Critical Span Protection with Pre-configured (P) Cycles

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ABSTRACT

Some spans [b] are always very critical in any network. These spans may be; i) Most heavily loaded spans in the network, ii) Spans with small MTTF (mean time to failure), iii) Spans with high MTTR (mean time to repair), iv) Spans having large amount of premium traffic etc. In this paper a new scheme is proposed to provide protection to these critical spans using p-cycles. Fully distributed method DCPC (Distributed cycle PreConfiguration) protocol for formation of p-cycle is developed[1]. Using this method of formation of p-cycles several p-cycles may be required (at least half of the total unit of traffic on the critical span) to cover entire traffic on the span. Hence management among p-cycles becomes very much difficult. Therefore, in the present work, a new concept of capacity of p-cycles is introduced and an effort has been made to protect entire traffic of 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 will protect double amount of traffic as compare to its capacity. For the test network taken the results are very much encouraging. For the same amount of protection capacity the number of p-cycles required is reduced to 49% on an average. For some critical links the reduction in number is up to 25%.

Keywords: Critical span, optical network, p-cycle, protection, straddling link,

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. Henceforth, incredibly large traffic volumes[2,3] 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[2,4,5] as shown in (Fig. 1). Protection is defined as pre provisioned failure recovery. The back up path, which is, link disjoint 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

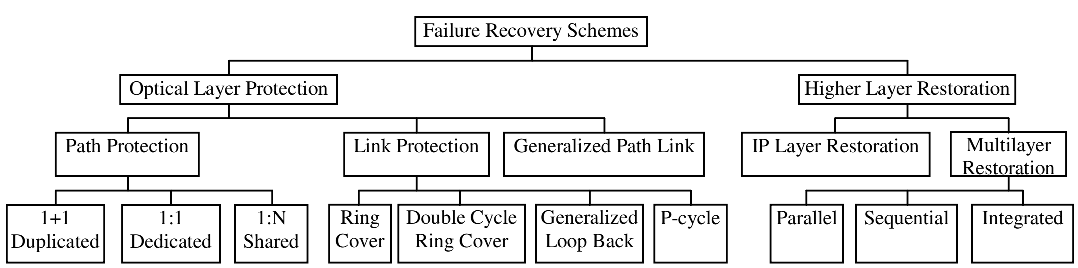

Figure 1: Protection & Restoration Schemes

[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 total number of working links in that span.

are re-configured to use the back up path. Restoration schemes refer to dynamic recovery after the onset of failure. 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.

1. P-CYCLE PROTECTION

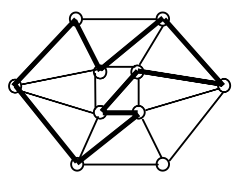

Figure 2 a: p-cycle

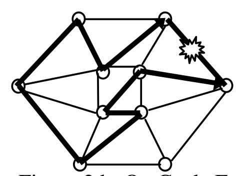

Figure 2 b: On Cycle Failure

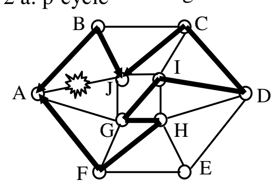

Figure 2 c: Straddling Link Failure

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. CRITICAL SPAN PROTECTION

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 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 a modified algorithm has been proposed to cover all the traffic in the critical span with minimum number of p-cycles. Fully distributed method DCPC protocol for formation of p-cycle is developed[1]. The p-cycles formed in this method are able to protect one unit of traffic on links, which are on the p-cycles, and two units of traffic on the straddling links. Using this method of formation of p-cycles several p-cycles may be required (at least half of the total unit of traffic on the critical span) to cover entire traffic on the span. Hence management among p-cycles becomes more difficult.

Therefore, in the present work, a new concept of **capacity** of p-cycles is introduced and an effort has been made to protect entire traffic of critical span with minimum number of p-cycles. The capacity of a p-cycle is defined as the minimum spare capacity among all the spans on the p-cycle. Thus for all on cycle failures, the amount of traffic protected will be equal to the capacity of p-cycle and for straddling spans failures the amount of traffic protected will be twice the capacity of p-cycle. 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 protect double amount of traffic as compare to its capacity. 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 algorithm used is based on DCPC protocol[1] (Distributed cycle PreConfiguration) and is given below:

i). First a critical span is selected (in the present paper it is done on the basis of maximum traffic), a cycler node is selected (other nodes will act as tandem node) and a sampling time (the p-cycles formed during this time are to be considered by the cycler node) is fixed.
ii). Cycler node broadcast to each of its span a statelet having six fields 1. Index no., 2. Send node, 3. Numpath, 4. Hop count, 5. Route & 6. Capacity.
    - Index no. field contains the no of particular span and it does not change in further broadcastings.
    - Send node field is having the name of cycler node. This field also remains same through out the broadcasting.
    - Numpath field is initially set to zero and it is calculated as follows:
      When statelet goes from one node to other i.e. through on cycle link, numpath increases by one and if the node to which statelet arrives, has straddling relation with nodes present in its route field, then numpath also increases by two for each straddling link present.
    - Hop count field increases by one at each broadcast.
    - Route field stores the node names through which statlet is coming.
    - Capacity field stores the number of spare links on each span of its path.
iii) When statelet reaches to adjacent nodes of cycler connected by spare links, then each field of the statelet has to be modified as explained above, at each node.
iv) When different statelets arrive at a tandem node, with different index, numpath and hop count value, then the incoming statelets to be broadcast first by the tandem node is selected on the following criterion:
    - All the statelets are grouped on the basis of index value. Then from each group of particular index, statelet with highest capacity value is selected. Then from all selected statelets, the statelet with highest capacity value is broadcast first by the node. If two statelets are having same capacity then statelet with higher numpath value is broadcast.
    - Statelet should be broadcast on each span except the span from which it arrives and on the critical span. Statelet can only be broadcast to a particular span if it has free link. If no free link is present then spans with incoming statelets are used for broadcasting. And if no input link is present, then statelet will not be broadcast at that span.

- In this way all the incoming statelets present at the node are broadcast one by one according to their numpath value.
- For the generation of simple cycles statelets shouldn't be broadcast to that node which is present on its route except cycler node.

v) When cycler receives any incoming statelet within sampling time, then it calculates its score on the basis of score= (numpath / hop count). It stores the score of that statelet only if the critical span is protected by that cycle. It also stores the capacity of the p-cycle i.e. minimum spare capacity among all the spans covered by p-cycle.

vi) When another statelet arrives at cycler then it compares, the capacity of newly arrived statelet with present capacity. It then stores the p-cycle with better capacity. If both have the same capacity then it compares the score of the two, and better one is stored, with the condition that critical span is protected.

vii) When sampling time runs out, then cycler node has the score, route and capacity of the best p-cycle discovered by it.

viii) Then it Hand-offs to other node to become cycler node & itself act as tandem node.

ix) Steps "ii to viii" are repeated until all nodes act as cycler node.

x) Then the cycle with maximum capacity and the highest score amongst that capacity is selected as p-cycle.

xi) Steps "i to x" are repeated to discover p-cycles in the remaining capacity, until all the traffic of critical span is protected or no more p-cycles can be found.

For the deployment of selected p-cycle the cycler node of the p-cycle sends instruction to the neighboring node for making the cross connection between the incoming link from the cycler node to the outgoing link to the next node in the route field. For the management and maintenance of p-cycles the cycler node of the selected p-cycle is responsible. The cycler node now applies and maintains a statelet into it that repeats the route field for continual self-checking of the continuity and correctness of the deployed p-cycle. As the number of p-cycles gets reduced the management amongst p-cycles at a node becomes simpler.

4. RESULTS

The test network taken for testing of the proposed scheme is shown in (Fig 3) along with spare capacity taken on each span. The total number of spans in the network is twenty-two. First the p-cycle in the network has been found without considering critical spans. The protection capacity available to each link is calculated and tabulated in (Table 1) along with the number of p-cycles, which offers the calculated capacity. For calculation of capacity, if the link is on cycle link then single unit of capacity is available for protection and if the link is straddling link then two units of protection capacity is available.

In the second case the same network is used to find the p-cycles for the critical spans. In any actual network, the critical spans have to be found. However, for generalized case, one by one each spans is considered as

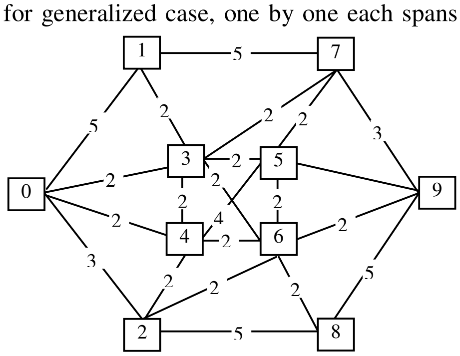

Figure 3 : Test network with spare capacity on each link

	Protection capacity for each link without considering critical links		**Protection capacity for each span when considered as critical span**	
Span	**Available Protection capacity**	**No. of p-cycles**	**Available Protection capacity**	**No. of p-cycles**
0-1	7	6	4	1
0-2	9	6	8	3
0-3	10	6	6	2
0-4	10	6	6	2
1-3	10	6	8	2
1-7	7	6	4	1
2-4	10	6	8	3
2-6	8	5	6	2
2-8	5	5	4	1
3-4	10	6	8	3
3-5	10	6	10	4
3-6	8	5	8	2
3-7	10	6	6	2
4-5	8	6	8	2
4-6	8	5	8	3
5-6	8	5	8	2
5-7	10	6	8	3
5-9	10	6	6	2
6-8	10	5	8	2
6-9	8	5	8	3
7-9	9	6	8	2
8-9	5	5	4	1
Total	190	124	152	48
0.65 p-cycle per unit of protection capacity			**0.32 p-cycle per unit of capacity**	

Table 1 : Showing the protection capacity vs. number of p-cycles

the critical span in the test network, and p-cycles are found. Only those p-cycles are considered which are having the critical span as straddling span. The total protection capacity is simply twice the total capacities of the found p-cycles. The results are again tabulated in (Table 1).

From the calculations it is clear that with consideration of critical spans and capacity of p-cycles the number of p-cycles required for the same amount of protection capacity is much less as compared to the first case. The average reduction in number of p-cycles is 49%. For some critical spans the reduction is even up to 25%.

5. CONCLUSION

Protection using p-cycles is an effort to combine the merits of mesh and ring networks. With p-cycles mesh like flexibility is available, as they do not interfere with the routing of primary paths. They are simply formed in the remaining capacity of the network off-line. The ring like speed is available, as after the formation of p-cycle only two switching actions are required to switch the traffic onto the protection path. After the detection of failure one switching action will be needed at the upstream node of the failure and other at the downstream node of the failure to switch the traffic of the failed link to the already found and configured p-cycle. Therefore p-cycles are one of the most promising techniques of the link protection schemes. Hence for the protection of critical spans p-cycles are the most suitable choice.

This paper proposed a general methodology for protection of critical spans using p-cycles. It introduced the concept of capacity of a p-cycle and developed algorithm to find the p-cycles which are formed in such a way that critical span will appear as straddling span on the formed p-cycle. A generalized study is made to find the total number of p-cycles for the test network by considering each span as critical span one by one. As far as the reduction in number of p-cycles is considered the results are very encouraging. However it has been observed that total capacity available for protection of critical span is less in some cases as compared to the first case (Table 1). This is due to the fact that p-cycles, which are having critical span as on cycle span, have not been considered. In future effort will be made to consider even those p-cycles, which are having critical spans as on cycle spans. This will increase slightly the number of p-cycles per unit of protection capacity. At the same time it will also increase the protection capacity available for critical spans. However, with present scheme, for every critical span two protection paths are available. That is an added advantage of the present scheme.

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