Reliability Improvement with Critical Span Protection using Modified Algorithm of Pre-configured (P) Cycles

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ABSTRACT

Among all the link[a] protection schemes discussed so far in the literature, the p (pre-configured)-cycle schemes are the most promising one in terms of efficiency and speed. The recovery is very fast (50ms for SONET rings) in ring-based networks. However, these networks are inefficient and inflexible as compared to mesh-based networks. P-cycles are the result of efforts to obtain ring like speed and mesh like capacities and flexibility. In the present work the modified algorithm of p-cycles has been used to cover the critical spans as straddling span. Some spans[b] are always very critical in any network. In the present work the spans with minimum reliability have been taken as critical spans. P-cycles are formed in such a way that these critical spans will appear as straddling links on the p-cycles, so two protections paths are available for these minimum reliability spans, improving the reliability of critical span. The reliability of the path from source to destination is computed and compared with path based protection scheme & p-cycle based protection of critical span. The result shows considerable improvement in the reliability of path in our scheme if critical span reliability is very low.

Keywords: Critical span, optical network, p-cycle, protection, reliability

1. INTRODUCTION

Future optical networks are emerging as optical networks providing services to the IP layer. The optical layer provides light paths between IP networks. Each fiber can have many light paths passing through it on different wavelengths using WDM. Since fiber has large bandwidth a large number of light paths (up to 160) in a single fiber can exist; each having a capacity of 10Gbps[1, 2]. Henceforth, incredibly large traffic volumes can be supported by a single fiber. In this scenario a single fiber failure (single fiber cut) can lead to simultaneous failure of all the light paths in the fiber. This will result in failure of thousand of higher layer paths and loss of significant amount of traffic and hence the revenue. Therefore network survivability issue is very critical in optical networks.

1.1 Protection and restoration schemes

The network failure recovery schemes can be broadly classified into two categories Protection and Restoration, as shown in Fig.1. Protection is defined as pre provisioned failure recovery[3-6]. The back up path, which is, link disjoint

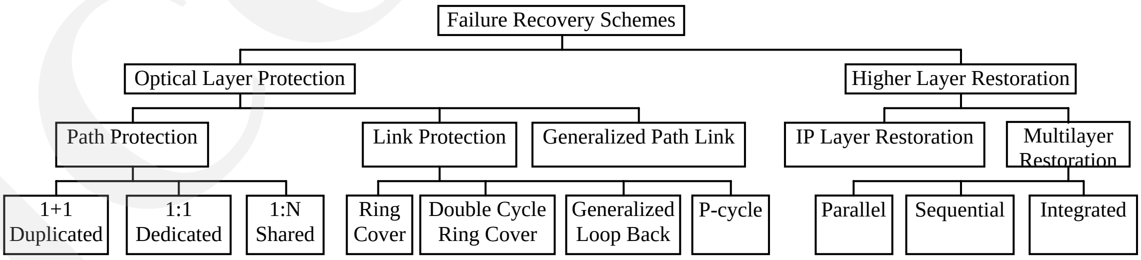

Figure 1: Protection & Restoration Schemes

[a] Link is used to represent the portion of one light path between any two nodes.
[b] Span is used to represent the entire capacity between any two nodes. It may be a single fiber or fiber conduit. The total traffic in a span is the traffic of all the links in that span.

and may be node disjoint also with the primary path, is set up along with the primary path. The primary path is used to transmit the data and back up path is reserved for use in the event of failure. After the detection of failure the switches are re-configured to use the back up path.

Restoration schemes refer to dynamic recovery after the onset of failure[3-6]. The restoration involves detection of a failure, new path computations for the failed connections and reconfiguration of switches for the restoration path. Usually optical layer can provide fast protection while higher layers can be used for intelligent restoration.

1.2 Path and link based protection

These schemes have been studied in depth in reference[6]. The optical layer protection schemes can be divided into path protection, link protection and generalized path-link protection schemes. The entire light path from source to destination is protected in path protection schemes. In the event of failure, fault localization is not required; instead traffic is switched over to link and node disjoint backup path. Another mechanism of protection is called link protection. These schemes are designed basically to provide Automatic Protection Switching (APS) of rings in the optical mesh networks. The protection mechanism for these schemes is fast, distributed and autonomous. Due to smaller scale of link and localization of fault, link protection schemes are faster in response. Another very important feature of link protection is that it can be preplanned once and for all since it is not dependent upon specific demand patterns. However, due to local recovery the total number of hops may be more and resource utilization may be less efficient. In optical layer protection schemes, the path protection schemes provide better resource utilization at the cost of more computational complexity, whereas link protection can be provided once and for all. However, resource utilization will be the issue in link protection schemes.

P-cycles have addressed this issue and tried to improve the resource utilization using protection for straddling link failures[7] also. This scheme calculates the backup path dynamically depending upon the demand pattern of traffic. Thus providing additional advantage of flexibility. The backup path calculation is done in non-real time. Hence calculation time is not so important as in case of restoration schemes. Among all the link based protection schemes p-cycle protection has been found very promising in terms of restoration time, flexibility and spare capacity utilization.

2. P-CYCLE PROTECTION

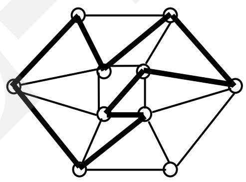
Figure 2 a: p-cycle

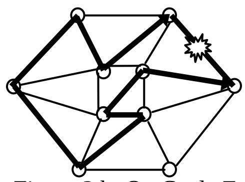
Figure 2 b: On Cycle Failure

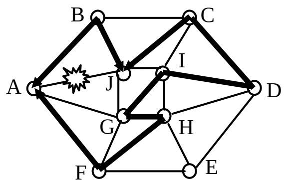

Figure 2 c: Straddling Link Failure

The recovery is very fast (50ms for SONET rings) in ring-based networks. However, these networks are inefficient and inflexible[8] as compared to mesh-based networks. P-cycles are the result of efforts to obtain ring like speed and mesh like capacities and flexibility. P-cycles are fully connected structures of spare capacity of mesh networks. In fact all spare capacity of the network is pre-connected and only two switching actions (as in rings) are needed in the event of failure to switch the traffic on the back up path. An example of p-cycle is shown in (Fig.2a). Thick lines represent the p-cycle. This is pre-connected cycle of spare resources in the links. The on cycle failure is shown in (Fig.2b). In this type of failure, the p-cycle recovery acts as ring recovery and the traffic of the failed link is switched to the other side of the cycle. The recovery in case of straddling link failure is shown in (Fig.2c). A straddling link is one that has its end nodes on the p-cycle, but is not itself part of the p-cycle. In case of straddling link failure ‘AJ’, two protection paths are available viz. ‘ABJ’ and ‘AFHGIDCJ’. The key difference between p-cycles and any ring or cycle cover[6] is the protection of straddling link failures. These links are having minimum spare capacity and efficiency of covering these failures is double that of on cycle failure because two back up paths are available from each side of p-cycle.

Another advantage is due to the fact that p-cycles are formed in the spare capacity only i.e. they do not interfere with routing of working paths. Any shortest path based scheme may be used for routing of primary working paths. Further p-cycles can be logically rearranged to adapt to changing traffic patterns as needed since they are formed in the spare capacity only. In short, p-cycles will not affect the flexibility of mesh networks. However, several p-cycles may be required to cover entire traffic on any span hence management among p-cycles becomes more difficult.

3. RELIABILITY IMPROVEMENT OF CRITICAL SPAN

In any network the critical spans may be identified on the basis of any one or more of the following;

i) Most heavily loaded spans in the network,
ii) Spans with high probability of failure i.e. with low reliability and small MTTF (minimum time to failure), e.g. spans passing through earthquake prone areas
iii) Spans with high MTTR (minimum time to repair), e.g. under sea cables, the repair of which may take many days or the spans failures in time of natural disasters,
iv) Spans having large amount of premium traffic, the traffic, which is to be restored in less than 50 ms of time.

In the present work span with lowest reliability has been taken as critical span and modified algorithm[9] has been used to cover the critical span as straddling span of the formed p-cycles. The concept of **capacity** of p-cycles defined in[9] is used and an effort has been made to protect critical span with minimum number of p-cycles. The p-cycles are formed with, as much capacity as possible and it is ensured that critical span will appear as straddling span on the formed p-cycle, so that selected p-cycle may provide double path to the traffic of critical span. The statelets used in the formation of p-cycles are modified to include the capacity of each span along its path in the additional, capacity field of the statelet. At the cycler node the selection procedure is also modified to ensure that only those p-cycles, which are having critical span as straddling span are considered. Then the p-cycle with maximum capacity and highest score is selected.

The path reliability of a series connection of links is given as

$$P(S) = P(X_1) \times P(X_2) \times \ldots\ldots\ldots\ldots\ldots\ldots \times P(X_n)$$

$$= \prod_{j=1}^{n} P(X_i)$$

Where X_1, X_2 ……represent the successful operation of link 1, 2……. and $P(X_1)$, $P(X_2)$…..represent the respective probabilities of successful operation i.e. reliability of link 1, 2…., assuming that successful operation of a link is independent of other. Hence the events are mutually exclusive.

$\overline{X}_1, \overline{X}_2$ represent unsuccessful operation i.e. the failure of respective link, hence

$P(X_1)$, $P(\overline{X_1})$ are probabilities of successful operation and failure of a system respectively and

$P(\overline{X_1}) = 1 - P(X_1)$.

The path reliability of a parallel connection of links is calculated as follows;

For complete failure of a path all n elements of the parallel connection have to fail simultaneously. If $P(\overline{S})$ is the probability of failure of the path, then

$$P(\overline{S}) = P(\overline{X_1}) \times P(\overline{X_2}) \times \ldots\ldots\ldots\ldots P(\overline{X_n})$$

$$= 1 - P(S) \text{ for mutually exclusive events.}$$

Hence $P(S) = 1 - [1 - P(X_1)][1 - P(X_2)]\ldots\ldots\ldots\ldots[1 - P(X_n)]$

$$= 1 - \prod_{j=1}^{n} [1 - P(X_i)]$$

The reliability of a path which is having mixed configuration is given as

$$P(X) = 1 - \prod_{i=1}^{k} \left[1 - \prod_{j=1}^{n_i} P(X_{ij}) \right]$$

where, there are n_i elements in a branch and k branches are there.

In the present work the reliability of path is calculated for link disjoint path protection using the formula given below

$$P(X)=1-\left[1-\prod_{j=1}^{n_1}P\left(X_{1_j}\right)\right]\left[1-\prod_{j=1}^{n_2}P\left(X_{2_j}\right)\right],$$ where 1 and 2 are the primary and link disjoint secondary paths. n_1 and n_2 are the number of elements in primary path and secondary path respectively.

We have taken the critical link as most heavily loaded link in the network. Then p-cycles have been found to protect the critical link as straddling link. Then for critical link two protection paths are available. Now for the path, which is passing through critical link, there are series elements from source to critical span, then there are three parallel branches; one of critical link and two of p-cycles, further series elements till destination node. In this case the reliability is calculated as

$$P(X)=\left[\prod_{j=1}^{all-series-elements}P(X_i)\right]\left[1-\prod_{i=1}^{all-branches}\left\{1-\prod_{j=1}^{all-series-element-in-a-branch}P\left(X_{i_j}\right)\right\}\right]$$

4. SIMULATIONS AND RESULTS

The test network[10] is shown in Fig. 3. For the given[10] traffic matrix the primary path is calculated then links of the primary path have been removed and link disjoint secondary path is calculated. P-cycles have been formed in the spare capacity such as critical span appears as straddling span on the p-cycle. The spare capacity taken is same as required in case of link disjoint path protection. The reliability of all the links has been taken as 0.9, and the reliability of critical span is taken as 0.2. All the paths which are passing through critical span have been selected. Their reliability with path protection has been calculated. The reliability of these paths with critical link protection is also calculated and improvement in the reliability of paths which are passing through critical span is shown in Fig. 4. The improvement is due to the fact that now for least reliable link, two more paths are available. The reliability depends upon the number of elements in the path. Higher is the number of elements in the path smaller will be the reliability. Hence different paths are having different reliabilities.

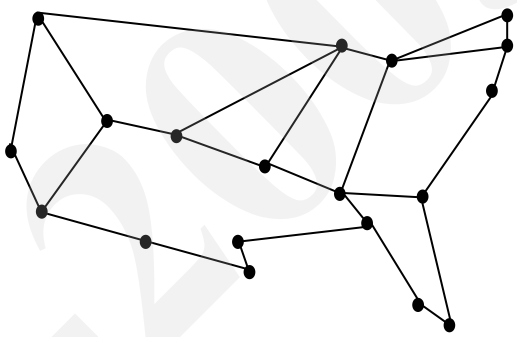

Figure 3: Test Network

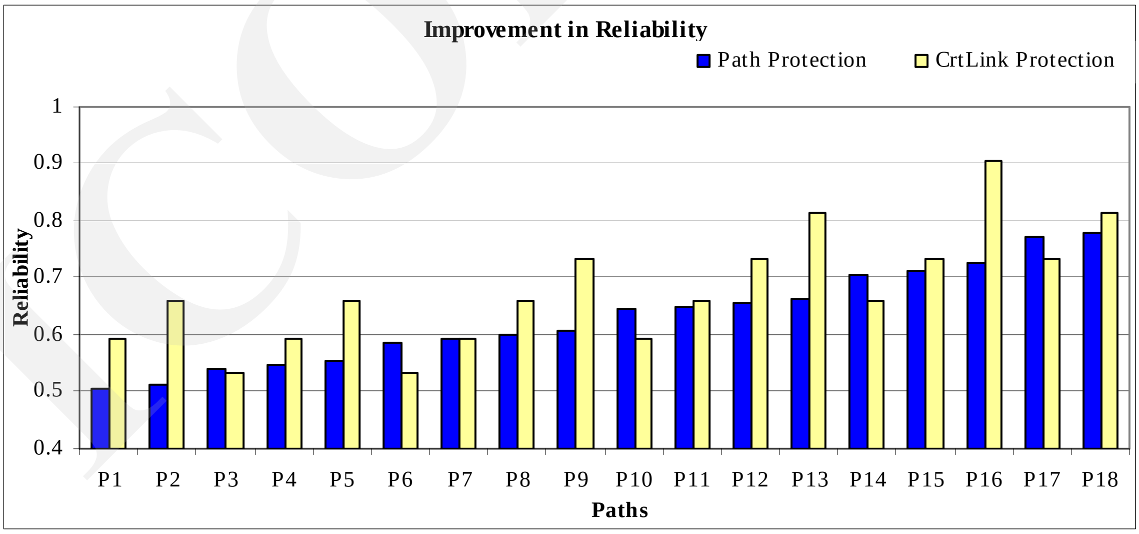

Figure 4: Improvement in the Reliability of Path with CrtLink Protection

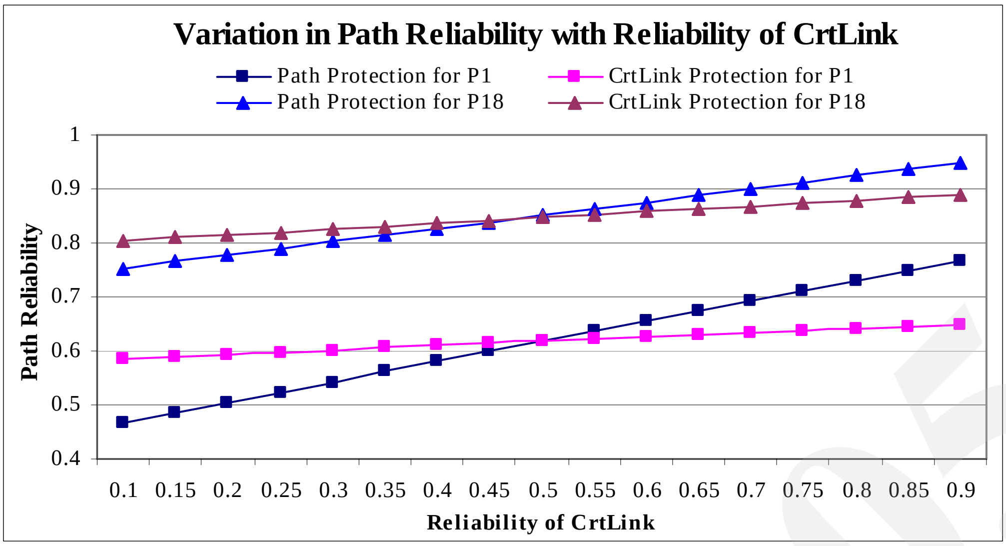

Figure 5 (a): Variation in the reliability of two random paths with different reliabilities of critical span

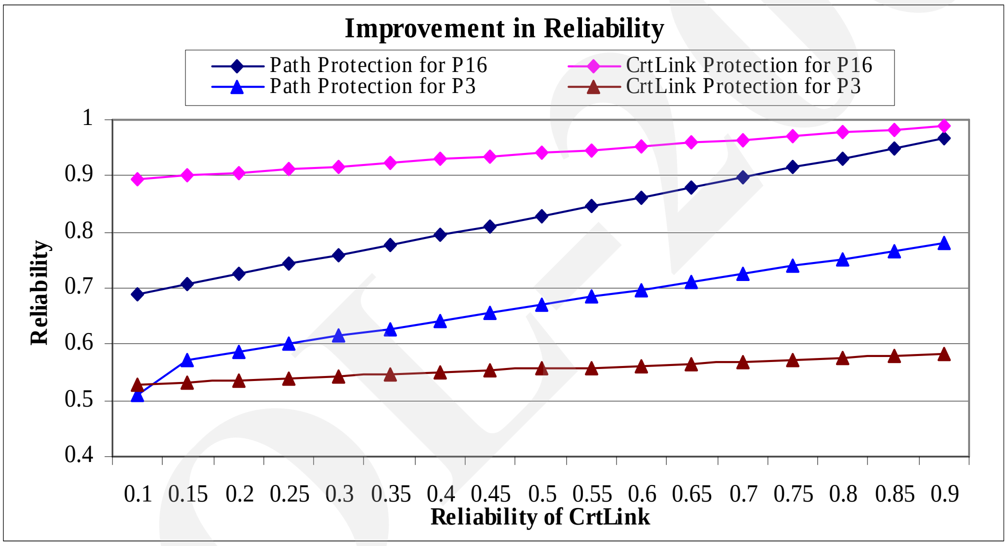

Figure 5 (b): Variation in the reliability of P16 and P3 paths with different reliabilities of critical span

In Fig. 5 the variation in the reliability of critical span is taken into account. The reliability of the critical span is made to vary from 0.1 to 0.9 and the reliabilities of P1 and P18 with varying critical span reliability are plotted in Fig. 5 (a). P1 and P18 are selected randomly. In Fig. 5(b) variations in the reliabilities of P16 and P3 have been plotted. These are the two extreme cases. With critical link protection scheme, P16 is the path with maximum reliability and P3 is the path with minimum reliability. With P16 the reliability with proposed schemes is always better, whereas for P3 the reliability is better with the proposed scheme only for small values of reliability of critical link.

5. CONCLUSION

It is clear from the results that with the proposed critical link protection scheme there is increase in the path reliability for more than 70% of the paths passing through critical span. As the reliability is function of number of elements in the path, therefore for some paths the reliability is more with path protection. It has been found for these paths that the lengths of the primary and secondary paths are same in terms of hop counts. The variations in the path reliabilities with reliability of critical link shows that for smaller values of reliability of critical link, the proposed scheme of p-cycle protection with critical link protection gives better results. However, for higher values of reliability of critical span i.e. for the reliability values above around 0.5, the path reliability is better with link disjoint path protection scheme. The proposed scheme is therefore better for protection of links with very low values of reliability.

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