Survivability with P-Cycle in WDM Networks

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Abstract: *In this paper we discuss about the Pre-Configured survivability schemes. Network survivability is the ability to provide services during failures, which is an essential issue for telecommunication networks, which becomes more and more crucial with the emergence of the advanced fiber telecommunication techniques. With the support of Wavelength Division Multiplexing(WDM) technique, optical communication systems integrate huge amount of traffic data onto a single fiber. In optical networks the failures can be of two types, component failure and fiber cuts. In WDM networks, failure of a network element may cause failure of several optical channels leading to large data loss which can interrupt communication services. Therefore, measures should be taken for the network failure restoration and methods should be explored to design highly reliable networks. The P-Cycle became an effective technique for recovery in mesh networks because P-Cycle having the combined benefits of ring like speed recovery and mesh like capacity efficiency. In this we discuss algorithms for shortest path routing, wavelength assignment and BFS,DFS methods to select fundamental cycles. One or more fundamental cycles are joined to form a candidate P- Cycle. This paper describes a new optimization model which reduces the redundancy and improves the capacity utilization compared to SBPP. The P-Cycle survivability is more capacity efficient,failure independent and very fast restoration compared to other techniques.*

Keywords: BFS (Breadth First Search), DFS (Depth First search), P-Cycle, Survivability, Restoration, Shared-Backup Path Protection (SBPP), Shortest Path Routing, Wavelength Assignment, Protection.

1. Introduction

1.1 Back Ground

The optical networks using wavelength division multiplexing (WDM) could provide huge bandwidth capacity for next-generation Internetand these are backbone for modern communication because of their throughputs of order of terabits per second. These networks are promising, candidate to meet the bandwidth demands from various emerging multimedia applications. In optical communication, WDM is a technology which carries a number of high speed optical carrier signals on a single fiber by using different wavelengths of laser light.Therefore, it is important to maintain WDM network survivability because a single link or node failure would affect a large number of communication sessions.

1.2 Routing and Wavelength Assignment (RWA)

RWA is the basic control problem for transmission of data in a WDM network. RWA is classified into two types of problems depending on traffic demand. For static traffic, the connection requests are known in advance and lightpaths for these connections are set up. The main objective is to minimize the number of wavelength channels requested for a given network. RWA problem for static traffic is known as *Static Lightpath Establishment* (SLE). On the other hand, for dynamic traffic, a lightpath is established for each connection request when a connection request arrives. The objective is to establish a lightpath and assign wavelengths to maximize connection probability or improve the blocking performance. The RWA problem for dynamic traffic is known as *Dynamic Lightpath Establishment* (DLE).

The RWA problem can be decoupled into two sub problems: the routing sub sub-problem and the wavelength assignment sub-problem. For routing sub-problem fixed routing ,fixed alternate routing and adaptive routing are well-known approaches. First Fit, Random, Most used and Least used wavelength assignment are different approaches for wavelength assignment sub-problem.

1.3 Network Survivability

Optical WDM networks are required to satisfy the growing network traffic demands. Therefore, survivable network design against failure in WDM network becomes acritical issue since a channel failure such as fiber cuts or components can lead to huge data losses.Interrupted service for even short time may have disastrous consequences unless the failure of the channel is immediately recovered. The failure at the links is called Link failure and is caused by cable cuts while node failure refers to the failure of components at the network nodes caused due to failure of the equipment. The survivability of a network refers to a network's capability to provide continuous service and maintain quality of service in the presence of such failures. Survivability technique in optical networks can be classified into two categories. 1. Pre-Planned Protection 2. Dynamic Restoration

1.3.1 Pre-Planned Protection
Pre-Planned protection reserves backup paths against failure at the same time as the working paths are allocated.Ring topologies used for small scale networks and mesh topologies for large scale networks. This is because the network survivability offers high capacity utilization mesh network based survivability is classified into two categories: Path protection and Link protection.

A. Path Protection
In Path Protection, the fault notification message informs the source node and the destination node of each path that traverses the failed link. When network failure occurs, the working path is switched to the back up path which should be disjoint from the corresponding working path. For example, failed link (B-E) is recovered by the reserved path (A-C-D-F) as shown in Fig 1 (a). Primary path means working path and reserved path means alternate path.

B. Link Protection

Upon a link failure, the end node pairs of the failed link are immediately switched to the backup path. Fig 1 (b)the node pairs of the failed link (B-E) are automatically switched to the reserved path (B-C-D-E).
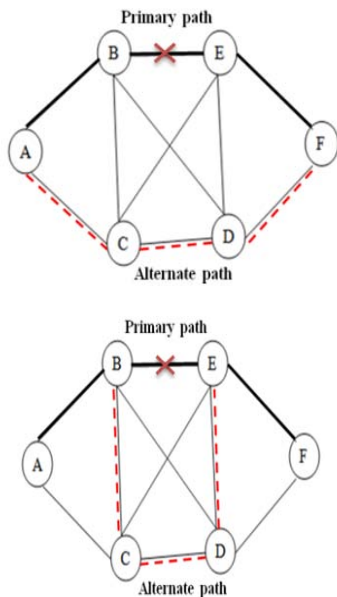

Figure 1: (a) PathProtection**Fig 1 (b)**Link Protection

1.3.2 Dynamic Restoration

Dynamic Restoration dynamically discovers backup paths in the network after a link fails.This mechanism can be classified into two types: Path restoration and Link restoration.

A. Path Restoration

When a failure occurs an alternative path is immediately determined from the source node to the destination node in this method. This technique is not able to guarantee maximum restorability since the path for recovery may be blocked easily.

B. Link Restoration

Spare capacity is reserved at the time of failure in link restoration. It dynamically discovers a backup channel around the adjacent nodes of the failed link.

The classification of the survivability techniques are Shared Backup Path Protection (SBPP) and Pre-configured protection cycle (P-cycle), in which the protection paths are known in advance.

1.3.3 Shared Backup Path Protection

This scheme is able to share spare capacity over the backup channels from multiple services. For this reason, SBPP can offer efficient capacity utilization. In SBPP, one or more backup paths are found between the source and the destination node of the primary working path, but only one backup path is selected to protect against network failures. The backup path has to be link and node disjoint from the primary path. This is because link or node on a working path may be affected when that working path fails. Fig 2 shows a set of three working paths that can share spare capacity in SBPP. Each working path has a backup path that is pre-computed and a number of backup paths can share spare capacity on some spans. For example, every working path

shares link E-F for backup in Fig 2 this is possible since they are disjoint with their corresponding primary paths. Also, link E-G shares two backup paths. The spare capacity is pre-allocated to protect against network failure. SBPP offers great capacity efficiency, but with a slow computation time. This became the major disadvantage for this Shared Backup Path Protection method.P-cycle over comes the disadvantages of other survivable protection methods such as slow computational time of SBPP.
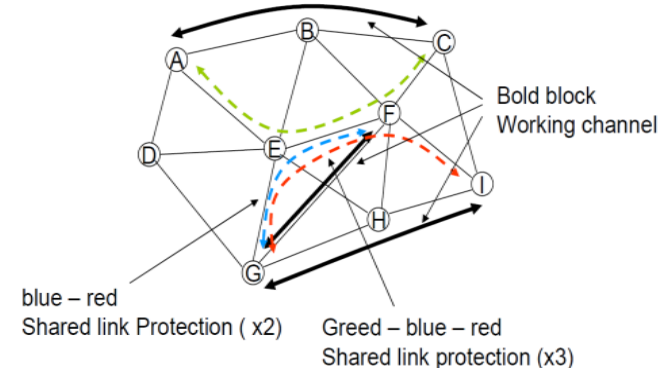

Figure 2: Sharing of Spare Capacity in SBPP

2. P-Cycle Survivability Using BFS

The p-cycle protection scheme combines the advantages of ring and mesh: it realizes ring-like speed while retaining the spare capacity efficiency of the mesh based methods. The main principle of p-cycle protection is shown in Fig 3 (a), is a closed path composed of spare capacity links. When a failure occurs on a span covered by the cycle, the p-cycle provides one backup path for restoring one link on the failed span, as shown in Fig 3 (b). The main difference between ring and p-cycles is that p-cycles can also protect straddling spans which is shown in Fig 3 (c).
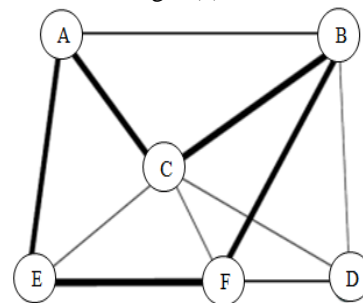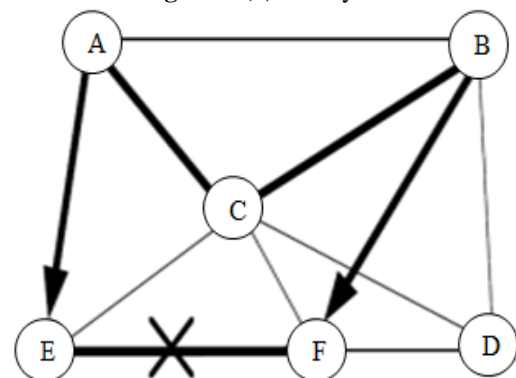

Figure 3 (a)AP- Cycle

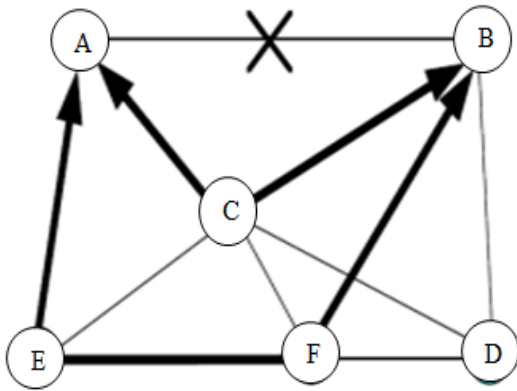**Figure 3 (b):** Failure of Cycle span

Figure 3 (c): Failure of Straddling span

3. Design Methods and Formation of P-Cycles In WDM Network Using BFS

In this first create a WDM mesh topology with required number of nodes and links.
Step1: At first Generation of fundamental cycles based on Breadth First Search (BFS) method.
Step2: Generation of candidate p cycles.
Step3: Now selecting the best cycle from the generated candidate p-cycles.
Step4: Dijkstra's algorithm i.e. by shortestpath routing the best route is selected.
Step5: After choosing route wavelength to the provided light paths based on the wavelength allocation scheme.

Step1: Generation of Fundamental Cycles Using BFS
The Breadth First Search (BFS) algorithm is used to determine all fundamental cycles. BFS algorithm needs atleast two neighbouring nodes from the root node to form a fundamental cycle. This is because a cycle cannot be formed if there is only a single neighboring node.

A. BFS Algorithm
1. Visit all neighbouring nodes that are one edge from the source node.
2. Visit all the neighbour's neighbours that are two edges from the source node.
3. Continue this procedure till end of graph.

B. Pseudo code
Input: An undirected graph G(V; E)
Output: Set of all fundamental cycles
Node ← 1
N= |V |
While N ≥ 3 do
nei ← set of neighbour nodes from s
Queue ← [s, node.nei]
while queue ≠ Φ **do**
cycle ← top(queue)
queue ← queue - cycle
d ← last node of path
if d == s **then**
P ← cycle
else
adj ← set of neighbors of d
queue ← [queue, node.adj]
end if
end while
Remove node from G (V, E)
Node1 = Node1+1

N = N-1
end while
Step2:Generation of Candidate P Cycles
An efficient set of p-cycles is computed by joining fundamental cycles.By merging fundamental cycles with common link formcandidate P-Cycle.

A.   Join Algorithm
1. First fundamental cycles from selected node are identified.
2. Fundamental cycles of that particular node with a common link are joined to form P-Cycle.
3. If common link does not exist then another fundamental cycle is selected.
4. This process is repeated until no further P-Cycles are found.

B. Pseudo code for Join Algorithm
Input: Set of fundamental cycles
Output: Candidate *p*-cycles
pcycleset ← Φ
F ← set of fundamental cycles
forj= 1 to |F|**do**
pcycle ←F(j)
whilepcycle is not empty **do**
Determine fundamental cycles which have one common link with pcycle from F
if Exist **then**
mergepcycle with smallest cycle to create new pcycle
Add new pcycle to pcycleset
pcycle ←new pcycle
else
pcycle ← Φ
end if
end while
end for
Candidate pcycles ←pcycleset UF

Step3:Selection of Best Cycle
This algorithm has proposed to minimize the total spare capacity. This algorithm selects cycles according to the redundancy of a *p*-cycle, which is the ratio of the spare capacity of the cycle to the working capacity protected by the cycle.
The redundancy (*R*) is expressed as

$$R = \frac{\sum_{i \in s} Pi}{\sum_{i \in s} Wi}$$

Algorithm for Finding Best Cycle
1. Generate all P-Cycles in the network.
2. For each candidate P-Cycle, calculate Redundancy.
3. Then Select minimum*R* of a set.
4. Remove the working capacity protected by the selected cycle and update the working capacity.
5. Go back to step 3 until every span working capacity is zero.

Step 4:Shortest Path Routing Scheme
In graph theory, much research has been done to tackle the single shortest path i.e Dijkstra's algorithm for finding a path with a minimum cost from a source to a destination through a connected network.
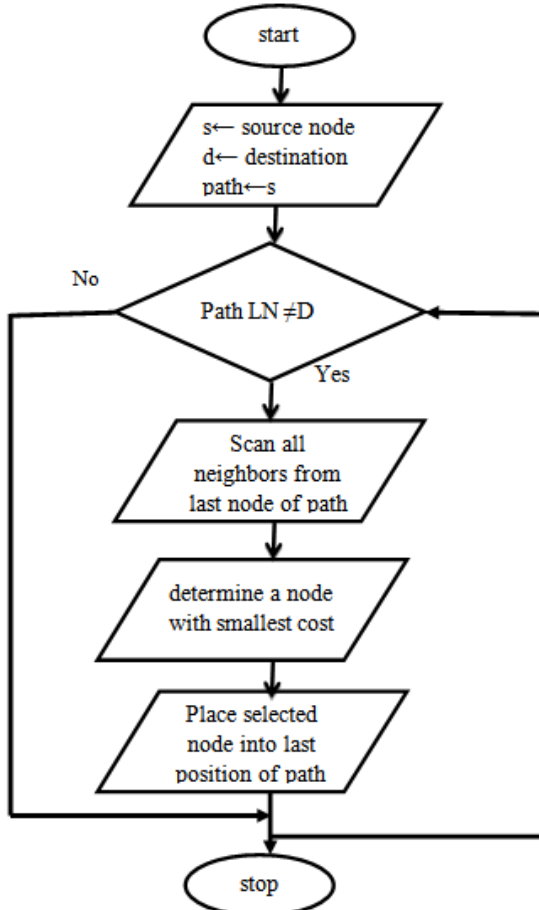
A. Pseudo codefor Shortestpath Routing
Input: *G* (*V; E*)
Output: Shortest path found

S ← source node
D ← destination node
Path ← S
whilelast node of path is not equal to D **do**
scan all neighbours from last node of path
determine a node with smallest weight or cost
place selected node into last position of path
end while

B. Flowchart forDijkstra's algorithm

Step 5:Wavelength Allocation Scheme
Once the route has been chosen for every lightpath, the number of lightpaths in a physical fiber link refers the congestion onthat link. It need to assign different wavelengths if more than one ligthtpath passing through the physical link.

Algorithm for First Fit Wavelength Allocation
1. Find Wavelength Available on all links.
2. Sort Wavelengths Available.
 3.Assign the available wavelength which is in sequence.
4. If all paths are completed then process will end.
5. Otherwise process from step2 is repeated.

4. Design Methods and Formation of P-Cycles in WDM Network Using DFS

In this first create a WDM mesh topology with required number of nodes and links.
Step1: At first Generation of fundamental cycles based on Breadth First Search (DFS) method.
Step2: Generation of candidate p cycles.

Step3: Now selecting the best cycle from the generated candidate p-cycles.
Step4: Dijkstra's algorithm i.e. by shortestpath routing the best route is selected.
Step5: After choosing route wavelength to the provided light paths based on the wavelength allocation scheme.
Step1:Generation of Fundamental Cycles Using DFS (Depth First Search)
By this Algorithm, all fundamental cycles traveling over each node are explored by DFS. The BFS checks each possible path from each node to determine if it forms a cycle, exploring the shortest cycles first. On the contrary, DFS explores each possible path from the first node. If the path contains no destination node, another path is explored by backtracking until a cycle is found.
A. DFS Algorithm
1. First visit starting neighbour of the source node.
2. Then neighbour's first neighbour is visited.
3. The above process is repeated until no neighbours in that path.
4. After that visit next neighbour of the source node.
5. That neighbour's neighbour is visited and process is repeated until no nodes found.
B. Pseudo code for Generation of Fundamental Cycles Using DFS
Input: An undirected graph G(V;E)
Output: Set of all fundamental cycles
Nei ← set of neighbors of node root
if|Nei| ≤ 2 **then**
return
end if
for i = 1 to |Nei|-1 **do**
forj = i + 1 to|Nei|**do**
s ← Nei(i)
d ← Nei(j)
ifd is a neighbor of s **then**
Create fundamental cycle
else
pathlist = [s]
while Pathlist is not empty **do**
currentpath ← pathlist(1)
s ← last node of currentpath
removes s from pathlist
if d is a neighbor of s then
Create fundamental cycle
end if
end while
end if
end for
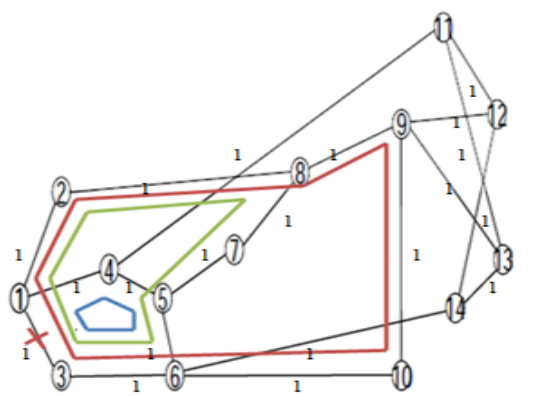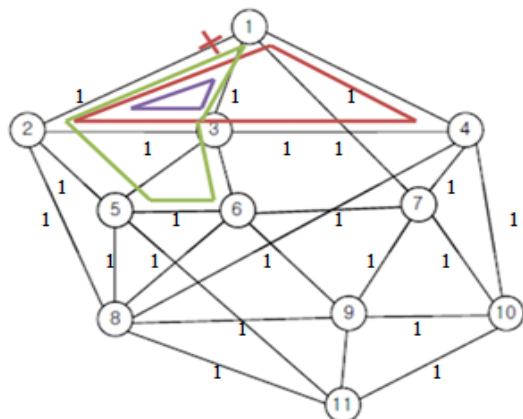**end for**
After finding all fundamental cycles based on DFS method P-Cycle generation, best cycle selection, shortest path routing and wavelength assignment is same as that of P-Cycle survivability with BFS.

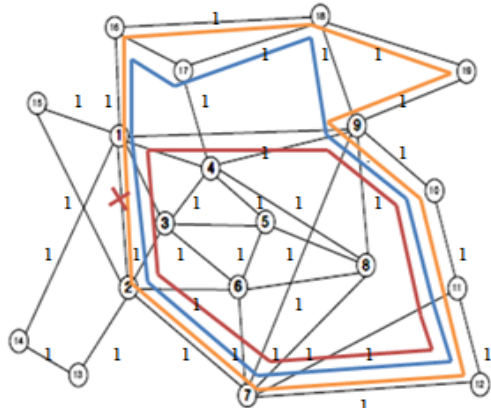## 5. Comparison of Four Test Networks

The proposed algorithm has been implemented and evaluated for different test networks. These test networks, namely the National Science Foundation Network (NSF Net), COST 239, European optical network and USA network are employed.
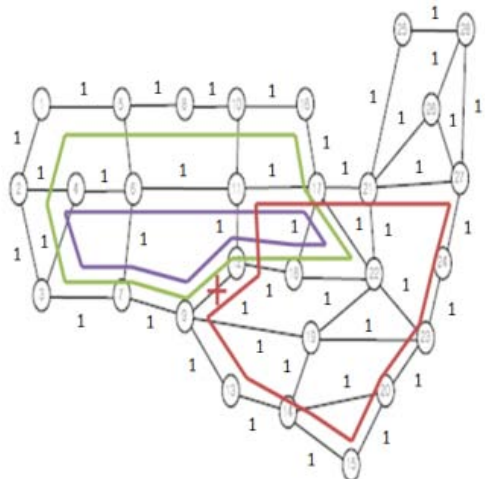
(a) NFSNetNetwork (N=14,S=21)

(b)COST239Network (N=11,S=26)

(c) EON Network(N=19, S=38)

(d)USANetwork(N=28, S=45)
Figure 4: The four test Networks used

6. Numerical Results

Number of fundamental cycles and Redundancy of NSFNet,COST239,EON network and USA networks are given in below table.Fundamental cycles are determined based on BFS and DFS methods.

Redundancy of test network is the ratio of the spare capacity of the cycle to the working capacity protected by the cycle. The redundancy (R) is expressed as

$$R = \frac{\sum_{i \epsilon s} Pi}{\sum_{i \epsilon s} Wi}$$

Where Wi is the number of units of working capacity on span i and$pi$is the corresponding number of spare capacity units on span i.

Table 1 Four test networks information

Network	NSF Net	COST239	EON NETWORK	USA NETWORK
No. of nodes	14	11	19	28
No.of spans	21	26	38	45
Fundamental cycles	7	42	44	46
Redundancy	76.%	32%	63.14%	73.3%

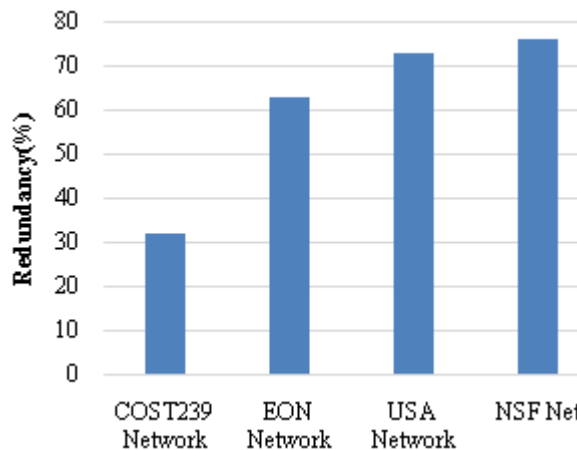## 7. Performance Evolution

Figure 5: Shows the redundancy Vs different test networks
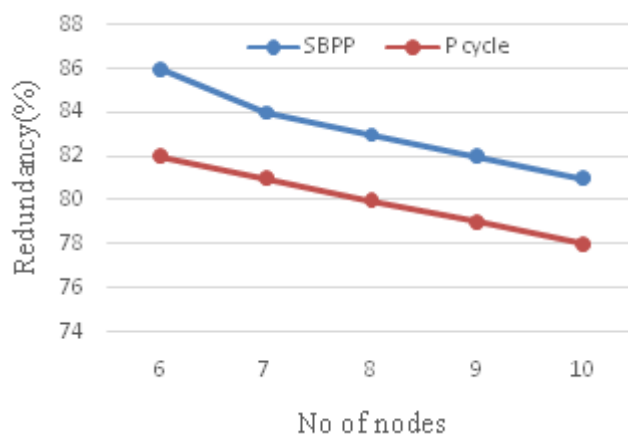

Figure 6: No. of nodes Vs Redundancy

In above graph, we observe comparison of two protection schemes i.e Shared backup path and P-cycle based on redundancy.SBPP having more redundancy and P-cycle having less redundancy than that of SBPP. With the reduction of redundancy total spare capacity reduced.
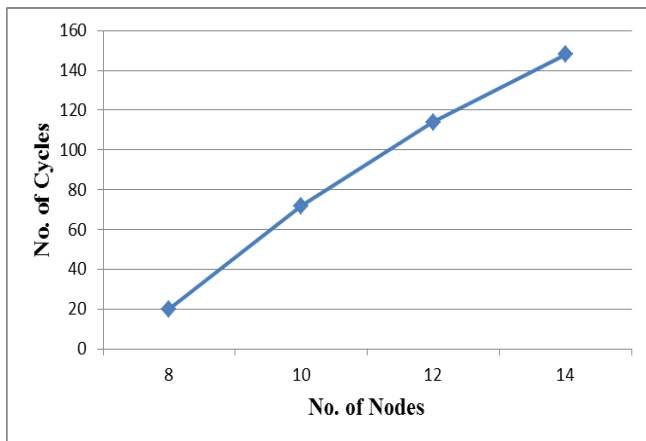
NSFNet

Figure 7: Number of p-cycles Vs Number of nodes

In any network number of cycles depends on the number of nodes if number of nodes increases then number of cycles also increased automatically.

8. Conclusion and Future Scope

The most promising approach is the pre-configured protection cycle (*p*-cycle) approach, which can offer the computation speed of ring networks and the capacity efficiency of mesh networks. We developed a new p-cycle based protection method for dynamic traffic in WDM network. We first find an optimal solution for *p*-cycle designs, the initial step requires formation of fundamental cycles by Breadth First Search (BFS) and Depth first Search (DFS) and then candidate P-Cycles are generated by using Join algorithm and best cycle is selected based on redundancy. Four different test networks redundancies are obtained based on spare capacity and working capacities of that network with unity weights. By using p-cycles to cover a network and reserving capacity on the links that are on p-cycles, the design can achieve maximum protection against single link failure for dynamic traffic. It can be concluded that the proposed p-cycle based design for dynamic traffic can achieve fast restoration while having comparable capacity efficiency as Shared Backup Path Protection.

This paper explains *p*-cycle design has been limited to static traffic. It aims to balance between fast restoration time and high capacity efficiency However, survivability in dynamic networks is more complex and it will be hard to achieve this objective. This is because the traffic demands arrive randomly and we do not have concise information on the traffic pattern. This can lead to high blocking probability and reduce the protection against network failure. Thus, dynamic traffic in real network is an important field of study for the design of survivable networks.

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