Performance Evaluation of Survivability in Optical Networks Based on Graph Theory

D.Sheela, S.Abinaya, G. Angelo Virgin, S.Archana

Abstract— Survivability is the ability of a network to withstand and recover from failures. Survivability in optical network is of prime concern since a node or a fiber link failure may result in huge amount of data loss. Network can be represented as a graph with nodes as vertices and links as edges. Interpretation of graph theory is very useful in evaluating and improving the performance of a network. In this paper, an important graph parameter known as algebraic connectivity is considered. The algebraic connectivity is the second smallest Eigen value of the graph which represents the robustness of the network. This paper proposes an approach in which the links are assigned with weights based on algebraic connectivity and the capacity is provisioned based on their weights. The performance of the proposed method is evaluated in terms of cost and loss of traffic due to link failures on real backbone optical networks.

Index Terms— Graph Theory, algebraic connectivity, survivabibilty, Eigen values, topology.

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1 INTRODUCTION

The massive growth of the Internet and other data traffic has paved the way for the relentless quest for higher capacity in communication networks. Optical networks are a promising answer to meet this growing demand for bandwidth, and to transmit data over long distances with minimum signal loss. The development of Wavelength Division Multiplexing (WDM) technology has increased the optical channel capacity by several orders of magnitude [1].The high bandwidth connection requests for the Internet domain have increased several fold [2]. Video delivery, health care applications etc. are the type of services of short duration, but which require a high bandwidth. The considerable amount of data transfer taking place in grid computing and other distributed computing applications, requires connections with very high data rates [3].

In optical networks, each link carries a high amount of traffic. These networks are prone to failure due to cable cuts, fiber cuts and node failures. A single link failure in an optical network will result in huge amounts of data loss and hence, survivability is of prime concern in optical networks [4]. Survivability is defined as the ability of the network to survive failures. The challenge in survivable optical networks is to efficiently allocate the network resources to reduce the cost, together with recovery of traffic from failures. Azodolmolky et al [5] proposed an offline Impairments Aware Routing and Wavelength Assignment, which considers the physical layer impairments. But the authors considered only the dedicated path protection. Askarian et al [6] considered the physical layer impairments in the design aspects of survivable all-optical networks. It is very important that the network protection measures must be provided at the network design stage itself to ensure that the network is resilient to failures. The key aspects that are taken into consideration are spare capacity requirement, operational complexity and viability [7].

Graph theory is a powerful tool for modeling the structure of different systems. A graph is represented as G = (V, E) where V is the set of vertices and E is the set of edges [8]. Because graph theory looks at pair wise relationships between objects in a collection, graph theory is well suited for modeling and analyzing different types of networks [9].

2 ALGEBRAIC CONNECTIVITY AND NETWORK ROBUSTNESS

When the graph G is connected, the second smallest Eigen value λ_2 is greater than zero. This Eigen value is named the algebraic connectivity of the graph [10] because it serves as a lower bound on the degree of robustness of the graph to node and edge failures. This follows from the following inequality given in Eqn (1).

$$\lambda_2 \langle G \rangle \leq v \langle G \rangle \leq \eta \langle G \rangle \quad (1)$$

where v(G) is the node-connectivity and η(G) is the edge-connectivity of a graph. The node connectivity number v(G) of a graph G is defined as the minimum size of a separating set, or in other words the minimum number of nodes that may be removed to separate the graph into more than one component. Similarly, the edge-connectivity number η(G) is defined as the minimum number of edges that may be removed to separate the graph into more than one component.

Algebraic connectivity is of great interest because of the inequality developed by Fiedler: which states that the algebraic connectivity of a graph G (defined as the second smallest Eigen value λ_2 (G) of the Laplacian) is less than or equal to the node-connectivity which is less than or equal to the edge- connectivity, Computing algebraic connectivity is much quicker than computing node-connectivity or edge-connectivity for large networks.

If the adjacency and Laplacian matrix are symmetrical, and Eigen value / eigenvector analysis can be performed, resulting in a series of Eigen values and corresponding Eigen vectors. It

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is assumed that the series of Eigen values and eigenvectors represent all information present in the graph. The second smallest Eigen value of the Laplacian matrix is called the algebraic connectivity. It is a measure of network robustness. If the algebraic connectivity is 0, the network consists of at least two disconnected components.

3 SURVIVABILITY BASED ON ALGEBRAIC CONNECTIVITY

The decrease of the spectral radius, an important characterizer of network dynamics, by removing links is investigated [11]. In this paper, we propose a method, where each link is assigned with weights based on the Algebraic Connectivity.Let G be a graph with at least two vertices. The second smallest Laplace Eigen value λ_2 is called the *algebraic connectivity* of the graph G.

The weight of a link

$$W_n = \lambda_2 \langle G \rangle - \lambda_2 \langle G_n \rangle \qquad 1 \le n \le L \qquad (2)$$

Where λ_2 (G_n) is the algebraic connectivity of the graph G when a link n is removed.

The links with higher weights are significant in the sense that they influence the robustness of the network. Therefore, additional care is to be taken on these links from both the protection and cost perspectives. In the single link scenario, backup light paths always take longer routes than primary light paths, which results in quicker network resource exhaustion. When additional fibers are added to the links with higher weights, the availability of the spare capacity is increased substantially which will help in improving the survivability of the network.

3.1 Algorithm

1. Consider a network G with N nodes and L links.
2. Calculate the λ_2 (G) is the algebraic connectivity of the network G.
3. For each link n, estimate the weight Wn.

$$W_n = \lambda_2 \langle G \rangle - \lambda_2 \langle G_n \rangle \qquad 1 \le n \le L$$

4. List the links based on their weights starting with the highest weight.
5. Assign multi fibers to the top five links
6. Simulate single link failures and calculate the loss of traffic and the cost incurred.

4 RESULTS AND DISCUSSION

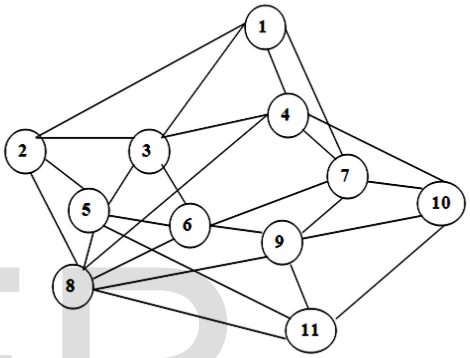
To evaluate the performance of the proposed approach two real backbone optical networks are selected which are COST 239 and ARPA2 networks as shown in Fig(1). These networks are selected since they are distinctly different from each other as evident from Table 1. ARPA 2 network is very poorly connected with the connectivity of 12 % whereas in COST239 has a 47% connectivity which is four times that of the ARPA 2 network. The average node degree of COST 239 is twice that of the ARPA2 network.

TABLE I

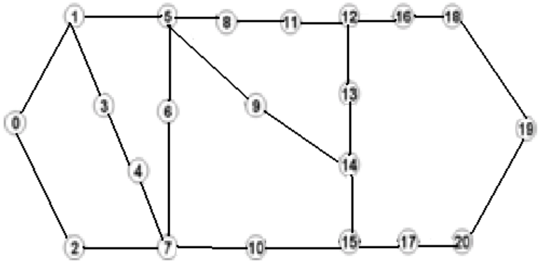
TOPOLOGY INFORMATION OF TWO CANDIDATE NETWORKS

Network	N	L	ΔMin	ΔMax	ΔAvg	co%
COST 239	11	26	4	6	4.73	47
ARPA 2	21	25	2	4	2.38	12

CO -CONNECTIVITY OF THE NETWORK = L / (N (N-1) /2)



(A) COST-239 NETWORK



(B) ARPA-2 NETWORK

FIG. 1 CANDIDATE NETWORKS

The proposed approach is named as Survivability based on Algebraic Connectivity (SBAC).The network cost and traffic loss are analyzed for the candidate networks. The results of the proposed method are compared with unprotected scheme, 1+1 (dedicated) protection, and shared path protection methods. In shared path protection, the performance is evaluated for 1:10 and 1:5 ratios.

4.1 Cost analysis

Cost is a primary factor in optical network design. Because of the high prices of optical equipment, a network designer strives for the most cost-effective solution. The following analysis summarizes the node cost and link cost of the two networks with various protection schemes that are deployed on the network.

4.1.1 Node cost

The node cost consists of OXC fixed, OXC port and the Transponder cost.

TABLE II

COMPARISON OF NODE COST FOR COST-239

NODE COST	OXC FIXED	OXC PORTS	TRANS-PONDERS
Unprotected	110,000	5,740	3,480
1+1 protected	110,000	9,740	5,440
Shared 1:10	110,000	9,640	3,630
SBAC 1:10	110,000	9,260	3,480
Shared 1:5	110,000	9,080	3,480
SBAC 1:5	110,000	8,860	3,480

TABLE III

COMPARISON OF NODE COST FOR ARPA-2

NODE COST	OXC FIXED	OXC PORTS	TRANS-PONDERS
Unprotected	210,000	33,500	10,240
1+1 protected	210,000	37,200	12,240
Shared 1:10	210,000	36,200	12,840
SBAC 1:10	210,000	35,840	11,540
Shared 1:5	210,000	33,840	12,240
SBAC 1:5	210,000	32,640	12,240

OXC- Optical Cross Connects

OXC fixed is related to the number of nodes in the network.COST-239 has 11 nodes and ARPA-2 network has 21 nodes.

4.1.2 Link cost

The link cost consists of WDM TM (Terminal Multiplexers), Muxponders and Transponders.

TABLE IV

COMPARISON OF LINK COST FOR COST-239

LINK COST	WDM TM	TRANSPONDERS
Unprotected	9,400.00	19,120.00
1+1 protected	13,800.00	23,520.00
Shared 1:10	12,800.00	23,520.00
SBAC 1:10	10,400.00	20,280.00
Shared 1:5	13,400.00	23,520.00
SBAC 1:5	11,600.00	22,120.00

TM-Terminal Multiplexers

TABLE V

COMPARISON OF LINK COST FOR ARPA-2

LINK COST	WDM TM	TRANSPONDERS
Unprotected	9,750.00	77,120.00
1+1 protected	15,600.00	87,120.00
Shared 1:10	12,200.00	83,120.00
SBAC 1:10	10,600.00	82,460.00
Shared 1:5	15,200.00	83,040.00
SBAC 1:5	13,480.00	82,520.00

Table II& III and Ttable IV&V show the node cost and link cost comparison of the existing schemes and the proposed approach SBAC. The OXC fixed cost is constant for all the schemes, since it is fixed on the number of nodes in a network. In other equipment cost the proposed method SBAC provides the cost effective solution compared to the other methods.

4.2 Loss Analysis

The loss of traffic in of Gb/Year is calculated for the various schemes on the two real optical networks. The loss of traffic is estimated using Eqn (3).

$$E_{xl} = [(1-A)] \mathrm{OCN} * 24\,(hr/day) * 365\,(days/year) * \\ [N * 0.05184(Gb/OC-48)] * 3600(\sec s/hr) \qquad (3)$$

Where, A is the availability as shown in Eqn (4).

$$A = 1 - \frac{\mathrm{MTTR}}{\mathrm{MTBF}} \qquad (4)$$

MTTR-Mean Time to repair
MTBF-Mean Time Between Failures

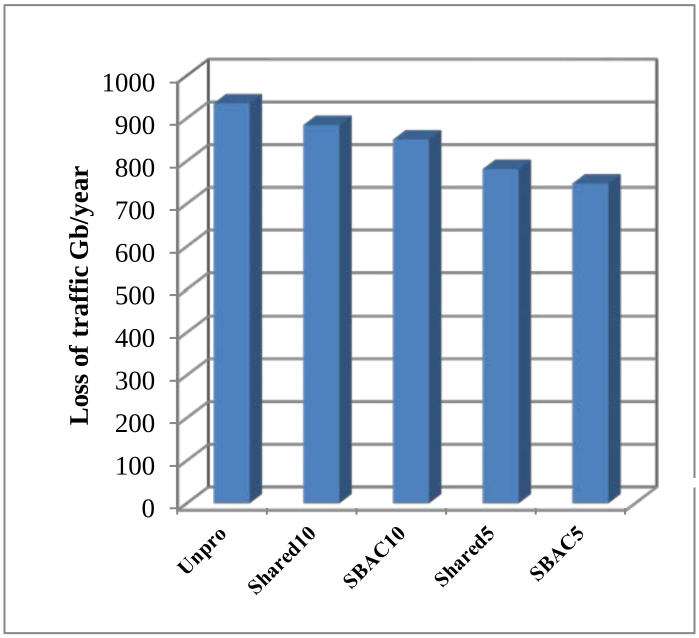


Fig. 2 Expected Loss of Traffic for ARPA 2

Fig (2) shows the excepted loss of traffic of ARPA2 .In the shared path protection both the ratios of 1:10 and 1:5 are taken for evaluation. In the ARPA2 network, the traffic loss is minimum in the proposed approach Survivability Based Algebraic Connectivity (SBAC) compared to the unprotected and shared path protection for both the ratios. Hence the expected loss of traffic for the shared path protection is 884.09. The proposed approach with additional fibers to the top five links shows the expected loss of traffic to be 850.03 which is lesser than the existing schemes. Hence this approach provides a better performance in terms of network reliability.

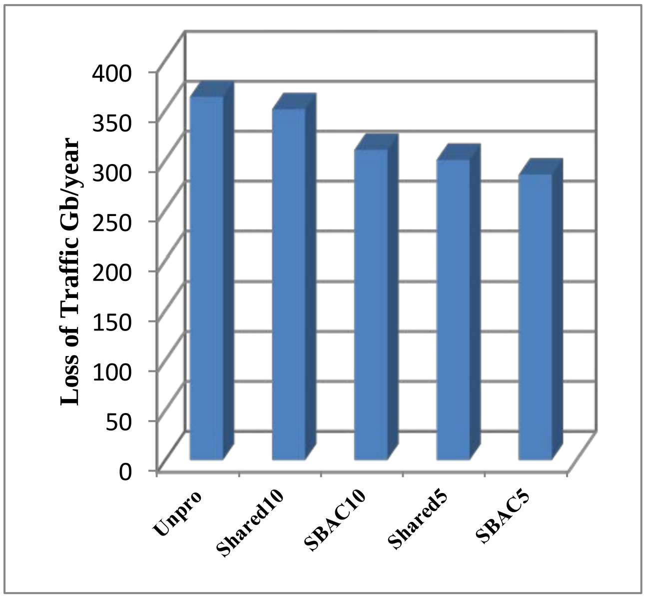


Fig. 3 Expected Loss of Traffic for COST 239

Fig (3) above shows the excepted loss of traffic of COST 239.In COST 239 network, the expected loss of traffic for shared path is 350.85. The SBAC approach with additional fibers to the significant links shows the expected loss of traffic to be 310.09 Gb/Year. It also results in minimum traffic loss for the shared path scheme in the ratio of 1:5. In SBAC approach, the resources are additionally assigned to the links, which are significant in terms of algebraic connectivity. Therefore, the availability of protection paths is increased, resulting in reduced cost and loss of traffic**.**

5 CONCLUSION

An approach known as SBAC is proposed in this paper in which the links are assigned with weights based on algebraic connectivity and the capacity is provisioned based on their weights. Two networks , COST 239 and ARPA2 are selected for performance evaluation due to their distinct features.The performance of the proposed method is estimated in terms of loss of traffic due to link failures and network cost in terms of link and node cost.. The proposed method is compared with unprotected, 1+1 protected and shared path protection schemes with different ratios. The results show that the SBAC approach results in reduced loss of traffic at a reduced cost and robust the topological features.

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