A Cost Effective Approach for WDM Network Protection under Critical Duct Constraints

[1]D.SHEELA and [2]C.CHELLAMUTHU

[1]Department of Electronics and Communication Engineering,
Tagore Engineering College,
Chennai, INDIA.
[2]Department of Electrical and Electronics Engineering,
R.M.K. Engineering College,
Chennai, INDIA.
E mail: [1] sheela_rajesh@rediffmail.com , [2] malgudi60@hotmail.com

Abstract:-In this paper, protection strategies of WDM networks are viewed from a cost perspective. The goal is to minimize the network cost while ensuring the network survivability. In WDM networks, multi fibers are kept in a duct and that duct can be treated as a link SRLG (shared risk link group). With the increase in size and number of shared risk link groups, capacity efficiency of shared-path protection decreases due to SRLG-disjoint constraints. As a result, a full SRLG failure protection is no longer a practical protection scheme. In a network, there are always some links with higher degree of usage compared to other links in the network. In the event of failure of such links, the survivability of the network is severely affected and these links are called as critical links. The ducts that carry these critical links are designated as critical ducts. This paper proposes an approach in which partial critical duct -disjoint backup path is provided by choosing the backup path with least number of critical ducts to make the impact of duct failures as low as possible. A dual-duct infrastructure is presented for these critical ducts as a solution to reduce the resource requirement and to provide flexibility in selecting the backup paths. Simulation results show that this scheme offers better survivability against both single duct and double duct failures with overall reduction in network cost.

Keywords: - Wavelength division multiplexing, Dimensioning, Network protection, Shared risk link group, Topology, Critical ducts.

1 Introduction

Recent advances in WDM technologies have increased the current backbone and metro network capacities significantly [1].The survivability against failures is of major concern in WDM networks since it will lead to huge amount of data loss and disruption of services. Network survivability is the ability of a network to maintain the connections intact against network failures and can be realized through protection and restoration [2]. The strategies for network protection mechanisms must be considered in the network design phase itself. The dimensioning process involves providing the required resources to the network so that all the connection requests are honored. It is equally important that the design phase should include an effective protection mechanism against failures [3]. During the design phase, the traffic demand is already known at least partially [4].The physical topology of the networks imposes significant effects on the number of resources required to honor the connection requests offered to it. [5].This paper proposes an approach in which the network dimensioning process considers protection mechanisms based on topological factor like critical links. The main objective of this approach is to improve the network survivability at reduced network cost.

2 Background and Previous Work

The network survivability can be classified as either protection or restoration mechanisms. In protection technique, the backup resources are computed before the network failure .In restoration schemes, backup resources are searched and identified after the event of failure [6].Previous literature has extensively studied various protection methods in optical networks. Authors in [7] consider the physical layer impairments in shared protection in translucent WDM mesh networks. The wavelength and capacity assignment for protection against failures is studied in [8] for regular meshed-ring architecture. Two integer linear program formulations for dynamic wavelength allocation are given in [9] for multi fiber wavelength-division multiplexing (WDM) networks but considered only single link failures. Yoshiyuki Yamada et al proposed an algorithm that provided dedicated protection based on waveband layer [10].

In optical networks, the links that shares the same failure risks are grouped as shared-risk link groups (SRLGs) [11]. Based on the SRLG constraints, the authors in [12] have discussed a full SRLG-disjoint protection (FSDP) algorithm to tolerate the single-SRLG failure. In FSDP, each connection request will be assigned to one working path and one SRLG-disjoint backup path. The authors in [13] have designed a model by considering a highly available backbone next to a less-reliable peripheral section of the network. In [14], an algorithm PSDP(partial SRLG disjoint protection) was proposed in which each connection request will be assigned one working path and one partial or full SRLG-disjoint backup path based on the differentiated reliability constraints but again considers only single SRLG failures.

3 Problem Statement

A physical topology consists of N number of nodes, and L links connecting the nodes. The links in the physical topology are bidirectional. D is the set of ducts that carry these links.

The objective:

The total network cost C_{NW} is the sum of node cost and link cost.

$$\text{Minimize } C_{NW} = \sum_{j \in L} Cj + \sum_{i \in N} Ci \qquad (1)$$

Subjected to the following constraints:

$$Ed \le E \text{ target} , \qquad \forall d \in D, \qquad (2)$$

where Ed is the expected loss of traffic when a duct in the network fails.

$$E \text{ target} = \begin{cases} E \text{ target}s \text{ for single duct failures} \\ E \text{ target}d \text{ for double duct failures} \end{cases} \qquad (3)$$

The expected loss of traffic in OC 48 per year is calculated as follows:

$$(1\text{-}A) \text{ OC-48} * 24 \text{ (hr/day)} * 365 \text{ (days/yr)} = \text{Ed OC-48 hr/yr} \qquad (4)$$

$$\text{Ed(OC-48 hr/yr)}*2.488 \text{ (Gb/OC-48)} *3600\text{(secs/hr)} = \text{Ed Gb/yr.} \qquad (5)$$

where A is the availability.

OC stands for optical carrier and 48 denotes OC -1 x48 which is 2.488 Gbps.

Table 1 The value for E target for various failures

Type of Failures	E target (OC48Hr/Yr)
Single Duct	4
Double Duct(Non Critical+ Non Critical)	6
Double Duct(Critical+ Non Critical)	8
Double Duct(Critical+ Critical)	10

In practical networks, with the increase in size and number of SRLGs, capacity efficiency of shared-path protection becomes poorer due to SRLG-disjoint constraints. Occasionally, a backup path cannot be found due to physical or algorithm constraint, which is referred to as trap problem. Traps can be classified into avoidable traps that are algorithm-induced and real traps that are topology-induced [15]. Sometimes, it is very expensive or impossible to provide 100% SRLG failure protection for every connection request. As a result, providing full SRLG failure protection is no longer an intelligent approach in practical scenarios. All these work have studied the effect of protection schemes based on shared-risk link group's concept. Practically a dimensioned network will have multi fibers kept in a duct and that duct can be treated as a link SRLG as shown in Fig.1. In general, a duct is a type of *Shared Risk Link Group* (SRLG) [16]–[18], that associates a group of links with a failure.

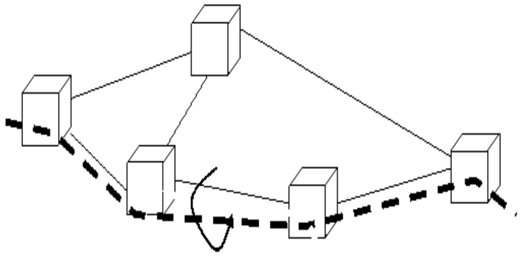


Fig.1 Link SRLG

When a duct is damaged, normally all of the fibers in the duct fail at the same time. A fault in a duct can affect all the connections that are carried through the fibers placed in the duct. Hence , a network which is designed to survive a single-link failure need not be survivable to double link-failures [19].So, rather than categorizing the group of links on risk basis, the significance of individual link SRLGs on network failures are of prime importance . In link layer topology, there are always some links with higher degree of usage compared to other links in the network. Once the wavelength resource is rapidly exhausted on such links that will lead to network congestion and these links are called as critical links. Generally links with congestion level above 90% are involved in the capacity exhaustion blocking of the network [20]. In the context of network protection, when a critical link fails, the number of lost connections will be more relative to the non critical link failures. In duct layer topology, the ducts that carry these critical links are called critical ducts. Hence it is very important to take these critical ducts into account while designing the network protection against failures. There is a need to develop a strategy in which the network topological factors like critical links are to be incorporated in network protection aspects aiming at improving the network performance over failures with considerable reduction in cost.

This paper proposes an approach called partial critical duct disjoint protection (PCDDP) in which each connection request will be assigned to one working path and one partial or full critical duct disjoint backup path based on the resource constraints. A dual-duct infrastructure is presented on these critical ducts as a solution to improve survivability and network resource utilization**.** The objective is to reduce the impact of single and double SRLG failures on network performance. This paper proposes a heuristic scheme which addresses both network survivability and dimensioning. It is shown that our approach results in lesser number of lost connections compared to shared path protection for both single SRLG and double SRLG failures with the reduction in total network cost incurred.

4 Partial Critical Duct Disjoint Protection

In best effort service [21] provides the backup paths that share the least number of SRLGs with the working path. The survivability factor is reduced with the increasing number of common SRLG links of working path and protected path .But in this paper if the protected path has more than two critical ducts, an alternate path is selected. To keep the resource requirement under limit, a limit on hop count is imposed on the alternate path. A dual-duct infrastructure is presented for critical ducts alone, for better survivability and cost effectiveness.

The PCDDP approach has three modules.

a. Identifying critical ducts in the network.

b. Providing dual duct infrastructure for critical ducts.

c. Dimensioning the network with partial critical duct disjoint protection.

The identification of critical links in previous studies is based on maximum flow calculation and residual bandwidth availability. In the proposed approach the critical links are identified offline which are topology specific to reduce the computational complexity.

4.1 Notations

N	Set of Nodes
L	Set of Links
D	Set of Ducts
j	Links, $j \in L$
Dj	Duct that carries a link j
K	Set of critical ducts $K \subset D$
n	Connection request
R	Set of routes obtained by the *k*-shortest path Algorithm
$Wbn(c)_{hop}$	Hop count of $Wbn(c)^{th}$ path,
δ jpn	1 if path p of demand n uses link j 0 otherwise

4.2 Identifying Critical Ducts

Frequency of usage of a link Fj, $j \in L$ relates certain link's importance relative to whole network. For a connection request n, the usage of a link j ,$j \in L$ for k possible routes are calculated. This value is calculated for all possible source destination pairs to obtain the frequency of usage of a link as given in Eqn(6).

$$Fj = \sum_{n=1}^{T} \sum_{p=1}^{k} \delta\, jpn, \qquad T = N(N-1)/2,\ j \in L \tag{6}$$

Fjmax is the link with highest value of Fj. The links with Fj / Fjmax ≥0.9 that influence the traffic congestion and eventually the network performance are designated as critical links. The ducts that carry fibers for these critical links are designated as critical ducts.

4.3 Provision of Dual Duct Infrastructure

Since the frequency of usage in critical ducts is high compared to other ducts, additional care is to be taken on these critical ducts on both protection perspective and cost perspective. In single duct scenario, backup light paths always take very long routes than primary light paths resulting in faster network resource exhaustion. In dual duct infrastructure the nodes that connect the critical links are connected by two duct-disjoint physical Links. Primary light paths are randomly assigned to either duct-1 links or duct-2 links and therefore the backup light paths are also evenly distributed between duct-1 links and duct-2 links. The purpose of this design is to reduce the number of connections that need to be switched during the occurrence of link failure. The backup light paths in dual-duct design take shorter routes than the backup light paths in single-duct infrastructure. Hence it utilizes less network resources than the single duct design for protection purposes. Moreover, since the dual ducts are provided only on specific links, the redundancy cost is also reduced. In the view of network protection the probability of finding a backup path with duct disjoint routes is increased compared to single duct case thus providing more flexibility in selecting the backup paths.

The algorithm for PCDDP (Partial Critical Duct Disjoint Protection) is described as follows.

Step 1: Compute the set R that contains *k* routes obtained by the K-shortest path algorithm for a connection request n. Choose the shortest path as working path WPn. If there are two shortest paths with same hop count select the one with lesser number of critical ducts.

*Step 2:*Prune the network and compute the set of shortest paths Rb for the connection request n on duct disjoint basis with working path Wpn. Select the shortest path Wbn (a) as candidate backup path.

Step 3: Compute the number of critical ducts $|K|_a$ in the candidate backup path Wbn (a)

Step 4: Select Wbn (a) as backup path if $Dj \cap K = \phi$ or $|K|_a = 1$

Else go to step 5.

Step 5: Select the shortest paths from the set route set Rb as candidate backup paths Wbn (r) if $Wbn\,(r)_{hop} \leq 4$, $r \in Rb$, $r \neq a$

Step 6: Compute the number of critical ducts $|K|_r$ in the candidate backup paths

Wbn (r) $r \in Rb$, $r \neq a$

Step 7: Among the candidate paths, choose the path Wbn(r) as backup path

if $Dj \cap K = \phi$ or $|K|_r = 1$

Else go to step 8.

Step 8: Choose the path with min ($|K|_a$, $|K|_r$) as backup path.

In this approach, for each connection request, the primary light paths are always routed on shortest paths based on hop count. If the backup path has no critical ducts included or has only one critical duct, then it is selected as the backup path for the light path demand. If the number of critical ducts on the backup path is more than one, alternate backup path is selected which has zero or maximum of one critical duct on its path even if the hop count is higher. In dual duct case, duct 1 and duct 2 are considered as disjoint in calculating the backup paths. But it is essential to balance both the network survivability and the network cost. Hence it is necessary to put a constraint on hop count of the backup paths selected that satisfies the critical duct constraints. The hop count limit depends on connectivity and average node degree of the network and for simulation on NSFNET the hop count limit is set to four. For wavelength assignment First Fit method is used.

5 Cost model

The cost model prescribed in this section includes various factors related to link and node costs. The total network cost is the sum of link and node cost.

C_{Link} = Total Link cost

$$= \sum_{j \in L} Cj \tag{7}$$

$Ci = Cwj + C_Fj + C_{OA}j + C_{TM}j + C_{REG}j + C_{CARD}j$

Cwj = Number of wavelengths used

C_Fj = Cost of the number of fibers used per link.

$C_{OA}j$ = Cost of the Optical Amplifiers

$C_{TM}j$ = Cost of the Terminal Multiplexers

$C_{REG}j$ = Cost of the Regenerators

$C_{CARD}j$ = Cost of the WDM Channel cards + Regenerator Cards

C_{Node} = Total Node cost

$$= \sum_{i \in N} Ci \tag{8}$$

$C_i = C_{WC+} C_{OXC} + C_{PORTS} + C_{TRANS}$

C_{WC} = Cost of wavelength converters

C_{OXC} = Cost of OXC (Optical Cross Connects)

C_{PORTS} = Cost of OXC Ports

C_{TRANS} = Cost of Transponders

The total network cost $C_{NW} = \sum_{j \in L} Cj + \sum_{i \in N} Ci$ (9)

6 Performance Evaluation

The performance of PCDDP has been evaluated on three well known networks- NSFNET, ARPANET and ARPA 2 (Fig.2.a,b&c) using OPNET. More emphasis is shown for NSFNET since the results for other networks follow similar pattern. Each fiber carries 40 wavelengths. All nodes are equipped with full wavelength conversion capabilities. The NxN entries in traffic matrix are randomly created. To make the system more robust to traffic fluctuations, various combinations of source to destination pairs in the traffic matrix are tried and the average value has been taken as result. Each demand is assumed for full wavelength and the problem of traffic grooming is not considered. For the comparison to be fair, the number of lightpath demands is set to be same for all the three networks. The connections honored remain active and new connection requests are accommodated by dimensioning the wavelength capacity.

Previous studies on SRLG have considered only single SRLG failures. This paper analyzes the performance of the proposed algorithm for both single duct (link SRLG) failures and double duct failures. The double duct failures are analyzed in detail under three categories a).both the ducts are non critical ducts b).one of the two ducts is a critical duct c).both the ducts are critical ducts. The characteristics are compared with no protection, shared protection and 1+1 protection schemes. The literature on network protection against link failures (and node failures), focuses mainly on blocking probability. This paper for the first time explores the impact of individual ducts for single duct failures and the impact of combination of ducts for double duct failures on network performance. Instead of generating random failures, defined failures are generated i.e. the impact of all possible single duct and double duct failures on network performance was studied. The snapshot of failure analysis on double duct failures using OPNET is shown in Fig.3.

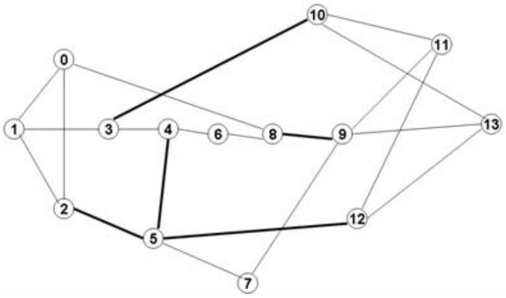


Fig.2 .a NSFNET Network with Critical Links marked

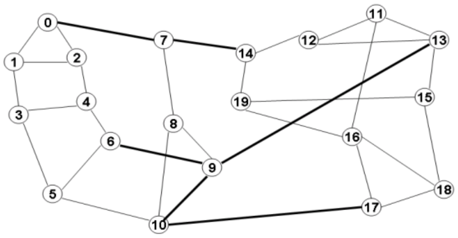


Fig.2 .b ARPANET Network with Critical Links marked

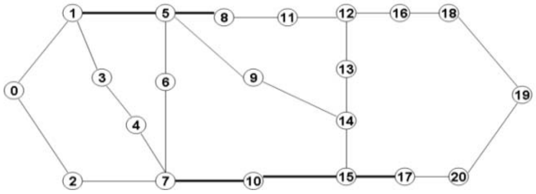
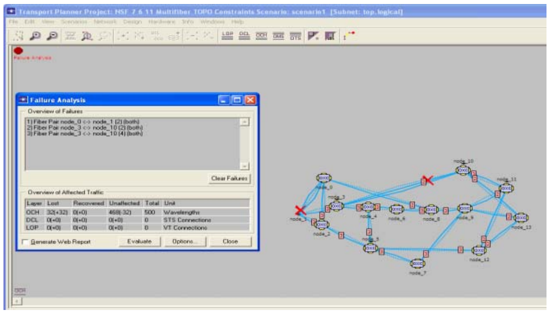


Fig.2 .c ARPA 2 Network with Critical Links marked


Transport Planner Project: NSF 7 & 11 Multifiber TOPO Constraints Scenario: scenario1 [Subnet: top.logical]

Failure Analysis

Overview of Failures

1) Fiber Pair node_0 <-> node_1 (2) (both)
2) Fiber Pair node_3 <-> node_10 (2) (both)
3) Fiber Pair node_3 <-> node_10 (4) (both)

Overview of Affected Traffic

Layer	Lost	Recovered	Unaffected	Total	Unit
OCH	32(+32)	0(+0)	468(-32)	500	Wavelengths
DCL	0(+0)	0(+0)	0(+0)	0	STS Connections
LOP	0(+0)	0(+0)	0(+0)	0	VT Connections

☐ Generate Web Report

Fig.3 Double Duct Failure Analysis using OPNET

By providing dual ducts on critical ducts in initial phase itself, additional capacity is available on critical links through which most of the connections traverse. Thus the connections need to traverse lesser hops in the network compared to single duct case. This results in lesser network cost. Since the dimensioning is focused more on critical links in the network, there is a concentration of routes through these links resulting in statistical gain over the network cost.

The availability setting is set globally for the value 0.99999. The service availability is evaluated under different failure scenarios (combining the selected failure elements) to inspect their impact on the selected traffic. Here ducts failures are considered in which the impact on the single and double duct failures on traffic is evaluated. The simulation method functions by examining the possible combinations of failures. Each combination is called a failure scenario.

From the failure analysis, the lost and recovered connections for each of the considered failure scenarios can be identified. The expected loss of traffic in OC-48 per year is calculated.Fig.4 shows the expected loss of traffic per year in OC-48 for single duct failures for the availability of 0.99999 for unprotected, shared and PCDDP methods for NSFNET network. The PCDDP scheme results in reduction in expected loss of traffic over the other methods. The difference in expected loss of traffic for PCDDP over other two methods rises with increasing demands.

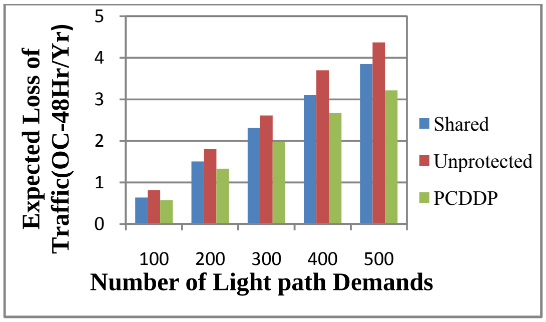


Fig. 4 Expected Loss of Traffic per Year in OC-48 for Single duct Failures (availability = 0.99999)-NSFNET

For double duct failures, the maximum number of simultaneous failures is set to two. The double duct failures are analyzed in detail under three categories a) one of the two ducts is a critical duct, b) both the ducts are non critical ducts, c) both the ducts are critical ducts in Fig.(5,6 &7) respectively. It is evident that among the three categories of duct combinations, the loss is highest when both the ducts failed are critical ducts followed by the combination of critical and non critical ducts. The traffic loss is least when both the failed double ducts are non critical ducts. These results show how crucial the critical ducts are over the network performance in terms of survivability against failures and network cost.

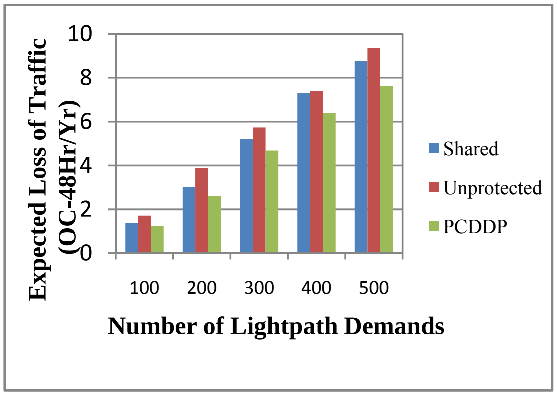


Fig.5 Expected Loss of Traffic per Year in OC-48 for Double duct (Critical duct + Non Critical duct) Failures (availability = .99999)-NSFNET

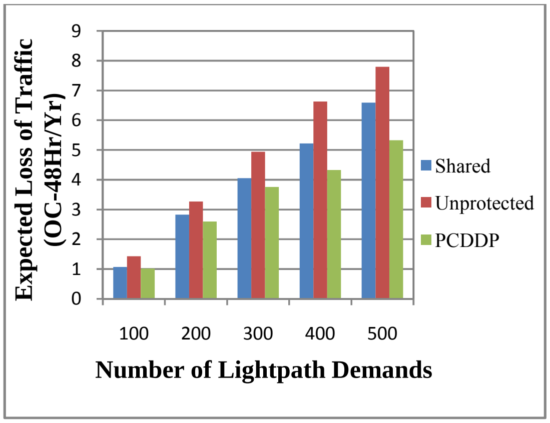


Fig. 6 Expected Loss of Traffic per Year in OC-48 for Double duct (Noncritical duct + Non Critical duct) Failures (availability = .99999) –NSFNET

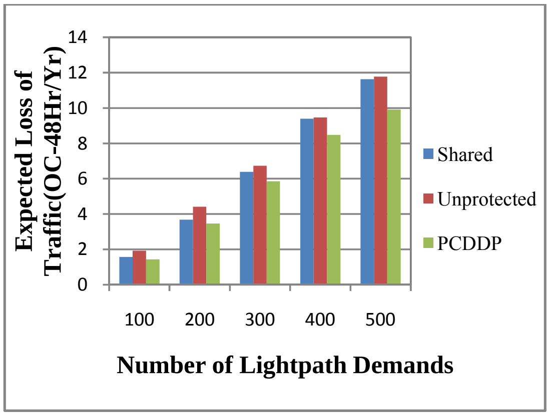


Fig. 7 Expected Loss of Traffic per Year in OC-48 for Double duct (Critical duct + Critical duct) Failures (availability = .99999)-NSFNET

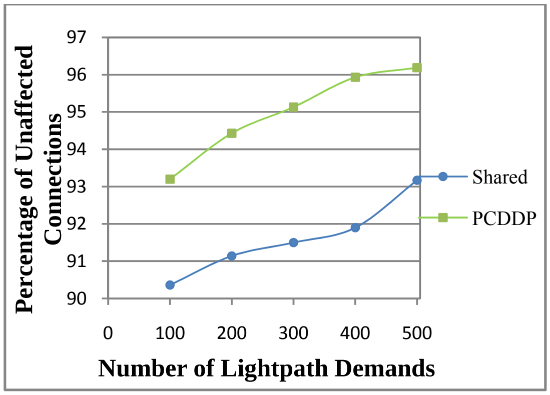


Fig. 8 Percentage of Unaffected Connections for Shared path protection and PCDDP-NSFNET

The number of lost connections and recovered connections are calculated for shared path protection and PCDDP for each individual link failure in the network. One link is failed at time and the network is returned to the initial state before the next link failure is attempted.

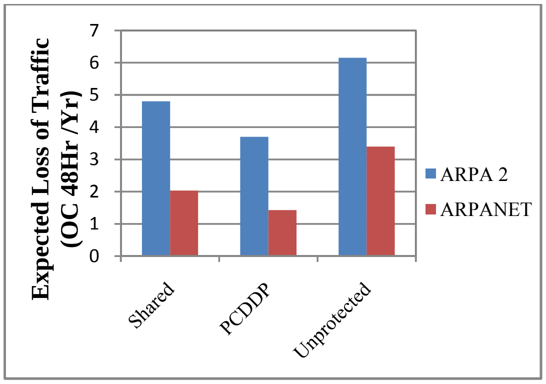


Fig. 9 Expected Loss of Traffic per Year in OC-48 for Single duct Failures (availability = 0.99999)

It is a usual procedure to calculate the recovery percentage to observe the number of recovered connections over failed connections. It is equally important to find out how many connections in the given traffic matrix remain unaffected in the event of a failure. This parameter is very significant because it avoids the recovery process, saves network resources and time.Fig.8 explains the percentage of unaffected connections over the total number of connections when a duct failure occurs for shared path protection and PCDDP. In the proposed approach (PCDDP), dual ducts are provided for the critical links that have higher frequency of usage. In addition to that the even distribution of working paths and backup paths over duct 1 and 2, results in more number of connections remain unaffected in the case of a duct failure.

Fig.9 shows the expected loss of traffic in terms of OC 48 per year for both the ARPA 2 and ARPANET networks for the lightpath demands of 500.It is evident that the PCDDP approach performs well in all the three networks and the least amount of expected loss of traffic in ARPANET network is attributed to the higher average nodal degree.

7 Cost Comparison

The performance of the proposed method has to be evaluated for cost effectiveness. The sites are positioned according to the maximum span length before amplification which is taken as 100Km.The maximum number of OA (optical amplifier) spans on a link before regeneration is set to be six. The site calculations are carried out according to the equations (10), (11) and (12).

$$\# \text{Total sites} = \text{fiber length} / \text{maximum span length before amplification} - 1 \quad (10)$$

$$\# \text{Regenerator sites} = \# \text{Total sites} / \text{maximum } \# \text{Amplifier spans before regeneration} \quad (11)$$

$$\# \text{Amplification sites} = \# \text{Total sites} - \# \text{Regenerator sites} \quad (12)$$

Table 2 shows the number of wavelengths required to honor the given light path demands in NSFNET network.. The number of wavelengths used is an important parameter since the cost of most optical network components is related to this parameter. The PCDDP approach results in lesser number of wavelengths used for the growing number of light path demands. The benefit of PCDDP is more pronounced at higher load as shown in table 2.

Table 2 Wavelength Requirements - NSFNET

#Light path Demands	Shared	1+1 Protection	PCDDP
100	390	404	382
200	862	877	848
300	1187	1274	1159
400	1544	1745	1454
500	1811	2172	1659

The percentage improvement in network cost savings normalized to the network cost of 1+1 protection scheme is shown in Fig.10. The PCDDP results in consistent improvement in network savings. The distribution of fiber pairs over links in the network is shown in Fig.11.It is clear that the maximum number of fiber pairs per link is lesser in PCDDP approach compared to other two schemes. In PCDDP, there are more links with smaller number of fiber pairs whereas in shared path and1+1 protection methods, the number of fiber pairs per link is distributed over higher values. In addition to that, the total number of fiber pairs in PCDDP method is lesser than that of the other two schemes. This behavior is attributed to the fact that since the dimensioning is focused on the critical ducts pertaining to a network 'hotspot' area, the added capacities to these links will serve the purpose of meeting the growing traffic demands. Hence the proposed method is more cost effective than 1+1 protection and shared path protection schemes.

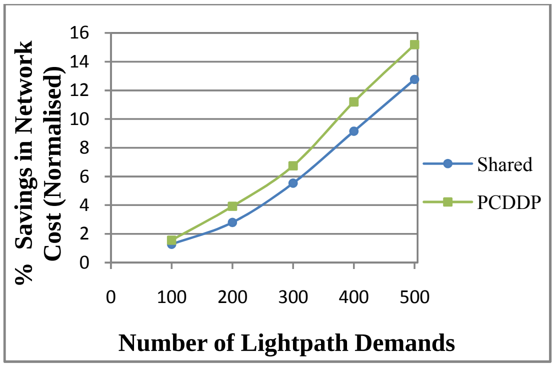


Fig.10 Improvement in percentage on Network Cost savings over 1+1 Protection Scheme-NSFNET

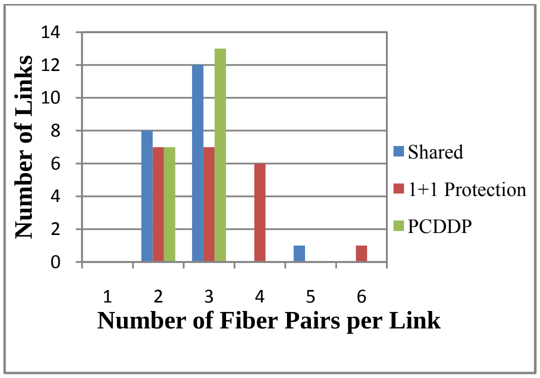


Fig.11 Distribution of Fiber Pairs over Network Links for Light path Demands =500 –NSFNET

Table 3 Wavelength Requirements-ARPANET

#Light path Demands	Shared	1+1 Protection	PCDDP
100	471	674	463
200	893	1248	872
300	1371	1721	1338
400	1761	2216	1707
500	2162	2786	2083

Table 4 Wavelength Requirements-ARPA 2

#Light path Demands	Shared	1+1 Protection	PCDDP
100	678	864	653
200	1228	1375	1207
300	1691	2120	1673
400	2321	2668	2175
500	2771	3428	2746

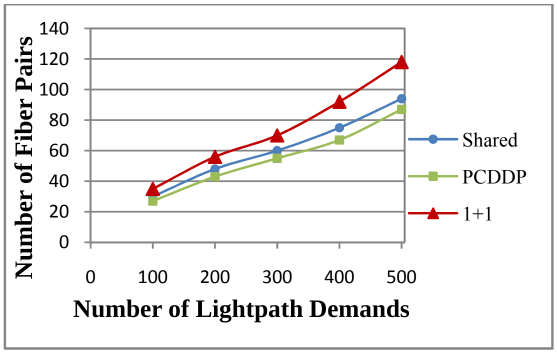


Fig.12 Number of Fiber Pairs used- ARPA2

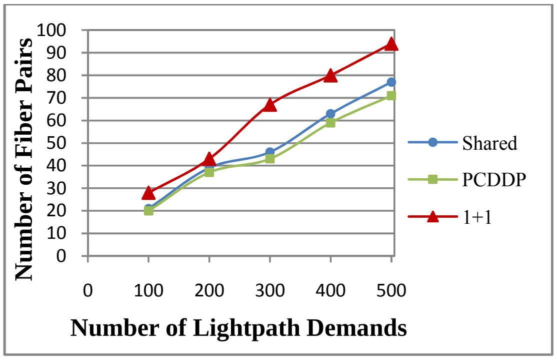


Fig.13 Number of Fiber Pairs used- ARPANET

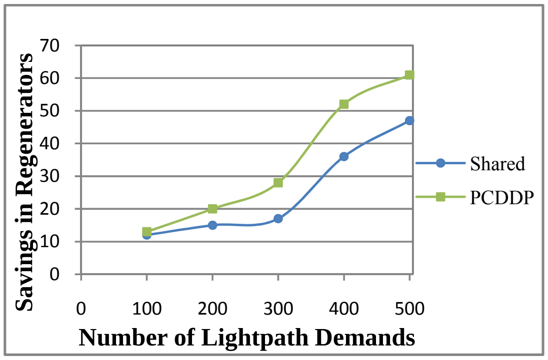


Fig.14 Savings in Regenerators – ARPA2

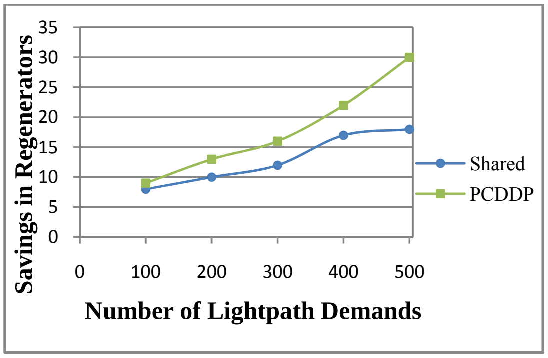


Fig.15 Savings in Regenerators-ARPANET

Table 5 Comparison of Shared and PCDDP Solutions on Networks for 500 Lightpath Demands

Network	N	Av	Co %	Solution	Ed (OC 48Hr/Yr) (Single Duct Failure)	No of Wavelengths	Distance (Protection)Km	%Improvement in Cost(Normalized)
NSFNET	14	2.38	23	Shared	3.8	1811	801990	12.49
				PCDDP	3.2	1659	718470	15.91
ARPANET	20	3.2	17	Shared	2	2162	646625	14.82
				PCDDP	1.25	2083	533892	18.83
ARPA 2	21	3	12	Shared	4.7	2771	1489065	16.62
				PCDDP	3.6	2746	1454063	21.89

In ARPANET and ARPA 2, rather than discussing the overall network cost, the emphasis is shown on number of fiber pairs and the number of regenerators which are the resources that affect the network cost significantly. Fig 12 and Fig .13 shows the number of fiber pairs used to honor the corresponding lightpath demands. It is evident that PCDDP results in reduced number of fiber pairs in both the networks. The savings in number of regenerators are calculated relative to the regenerator requirement in 1+1 protection scheme.

Savings in regenerators for shared scheme ,

$$\Delta_{\text{shared}} = \#\text{Reg}\ (1{+}1) - \#\text{Reg}(\text{shared}) \qquad (13)$$

Savings in regenerators for PCDDP,

$$\Delta_{\text{PCDDP}} = \#\ \text{Reg}\ (1{+}1) - \#\text{Reg}\ (\text{PCDDP}) \qquad (14)$$

$\#\text{Reg}_{1+1}$ = No. of regenerators used in 1+1
$\#\text{Reg}_{\text{shared}}$ = No. of regenerators used in shared
$\#\text{Reg}_{\text{PCDDP}}$ = No. of regenerators used in PCDDP

Fig.14 and Fig.15 shows the savings in number of regenerators Δ in ARPA 2 and ARPANET respectively. The value of Δ is high in PCDDP method over shared path protection. Table 3 and 4 shows the wavelength requirements for ARPANET and ARPA 2 respectively for the given number of lightpath demands. In both the networks, the wavelength requirement is lesser in PCDDP compared to other schemes. Out of three networks, the resource requirements either in terms of wavelengths, fiber pairs or number of regenerators are high in ARPA 2 network since it has the least value of average nodal degree and poor connectivity over other two networks. Table 5 gives an overall view on the performance comparison of shared protection method and PCDDP both in terms of expected loss of traffic and improvement in network cost for the three networks. Av is the average node degree and Co is the connectivity of the network. The proposed approach PCDDP yields lesser distance traversed for the protection path for all the three networks. Here the minimum value of the distance in ARPANET is attributed to the fact that for the network with high average node degree, availability of potential paths between a node pair is high.

8 Conclusion

In this paper, a new algorithm for network protection called PCDDP is proposed which addresses both network survivability and dimensioning. Here a duct is considered as a link SRLG. The ducts that carry those links which are very crucial on network functioning are designated as critical ducts .To improve both the survivability and cost effectiveness, a dual duct structure is provided on these critical ducts. For each lightpath request PCDDP algorithm computes one working path and one partial or full critical duct-disjoint backup path to satisfy the network requirements. The performance of the said approach is studied and compared with unprotected, shared and 1+1 protection schemes for mesh networks. The performance metrics are total network cost and expected loss of traffic. The expected loss of traffic is evaluated for both the single duct and double duct failures. It is shown that the PCDDP method results in reduction in traffic loss for both single duct and double duct failures with the reduced total network cost incurred.

This approach is more flexible in selecting the backup path, so that traps can be avoided. Since the limit on hop count is imposed, usage of long backup paths is prevented resulting in network resource savings. It is easy to implement and since the identification of critical ducts are done offline the computational complexity is also considerably reduced.

References:

[1] Hai-Chau Le, Hiroshi Hasegawa and Ken-ichi Sato, Hierarchical Optical Path Network Design Algorithm Considering Waveband Add/Drop Ratio Constraint, *Jnl of Opt. Commun. Netw*., vol. 2, no.10, 2010,pp.872-882.

[2] Wei Yang, Sofia A. Paredes, Henry Schriemer, and Trevor J. Hall, Protection of Dynamic and Flexible Bandwidth on Demand in Metro Agile All-Optical Ring Networks, *Jnl of Opt. Commun. Netw*. vol. 1, no. 2, 2009, pp.A160-A169.

[3] Norihiko Shinomiya, Takeshi Hoshida, Yuichi Akiyama, Hisao Nakashima, and Takafumi Terahara, Hybrid Link/Path-Based Design for Translucent Photonic Network Dimensioning, *Jnl of Lightwave Technology*, vol. 25, no. 10, 2007,pp.2931-2941.

[4] Siamak Azodolmolky et al, A Novel Offline Physical Layer Impairments Aware RWA algorithm with Dedicated Path Protection consideration, *Jnl of Lightwave Technology*, vol.28, no. 20, 2010 , pp.3029-3040.

[5] Penghui Yuan and Anshi Xu, The Influence of Physical Network Topologies on Wavelength Requirements in Optical Networks, *Jnl of Lightwave Technology*, vol.8, no.9, 2010,pp.1338-1343.

[6] Raul Muñoz, Ricardo Martínez, and Ramon Casellas, Experimental Performance of Shared Path Protection With Flooded Versus Collected Sharing

Resource Information in GMPLS WSON Networks, *Jnl of Lightwave Technology*, vol. 28, no. 23, 2010,pp.3372-3386.

[7] X. Yang, L. Shen, and B. Ramamurthy, Survivable lightpath provisioning in WDM mesh networks under shared path protection and signal quality constraints, *Jnl of Lightwave. Technology,* vol. 23, no. 4, 2005, pp. 1556–1567.

[8] Izhak Rubin, and Jing Ling, Failure Protection Methods for Optical Meshed-Ring Communications Networks, *IEEE Jnl on Selected Areas in Communications*, vol. 18, no. 10, 2000,pp.1950-1960.

[9] A. Jaekel and Y. Chen, Optimal routing and wavelength assignment for survivable multifibre WDM Networks, *Can. Jnl of Elect. Comput. Eng.*, vol. 33, No. 3/4, 2008, pp.201-208.

[10] Yoshiyuki Yamada, Hierarchical Optical Path Network Design Algorithm Considering Waveband Protection, *Jnl of Lightwave Technology*, vol. 27, no. 24, 2009,pp.5736-5748.

[11] D. Papadimitriou, F. Poppe, J. Jones *et al.*, Inference of shared risk link group, *Optical Internetworking Forum (OIF) Contribution OIF 2001- 066.* [Online]. Available: http://www.watersprings.org/pub/id/draft-manyinference-srlg-00.txt

[12] H. Wen, S. Wang, and L. Li, A routing algorithm for finding low-cost pair of no-shared-risk paths, *Jnl of Electron. Inf. Technology.*, vol. 25, no. 6, 2003, pp. 824–830.

[13] M. Tornatore, G. Maier, and A. Pattavina, Capacity versus availability trade-offs for availability-based routing, *Jnl of Opt. Netw.*, vol. 5, no. 11, 2006, pp. 858–869.

[14] Lei Guo, *Member, OSA*, Lemin Li, A Novel Survivable Routing Algorithm With Partial Shared-Risk Link Groups (SRLG)-Disjoint Protection Based on Differentiated Reliability Constraints in WDM Optical Mesh Networks, *Jnl of Lightwave Technology*, vol. 25, no. 6, 2007, pp.1410-1415.

[15] D. Xu, Y. Xiong, C. Qiao and G. Li, Failure protection in layered networks with shared risk link groups, *IEEE Network*, vol. 18, 2004, pp. 36– 41.

[16] J. Strand, A. Chiu, and R. Tkach, Issues for routing in the optical layer, *IEEE Commun. Mag.*, vol. 39, 2001, pp. 81–87.

[17] P. Sebos, J. Yates, G. Hjalmtysson, and A. Greenberg, Auto-discovery of shared risk link groups, *Proc. Optical Fiber Communications Conf.*, vol 3, 2001, pp. WDD3-1-WDD3-3.

[18] P. Sebos, J. Yates, A. Greenberg, and D. Rubenstein, Effectiveness of shared risk link group auto-discovery in optical networks, *Proc. Optical Fiber Communications Conf.*, 2002, pp. 493-495.

[19] Hui Zang, , Canhui (Sam) Ou, , Biswanath Mukherjee,, Path-Protection Routing and Wavelength Assignment (RWA) in WDM Mesh Networks Under Duct-Layer Constraints, *IEEE/ACM Transactions On Networking*, vol. 11, no. 2, 2003,pp.248-258.

[20] P. Rajalakshmi, A. Jhunjhunwala, Re-Routing at Critical Nodes to Enhance Performance of Wavelength Reassignment in All-Optical WDM Networks Without Wavelength Conversion, Jnl *of Light wave Technology*, vol. 26,no 17,2008,pp.3021-3029.

[21] Xu Shao et al; ,Best Effort Shared Risk Link Group (SRLG) Failure Protection in WDM Networks, *Proc of IEEE Int Conf on Commn*,2008 ,pp.5150-5154.

D. Sheela is working as a Faculty in the department of electronics and communication engineering, Tagore Engineering College and currently pursuing Ph.D. in the Faculty of Information and Communication Engineering, Anna University, Chennai, India. Her areas of interests are optical communication and networks, computer networks, and wireless communication.

C. Chellamuthu received his PhD degree in Power Electronics from IIT Chennai, India. After working as associate lecturer in GCT, Coimbatore India, he joined the Anna University Chennai, India as lecturer, asst professor and then professor. He is the former head of department of electrical and electronics engineering, Anna University, India. He is currently working as a Professor at R.M.K. Engineering College, Chennai, India. He has published his works in several International and National journals, pioneered several new research directions, made a number of landmark contributions in his field. His areas of interests are Power electronics, PMBDLC designs, Microprocessor based system design, Networking, and Image processing.