes a Multiobjective Optimization approach to solve the problem of selecting an optimal set of p-Cycles using *Multi-Objective Evolutionary Algorithms* (MOEAs). Thus, simulations are studied on a dozen network topologies and different MOEAs as NSGA II, CNSGA II, SPEA and SPEA 2. Experimental results show that the proposed approach is very promising, over performing a well-know state of the art heuristic called *Capacitated Iterative Design Algorithm* (CIDA).

Key Words: WDM, Optical Network, p-Cycle, Protection, MOEA, CIDA.

1. OPTICAL NETWORKS

The expansion of Internet technology makes WDM (*Wavelength Division Multiplexing*) optical transmission a potential successor of networks based on SONET/SDH technologies, to offer higher data transmission capabilities and resources [1]. Optical networks are prone to failures, often having catastrophic consequences for high traffic [2]. Therefore, optimizing protection against possible failure scenarios in WDM networks is a critical task in today Optical Communication systems.

2. PRE-CONFIGURE CYCLES (p-Cycles)

Considering the importance of fault tolerance in WDM Networks, Grover [3] proposed a new method; called p-Cycle (*Pre configured Protection Cycle*), where the optimal selection of p-Cycles is crucial to efficiently protect WDM Optical networks.

The optimal selection of p-Cycles consists in calculating a set of cycles that optimizes network link protection considering one or more objective functions as *Topological score* (TS), *a priori efficiency* (AE), and *redundancy* [8]. This problem belongs to the NP-complete class [4]. Typically, it is solved in two stages: first, a set of candidate cycles is built, and then, a subset of optimal p-Cycles is calculated using the set of candidates.

ILP (*Integer Linear Programming*) formulation was first proposed to solve the problem [3], but it is impractical for large and complex networks because of its high complexity. To solve the problem, a heuristic algorithm called *Capacitated Iterative Design Algorithm* (CIDA) was proposed, becoming one of most tested state of art algorithm [5].

3. MULTI-OBJETIVE FORMULATION

Table 1 presents symbols used in a multi-objective formulation.

Table 1. Symbols

Symbols	Description
$G=\{V, E\}$	Graph representing a network topology, where **V** is the set of nodes and E the set of links.
$v_i \in V$	Node v_i belongs to V, $i = 1, ..,\|V\|$, where |.| indicates cardinality.
$e_j \in E$	Link e_j belongs to E, with $j = 1, 2,, \|E\|$.
$p_k \subset E$	Set of links that form a cycle which passes through $\|p_k\|$ nodes in G, i.e. $p_k = \{e_1, e_2, \dots, e\|p_k\|\}$.
P	Set of cycles protecting G, i.e. $P = \{p_1, p_2,.., p_{\|P\|}\}$.
$X_k(e_j)$	Protection type provided to e_j by cycling p_k. If e_j is a straddling-link in p_k then $X_k(e_j)=2$, if e_j is an on-link in p_k $X_k(e_j)=1$, otherwise $X_k(e_j)=0$.
$Z_k(e_j)$	Variable indicating whether or not p_k provides protection to e_j. If e_j is on-link or a straddling-link in p_k, $Z_k(e_j)=1$, otherwise $Z_k(e_j)=0$.

The problem can be stated as: given a graph $G(V, E)$, calculate a set of p-Cycles $S \subset P$ that simultaneously minimize the *Total Cost* (z_1) and maximize the *Total Protection* (z_2) subject to a restriction of full protection of G:

$$\text{Total Cost} \qquad z_1 = \sum_{p_k \in S} |p_k| \tag{1}$$

$$\text{Total Protection} \qquad z_2 = \sum_{p_k \in S} TS(p_k) \tag{2}$$

where

$$TS(p_k) = \sum_{e_j \in E} X_k(e_j) \tag{3}$$

subject to Protection Restriction:

$$\sum_{e_j \in E} \sum_{p_k \in S} Z_k(e_j) \geq |E| \tag{4}$$

Alternatively, we define the objective function known as *Efficiency*, to be used in the simulations to be presented by a single objective Genetic Algorithm (GA) and CIDA algorithm for comparison proposes:

$$\beta(S) = z_1(S) / z_2(S) \tag{5}$$

4. MOEAs

This paper implements four state of art MOEAs (*Multi-Objective Evolutionary Algorithms*) presented in Table 2, to solve the p-Cycle optimization problem. The proposed approaches simultaneously optimize both objective functions (1) and (2). Results are compared to known GA [7] and CIDA algorithm [5]. It is interesting to notice that the goal of MOEAs is to calculate a set of non-dominated solutions called Pareto Front – *PF or* PF_{known}, considering dominance relations [6], while state of the art single-objective algorithms generally calculate only one solution per run.

Table 2 – MOEAs Approach

MOEA-ID	Description
NSGA-II	*Non-dominated Sorting Genetic Algorithm II*
CNSGA-II	*Controlled Non-dominate Sorting Genetic Algorithm II*
SPEA	*Strength Pareto Evolutionary Algorithm*
SPEA2	*Strength Pareto Evolutionary Algorithm 2.*

To compare the performance of different MOEAs, this work uses five performance figures presented in Table 3 [6]. These figures of merit measure quality of PF_{known} by comparing the calculated set of solutions to a Global Pareto Front or PF_{TRUE} which is conformed by all non-dominated solutions [6].

Table 3 – MOEAs Performance Figures

Figure ID	Description
O	ONVG (Overall Non-dominated Vector Generation)
OR	ONVGR (ONVG Ratio)
N	Number of Non-dominated solutions
ER	Error Ratio
ME	Maximum Error of a Pareto Front.

5. EXPERIMENTAL RESULTS

For each topology of Table 4, one set of p-Cycles candidates *P* generate by the Straddling Link Algorithm (SLA) [4] and GROW [5] is first calculated. Then, MOEAs, GA and CIDA approaches are running 30 times, for 10 minutes each run.

Table 4 – Tested Topologies

ID	Network Topologies	Nodes	Links	P
NSF	USA National Science Foundation Net.	14	25	756
BCB	Bell Core Yerse LATA	15	27	780
ULHN	USA Long Haul Network	28	45	780
ARPA	USA ARPA Backbone	21	25	30
BCN	Bell Core Backbone	25	28	404
PAN	PAN European COST 239	11	26	366
ELHN	European Long Haul Network - France	43	71	1683
GOBN	German Backbone Network	17	27	212
ECN	ECNet European Backbone	18	39	420
CNBN	China National Backbone	66	120	4257
NTT	Japan NTT Backbone Network	49	66	545
IRIS	RedIRIS Spanish Research Network	19	32	183

Table 8 presents the global comparison performance of the 4 MOEAs (a gray color indicates superiority), while Figure 1 presents a graphical comparison among MOEAs, GA and CIDA for the IRIS network.

Table 5 – MOEAs Global Performance

Figures	NSGA-II	SPEA	CNSGA-II	SPEA2
Average (O)	74,33	80,42	70,42	70,42
Average (OR)	0,15	0,16	0,19	0,66
Average (N)	14,75	15,92	18,42	68,92
Average (ER)	0,79	0,80	0,73	0,32
Average (ME)	33,91	11,27	19,60	0,00

In general, SPEA2 outperforms other alternatives in most figures of merit. Note also that the GA reaches better results than CIDA considering efficiency β (5). In fact, GA finds in general one non-dominated solution of the Pareto Fronts.

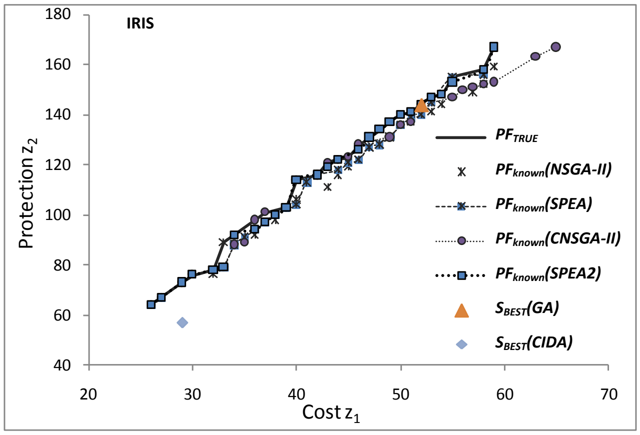

Figure 1 – Result IRIS topology network.

6. CONCLUTIONS

This paper proposes the use of MOEAs to solve the protecting network problem based on pre-configured cycles or p-Cycle, as a Multi-objective Optimization Problem. Four new approaches based on known MOEAs where implemented to simultaneously optimize two objective functions: (1) cost and (2) protection of the entire network. Experimental results indicate that the proposed multiobjective approach gets better results than CIDA state of the art algorithm. Multi-objective performance figures of merit indicate that SPEA2 shows the best performance of the 6 compared algorithms, followed by CNSGA-II considering a test bed of 12 well-known networks.

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