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Survivability and Protection of Nodes and Links from Failures in WDM Mesh Networks

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***Abstract*—**

This paper is the base for a new project about node and link protection in wavelength division multiplexing mesh networks to assure 100% node protection in addition to the protection against the single link failure and also dual link failures, for this purpose we propose a p-cycle protection scheme. Previous studies offer some node protection shows the expense of some overlapping p-cycle with very mild impact on the bandwidth efficiency, we can guarantee node protection. A design model and solution method is introduced for solving based on the large scale optimization tools namely column generation (CG).The role of the column generation computes the node and link protection offered by p-cycles. Earlier models offer a solution where we need to concentrate on a large number of potential cycles needs first, leading to very large ILP models which cannot be scaled. We compare our model and the work of Grover and Onguetou (2009).). Our proposed model clearly outperforms the design in terms of capacity efficiency and of the number of distinct cycles when compared with previous models.

***Keywords*— Survivable WDM networks, *p-cycle*s, node protection, column generation.**

I. INTRODUCTION

WDM techniques enable a single fibre to carry multiple non-overlapping channels, and a single channel can operate at the speed of up to 100 Gbps. WDM networks carry large quantity of traffic. We already know that optical WDM networks are occasionally prone to a single failure of network infrastructure (e.g., a fibre cut or a node failure), survivability of the network is an important criteria in the design of WDM networks

The approaches have been proposed in various types of protection for providing the survivability of WDM mesh networks. Lot of approaches are there, in those the p-cycle (pre configured protection cycle) approach [1] holds the unique characteristic of ring- like restoration speed and mesh-like capacity efficiency. The studies have been made anonymously which explored for survivability of protection of WDM mesh networks against the single link failure and did not worry about single node failure.

As the disasters occur naturally this may cause for the single node results in the entire node that leads to the bad result. Even a single node failure may occur due to some disasters such as floods and fires which takes the entire node down thereby the failure of all its corresponding links and thereby entire network. Hence the significance of failures of nodes will continue to shut the network. In admit to these the node ports are not protected due to the cost of node and limitation in the space. Hence the result of the failure of the node port which disturbs the multiple channels and there usually can't be handled by link protection approaches i.e., conventional p-cycles model.

Besides the path-segment-protecting *p-cycle*s [2] and path- protecting *p-cycle*s [3] approaches which, with the use of *p-* cycles, resemble the segment and path protection schemes, few studies have investigated node protection with *p-cycle*s. Stamatelakis and Grover [4] proposed node-encircling *p-* cycles (NEPCs), which are rather spare bandwidth consuming. Schupke [5] proposed and evaluated an Automatic Protection Switching (APS) protocol enhancement to provide means for node failure with *p-cycle*s. Onguetou and Grover [6] proposed new concept for protection of nodes and links against the failures, with the help of overlapping segment *p-cycle*s either spanning or lying on the *p-cycle*s, allow partial or full protection of all the intermediate nodes of the routing paths. The same authors in [7] later restrict the segments to two hop segments in order to retain the simplicity of *p-cycle* switching operations and to keep the ILP models easier to solve.

The conventional p-cycle design method formulates the design problem as an Integer Linear program (ILP).Two approaches have been used to solve the Integer Linear Program. The first approach gives the off-line generation of either the whole set of potential p-cycles[1],[8] or a restricted set of promising candidate p-cycles[9],[10].The first approach leads to either to huge ILP or to a heuristic solution with an unknown accuracy . The second approach relies on an implicit enumeration of the set of cycles and i.e. the order list of all items in complete form..So, here the column generation technique [1] helps to find the solution which jointly generates and provisions the *p-cycle*s.

First for a while let's brief about the p-cycles. P-Cycles are protection cycles for mesh networks that are created out of spare capacity.

The main attributes of a p cycle are as follows.

- Preconfigured in a network like a ring
- Protect both On Cycle and Straddling Links
- Allow working capacity to be routed using shortest path routing schemes.
- Efficiency similar to that of mesh and restoration speed similar to that of link.
- Easy to Configure
- Bridge the divide between the ring and mesh.

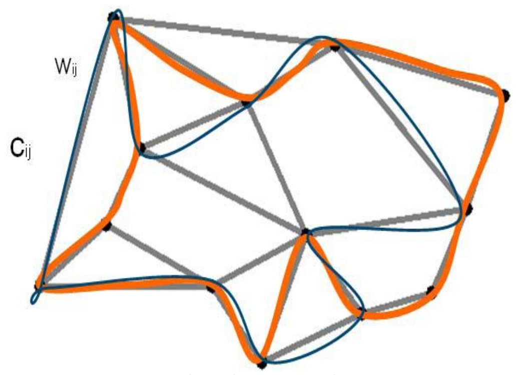


Fig. II. Illustration of the formation of *p*-cycle.

In this paper, we investigate the design of *p-cycle*s with 100% node protection. The underlying idea comes from the observation that a node is protected if its two adjacent links on the working path are supported by two on-cycle links belonging to the same *p-cycle*. It resembles the two hop approach of Grover and Onguetou [7], with one additional feature, i.e. the 2-hop strategy of Grover and Onguetou [7] only allows a *p-cycle* to protect a node with respect to only one affected working path. We allow the node protection of a node lying on several paths if the paths require disjoint protection for that node protection.

The remaining paper is organized as follows. In Section IV, we explain the node protection scheme that we propose and its difference with the two hop approach of Grover and Onguetou [7].

In Section V, for ensuring full node protection, we evaluate an efficient large scale optimization mathematical model for the design of *p-cycle*s.

In section VI computational results are displayed, where we compare our design with conventional *p-cycle*s and with the method of Grover and Onguetou [7].and the conclusions are drawn.

II. EXISTING SYSTEM

Algorithms which are made for the protection against the link failures have occasionally shown the single link failure. At the same time the dual link failures also spotted eventually because of two reasons. As we know the links in the network access the resources by sharing including conduits, ducts and others which leads the result in the failure of multiple links and there by failure in the entire network. Second reason is that the average repair the link where it was failed may take few hours even to few days. And the repair time is sufficiently far for a second failure to occur. Although algorithms which are developed for single-link failure resiliency which helps to solve or to get a solution of the dual-link failures, in such cases includes links which are separated far from each other. By considering the fact that these algorithms are not proposed for dual-link failures but the scenario may serve as an alternate for recovering from dual-link failures which are independent. However, dependence on such approaches may not be preferable if the links close to one another in the network share resources, in such cases it leads to correlated link failures. And hence it is to prove or make a solution for Dual-link failures where it occurs.

III. PROPOSED SYSTEM

This paper formally classifies the approaches for providing protection for dual-link failures and when the link failures have sorted out then the protection of nodes automatically gets solved. The dual-link failures can be recovered using an extension of link protection for single link failure which results in a constraint. The constraint is referred to as backup link mutual exclusion (BLME) constraint, its satisfiability allows the network to recover from dual-link failures by avoiding the broadcasting of failure location to all the nodes. This paper develops the necessary theory for deriving the sufficiency condition for an existing solution, which derives the problem of finding backup paths for links satisfying the BLME constraint as an Integer Linear Program (ILP), and latter develops a polynomial time heuristic algorithm. The formulation and heuristic which are applied to different networks and those results were compared. The compared results shown to obtain a solution for most scenarios with an assurance of high failure recovery, although such a solution may have longer average hop lengths when compared with the optimal values. This paper also provides the potential benefits of knowing the precise failure location in a four-connected network that has lower installed capacity than a three-connected network for recovering from dual-link failures.

IV. NODE AND LINK PROTECTION IN P-CYCLE

Node failures in a network are usually protected against by using node redundancy thus there is not much research in the area of node protection using P-Cycles. However the most common failure in today's IP networks is Router Failure. This is a kind of node failure so it is important to look at this aspect of P-Cycles. We can protect against node failures by encircling all the neighbors of the node to be protected by a node encircling p-cycle. In case the node fails all connections passing through that node effectively become straddling spans of the cycle hence are protected. However it may not be possible to use simple cycles for node encircling in such a case, assuming the graph is bi connected we can use a non simple cycle to do node encircling. The following diagrams explain the working of node encircling P-Cycles.

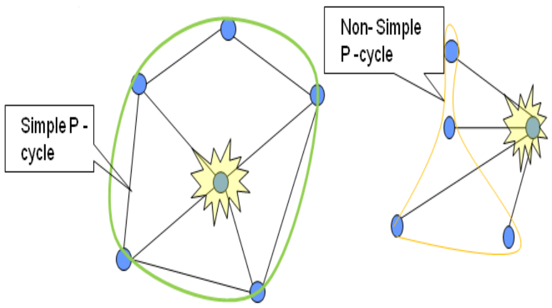


Fig. II. Node enriching p-cycles

In order to assure the 100% node protection we propose the concept of overlapping p-cycles. As proposed in [7], it mainly generalizes the node protection into two sequences. The first thing is the node protection is embedded in the generation and the protection provisioning of the p-cycles and does not require a second optimization step once the (link) p-cycles have been selected. The latter i.e. Secondly p-cycles has the tendency to handle the node protection even if they crossed by several paths as long as those paths which require independent protection from the p-cycle. Finally this allows the spare bandwidth requirement which is reduced in the form of numerical results. So here we describe the node protection in overlapping p-cycles and the nodes which intersecting paths.

A. Node protection in overlapping p-cycles

p-Cycles are established by configuring the spare capacity into pre-cross-connected cycles. Upon a link failure, protection switching is performed at the two end nodes of the failed link and other switching nodes will not be reconfigured.

The overlapping p-cycle concept is alike the concept of overlapping segment protection. Indeed, while segment protection has been defined which is a compromise between link as well as path protection, there are two types of segment protections, the regular segment protection when protection segments have the same endpoints as the working segment, and the overlapped segment protection where segments overlap in order to guarantee node protection in addition to link protection, see [12]. We investigate here the overlapping of p-cycles in order to guarantee 100% node protection.

An illustration is provided in figure III. In order to offer node and link protection to the request demand between nodes v5 and v11, one needs two p-cycles C1 (small dashes) and C2 (big dashes). All links of the working path are protected as each of them is either an on link or a straddling link of C1 or C2. Each intermediate node is also protected as its two adjacent links on the working path are protected by the same p-cycle, e.g., node v7 has its two adjacent links {v7, v9} and {v7, v11} protected by C1.The following figure illustrate about the overlapping p-cycles.

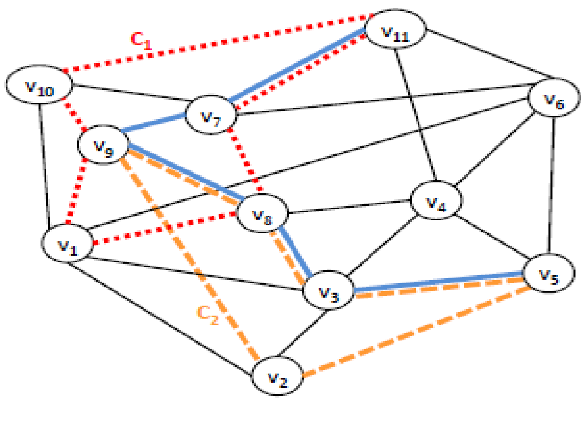
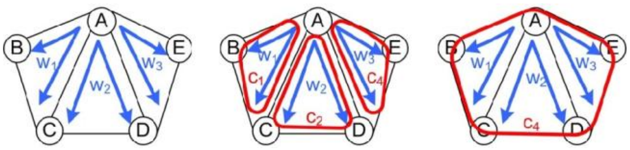


Fig. III. Overlapping *p-cycle*s and node protection

B. Node intersecting paths

The 2-hop strategy [7] only allows a p-cycle to protect a node with respect to only one affected working path. We allow the node protection of a node lying on several paths if the paths require disjoint protection for that node protection. Fig. IV illustrates the idea. A network topology with five nodes is shown in Fig. IV (a), with three demands which are routed on routing paths w1, w2 and w3, respectively are three demands routed. Fig. IV (b) shows the solution from the design strategy proposed in [7]. Therein, three p-cycles, c1 and c2 and c3 are required to provide full node protection. The resulting spare capacity usage is nine channel units. However, with our approach, one p-cycle c4 suffices to provide full node protection. Upon the failure of node A, on-cycle links B-C, C-D and D-E can be used for recovering the three disrupted demands . The associated spare capacity cost is five units of channels. Thus, compared to the 2-hop strategy of [7], our solution cuts 44.44% spare capacity usage



a) Working paths (b) Solution of [7] (c) Our solution

Fig. IV. A multi cycle p-cycle

V. COLUMN GENERATION MODEL

Consider a WDM mesh network. It is represented by a graph $G = (V, L)$, V is set of the nodes which indexed by v. L is the set of fibre links indexed by l.The working path which is given is $p \in P$ and d_p be the no. of connection requests which it carried on it and let V_p be the set of its intermediate nodes.

Here we introduce the optimization method that is based on Column Generation technique for full protection of nodes in the design of p-cycles using the overlapping p-cycles strategy as we mentioned in the Section IV.

The main objective is to reduce the spare capacity of the bandwidth usage. So when the spare capacity of the bandwidth minimized we can ensure such that the 100% guaranteed survivability with respect to single failure of a link and node and either or.

By proposing the Column Generation technique, the problem will comprises of two subproblems. First one is Master problem and second is the pricing problem.

(i) The master problem deals with by selecting the best combination of p-cycles which it will guarantee the node or link protection.

(ii) Second the price problem gives the improved new p-cycles, single iteration after the other, and the current value of the master problem.

A. The master problem

The master problem relies on the concept of configurations where a *p-cycle* configuration *c* is made of a one unit cycle, and the set of links and nodes protected by that cycle. Note that each node protection corresponds to a pair made of a node *v* and a working path *p* where *v* is an intermediate node of *p*.

The configuration of a p-cycle c is denoted by a vector $(a_l^c)_{l\in L}$ and a matrix $(a_{pv}^c)_{p\in P, v\in V_p}$.The number of protection paths provided by the p-cycles c for the protection of link l is represented by the vector component $a_l^c \in \{2,1,0\}$.The element i.e. $a_{pv}^c \in \{1,0\}$ is equal to 1 then the situation made the p-cycle c providing the backup path in order to overcome the failure of the node v with respect to the working path p. It is to mention the spare cost of the p-cycle c and variables which denotes the number of copies of the p-cycle configuration c which are to be selected to get the solution in the protection scheme.

Let spare cost of the p-cycle c be $COST^c$.and let the variables be z^c.

Then the representation of the mathematical model as

$$\min \sum_{c\in C} \text{COST}^c z^c$$

And it is Subject to

$$\sum_{c\in C} a_\ell^c z^c \geq \omega_\ell \qquad \ell \in L \qquad (1)$$

$$\sum_{c\in C} a_{pv}^c z^c \geq d_p \qquad p \in P,\ v \in V_p \qquad (2)$$

$$z^c \in \mathbb{Z}^+ \qquad c \in C \qquad (3)$$

The use of deriving the constraints is briefed as follows. The constraint (1) ensures the overall traffic which is protected against the single link failure. Constraint (2) ensures ensure that all demands are protected against a single node failure at a node *v* lying on working path *p*, for all intermediate nodes on all working paths. Constraints (3) are variable domain constraints.

B. The pricing problem

As we mentioned earlier the pricing problem gives the improvised p-cycles. Here it will generates the required promising p-cycles which it will decrease the value of the master problems current solution. The pricing problem corresponds to the optimization problem with the main goal of minimizing or reducing the cost of the master problem solution which it subject to a set of constraints for generating the new p-cycle and for its set of protection of links or nodes from failures. Hence the pricing problem objective is to minimize the solution from the master problem and the objective function can b represented as

$$\min \quad \text{COST}^c - \sum_{\ell \in L} u_\ell \, a_\ell^c - \sum_{p \in P} \sum_{v \in V_p} u_{pv} \, a_{pv}^c$$

Where u_l and u_{pv} are dual variables associated with constraints (1) and (2) respectively. $COST^c$ IS the spare capacity cost of the p-cycle configuration c, which derives the sum of Λ_l of its on-cycle links.

Before stating the mathematical model of the pricing problem, it is mandatory for deriving the following terms. They are sets and variables. These are the two terms which is used for the mathematical model for both the master and pricing problem. The pricing model will minimizes the solution which is from the master problem

Sets are as follows:

- $w(v)$ The set of links adjacent to the node v.
- V_p The set of intermediate nodes working path p.
- P_v The set of paths passing across node v.
- $\delta(v)$ The set of nodes passing adjacent to node v.

Variables are as follows:

b_l = 1 if the link l is in the current cycle, otherwise 0.

s_l = 1 if the link l straddles the current cycle, otherwise 0

x_{pv}^l = 1 if the link l is used to protect a working path p against The failure of its intermediate node v, 0 otherwise.

y_v = 1 if the node v is on the current cycle, 0 otherwise.

With these terms which are mentioned above, the pricing problem objective function represented as

$$\min \overbrace{\sum_{\ell \in L} \Lambda_\ell b_\ell}^{\text{COST}^c} - \sum_{\ell \in L} u_\ell \overbrace{(b_\ell + 2s_\ell)}^{a_\ell^c} - \sum_{p \in P} \sum_{v \in V_p} u_{pv} \overbrace{\sum_{\ell \in \omega(e_{pv}^1)} x_{pv}^\ell}^{a_{pv}^c}$$

The pricing problem has two groups of constraints from the objective function.

(i)The first group of the constraint is associated with the generation of the simple cycle and the identification of the set of links which are protected by this cycle.

(ii)The second group of constraints deals with determining the pair (p, v).

As mentioned earlier the first group is defined below.

$$\sum_{\ell \in \omega(v)} b_\ell = 2\, y_v \qquad v \in V \qquad (4)$$

$$s_\ell \le y_v - b_\ell \qquad v \in V,\ \ell \in \omega(v) \qquad (5)$$

$$s_\ell \ge y_v + y_{v'} - b_\ell - 1 \qquad v, v' \in V,\ \ell = \{v, v'\} \in L \qquad (6)$$

$$\sum_{\ell \in \omega(V')} b_\ell \ge y_v + y_{v'} - 1 \qquad V' \subset V,\ 3 \le |V'| \le |V| - 3$$
$$v \in V',\ v' \in V \setminus V' \qquad (7)$$

The given cycle consists of all nodes and each node must have incident links on the cycles. And that is ensured by constraint (4) as mentioned above. For identifying the straddling links constrains (5) and constraint (6) are used and these two can be considered as the straddling links only when if its two end nodes are on-cycle and the link itself is not. Constraint (7) is used to prevent from generation of a new p-cycle that includes multiple cycles. Otherwise, it may become burdens for identifying straddling links.

$$x_{pv}^\ell \le b_\ell \qquad p \in P,\ v \in V_p,\ \ell \in L \qquad (8)$$

$$x_{pv}^\ell = 0 \qquad p \in P,\ \ell \in \omega(v),\ v \in V_p \quad (9)$$

Constraint (8) mentions that only on-cycles which are eligible for protection of the working path p against the single failure of its relay node. Constraint (9) is used for the condition only if a link is adjacent to the relay node v of the working path p ,then the link should not used by the associated protection paths.

$$\sum_{\ell \in \omega(v_1)} x_{pv}^\ell = \sum_{\ell \in \omega(v_2)} x_{pv}^\ell \qquad p \in P,\ v \in V_p \qquad (10)$$

$$\sum_{\ell \in \omega(v')} x_{pv}^\ell \le 2 \qquad p \in P,\ v \in V_p,\ v' \in V \qquad (11)$$

$$\sum_{\ell \in \omega(v') | \ell \ne \ell'} x_{pv}^\ell \ge x_{pv}^{\ell'} \qquad p \in P,\ v \in V_p,\ \ell' \in \omega(v')$$
$$v' \in V \setminus \{v_1, v_2\} \qquad (12)$$

Constraint (10) to Constraint (12) considered as the flow conservation constraints, which are used to define the associated protection paths. Constraint (10) as a protection must end at two end nodes of the associated 2-hop segment which is defined by working path p and its relay node v.The constraints (11) and constraint (12) both are used to ensure for those nodes except two end nodes of the 2-hop segments which are associated and number of outgoing and incoming flows should be identical. On the failure of a node, working paths which are passing through the nodes are disrupted.

$$\sum_{p \in P_v} x_{pv}^{\ell} \leq 1 \qquad \ell \in L,\, v \in V \qquad (13)$$

$$b_\ell,\, s_\ell,\, y_v,\, x_{pv}^{\ell} \in \{0,1\} \qquad \ell \in L,\, v \in V,\, p \in P \qquad (14)$$

Constraint (13) considered as a link channel and it is used to recover one unit disrupted 2- hop segment. Constraint (14) is the final set which contains the variable domain constraints .

VI. COMPUTATIONAL RESULTS

The computational results will compute the results and for gives the accurate solution or design model. So, in this section we take the solution from column generation model for node protection. So let it be denote as (VMpCycle).we made a comparison between the VMpCycle with the RMpCycle which is proposed in[7] as capacity redundancy. The capacity redundancy is the ration of spare capacity usage over the working capacity usage. We has to compare capacity redundancy between p-cycles for node protection i.e. VMpCycle with conventional p-cycle which only guarantees 100% link protection (GKpCycle)

From the above,the evaluation of the p-cycles which is associated with the dual link failure restoration ratio with the solution from the column generation for node protection (VMpCycle), link protection (GKpCycle) and capacity redundancy (RMpCycle).The dual link restoration ratio (R_2) is calculated as the total number of recovered traffic units and over all dual link failure scenarios divided by the overall total number of dual failure affected traffic link pairs. The dual link restoration ratio is calculated as in[14] for link protecting p-cycles. And for node protecting is like in the similar way as for conventional link p-cycles. These three aspects i.e. VMpCycle, GKpCycle, RMpCycle all implemented in C++ programming language .The proposed three models will get gap optimally less than to 1.0%

A. *Data instances*

Experimenting on different networks will give us a clear vision for the paper and it is compared and evaluated. The network consists of the number of nodes, links, and the average nodal degree (act as an indicator for network connectivity). In addition to that we mixed up with the number of demand requests and working capacity usage i.e. the number of link wavelength channel for each and every traffic instance. Each demand request correspond to a one unit demand between a given node pair. The random value generated with a uniform random distribution on the interval [1…..20]. Each demand request is routed along a shortest path. The following table I present the network instances and their associated topology characteristics. The table below gives the scope for the different networks. We made clear comparison for these kinds of networks for better convenience.

Table I. NETWORK INSTANCES

Networks	**Nodes**	**Edges**	**Node Degree**	**Num. Demands**	**Working Cost**
GERMANY[15]	17	26	3.1	136	4050
NSF	14	21	3.0	91	1970
COST239[17]	11	26	4.7	55	792
BELLCORE[12]	15	28	3.7	105	2610
NJ LATA[16]	11	23	4.2	55	943

B. *Capacity redundancy*

Comparisons have been made over five networks and for capacity redundancy of three designs models. For each and every instance, the p-cycles for protection for nodes will resulted from RMpCycle are high in capacity redundancy those from VMpCycle, with the example which we discussed in the section IV (b), the Differences in their redundancy between these two i.e. RMpCycle and VMpCycle may varies from ~6% to ~15%.More over we will observe that p-cycles for protection of nodes will b higher in the capacity redundancy those from the conventional p-cycles. However, using the VMpCycle design, only marginal extra spare capacity is required for full link and node protection compared to that for link protection, which ranges from ~1% to ~13%.In figure V(a),the comparisons between the three designs that is for(VMpCycle, GKpCycle, RMpCycle) are made over five different networks.

C. *Dual link failure restoration ratio*

The dual link failure restoration ratio (R_2) of the p-cycles sets obtained from VMpCycle, GKpCycle, and RMpCycle for five different networks is depicted in the figure V (b). The dual link failure restoration ratio (R_2) of the p-cycles set from VMpCycle is greater than to that of the dual link failure restoration ratio (R_2) of the p-cycles set from GKpCycle, but it is smaller than to that of the dual link failure restoration ratio (R_2) of the p-cycles set from RMpCycle. From this it is facts that RMpCycle is most capacity redundancy from all these three design models and considered as effective among these three models. The dual link failure restoration ratio (R_2) between VMpCycle and GKpCycle ranges from ~1% to ~8%. For instance, in the NSF network the *p*-cycles from VMpCycle can achieve ~7% more R_2 than those from GKpCycle while only requiring no more than ~2% extra redundant capacity. It is made easier to find out which one is effective among three design models by the dual link failure restoration ratio (R_2) of the p-cycles sets.

D. *Number and length of distinct cycles*

The figure V(c) and figure V(d),we present the number of distinct cycles in the optimal solutions of three design model respectively i.e. for (VMpCycle, GKpCycle, RMpCycle).Here we took five different networks for each network, GKpCycle needs the smaller number of distinct cycles among these design models. The differences between GKpCycle and RMpCycle (or VMpCycle) range from ~37% to ~83%. Hence the advantage of link-protecting *p*-cycles is therefore considerable over node-protecting *p*-cycles. The p-cycle design methods for node protection i.e. for VMpCycle gives the protection with the smallest number of distinct p-cycles than in RMpCycle with a similar comparable number in the GERMANY and COST239 networks for instances. The differences range from ~13% to ~27%. Thereby, in terms of the management, VMpCycle outperforms RMpCycle design model. Except for these networks i.e. for BELLCORE and the Germany, the length of the node protection *p*-cycles is smaller than the length of the node protection *p*-cycles of [7], and it is always smaller or equal to the length of the conventional *p*-cycles. With these pictures the calculating of the data link restoration ratio gives the clear scope on the project. The conclusion of the paper says that the dual link failure which occurs will resolves and within the time it rectifies and responsible for the working in the network successfully.

RMpCycle VMpCycl GKpcycle

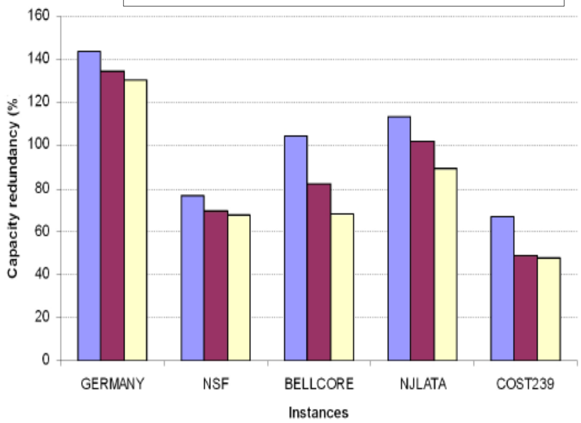


Fig. V (a). Capacity redundancy

RMpCycle VMpCycl GKpcycle

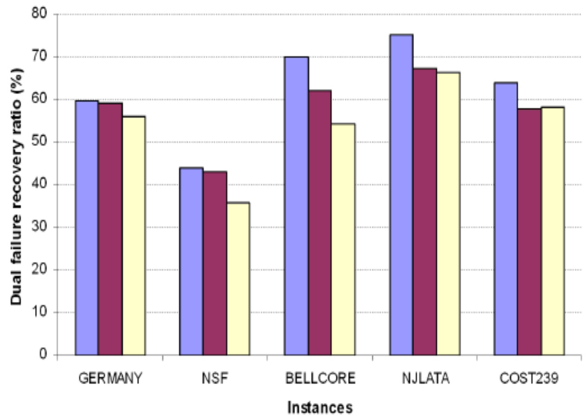


Fig. V (b). Dual link restoration ratio

RMpCycle VMpCycle GKpcycle

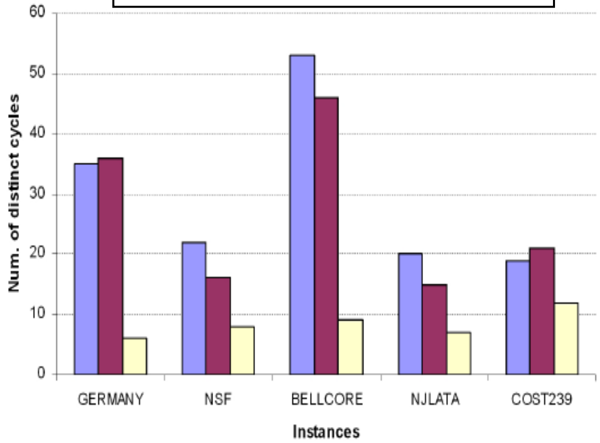


Fig. V (c). Number of distinct cycles

RMpCycle VMpCycle GKpcycle

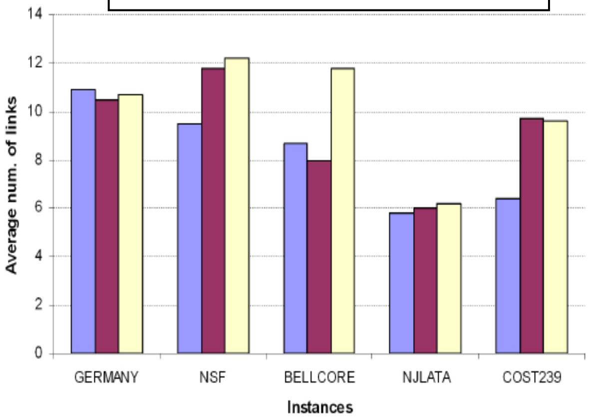


Fig. V (d). Average number of links

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C.UPENDRA G.GOPICHAND

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