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Neeraj Mohan*, Surbhi Gupta and Abhay Bhandari

Link failure recovery using p-cycles in wavelength division multiplex (WDM) mesh networks

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Abstract: Network survivability has become a crucial requirement in all types of computer networks. It becomes even more significant for wavelength division multiplex (WDM) mesh networks due to their high speed and capacity. These networks are prone to link failures. A link failure may be a single or multiple link failure. A single-link failure is easy to locate and fix as compared to multiple link failures. A dual-link failure recovery technique has been proposed using p-cycles. This technique uses a replication method for the p-cycle circle. It is an enhancement of the original failure independent path protection p-cycle scheme. The replica properties of p-cycle have been used to protect the nodes through the same p-cycle available. Creating a new p-cycle always adds to the cost of the network, whereas using a replica of already existing p-cycle significantly reduces the network cost. The proposed technique is implemented using network simulator in three phases.

Keywords: link failure; p-cycle; WDM mesh networks.

1 Introduction

Wavelength division multiplex (WDM) mesh networks provide an inexpensive way to provide broadband internet access. In a WDM mesh network, a single node is able to communicate with multiple nodes using multiple data flows in both directions. The WDM network relies on a high-speed backhaul network, which is further composed of WDM routers. The primary use of WDM mesh networks is broadband internet access or mobile telephony backhauling. These networks can provide gateways for wired internet and other WDM services. A typical WDM network is shown in Figure 1. The network performance of a WDM network may be optimized by using multiple radios [1, 2].

The survivability schemes may be proactive and reactive in nature. Alternate routes are precalculated for a proactive scheme, whereas the alternate routes are calculated after the actual fault occurs, in the case of the reactive scheme. These schemes may be classified as protection and restoration schemes. These schemes may be used independently or jointly to make the networks more survivable. The decision to choose a proactive or reactive scheme depends on various network parameters and the nature of services. p-cycles are currently a genuinely understood plan with numerous fascinating and appealing properties. They can ensure proficient, quick and guaranteed recovery against failures [3, 4, 5]. The remaining paper is divided as: Section 2 presents the related work. The proposed method is demonstrated in Section 3. Section 4 is about results and discussion. Finally, the conclusion is presented in Section 5.

2 Related work

A lot of research has been carried out regarding in network survivability. There are many reasons for network failure, so different survivability schemes are required to handle these failures. In the present study, we are only concentrating on p-cycle based failure recovery in this section. Schupke [6] has analyzed the dual-link failure restorability using p-cycles. p-cycles were able to provide fast failure recovery in WDM networks. The number of p-cycles deployed and further survival of dual-link failures were considered in a Pan-European network case study. Using p-cycle protection, high capacity efficiency, and faster protection switching was achieved. Yadav et al. [7] have used intercycle switching (ICS) for network survivability. An idle p-cycle was used to reduce the length of the p-cycle restoration segment by using an idle p-cycle. An enhanced ICS was also used to improve effectiveness.

Zhong and Zhang [8] investigated the performance of flow p-cycle and optimal path pair based dual-source protection approaches. The results have been analyzed for source failure recovery. It was observed that the importance of source failure recovery is more as compared to the

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***Corresponding author: Neeraj Mohan**, I. K. Gujral Punjab Technical University, Kapurthala, Punjab, India,
E-mail: erneerajmohan@gmail.com
Surbhi Gupta, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, Telangana, India
Abhay Bhandari, Lovely Professional University, Jalandhar, Punjab, India

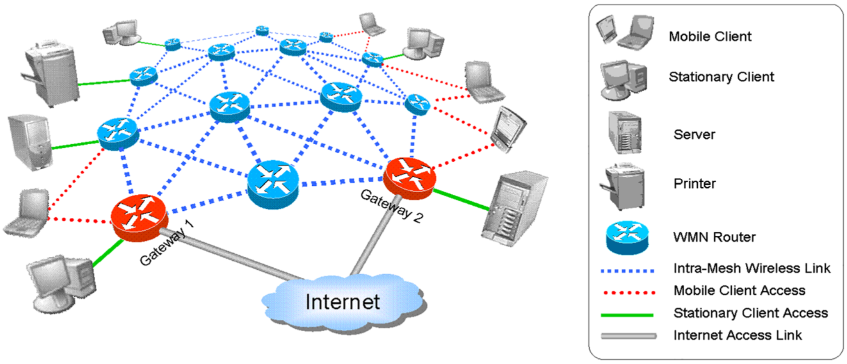

Figure 1: A typical wavelength division multiplex (WDM) network.

recovery of any other node or link. Singh [9] proposed a method of double p-cycles to provide dual failures survivability. The system used to select the best route of p-cycles on the occurrence of failure. The data on a failed link was categorized as a high priority and low priority data. The higher priority data packets were transmitted using the shortest distance route of p-cycles, whereas lower priority data packets were transmitted using longer distance routes of p-cycles.

Onguetou and Grover [10] have investigated that two-hop protecting segments were sufficient for the prevention of single span and node failures. It was shown that a two-hop protecting p-cycles was preferred as compared to span and path protecting p-cycles for some network instances. The two-hop p-cycle protecting approach has shown high competitiveness over other p-cycle survivability schemes in terms of simplicity of design and node failure restoration capabilities. Liu et al. [11] proposed a p-cycle based method for segment protection. A multicast light tree was divided into different segments. Multiple p-cycles were used to protect various nodes, links, subtrees, and multicast tree failures. The p-cycle protection performance was evaluated using the efficiency score of p-cycles. The p-cycle with the highest efficiency score was selected as a multicast route protection p-cycle.

Jaumard et al. [12] have proposed an enhanced p-cycles scheme for survivability. It was called node p-cycles (Np) scheme. It was different from the failure independent path protecting (FIPP) p-cycle scheme. It provided almost 100% protection for single node failure. It has shown better results in terms of capacity efficiency. Singh and Yadav [13] proposed a partitioning based method to minimize the length of restored paths. Network was partitioned into different domains, and p-cycles were constructed domain wise. The length of restored paths was reduced with this method. Simulation results have shown that, restored path length was reduced by 50% (approximately) for a network that was partitioned into two domains. Further, if the network was partitioned into four domains, the restored path lengths were equal to that of working path lengths.

Das et al. [14] proposed a distance adaptive p-cycle based multicast routing and spectrum allocation heuristic approach. It addressed the single-link failure problem in elastic optical networks. The problem considered was the NP-Hard problem under a static environment, where the requests are known in advance. The simulation has shown better spectrum utilization. The results have shown quick recovery as compared to a shared backup path protection based approach. Choudhury et al. [15] have proposed a protection approach and compared it with existing approaches. The results have been evaluated on elastic optical networks with various network topologies. It was observed that the p-cycle approach had performed better as compared to the segment-based approach in terms of spectrum utilization and resource utilization ratio.

A p-cycle based approach was proposed by Yue et al. [16]. Integrated linear programming (ILP) models have been developed to optimize spectrum utilization and protection in elastic optical networks. The results have suggested that the p-cycle based approach has performed better than the ring cover method for spare capacity efficiency. It was shown that the p-cycle based approach has a better chance of restoration as compared to the ring cover method. Oliveira and Da-Fonseca [17] have presented various algorithms to support the FIPP p-cycles protection. These algorithms were evaluated on various topologies with different network loads. Most of these have provided 100% protection for single failures. Some of them have provided 100% protection for two simultaneous failures. The p-cycle approach has the advantage of faster restoration and high capacity efficiency. It was observed that results for p-cycle schemes were lower bound to the results when adaptive modulation was employed.

The p-cycle technique was applied to the elastic optical network for survivability by Yue et al. [18]. Two cases i.e., full spectrum conversion and no spectrum conversion were considered. ILP models were developed to minimize the required protection capacity and used link spectra. It was observed that the improvement is not too significant using the spectrum conversion capability for the static traffic scenario. Further, it was also shown that the p-cycle technique could achieve 20% better spare capacity redundancy as compared to the ring cover technique. Lo et al. [19] have provided a hybrid protection scheme. In this scheme, interdomain links were protected using p-cycles, and FIPP p-cycles were used to protect intradomain segments. The cost-cutting was achieved through the decomposition of the column generation ILP model.

Li et al. [20] have proposed a p-cycle based protection scheme with cycle multiplexing and capacity balance. It was used to protect the multicast services under a single-link or node failure scenario. The classical Prim algorithm was improved to generate optimized multicast light-trees. The protection resources utilization was also improved. Simulation results have shown a significant reduction in redundancy and blocking probability. Zou et al. [21] proposed methods for selecting p-cycles for link protection and FIPP to survive against single-link failures. Two evaluation metrics namely, individual p-cycle cost and set of cycles cost were calculated and analyzed. Further, two algorithms were proposed: Traffic Independent P-cycle Selection and Traffic-Oriented P-cycle Selection based upon the requirement of traffic information.

Mirzaeinia et al. [22] proposed a Min-Edge P-cycle approach for network protection. The proposed approach has used an iterative algorithm. This algorithm used the minimum-weight edge in each iteration for protection. It has significantly reduced the processing time of computing P-cycles in large scale optical, server-centric networks. Guo et al. [23] proposed a genetic p-cycle combination protection strategy, which was based on an improved genetic algorithm (IGA) for elastic optical networks. In the proposed strategy, an IGA was devised to optimize the basic cycles. This strategy has reduced the bandwidth blocking probability and improved the spectrum resource utilization.

3 Proposed method

It is clear from the above literature that a lot of research has been done on p-cycle survivability. Still, some areas need attention for improvement. We have proposed a survivability method to achieve better network survivability. The proposed method is an enhancement of the original FIPP p-cycle scheme. This method has optimized the existing p-cycles for dual-link failure using the replica method. It has been implemented in three phases:

1st Phase: This phase covers the study of existing node p-cycle implementation, including simulation of global traffic in accordance with a country traces so that the scenario given can be simulated [19].

2nd Phase: After the simulation of node p-cycle, a dual-link connection has been created. Further p-cycle is also created on it so that a dual-link failure can be shown.

3rd Phase: A new p-cycle is created with a cost, but it may be replicated without any additional cost. We have applied the p-cycle replica, which hasn't added any additional cost in terms of creation and defining the new p-cycle. We have used replica properties of the p-cycle policy, process communication, and protection of nodes through the same p-cycle available. A newly built p-cycle needs additional resource list, which could include new policy according to nodes and area, weighing information of cycle and listing of the cycle with updating all tables of p-cycle throughout the network.

This process uses to take whole new resources and add up the cost to the overall network. But the addition of replica only added up in the network and updated the network without adding any weighing information, new policy creation and listing of the cycle. These things are already taken care of by the primary p-cycle from which we have created a p-cycle replica. Parameters like dual-link failure restorability have been used for evaluation. The whole process to recover from dual-link failure with p-cycle replica can be illustrated using flow chart as shown in Figure 2:

The steps of the flowchart are as follow:

(1) The multicast request is received at the ingress point.
(2) The wavelengths are assigned, and the request is routed on the tree.
(3) This multicast request is protected with the available existing p-cycle.
(4) In the case of unavailability of the existing p-cycle, there is link finding and node of the new request tree. Then configure p-cycles using the dual-link failure recovery method.
(5) If the configuration of dual-link recovery is failed, then the request is blocked. Now the whole process is repeated from the initial point.
(6) If the configuration of p-cycles using the dual-link recovery method is successful, then the request to recover from dual failure is forwarded to the p-cycle replica.

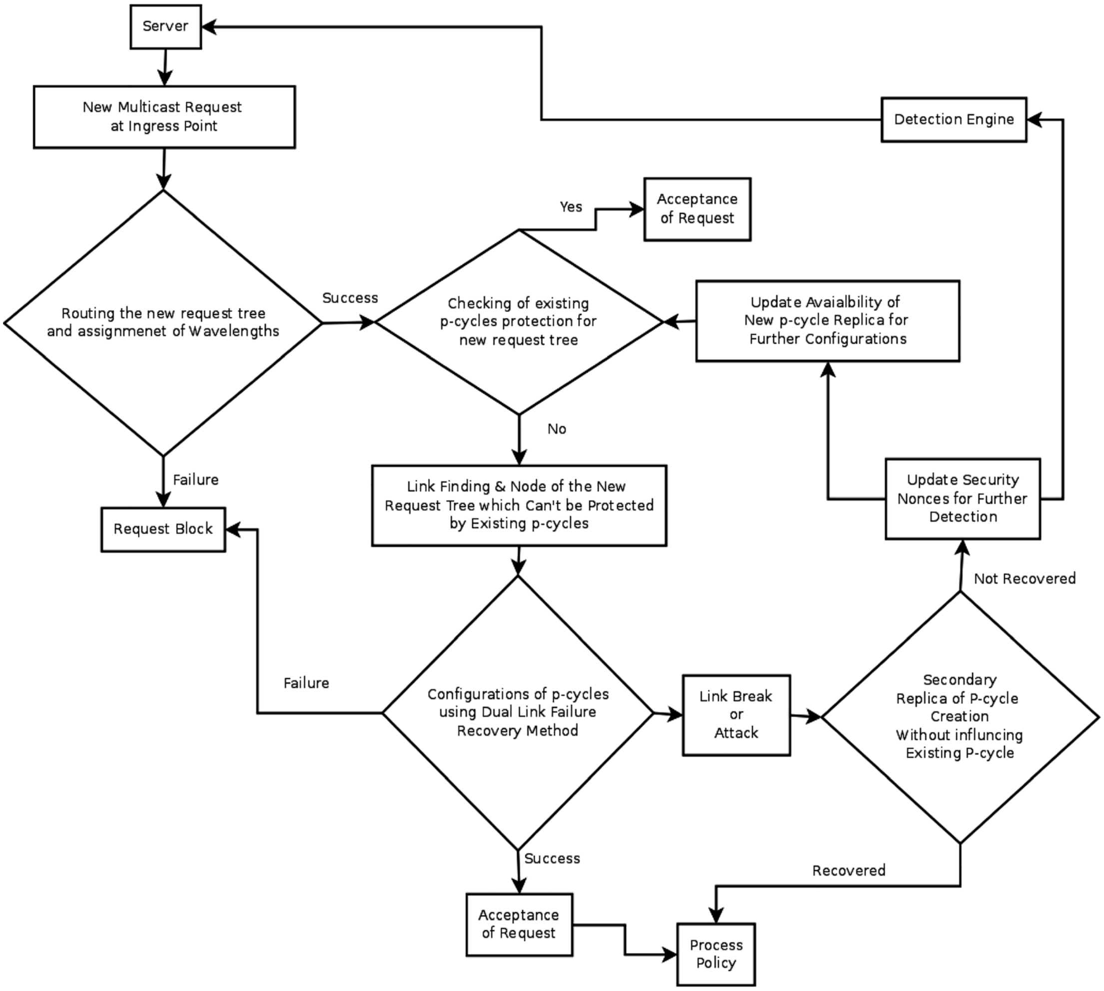

Figure 2: Flowchart for the proposed method.

4 Results and discussions

The results of the proposed technique have been obtained using Network Simulator, version 2. WDM mesh networks are used on the Ubuntu operating system for simulation. The Ubuntu operating system is an open-source operating system that provides tool command language. It is very convenient and suitable for coding and programming of network simulator. The network field is used as the logical area with different nodes acting as WDM mesh nodes with a clustered view. The pre-deployment of WDM mesh nodes is carried out, and then traffic is implemented on the network field. After this process, the predefined asymmetric keys are distributed to all wireless mesh nodes. The key distribution provides public encryption to the deployed network. It is a basic requirement for WDM p-cycle functioning.

The energy of the nodes is fixed manually, and it is kept equal initially. The simulation generates five points (used for limiting the simulation nodes for experimentation purpose) in the range of 10,000 × 10,000 m plane randomly. The coordinates for the base station is decided. The residual energy of nodes is considered for the selection of cluster heads. The nodes having higher residual energy are candidates for cluster head selection. A node having the highest residual energy is selected as a cluster head. A receive signal strength identifier is used to fetch cluster head and cluster information. Thus a secure p-cycle scheme is generated, where the base station is providing unique encrypted keys to the selected cluster head. These keys are regenerated by the base station after a particular time interval with fetching of history information from the nodes which use to store p-cycle communication. The various parameters which are used in experimentation are shown in Table 1 below:

Table 1: Parameters used for the experimentation.

Parameters	Value
Simulation time	30 s
No of subnets	5 logical subnets
No of nodes per autonomous system	5
Traffic model	Optical
Pause time	100 s
Speed	20 Gbps
Number of sources	2
Network diameter	3 hops/km
Demands working cost	92
Node degree	21
Link length	400

Table 2: Capacity redundancy percentage with variation in p-cycle length.

	Np-cycle scheme	Proposed scheme
Capacity redundancy percentage (p-cycle length = 2)	155	152
Capacity redundancy percentage (p-cycle length = 4)	154	151
Capacity redundancy percentage (p-cycle length = 6)	153	151
Capacity redundancy percentage (p-cycle length = 8)	153	150
Capacity redundancy percentage (p-cycle length = 10)	152	150
Capacity redundancy percentage (p-cycle length = 12)	141	146
Capacity redundancy percentage (p-cycle length = 14)	139	136
Capacity redundancy percentage (p-cycle length = 16)	135	131
Capacity redundancy percentage (p-cycle length = 18)	133	131
Capacity redundancy percentage (p-cycle length = 20)	132	130

These bits, store the intermediate information of whole network processes in term of traffic traveling through p-cycle. Finally, various results are obtained using various network parameters such as capacity redundancy, dual-link failure restorability, and number of p-cycles. The results are obtained and compared with existing methods [12, 24] based on the simulation results of the WDM mesh network for dual-link failure. The results obtained for these parameters are discussed below.

4.1 Capacity redundancy

Additional spare capacity is required for node protection as compared to link protection by the p-cycles for any network instance. Minimum length paths are computed as working paths subject to the condition that there exists at least one potential protection path that is link and node disjoint with the working path.

The results for capacity redundancy are shown in Figure 3 and Table 2. In Figure 3, X-axis represents the p-cycle length, and Y-axis represents the percentage of redundancy. It is observed that the capacity redundancy of the proposed work is quite low as compared to the previous Np-cycle communication. It indicates that more bandwidth is required for node Np-cycle to provide 100% protection against single-link and node failures as compared to the proposed method. Table 2 represents the detailed view of the results obtained for capacity redundancy for different p-cycle path lengths. It is observed that the value of capacity redundancy is decreased with an increase in path length. The proposed scheme is providing better performance as compare to the Np-cycle scheme.

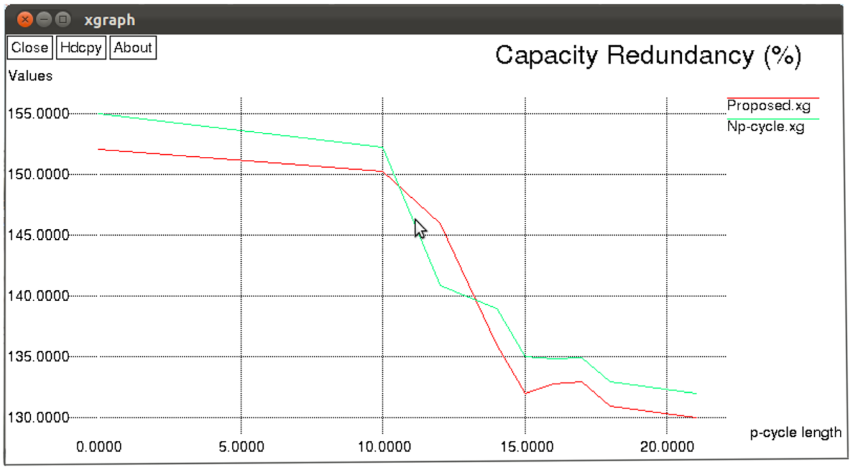

Figure 3: Results for capacity redundancy.

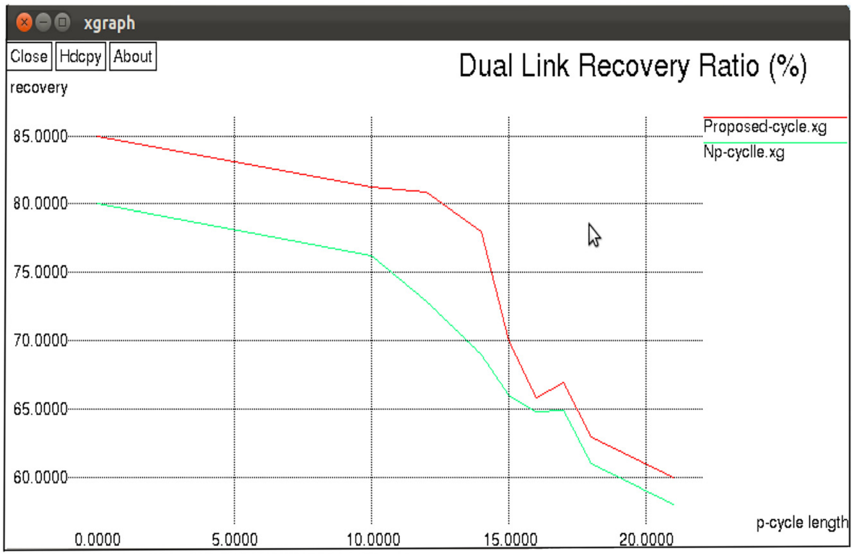

Figure 4: Results for dual-link restorability.

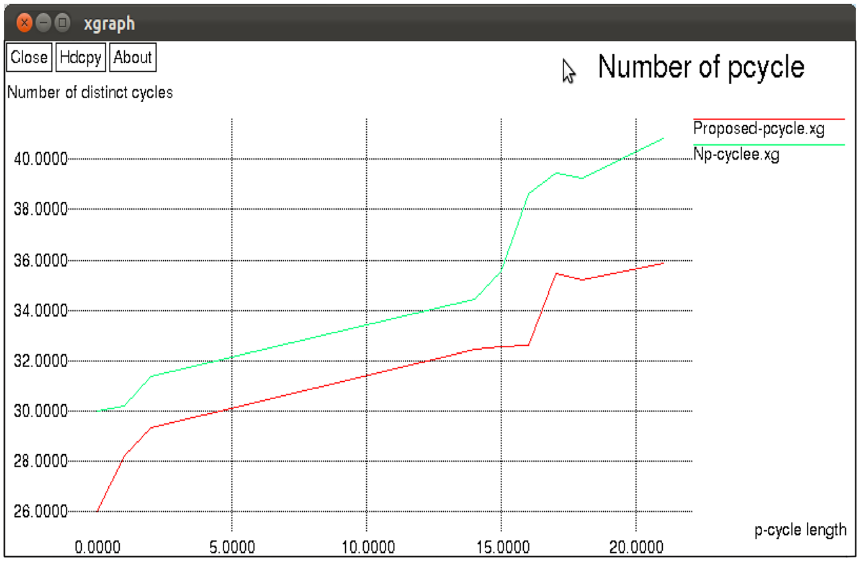

Figure 5: Comparison of the proposed scheme with the existing technique in term of number of p-cycles.

4.2 Dual-link restorability

Dual-link restorability is the parameter to provide an exact view of the recovery of p-cycles in dual-link communication in WDM mesh networks. The protection schemes w.r.t. to dual-link failure restoration ratio are compared, which are represented as dual-link recovery ratio over various network instances. The X-axis represents the p-cycle length for communication, and Y-axis represents the recovery communicated per second. These results are shown in Figures 4 and 5 and Tables 3 and 4. It is clear from the results that recovery in our proposed method is better than the previous method. The proposed method provides long term advantage with 75% of total p-cycle length. Recovery reaches a high of 84% as compared to 74% in the Np-cycle scheme.

5 Conclusions

In this paper, an enhanced p-cycle technique has been proposed for dual-link failure. It is an enhancement of the original FIPP p-cycle scheme. The p-cycle replica of the existing p-cycle is used for survivability rather than creating a new p-cycle. As a new p-cycle is not used for recovery, so number of total p-cycles required has decreased. It reduced the overall network cost significantly. Moreover, the overhead to manage additional p-cycles was also avoided. The simulation results are

Table 3: Dual-link restorability views with variation in p-cycle length.

	Np-cycle scheme	Proposed scheme
Dual-link restorability % (p-cycle length = 2)	79	84
Dual-link restorability % (p-cycle length = 4)	78	84
Dual-link restorability % (p-cycle length = 6)	78	83
Dual-link restorability % (p-cycle length = 8)	77	82
Dual-link restorability % (p-cycle length = 10)	76	81
Dual-link restorability % (p-cycle length = 12)	73	81
Dual-link restorability % (p-cycle length = 14)	69	78
Dual-link restorability % (p-cycle length = 16)	65	66
Dual-link restorability % (p-cycle length = 18)	61	63
Dual-link restorability % (p-cycle length = 20)	58	61

Table 4: Number of cycles view with variation in p-cycle length.

	Np-cycle scheme	Proposed scheme
Number of cycles (p-cycle length = 2)	31	29
Number of cycles (p-cycle length = 4)	31	29
Number of cycles (p-cycle length = 6)	32	30
Number of cycles (p-cycle length = 8)	32	30
Number of cycles (p-cycle length = 10)	33	31
Number of cycles (p-cycle length = 12)	34	32
Number of cycles (p-cycle length = 14)	34	32
Number of cycles (p-cycle length = 16)	38	32
Number of cycles (p-cycle length = 18)	39	35
Number of cycles (p-cycle length = 20)	40	35

obtained for various parameters, such as capacity redundancy, dual-link failure restorability, and number of p-cycles of WDM mesh networks. The results have shown significant improvements as compared to the existing methods.

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