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Link Failure Localization in All-Optical Network

Dr. N Radhika*, Sindhu Raj K
Department of Computer Science
Amrita Vishwa Vidyapeetham, India

Abstract— In this world of advanced technologies, the demand for high speed terabit level data transmission is increasing. Recent advances enable All-optical networks to carry terabit level data transmission. In each such network, any disruptions to the network may lead to huge amount of data loss. So it is mandatory to identify such network faults. Link failure localization is an important and challenging problem for All-optical networks. It is very difficult and challenging problem as compared to normal optical network. This difficulty arises due to the lack of optoelectronic regenerators. Numerous schemes have been proposed for the fast and efficient link failure localization in All-optical networks. We consider an optical layer based novel approach for link failure localization. The main aim of this work is to achieve unambiguous localization of link failures in the networks with minimized cost. This paper proposes an efficient method for link failure localization for improving the reliability of All-optical networks. A detailed comparative study of the monitoring schemes pertaining to m-cycle and m-trail was carried out. On the basis of this study the new approach is proposed by taking the m-trail scheme as the background idea. The whole network is considered as a graph and per-defined set of paths in the graph is considered as m-trails. The link failure localization is considered as a special case of Set Covering Problem. The link failure localization is successfully solved by applying Ant Colony Optimization algorithm on the modified set covering problem. Simulation runs showed that the new approach performs better than existing link failure localization methods.

Keywords— All-optical networks, m-cycle, m-trails, Evolutionary Algorithms, Ant Colony Optimization, Set Covering Problem.

I. INTRODUCTION

Over the last twenty years All-optical network plays an important role in communication system as they support terabit per second data transmission. All-optical network is a network where the user-network interface is optical and the data does not undergo optical to electrical conversion within the network. All-optical networks are emerging as a promising technology for terabit per second class communications. This avoids the electronic bottleneck in optical network. The key component in all-optical network is the all-optical switches. All-optical networks provide pure end-to-end paths between the source and destination. They are widely applicable in almost all network hierarchical levels. They deploy all-optical (OOO) node structure which allows optical signals to stay purely in the optical domain. Unlike OEO nodes, OOO nodes do not perform optical-electrical-optical conversion of wavelength channels. They make use of optical by passing for supporting terabit level data transmission.

The major problems in all-optical network include service disruption and tapping. Among this the service disruption covers problems like link failures, node failures, etc. This work focuses on link failures in All-optical network. Link Failure is a state of anonymous closing of connection between two nodes in a network that typically appears as a period of consecutive packet loss and can last for many seconds, followed by a change in delay, after which the link is re-established. Link failure can be single link failure and multi-link failure. As the technology advances, a need arises to identify a strong relationship between failure modes and corresponding recovery techniques. Even if it is link failure for one hour, it can result in the loss of millions and millions of dollars due to the interruption in communication.

The link failure localization is an important and challenging problem for all-optical networks. On identifying the need for a fast failure localization method, many researchers turned their attention to this area. Lot of solutions is already suggested for failure localization and a large number of related studies have been reported in the literature. Proposed work deals with a new cost effective link failure localization scheme which in turn improves the reliability of the telecommunication system. The background idea of the proposed work is the M-trail Solution for failure localization. In this work the existing solution for link failure localization problem in all-optical networks is improvised in such a way that it can be easily applied in the fields of grid computing, data warehousing and optical VPN in a reliable manner. First of all a comparative study on monitoring cycle and monitoring trail methods is carried out to prove that m-trails based schemes provides better results than m-cycle based schemes. Based on the result a new approach for link failure localization is proposed. Here, the All-optical network is considered as a graph. A set of connected edges in the graph is considered as monitoring trails (m-trails). Any failure to the link causes the failure of m-trails, which in turn broadly identifies the failed link. These m-trails require detectors, amplifiers, some amount of bandwidth etc for the proper link failure localization. So a new approach satisfying the existing demands is required i.e. a new approach that will increase the revenue. The failure localization is formulated as a special Set Covering Problem (SCP). Here the proposed work uses the evolutionary algorithm, Ant Colony Optimization (ACO) for the purpose of solving this special Set Covering problem.

The rest of the paper is organized as follows. Section II provides a detailed literature review on existing approaches for link failure localization. Section III provides a detailed study on the concept of monitoring cycle (m-cycle). Section IV gives an analysis of the concept of monitoring trails (m-trails). Section V gives an overview of the proposed approach. The proposed method is explained at section VI. The experimental analysis is explained at section VII. Section VIII summarizes the entire work.

II. RELATED WORKS

Localization of link failure is a challenging problem in the area of all-optical network. The failure of optical components like the malfunctioning of amplifiers or detectors, fiber cuts etc can lead to large amount of data loss. So the failure localization is an important challenge in the field of all-optical network. The failure recovery protocols are implemented at different layers. But the upper layer protocols require longer detection time than that of the lower layer protocols. For the proper working of All-optical network, an efficient mechanism is mandatory at the optical layer. While considering the optical layer, the link failures can be detected using monitors. In the case of a channel based monitoring scheme each channel requires a monitor. A link-based scheme is more reliable than channel based scheme as it requires only one monitor per link. As the number of monitors reduces, the hardware cost and network management efforts gets reduced, and makes the All-optical network more scalable. Most of the existing monitoring schemes deploy monitors that are responsible for creating an alarm signal upon a link failure [1-3]. The information that is derived from the monitoring scheme is submitted to the control plane of the all-optical network. This helps to localize the failure and it will make the link failure restoration much easier. Supervisory channels are used for monitoring purpose but they are not suitable for carrying real traffic. These monitoring schemes are called out-of-band monitoring. If the monitors are supervisory light paths, they are called in-band monitoring schemes. A large number of approaches for protecting link failures in mesh networks can be found. In the case of out-of-band schemes, the cost is highlighted by the number of laser diodes, and the count of supervisory channels. [4-5] In-band monitoring reduces the overhead caused by the out-of-band monitoring. They consider the parameters like the required light paths, number of transponders and monitors, band width, light path reservation and maintenance. Hybrid schemes can also be proposed as a solution for problems created by in-band and out-of-band schemes. The main aim of such hybrid methods will be to achieve Unambiguous Failure Localization. For in-band monitoring schemes the cost is calculated based on the number of required all-optical monitors. The main aim of all the researchers in the area of All-optical network is to establish a fast and cost-effective method for the localization of failed links.

In [6] a ring-like protection mechanism, where an embedded cycle on a mesh topology is proposed for protecting the mesh networks from link failures. 2-edge connected graphs are required for recovery from single-link failures. Digraphs are covered by two directed cycles such that each link is covered by a cycle in each direction exactly once. A set of cycles that has this property can be found in polynomial time for planar graphs. One of the major goals in [6] is to find the minimal backup digraph, i.e., a digraph that contains the smallest number of edges, while still covering all the nodes. Then, those edges that are not in the backup digraph need not be allocated for protecting capacity and the capacity thus freed up can be used for traffic. They do not require any protection. In spite of that, protection of all active traffic was guaranteed by this approach. The problem of finding the minimal backup digraph is to find whether a Hamiltonian cycle exists in a digraph, which is a well-known NP-complete problem. The crucial requirement in high-speed All-optical networks is the Network survivability. A number of approaches for providing survivability have considered the failure of a single component such as a link or a node as the central point. In [6], it considers the need for considering double-link failures and presented some approaches for handling such failures. It is possible to achieve recovery from double-link failures by pre-computing backup paths for links and it is possible to achieve almost 100% recovery from double-link failures with a good increase in backup capacity.[6] Connectivity plays an important role in network performance and is the fundamental vulnerability assessment factor in the network. Existing Vulnerability assessments in the networks mainly considers the inhomogeneous properties of graph elements but these solutions cannot provide an accurate evaluation over general network topologies. They cannot guarantee an increase in the performance to large scale networks. A suitable framework towards the vulnerability assessment is to consider the pair wise connectivity and formulate an optimization problem, β-disruptor on general graphs, which consists of two division β-vertex disruptor and β -edge disruptor and this approach is explained in [7]. It identifies the set of nodes and edges whose removal may lead to disruption in the global pairwise connectivity.

[8][9] explains methods like optical spectral analysis, power detection, pilot tones and optical time domain reflectometry. The problems with these methods are the lack of scalability and high implementation cost. [10] introduces a new failure localization technique in which a set of probe signals are sent along pre-defined light paths and thus the link failures were inferred. The drawbacks of these methods include high implementation cost as they require monitors to be placed on all the nodes in the All-optical network. Methods like monitoring-paths, monitoring-cycles and monitoring-trails are described in [11][12][13]. They solve the UFL problem, which is known to be an NP-complete problem, as they use a set of m-trails for failure localization [13]. The UFL problem can be explained in such a way that the All-optical network is considered as a graph and the entire graph should be covered by a set of m-trails in a way that any failure to the network links causes failure to the m-trail, which in turn unambiguously determines the link failures. This can be

achieved efficiently only if all the edges (links) in the graph are covered by unique m-trails. As the size of the task increases, the computation time becomes complex even for today's super computers. Optimal solutions for UFL task are not possible. Only sub-optimal solutions are achievable for the UFL task. But these techniques cannot be evaluated logically. So they can be evaluated by comparing them with other existing solutions with the help of simulations. Various researches in the area of All-optical network extend its scope to the field of Traffic Engineering. [14] introduces a solution for the problem of multi-link failure localization. For small dense networks, a tree-decomposition based algorithm is suggested and on the other hand, a random walk based localized algorithm is performed for large scale sparse networks. In the case of all-optical network no electronic switches are existing to identify individual link failures. For small networks with an arbitrary density and multiple monitoring locations, a tree-decomposition based method is used. For large scale networks whose monitors can only be placed at the transmission terminals, a random walk based algorithm is used in [14]. Link failure localization is important for improving the reliability of telecommunication systems. Unbounded-length random walk that originates at a source node and terminates at a sink node or destination node is considered in [15]. Both the source node and the sink node were chosen uniformly at random. A random tree originating at the sensor nodes and terminating at the sink without any cycle is realized here. There exist a very close connection between random walks and randomly generated trees. The main aim of this approach is to find the defective edges and vertices. The problem of finding defective vertices is defined as vertex group testing and that of edges is termed as edge group testing [15]. All-optical networks promise significant cost benefits, such that broadband network services can potentially be delivered to large populations at much lower cost. The significant cost savings are due to optical switching of high data-rate light paths at network nodes and this in turn helps to reduce the electronic processing costs as in the normal optical network. As in other networks, all-optical networks are susceptible to various failures, e.g., fiber cuts, switch node failures, transmitter/receiver breakdowns, and optical amplifier breakdowns. These failures can result in the disruption of communication, and is difficult to detect, localize and repair. Hence, when parts of a network are malfunctioning it is difficult to locate and identify these failures. [16] focuses on a proactive fault diagnosis framework, in which a set of probes are sent along light paths to test whether they have failed. The key objective of the non-adaptive method is to minimize the number of probes sent, in order to minimize the total hardware cost. The non-adaptive fault diagnosis problem for all-optical networks is equivalent to the combinatorial group testing problem over graphs. In the latter problem, probes can only be sent in walks over the graph. The non-adaptive fault diagnosis algorithms gives the idea that a fault-free sub-graph should be identified in the network that serve as a hub to navigate other necessary probes and also to diagnose failures in the network [16]. The approach in [17] clearly specifies that overloading of existing links may lead to degradation of the entire network throughput. So specifying the path for m-trails should be done carefully. Instead of taking arbitrary m-trail, considering predefined set of paths as m-trails makes it more realistic and cost-effective, which in turn achieves maximum throughput in the All-optical network. But in some cases these existing methods fails to deal with UFL problem. So this paper proposes a new efficient mechanism for solving UFL problem.

Firstly, a comparison between the m-cycle and m-trail methods is carried out. It was proved that the m-trails work better than m-cycle scheme. The UFL problem is defined mathematically by an NP-Hard problem called SCP [18]. The existing SCP cannot be applied directly so some simple modifications are carried out and this made it suitable for failure localization problem in All-optical network. The evolutionary algorithm, Ant Colony Optimization was applied successfully in many SCP based fields [19]. So ACO is applied to the new SCP model. Moreover, the evolutionary optimization techniques are capable of finding optimal solutions with short computation time. The major concern here is to minimize the monitoring cost and to increase the overall throughput of the All-optical network.

III. MONITORING CYCLES

A new monitoring scheme is introduced based on decomposing the whole network into a set of cycles in such a way that all the nodes and links are covered by atleast one cycle. This is called monitoring cycle (m-cycle). An m-cycle is a loop-back optical connection with a pair of laser diodes and optical monitors. It uses a supervisory wavelength on each link it traverses. If a failure occurs on the network link, the supervisory signal gets disturbed. The monitor detects this disturbance and generates an alarm signal. This scheme uses M m-cycles for covering the entire links in the network. These cycles can be represented as $\{c_1,c_2,c_3,\ldots,c_M\}$. When a network link gets failed, the monitors associated with the cycle covering that link will generate alarms. The alarm code can be represented as $\{a_1,a_2,a_3,\ldots,a_M\}$ where,

$$a_i = \begin{cases} 0, & \text{if cycle } c_i \text{ traverses through the failed link;} \\ 1, & \text{otherwise} \end{cases}$$

Consider the Figure 1, which shows a monitoring scheme consisting of three m-cycles. If a failure occurs at link 'a' the monitors associated with cycle c_1 will generate alarm code {1,0,0}. The alarm codes generated by different cycles are showed in the Table 1.In the Figure 1 we can see that the links 'c' and 'd' are on the same segments so a failure to the link 'c'or'd' generates the same alarm code. They produce the alarm code {0,0,1} which gives a decimal value of '1' as shown in Table 1. This creates confusion to the network operator in identifying where the failure occurred. To eliminate this problem we can use an additional link-based monitor for either 'c'or'd'. This increases the number of monitors and supervisory channels. This in turn increases the implementation cost. In total, the monitoring scheme based on m-cycle showed in Figure 1 requires four monitors and eleven optical channels. A large number of algorithms are proposed based on the concept of m-cycle. Heuristic depth first searching (HDFS), shortest path Eulerian matching (SPEM) and heuristic spanning tree (HST) are some of them. These algorithms try to localize the link failures in the network by minimizing the resource utilization. Among this HST yields a better performance. The m-cycle based scheme is introduced to reduce the number of laser diodes and optical monitors. But the m-cycle scheme is having the drawback that it fails in distinguishing multiple links in the same network segment as shown in the Table I.

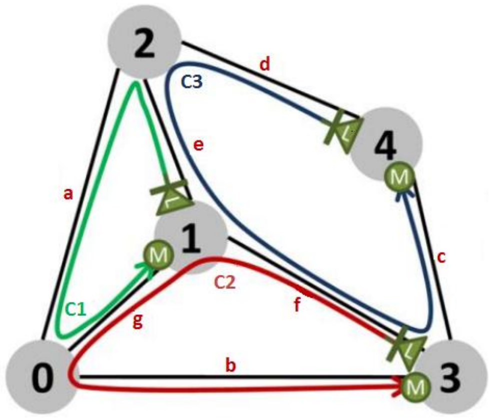

Fig.1 m-cycle based monitoring scheme.

TABLE I
ALARM CODES FOR M-CYCLE SCHEME

	C_1	C_2	C_3	Decimal
a	1	0	0	4
b	0	1	0	2
c	0	0	1	1
d	0	0	1	1
e	1	0	1	5
f	0	1	1	3
g	1	1	0	6

IV. MONITORING TRAILS

To eliminate the disadvantages in m-cycle scheme, a new method called monitoring trails (m-trails) was established. A loop-back monitoring scheme is not suitable for network topologies containing segments. So the concept of m-trail was introduced. An m-trail scheme works in the same manner as that of m-cycle but the only difference is that it is not a closed loop and the cycle structure constraint is removed.

TABLE II: ALARM CODES FOR M-TRAIL SCHEME

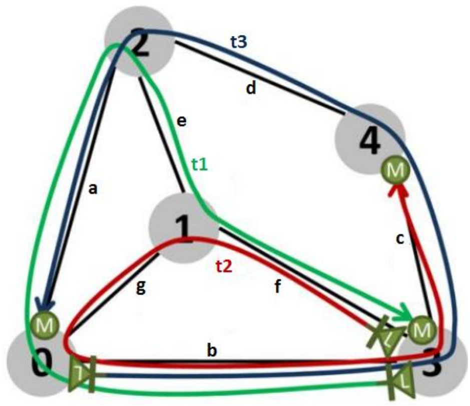

Fig.2 m-trail based monitoring scheme.

	C_1	C_2	C_3	Decimal
a	1	0	1	5
b	1	1	1	7
c	0	1	1	3
d	0	0	1	1
e	1	0	0	4
f	1	1	0	6
g	0	1	0	2

Fig. 2 shows an m-trail based monitoring scheme. M-trails can traverse a node multiple times but it traverses through the link only once. It generates unique alarm code for all links and thus it can identify the link failures occurring in the network easily. It is clear from the Table II that, m-trails can distinguish multiple links in the same segment. Links ‘c’ and ‘d’ lies on the same segment but the alarm code generated by the m-trail scheme is different for these links as shown in the Table II. For ‘c’ it produces the alarm code{0,1,1} and for ‘d’, it produces the alarm code {0,0,1}. The m-trail mechanism described here consumes three laser diodes, three optical monitors and 12 optical channels. The m-trail mechanism is designed to reduce the monitoring cost which is a combination of monitor cost and bandwidth cost. The bandwidth cost is determined by the cover length which is the sum of all the required supervisory wavelength links or m-trails in the solution. This reduces the monitoring cost by 13% over the m-cycle scheme. It is clear that, as the number of laser diodes and optical monitors increases, the required number of supervisory channels for the link failure localization also increases. So the m-trail performs better than m-cycle based monitoring schemes. The m-trail scheme tries to balance the increase in the cost due to the additional number of supervisory channels. The gain in the cost is due to the reduced number of laser diodes and optical monitors.

V. OVERVIEW OF THE MODEL

In order to understand the new complex approach proposed here it is necessary to give an idea about the evolutionary algorithms.

A. Evolutionary Algorithm

By the second half of 20th century the computational intelligence or soft computing techniques emerged. They provided optimal solutions for highly difficult problems by replacing the existing sub-optimal solutions. These strategies solve the problems with relative time complexity. Some problems cannot be described logically as the knowledge about some fields remains unknown. The evolutionary approach can be applied here too. Higher implementation cost is one of the major factors that restrict its applicability to areas where the efficiency and low computational demands are the major considerations. Evolutionary computation are stochastic optimization techniques providing better solutions by taking inspiration from the nature i.e, the competition between species and individuals in the nature. Evolutionary algorithms posses a large number of features. They can be considered as a type of generate and test method. They can process multiple candidate solutions simultaneously. They combine the results of different candidate solutions to generate an optimal solution. Evolutionary algorithms are powerful search techniques. They act as candidate solutions for various optimization problems. If they are modified properly, they can be used to generate optimal solutions for various optimization problems. Ant Colony Optimization, Swarm intelligence technique etc are sub-categories of these evolutionary algorithms.

B. ANT Colony Optimization

The ant colony optimization algorithm (ACO) is a probabilistic technique for solving computational problems which can be used to find the good paths through graphs. ACO is an evolutionary optimization algorithm that took inspiration from the nature. It is a branch of soft computing, that can be applied to various optimization problems even in the case of non-linear high dimensional problems. The natural evolution of biological organisms can be considered as an efficient optimization technique. The ACO was evolved by taking inspiration from these natural optimization techniques. Some other evolutionary techniques that took inspiration from nature includes Swarm intelligence techniques, which is based on the behavior of different communities in the nature like bird flocks etc.. Evolutionary algorithms are identified as strong search techniques. ACO is a population-based metaheuristic technique that can be used to find appropriate solutions for various optimization problems. In ACO, a set of software agents called artificial ants search for good solutions to a given optimization problem. To apply ACO, the optimization problem should be transformed into the problem of finding the best path on a weighted graph. The artificial ants incrementally build solutions by moving on the graph. The solution construction process is stochastic and is biased by a pheromone model. ACO has been applied in lots of applications in All-optical network like network routing RWA problem and so on. This work makes use of ant colony optimization process concept in link failure localization for the improvement of reliability in telecommunication network. The major components in ACO includes Ants (ants are set of software agents that search and find good solutions for a given optimization problem), Move ant (This is the process of selecting the path from a constant solution), Pheromone (The solution construction process in ACO is stochastic and is biased by a pheromone model. A pheromone is a set of parameters associated with graph components (either nodes or edges) whose values are modified at runtime by the ants), Memory (The ant starts from a randomly selected vertex of the construction graph. At each step it moves along the edges of the graph and they keeps a memory of its path, and in the subsequent steps it chooses among the edges that do not lead to vertices that it has already visited) and Next move (This is the process of selecting the next path in the graph). The first ant moves randomly until it finds a food source (F), then it returns to its nest (N), laying a pheromone trail. Other ants follow one of the paths at random and they also deposits pheromone trails. Since the ants on the shortest path deposit pheromone trail faster, this path gets filled with more pheromone, making it more alluring to future ants. The ants follow the shortest path since it is constantly filled with a larger amount of pheromones. The pheromone trails of the longer paths evaporate faster. The main goal of ACO is to generate a solution for optimization problem. The pseudo code can be shown as follows.

```
begin
    initialize parameters;
    initialize array heuristic;
    initialize pheromone value based matrix;
    while(stopping conditions like iteration limit or time limit is not fulfilled)do
        while (exist any ant, which has not worked (not reached the food source)) do
            while (a solution has not been completed) do
                choose a path to the food source with a selection probability;
                update solution;
            end
            save and update a best solution if a better solution has been found;
            update the optimum solution;
        end
        update a global best solution if a better solution has been found;
        update pheromone value;
    end
    end
```

The individual ants in the ant colony move towards the food source randomly. But in some cases they travel based on some intuitions and in some other cases they travel by following the pheromone trail left by other ants.

Whenever these new ants travel, they also leave pheromone trails behind them. This pheromone evaporates as the time passes. The ants travel with higher probability in the direction of stronger pheromone trail. ACO works in the same way as that of the ants searching for food in the ant colony. The ant starts from a randomly selected vertex of the construction graph. Then, at each construction step it moves along the edges of the graph. Each ant keeps a memory of its path, and in subsequent steps it chooses the edges that do not lead to vertices that it has already visited. An ant has constructed a solution once it has visited all the vertices of the graph. At each construction step, an ant probabilistically chooses the edge to follow among those that lead to yet unvisited vertices. The probabilistic rule is biased by pheromone values and heuristic information that higher the pheromone and the heuristic value associated to an edge, the higher the probability an ant will choose that particular edge. Once all the ants have completed their tour, the pheromone on the edges is updated. Each of the pheromone values is initially decreased by a certain percentage. Each edge then receives an amount of additional pheromone proportional to the quality of the solutions to which it belongs. This procedure is repeatedly applied until a termination criterion is satisfied. The pheromone trail starts to evaporate as the time passes, thus reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more time the pheromones have to evaporate. A short path, by comparison, gets marched more frequently, and thus the pheromone density becomes higher on shorter paths than longer ones. Pheromone evaporation also has the advantage of avoiding the convergence to a local optimal solution.

C. Set Covering Problem

The SCP is a well known NP-hard problem with many practical applications [N11]. In this work ACO is successfully applied in the SCP. The set covering problem can be formally defined as follows. Let A = (aij) be an m- row, n-column, zero-one matrix. We say that a column j covers a row i if $a_{ij} = 1$. Each column j is associated with a non-negative real cost c_j. Let I = {1, . . . , m} and J = {1, . . . , n} be the row set and column set, respectively. The SCP calls for a minimum cost subset $S \neq J$, such that each row $i \in I$ is covered by at least one column $j \in S$.

Let U be a finite universe and C be a covering set such that C is a subset of U. The cost of covering set C can be represented as c. The covering set is selected in such a way that the union of sets of all covering sets forms the whole universe U. The main task here is to cover the whole elements of U with minimum cost. This can be represented as follows: consider a set L, if $X_L : U \rightarrow \{0,1\}$ is a function of the set L.

VI. PROPOSED METHOD

The comparative study at section III and section IV clearly describes that the m-trail system works better the previously existing method m-cycle. Simulation runs were carried out and results also proved this. They localize the link failures by forming a set of m-trails. They can solve the Unambiguous Failure Localization (UFL) problem also. By considering the All-optical network as a connected graph of edges and vertices, the UFL task is to cover the graph by connected edge sets (m-trails) in such a way that the failure to any of the link causes the failure of the m-trails, which unambiguously identifies the failed link. This can be achieved if every edge in the graph of the All-optical network is covered by unique m-trails. But this should be done in a cost-efficient manner ie, the number of m-trails required for solving UFL problem should be minimum. This makes the link failure localization problem an optimization problem. The major drawback associated with most of the existing solutions for UFL problem is that they require the freedom to use arbitrarily selected m-trails in the graph of the All-optical network. Predefined set off paths in the graph are permitted to be cost-effective and this is used to achieve maximum throughput for the network.

As specified earlier, the proposed system considers the UFL problem as a special Set Covering Problem and applies the evolutionary algorithm called Ant Colony Optimization to localize the link failures in All-optical network and to enhance the overall throughput of the All-optical network. The existing Unambiguous Failure Localization problem is modified slightly to convert it into a special Set Covering Problem. The covering set should be selected in such a way that it should cover the entire elements in the universe. Here in the proposed system different sets of the covering set corresponds to different elements in the universe U. The elements of the coverage family in the proposed system can be considered as unambiguous coverage sets.

Ant Colony Optimization algorithm should be adapted to the new SCP in such a way that it can improve the reliability of the All-optical network. The major components in ACO include selection of path towards the food source, the identification of length of the path towards the food source and the updation of pheromone trails. If the path towards the food, length of the path and food source is identified by the covering sets, and the coverage cost and the coverage of whole elements in the universe is found to be maximum, then we can say that the ACO can easily solve this modified set covering problem.

The first phase is initialization. During this initialization phase a covering matrix is defined. The edges are considered as the rows and m-trails are considered as the columns for the covering matrix. Each element in the matrix carries a value and it can be defined in such a way that let $A = (a_{ij})$ be an m- row, n-column matrix and a column j covers a row i if $a_{ij} = 1$ and if $a_{ij}=0$ means that the corresponding m-trail is not covering the edge . Each column j is associated with a non-negative real cost c_j. On considering the columns in the matrix, certain values are associated with each column and they get updated during the execution of the entire process. These values include the non-negative real cost of the covering sets, a experimental heuristic value that helps the ants to select the covering sets or m-trails, the pheromone value which will be zero at the initial phase and gets updated according to the path selected by the ants and a probability value based on which the selection of the covering sets occurs. All these together reduce the computational complexity and increase the throughput of the All-optical network.

Every ant in the ant colony has a covering set family associated with it. This family is a set of covering sets whose union will cover the entire universe with minimum cost. During the initial phase this covering set family will be empty. During every iteration, the ants are allowed to select a covering set to the covering set family. The ant continues this until the union of the covering sets forms the whole universe. When a new covering set is selected by an ant, a decision making process is carried out. This process determines the number of elements covered by the new covering set that was previously covered by the existing covering set. If multiple covering sets cover the same elements, it will make the entire system complex and also makes it less optimal. In order to solve this problem a random decision making process is carried out on the last covering set to select another one or not. If the covering set in a covering set family of a particular ant covers the whole universe unambiguously, then a pre-defined set of local search process is carried out. During this, if an unselected covering set close to the selected one i.e., one which is not a member of the covering set family, gives a better solution, then the previously selected one is exchanged by the new one. If none of the exchange gives better results, then the previously selected covering set itself is kept in the covering set family. The pheromone value should be updated according to the evaporation rate and the strength of the pheromone. The updated new pheromone value is calculated according to the pre-existing pheromone value. As the evaporation rate increases the pheromone value of the m-trails decreases and they get increased based on the number of times they were selected for the current iteration. The probability values for the selection process get updated according to the updation of pheromone values. The whole algorithm continues until it satisfies some termination conditions.

The All-optical network can be represented as a directed graph. In this proposed system the m-trails are considered in such a way that every m-trails 'm' have a corresponding reverse pair also i.e, m**'**. In this case, a network link 'e' is in m if and only if it is in m**'** so that when an m-trail is selected to the covering set family by an ant then its reverse path is also added to the covering set family.

VII. EXPERIMENTAL ANALYSIS

All-optical network is a network where the user-network interface is optical and the data does not undergo optical to electrical conversion within the network. All-optical networks avoid the electronic bottleneck in optical network. The first phase of this work is a comparative study between the monitoring approaches called m-cycle and m-trails.

A network topology of 21 nodes and 25 bi-directional links are considered. We developed a network topology of 21 nodes and 25 bi-directional links for making the first phase experimental study more clear. The m-cycle and m-trail schemes are compared using this network topology. As a result of detailed experiments it was found that the monitoring cost for m-trail is less than that of m-cycle scheme. The number of m-cycles used is 4 and the monitoring cost calculated is 147. But in the case of m-trail scheme, the monitoring cost was reduced to 99. This m-trail solution reduced the monitoring cost to a great extent. For further clarification another network topology is also considered in the second phase of the work. This second one consists of 10 nodes and 21 bi-directional links. Here the theoretical minimum number of m-trails required for covering all the links is 6. Here during the experimental analysis it was found that the number of laser diodes and optical monitors required for m-trail based monitoring scheme is very less as compared to that of m-cycle. Here the maximum number of m-trails allowed in the solution is set as 9. The m-trail based scheme provided a reduced monitoring cost of 70 as compared to that of m-cycle scheme. In the case of m-cycle scheme the monitoring cost is calculated as 75. As a result we can prove that the monitoring cost obtained is very less for m-trail based failure localization schemes as compared to the m-cycle. Based on this analysis a new approach based on m-trail monitoring scheme is proposed for improving the throughput and reliability of All-optical network. In the proposed system the All-optical network is considered as a directed graph. The link failure localization problem is considered as a special set covering problem. For solving this SCP task, the evolutionary algorithm, ACO, is successfully applied. Simulation runs were carried out using the Network Simulator tool. The simulation runs are carried out with different number of nodes and edges. The number of nodes varied from 15 to 30 and the number of edges varied from 35 to 75. For simplicity the covering set cost is set to 1. The basic Network Simulator tool will not support the All-optical network simulation so an additional module is added to the Network Simulator tool version 2.27. The modification is carried out in NS 2.27 in such a way that the electrical to optical conversion as in normal optical network is avoided. The set of permitted m-trails was generated in a systematic way. First of all the shortest path between every pair of nodes is calculated. After this path selection is carried out randomly. The reverse path for these selected paths is also considered.The Simulation results showed the improvement in the performance. Thus the link failure optimization problem is converted to a task of finding the minimum number of m-trails that unambiguously cover all the links in the All-optical network topology. Previously fixed value is used as the pheromone value. It is suitable to fix the evaporation rate as 1 for simplicity. This new approach showed satisfying improvement in the computation time also.

The technical details of the optimization process for the simulation can be shown as follows:

TABLE III
TECHNICAL PARAMETERS FOR PROPOSED SYSTEM

Parameters	Values
Number of ants in the ant colony	8
Pheromone strength	0.5
Evaporation rate	1
Weighting parameter	1.5
Reselection parameter	1

Number of search in each iteration	1
Simulation time limit	50 secs
Number of runs carried out	15

VIII. SIMULATION RESULT AND DISCUSSION

Nevertheless, it can be observed from the simulation results that with the consideration of the new approach, the entire All-optical network has promising large number of inherent possibilities. The following analysis shows the performance enhancement in the all-optical network. The first phase of the work is a comparative study between the monitoring schemes called m-cycle and m-trail. An all-optical network topology with 21 nodes and 25 bi-directional links are considered. The monitoring cost calculated by using m-cycle and m-trails are shown in Table IV and Table V.

TABLE IV
M-CYCLE SOLUTION

Parameters	**Value**
M-cycles required	4
Link monitors	15
Monitoring Cost	147

TABLE V
M-TRAIL SOLUTION

Parameters	Value
M-trails required	8
Maximum m-trails allowed	9
Monitoring Cost	99

From the table IV and V it is clear that m-trails performs better in a cost efficient manner that m-cycle. To make its performance clear we considered one more small network topology and compared m-trail scheme with m-cyclescheme. In the second phase of the work we took an all-optical network topology of 10 nodes and 21 bi-directional links. In this case the minimum number of the trails required to detect the link failure is 6. The market value of laser diodes and optical monitors are almost equal, which is two to three times more expensive than the supervisory channels. By using this topology we compared the m-trail and m-cycle schemes and here also we proved that the m-trail works better than m-cycle scheme. The monitoring cost calculated shows the performance improvement in the m-trail schemes. Table VI summarizes the entire analysis.

TABLE VI.
MONITORING SCHEMES FOR AN ALL-OPTICAL NETWORK WITH 10 NODES AND 21 BI-DIRECTIONAL LINKS.

	m-cycle scheme	m-trail scheme
Number of nodes	10	10
Number of bi-directional links	21	21
Monitoring cost	75	70

So from above analysis it is clear that the m-trail works better than any other existing schemes. So we took m-trail concept as the background idea for the new proposed approach. As explained in Section VI the new approach worked better in the link failure localization in All-optical network. The following analysis compares the existing normal All-optical network to the ACO integrated all-optical network. The analysis is done by running the simulation many times by considering the parameters like packet delay, average delay rate, average packet loss rate, and throughput.

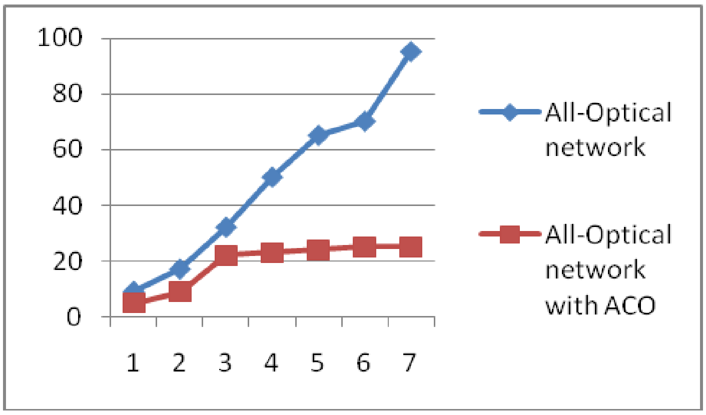

Fig. 3 Packet loss versus time

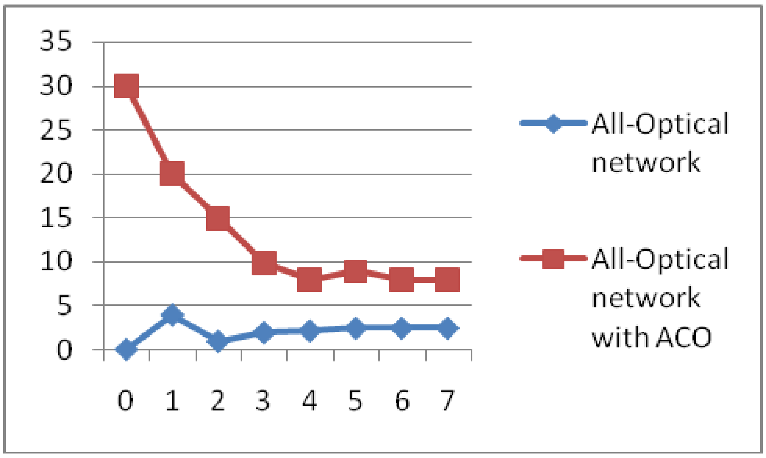

Fig.4 Average delay versus time modified All-optical network

In Fig.3 the time is taken in the x-axis and the corresponding packet loss is taken in the y-axis. Fig.3 makes it clear that the packet loss rate is less in the all-optical network when ACO is integrated into it.

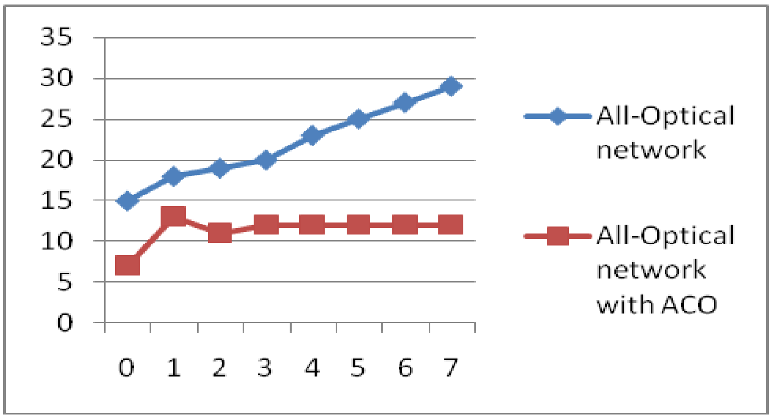

Fig.5 Data packet loss rate versus time

In Fig.4 the average delay rate is taken in the y-axis and the time is taken in the x-axis. In Fig.5 packet loss rate is taken in y-axis and time is taken in x-axis. It is clear from the fig.4 and Fig.5 that the average delay rate and data packet loss rate is also less in the modified new approach. So we calculated the throughput and compared it with the existing normal all-optical network.

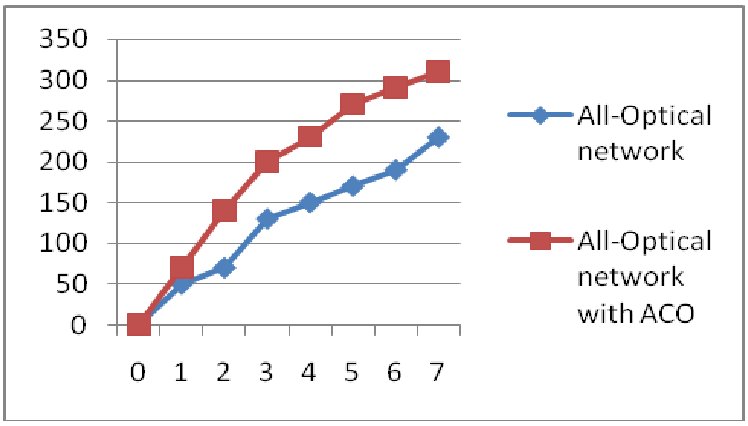

Figure 6. Overall throughput versus time.

Fig.6 shows the overall throughput comparison between normal All-optical network and All-optical network integrated with ACO. In the Fig.6 time is taken in x-axis and the throughput is taken in y-axis. From the analysis it is clear that the new approach increases the reliability of the All-optical network by reducing the packet loss rate. It increases the network throughput to a great extent. Moreover it efficiently identifies the link failures and localizes it easily. The proposed system efficiently localizes the link failures in all-optical network and in turn increases the reliability of the entire network.

IX. CONCLUSIONS

This paper proposes a novel method for link failure localization in All-optical network. The inspiration for this new approach is from the nature but done with smarter agents. Here the reliability of the All-optical network is improved by considering the link failure localization problem as a special Set Covering Problem. The link failure localization is carried out successfully by applying Ant Colony Optimization algorithm. Here the paths found by the smarter agents called ants contribute to the solution. The choice of solution is influenced by the previous results during iterations. Instead of taking arbitrarily selected m-trails, a pre-defined set of monitoring trails are considered for the proposed method. A detailed comparative study on monitoring cycle and monitoring trail schemes are carried out. The study showed that monitoring trail based system shows better performance. It exhibited fast link failure localization. So the new approach for link failure localization considered m-trail as the background idea. In this work the link failure localization was performed by applying the ACO to the modified Set Covering Problem. Simulation results showed the improvement in the performance as expected. The ACO is successfully applied in large number of areas in operational research. The heuristic approach is a hybrid combination of ACO and SCP. This proposed approach will increase the reliability of All-optical network to a great extent and promises significant cost effectiveness such that broadband network services can potentially be delivered to large populations at much lower cost than today's technologies.

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