Resilient Optical Networks Design using Particle Swarm Optimization Algorithms

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***Abstract*— Dropping of Information Communication Technology (ICT) based applications and facilities due to cable cuts failures in optical backbones leads to loss of many resources and opportunities. Therefore, resilience is an important issue toward reliable next generation networks which is a complicated designing issue and known to be an NP-hard problem. This paper presents an intelligent particle swarm optimization (PSO) algorithm to design resilient Dense-Wavelength-Division-Multiplexing (DWDM) optical networks. The path protection architecture is employed for single link failure covering in working lightpaths and the First-Fit algorithm is used for wavelength assignment to working and spare paths. The simulation results achieved from Italian network test bench for a given demand matrix demonstrate the efficiency of proposed approach for establishing two failure-disjoint paths in resilient optical networks design. The proposed approach could be extended for other resilience architectures.**

I. Introduction

Communication networks provide modern web based facilities in societies. Recently, some of daily operations and activities such as e-shopping and e-banking are mainly dependent on Internet service availability. Therefore, dropping of many Information Communication Technology based applications due to Internet operational and physical failures lead to loss of many resources and opportunities. Consequently, resilience which is the ability of the network to continue at acceptable level of service in the presence of failures and attacks is a key designing issue toward reliable high speed next generation communication networks [1].

The Dense Wavelength Division Multiplexing (DWDM) optical networks based on nodal devices such as Optical Cross-Connects (OXCs), Optical Add-Drop Multiplexers (OADMs) and developed fiber optics are widely considered as the backbones for Global Internet network [2]. The DWDM technology provides an excellent platform to exploit the huge capacity of optical fibre by multiplexing non-overlapping wavelength channels offering multiple terabits per second (Tb/s) transmission rates. The increasing deployment of Internet Protocol applications over optical backbones means that fault tolerance is essential for carrying QoS based applications [3].

The unexpected failures in optical network components such as cable cuts can potentially lead to loss of data and revenue thus producing an unacceptable deterioration in the delivered quality of service. Generally, the integration of resilience into optical core networks requires some additional resources such as redundant wavelengths through setting up spare lightpaths to restore traffic demands in the event of link failures of working ligthpaths.

Design of optical networks subject to service recovery requirements has become a crucial and complicated designing issue which known as an NP-hard problem [4]. Therefore, meta-heuristic algorithms which are generally based on some biological and natural processes such as genetic algorithms [5], bin packing [6] and particle swarm optimization are employed for solving routing and wavelength assignment and other failure covering problems.

A. Particle Swarm Optimization Algorithm

The particle swarm optimization (PSO) algorithm was proposed by Kennedy and Eberhart [7]. PSO is a population-based optimization algorithm which is based on a swarm of particles where each particle represents a potential solution in search space [8,9]. The PSO algorithms have been potentially employed for communication networks design. Joo and Smith [10] proposed a particle swarm optimization based meta-heuristic bandwidth allocation approach for Ethernet passive optical networks. A quality of service based multicast routing using a quantum-behaved particle swarm optimization algorithm was proposed in [11]. In [12] a tree-based particle swarm optimization for multicast routing was presented.

In this paper a PSO based algorithm is developed for resilient DWDM optical networks design based on dedicated path protection for single link failure covering where both working and spare ligthpaths are established during configuration of the network for arrival requests. The routing and wavelength assignment problems are solved for both working and spare lightpaths using the K-shortest paths between each node pair in demand matrix.

The rest of the paper is as follows; section II presents a mathematical model of path protection based resilient optical networks design. Section III provides a novel intelligent PSO based solution. The simulation results are described in section IV using ITALAIN test bench, while the overall conclusions are presented in section V.

II. PROBLEM STATEMENT

In this section, the mathematical model of resilient optical networks design for dedicated path protection architecture is developed. The main sub-problem for finding link-disjoint working and spare lightpaths is the routing and wavelength assignment problem [13,14] which should be solved for different traffic demands. The objective is minimizing the total number of utilized wavelengths in the network and consequently the cost of network planning.

A. Notations and Assumptions

The following notations and assumptions are used for problem formulation.

E : Set of nodes in the optical network.

V : Set of links in the optical network.

Q : Set of wavelengths on each link which is the same for all links in the network.

(s,d): A typical source and destination node pair in demand matrix.

$R^m_{s,d}$: Connection request between source and destination node pair (s,d) for m bandwidth request in terms of required wavelengths.

$L[R^m_{s,d}]_{E\times E}$: Demand matrix which includes all connection requests.

$c^{(s,d)}_{v,w}\in\{0,1\}$: is set to 1 if wavelength $w\in Q$ on link $v\in V$ is carrying traffic from source node s to destination node d for working lightpaths and to 0 otherwise.

$g^{(s,d)}_{v,w}\in\{0,1\}$: is set to 1 if wavelength $w\in Q$ on link $v\in V$ is carrying traffic from source node s to destination node d in spare lightpaths and to 0 otherwise.

$p^{(s,d)}_v$: The number of allocated wavelengths on link $v\in V$ for working path between source and destination node pair (s,d).

$s^{(s,d)}_v$: The number of allocated wavelengths on link $v\in V$ for spare path between source and destination node pair (s,d).

B. Objective Function

The objective function is to minimize the wavelengths utilized by working and spare ligthpaths to service a given demand matrix:

$$Minimize \sum_{(s,d)}\sum_{v}(p^{(s,d)}_v + s^{(s,d)}_v) \qquad (1)$$

C. Constriants

Constraint 1: The number of total occupied wavelengths, working and spare wavelengths, on each link is bounded by Q .

$$\sum_{(s,d)} p^{(s,d)}_v + \sum_{(s,d)} s^{(s,d)}_v \le Q,\quad \forall v\in V \qquad (2)$$

This constrained called the link-capacity constraint, that means the total wavelengths assigned to working and spare ligthpaths on each link v must be less than or equal to the whole wavelengths on that link.

Constraint 2: Each link of the working and spare paths that are assigned to a connection request between each node pair (s,d) must satisfy the demand between that node pair.

$$\sum_{w} c^{(s,d)}_{v,w} = m,\ \forall v\in V,\ \forall R^m_{s,d}\in L$$

$$\sum_{w} g^{(s,d)}_{v,w} = m,\ \forall v\in V,\ \forall R^m_{s,d}\in L \qquad (3)$$

This constrained called the satisfaction constraint, that means the total wavelengths assigned to working and spare ligthpaths on link v must be less than or equal to the whole wavelengths on link v.

Constraint 3: Each wavelength can be utilized only, by working paths or by spare paths. This constraint called wavelength utilization constraint.

$$\sum_{v} c^{(s,d)}_{v,w} + \sum_{v} g^{(s,d)}_{v,w} \le 1 \qquad (4)$$

Constraint 4: The working path and the spare path between each node pair (s,d) must be link-disjoint. This constraint guarantees that in the event of failure only one of the working path and spare path will fail, and the failure would be covered by spare path.

III. PARTICLE SWARM OPTIMIZATION BASED SOLUTION

The particle swarm optimization approach is employed to find the shortest path between each source and destination node pair (s,d) in optical network. The key issue for developing a particle swarm optimization model of shortest path problem is to encode the lightpaths into the location of particles in swarm. The location of a typical particle in the swarm is represented by an array with length E equals to the number of nodes in the network, and each element of this array is assigned with a priority number [15]. The particle's location could be encoded by a fix length array with priority values and the actual path could be decoded from the array.

At each iteration every particle maintains two best values called *PBEST* and *GBEST* which are the best value of achieved particle's fitness and the overall best value obtained by any particle in the swarm so far, respectively. Furthermore, each particle is represented by two vectors which are the position and the velocity vectors.

A. *Fitness Function*

The fitness function for the shortest path problem is to minimize the length of path.

$$Fitness = \sum_{v \in Path} L_v \tag{5}$$

where L_v is the length of link v in optical network.

The steps of PSO based model for the shortest path problem is as follows;

Step 1: Setting the particle swarm optimization parameters including particle swam size (S_{pso}), number of iterations (I_{pso}), inertia weight (w), and acceleration coefficients (c_1, c_2).

Step 2: Randomly initializing priority valued position and velocity of particles [15].

Step 3: Decoding the priority based vectors of each particle into valid path from source node s to destination node d.

Step 4: Calculating the fitness value of *kth* particle, F_k, using equation number (5).

Step 5: Comparing the F_k with $PBEST_k$. If F_k is better than $PBEST_k$, then set $PBEST_k$ value equal to F_k, and the associated position coordinate equal to the current location vector values.

Step 6: Comparing the fitness value with *GBEST*. If the current value is better than *GBEST*, then set *GBEST* to the current particle's position vector values.

Step 7: Updating the velocity and position vector of each particle according to following equations.

$$v_{t+1} = wv_t + c_1 r_1 (PBEST - x_t) + c_2 r_2 (GBEST - x_t) \tag{6}$$

$$x_{t+1} = x_t + v_{t+1} \tag{7}$$

where v_t and x_t are the velocity and position vector of particle in iteration number t, r_1 and r_2 are the uniformly distributed random number independently generated with in $[0 \quad 1]$.

Step 8: Repeating steps 4-7 for the number of iterations, $t \le I_{spo}$.

Step 9: Finding the best feasible solution. If the solution of step 3 is feasible, then select it as the shortest path; otherwise the last *GBEST* which is feasible.

IV. SIMULATION RESULTS

This section presents some simulation results to evaluate the PSO based resilient approach in optical core networks. The simulation program was developed in MATLAB. The ITALIAN network shown in Fig. 1 was considered as the test bench topology. The topology was considered as a representative of optical mesh backbones for client networks. In the physical layer, all optical links were assumed to be bidirectional which could carry signals in two opposite directions and all nodes were capable of full wavelength conversion. The number of pre-computed shortest paths was assumed to be four paths.

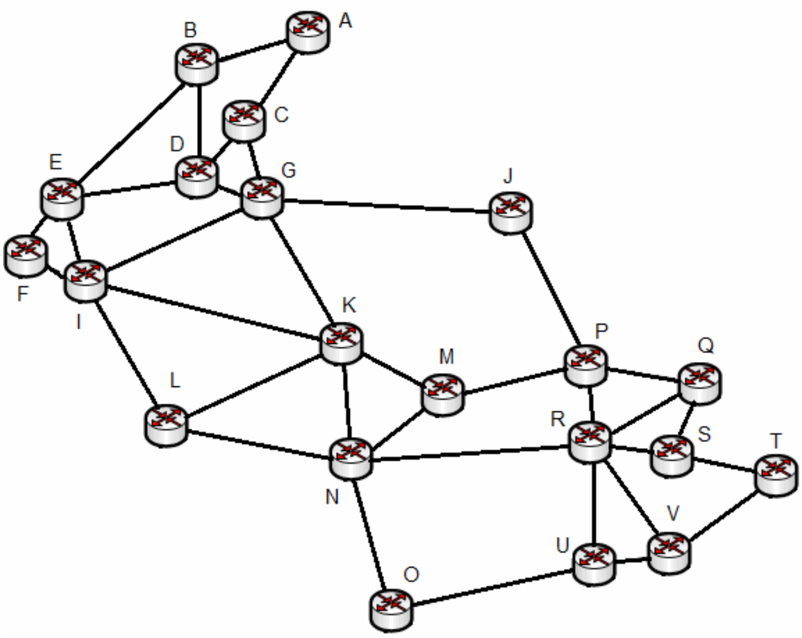

Figure 1. The ITALAIN Network Topology

The simulation results for setting up working and spare failure-disjoint paths considering a given demand matrix consisting eight connection requests were presented in Tables I and II. The first column of both indicates the (s,d) node pair and the volume of each connection request in terms of the number of required wavelengths. The second and third columns show the routing and wavelength assignment solutions. The number of assigned wavelengths to working paths was 88 wavelengths using the “First-Fit” approach.

The routing and wavelength assignment solutions for dedicated path protection architecture for finding spare ligthpaths were shown in Table II. The number of utilized wavelengths by spare ligthpaths was 153 wavelengths. The primary and spare ligthpaths of all connection requests are link-disjoint; therefore the spare lightpaths protect the working ligthpaths upon any single link failure.

The first shortest paths were assigned to working paths and the wavelength redundancy is 173% for covering single cable cuts which could be reduced by employing shared path protection architectures.

TABLE I.
WORKING LIGHTPATHS

(s,d),m	Working Path	Wavelengths
(A,B),7	A-B	7
(G,J),6	G-J	6
(E,K),4	E-I-K	8
(R,T),3	R-S-T	6
(J,N),8	J-P-M-N	24
(O,T),5	O-U-V-T	15
(I,M),2	I-K-M	4
(F,L),9	F-I-L	18

TABLE II.
SPARE LIGHTPATHS

(s,d),m	Spare Path	Wavelengths
(A,B),7	A-C-D-B	21
(G,J),6	G-K-M-P-J	24
(E,K),4	E-F-I-L-K	16
(R,T),3	R-V-T	6
(J,N),8	J-G-K-N	24
(O,T),5	O-N-R-S-T	20
(I,M),2	I-L-N-M	6
(F,L),9	F-E-I-K-L	36

V. CONCLUSION

Recently the meta-heuristic algorithms are widely employed for modeling and solving complex and NP-hard problems in network engineering. In this paper a particle swarm optimization based algorithm was proposed for designing resilient optical backbones. The dedicated path protection approach was considered for traffic recovery upon single fiber cuts in working lightpaths. The proposed PSO based approach was evaluated for a predefined demand matrix considering ITALIAN test bench network. The simulation results demonstrated the ability and efficiency of PSO for finding a pair of link-disjoint working and spare lightpaths between each node pair in demand matrix. The wavelength redundancy was 173% which could be reduced by shared path protection approaches.

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