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A Memetic based Approach for Routing and Wavelength Assignment in Optical Transmission Systems

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Abstract: In optical networks, Routing and Wavelength Assignment (RWA) problem is one of the major optimization problems. This problem can be solved by different algorithms such as Genetic Algorithm (GA), Artificial Bee Colony (ABC), Ant Colony Optimization (ACO), etc. Shuffled Frog Leaping Algorithm (SFLA) is implemented in the proposed work, to solve the RWA problem in long-haul optical networks. The goal is to use minimum number of wavelengths and to reduce the number of connection request rejections. Cost, number of wavelengths, hop count and blocking probability are the performance metrics considered in the analysis. Various wavelength assignment methods such as first fit, random, round robin, wavelength ordering and Four Wave Mixing (FWM) priority based wavelength assignment are used in the analysis using SFLA. Number of wavelengths, hop count, cost and setup time are included in the fitness function. The SFLA algorithm proposed, has been analyzed for different network loads and compared with the performance of genetic algorithm.

Keywords: ACO, GA, RWA, SFLA

Memetični pristop za usmerjanje in dodeljevanje valovnih dolžin v optičnih prenosnih sistemih

Izvleček: V optičnih omrežjih je največji problem optimizacije usmerjanje in dodeljevanje valovnih dolžin. Problem je rešljiv z uporabo različnih algoritmov, kot so genetični algoritem (GA), umetna kolonija čebel (ABC) in optimizacija kolonije mravelj (ACO). V članku je, za reševanje problema RWA v optičnih omrežjih na dolgih razdaljah, implementiran algoritem mešanega žabjega skakanja (SFLA). Cilj je uporabiti najmanjše število valovnih dolžin in zmanjšati število zavrnitev zahtevkov za povezavo. Stroški, število valovnih dolžin, število preskokov in verjetnosti blokiranja so parametri analize uspešnosti. V analizi se z uporabo SFLA uporabljajo različne metode določanja valovnih dolžin, kot so prvo prileganje, naključno, krožno določanje valovnih dolžin in dodelitev valovne dolžine s štirimi valovnimi mešanji (FWM). Predlagani algoritem SFLA je bil analiziran za različne obremenitve omrežja in primerjan z učinkovitostjo genetičnega algoritma.

Ključne besede: ACO, GA, RWA, SFLA

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1 Introduction

In long-haul, high capacity communication networks, Optical systems and networks are vital. The optical data is routed at intermediate nodes, depending on their wavelength (Le et al 2005 and Bisbal et al 2004). Different optical components are used to regulate the data traffic and to direct it to the end user like optical splitters / combiners being used to separate the optical signals and collect them as they propagate through the network (Ramaswami & Sivarajan 2000). Wavelength based services like routing and grooming are the provided by optical networks. Transmission capacity and communication range are better in optical fiber communication (Vidmar 2001).Transferring more information with minimum equipment is the goal of an optical communication system (Batagelj 2014).

The capacity of optical system can be improved by Wavelength Division Multiplexing (WDM). These systems and networks make use of the features of optical fibers and WDM components. Different problems that persist in optical wavelength division multiplexing are optimal routing, traffic grooming and wavelength assignment, survivability and Quality of Service (QoS) problems (Bhanjaa and Mahapatra 2013 and Adhya and Datta 2009). More computational time is involved in solving these problems using conventional methods (Wang et al 2014 and Triay et al 2010). Selecting a suitable path and allocating a available wavelength for an optical connection results in the problem called Routing and Wavelength Allocation (RWA) problem (Srinath & Janet 2013). To solve the RWA problem, which are in real- world optical networks, Multi-objective evolutionary algorithms based on swarm intelligence are used (Kavian et al 2013 and Largo et al 2012). Also Genetic Algorithm is used in many application due to less complex computation (Başak et al 2014). Shuffled Frog Leaping Algorithm is used to solve this RWA problem in the proposed research. Certain simpler or similar algorithms lead to poor performance or are too complex to be used. Therefore, a computationally feasible algorithm is used for a good performance of the network.

In this research paper, two optimization algorithms - genetic algorithm and shuffled frog leaping algorithm are used in the routing and wavelength assignment problem model. In variety of fields, Genetic Algorithm is used to solve many problems and hence comparison between these two algorithms are done. The simulation results and analysis are discussed and the conclusions of the study and possible future work are presented.

2 Routing and wavelength assignment

In dynamic routing and wavelength assignment, the requests for lightpath will arrive dynamically. Wavelength continuity constraint is that, on all the links in its path, a lightpath should use same wavelength. The time for which a lightpath and the required resources remain occupied is called as holding time. When the holding time expires, the resources allocated are made free and are made available to support other lightpath requests. The RWA model involves a network model, routing model, wavelength assignment model and an optimization algorithm (Bhanjaa et al 2013). Routing and Wavelength Assignment model with optimization is shown in Fig.1.

Figure 1: Block diagram of an RWA model with optimization

2.1 Network and Routing Model

A network which contains N number of nodes can be modeled as a graph NG(R,E), where E denotes the set of edges representing the connectivity between the nodes and R represents the set of nodes like routers or switches. It is assumed that the links between the nodes are bidirectional. National Science Foundation Network (NSFNET), Advanced Research Projects Agency Network (ARPANET) and European Optical Network (EON) are few standard network architectures currently in use.

One of the major problems in optical networking is Routing and Wavelength Assignment (RWA). The goal is to reduce the rejection of connection requests i.e. to maximize the number of optical connection. For every connection request, a particular route and a wavelength should be assigned. If wavelength converters are not used in the network, then same wavelength should be used throughout the path. Same optical link may be shared by two connections requests, if different wavelengths are provided (Bhanjaa et al 2012).
Fitness function to be maximized is given by

$$f_x = \frac{W_x}{\sum_{j=1}^{k_x-1} C_{gx(j),gx(j+1)}} + \frac{W_x}{\sum_{(i,j)\in E} H_{i,j}^x} + \frac{W_x}{T_x} \quad (1)$$

W_x is the free wavelength factor. The value of this factor is one, if same wavelength is available in all the links of path x or otherwise, zero. In the first term, the summation defines the total link cost of the path and similarly in the second term, the summation represents the total number of hops in the path. If link (i, j) is a part of path x, the variable $H^x_{i,j}$ takes the value of one and otherwise, it is zero. The set up time of the path x is represented by the variable T_x. Variable K_x represents the length of the x-th chromosome or number of memeplexes. The route is optimal when the objective function maximizes with the following constraints being satisfied.

$$\sum_{(i,j)\in E} I_{ij}^{lp} - \sum_{(j,i)\in E} I_{ij}^{lp} = 1, \text{ if i=S, Ip ÎLP} \quad (2)$$

$$\sum_{(i,j)\in E} I_{ij}^{lp} - \sum_{(j,i)\in E} I_{ij}^{lp} = -1, \text{ if i=D, IpÎLP} \quad (3)$$

$$\sum_{(i,j)\in E} I_{ij}^{lp} - \sum_{(j,i)\in E} I_{ij}^{lp} = 0, \text{ if i}\neq\text{S, i}\neq\text{D, IpÎLP} \quad (4)$$

$$\sum_{\substack{i\neq j\\(i,j)\in E}} I_{ij}^{lp} \leq 1, \text{ if i}\neq\text{D, IpÎLP} \quad (5)$$

$$\sum_{\substack{i\neq j\\(i,j)\in E}} I_{ij}^{lp} = 0, \text{ if i=D, IpÎLP} \quad (6)$$

$$\sum_{(i,j)\in E} I_{ij}^{lp} \leq h_0, \text{ for t} \leq \text{T} \quad (7)$$

$h_0 < \sum_{(i,j)\in E} I_{ij}^{lp} \leq (N-1)$, for t > T (8)

Equations (2) to (6) represent the flow conservation constraint. Equations (7) and (8) represent the hop count constraint.

2.2 Wavelength Assignment Model

First fit and Random fit are the wavelength assignment techniques are the generally used techniques. First Fit method chooses the available wavelength with the lowest index whereas random fit method identifies the available wavelengths and chooses one amongst them in a random manner. For both the algorithms, O(w) is the complexity and w indicates the number of wavelengths. First Fit performs better than Random Fit. Other wavelength assignment techniques such as round robin technique, wavelength ordering technique and Four Wave Mixing aware wavelength assignment technique are also used for the analysis. One of many fiber nonlinear effects is a four-wave mixing (FWM) phenomenon (Batagelj et al 2004 and Batagelj & Vidmar 2002). When more than two wavelengths of light interact with each other while propagating through the medium, a spurious component is produced. Since the FWM crosstalk power will be more over the center of transmission window, in the FWM aware wavelength assignment technique priority is given to the wavelengths towards the edges of the transmission window. Complexity of this method is $O(N^3 \log^2 N)$, where N is the number of nodes in the network. In the fitness function proposed, Wx the free wavelength factor is updated after the wavelength assignment phase. In the wavelength assignment model, if the link (i, j) is used by the lightpath lp, the variable I_{ij}^{lp} assumes one else it assumes zero. Variable I_{ijw}^{lp} is the lightpath wavelength indicator. It shows whether the lightpath lp uses wavelength 'W' on link (i, j). Variable $I_{ijw}^{lp}(x,y)$ is the lightpath wavelength link indicator and this is one when the lightpath uses wavelength 'W' on link (i, j) between the nodes x and y. l(x,y) takes one if a physical link exists between the nodes x and y (Bhanjaa et al 2010).

The wavelength continuity constraints are

$$I_{ij}^{lp} = \sum_{w=0}^{W-1} I_{ijw}^{lp}, \ \forall \text{ (i,j)} \quad (9)$$

$$I_{ijw}^{lp(x,y)} \leq I_{ijw}^{lp}, \ \forall \text{ (i,j)}, \ \forall \text{ (x,y)}, \ \forall \text{ w} \quad (10)$$

$$\sum_{i,j} I_{ijw}^{lp(x,y)} \leq 1, \ \forall \text{ (x,y)}, \ \forall \text{ w} \quad (11)$$

$$\sum_{w=0}^{W-1}\sum_{x} I_{ijw}^{lp(x,y)} l^{(x,y)} - \sum_{w=0}^{W-1}\sum_{x} I_{ijw}^{lp(y,x)} l^{(y,x)} = I_{ij}^{lp}, \text{ y=j} \quad (12)$$

$$\sum_{w=0}^{W-1}\sum_{x} I_{ijw}^{lp(x,y)} l^{(x,y)} - \sum_{w=0}^{W-1}\sum_{x} I_{ijw}^{lp(y,x)} l^{(y,x)} = -I_{ij}^{lp}, \text{ y=i} \quad (13)$$

$$\sum_{w=0}^{W-1}\sum_{x} I_{ijw}^{lp(x,y)} l^{(x,y)} - \sum_{w=0}^{W-1}\sum_{x} I_{ijw}^{lp(y,x)} l^{(y,x)} = 0, \text{ y}\neq\text{i, y}\neq\text{j} \quad (14)$$

3 Optimization algorithms

3.1 Genetic Algorithm

The flow involved in Genetic Algorithm is shown in Fig.2. Initial population is created and it works iteratively on this initial solution set. The algorithm converges to arrive on best solution (Kavian et al 2009).

Chromosome is the route or path encoded from source to destination. A sequence of nodes creates each chromosome and is generated based on the topology of a particular network. Each chromosome may be of different length and each of them encodes the path from the sender node S to the receiver node D. By random selection of solutions, initial population is created. The initial population has only one chromosome.

Position of the nodes in routing paths do not affect the crossover. One pair is randomly chosen and the crossing site of each chromosome is identified by the locus

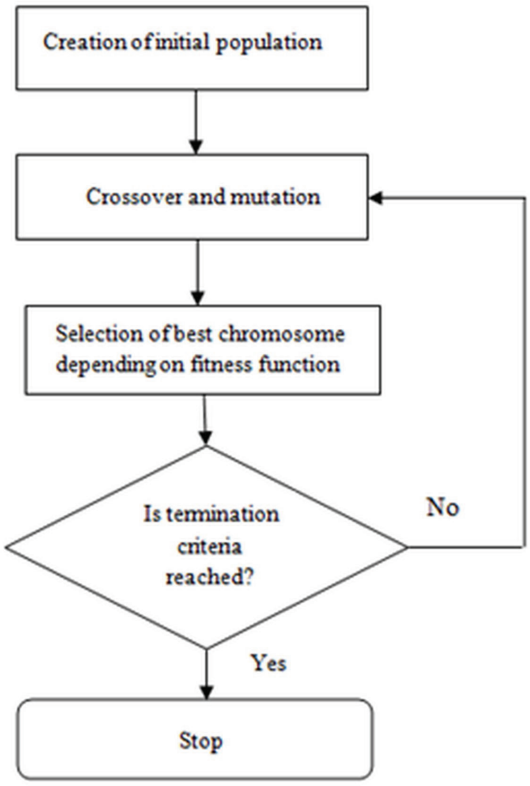

Figure 2: Flowchart of GA

of each node. The crossing points of two chromosomes may be different from each other (Ahn and Ramakrishna 2002). During mutation, the mutation site of the parent chromosome is chosen randomly. Based on the topology database, different path is chosen from the mutation site to the destination.

The fitness function is formulated as in equation (1) and is to evaluate the quality of the chromosomes.

3.2 Shuffled Frog Leaping Algorithm

Shuffled Frog Leaping Algorithm (SFLA) is a meta-heuristic algorithm inspired by nature. Novelty of this algorithm is its fast convergence speed (Hemalatha and Mahalakshmi 2017). Various other factors that cause latency or delay in the optical network at the physical layer are the optical fiber, optical amplifiers and other modules in the network out of which the propagation delay caused by the fiber is more predominant (Eržen and Batagelj 2015). Advantages of both the genetic-based memetic algorithm and the behavior-based Particle Swarm Optimization (PSO) algorithm are combined together in SFLA. SFLA combines the benefit of the local search tool of Particle Swarm Optimization (PSO) and the idea of mixing information from parallel local searches, to move towards a global solution (Muzaffar et al. 2006). In the SFLA, group of frogs that define possible solutions are referred to as population. These groups of frog are partitioned into several communities and are called as memeplexes. Each frog in the memeplexes perform local search. Behavior of each frog within the memplex influences the behavior of the other frogs and through a process of memetic evolution it is developed. After a certain number of memetic evolutions, the memeplexes are forced to mix together and through shuffling process, new memeplexes are formed. Until convergence criteria are satisfied, the local search and the shuffling processes continue. The flowchart of Shuffled frog leaping algorithm is illustrated in Fig.3 (Roshni et al 2016).

The steps involved are given as below:

a) SFLA involves a population 'P' of possible solution, defined by a group of virtual frogs(n).
b) Frogs are sorted in descending order based on their fitness and partitioned into subsets called as memeplexes (m).
c) Frog i is expressed as $X_i = (X_{i1}, X_{i2}, \ldots X_{i3})$ where X represents number of variables.
d) Frogs with worst and best fitness are identified as X_w and X_b within each memeplex.
e) Frog with global best fitness is identified as X_g.
f) The frog with worst fitness is improved based on the following equation.

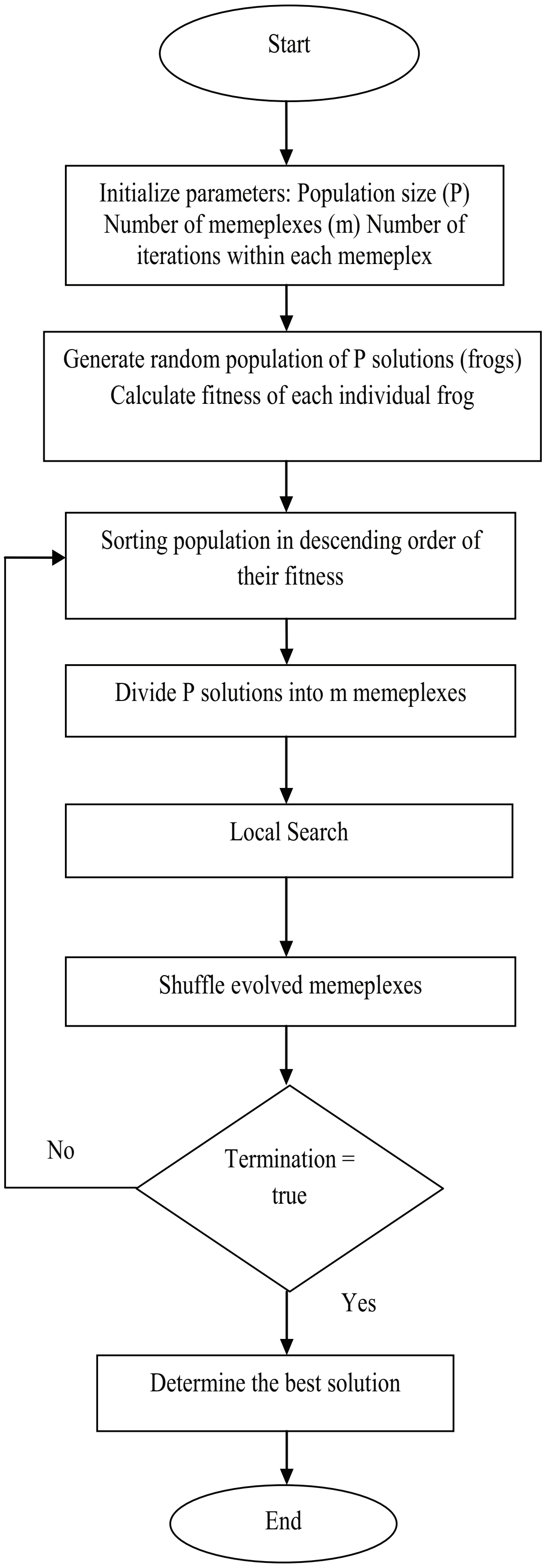

Figure 3: Flowchart of SFLA

$$D_i=rand()\ (X_b - X_w) \quad (15)$$

$$X_{neww}=X_{oldw}+D_i \quad (16)$$

Rand() is a random number in the range of [0,1] (Muzaffar 2006).

D_i is the step size of i-th leaping frog and D_{max} is the maximum step size allowed. If the fitness value of new X_w is better than the current one, X_w will be accepted. Otherwise, the calculated step size of leaping frog D_i and new fitness X_{neww} are recomputed with X_b replaced by X_g. Further if no improvement is achieved, a new X_w is generated randomly. The update operation is repeated for specific number of iterations. After a predefined number of memetic evolutionary steps within each memeplex, the solutions of evolved memeplexes are replaced into new population. This is called shuffling process. Global information exchange among the frogs is promoted by the shuffling process. The population is then sorted in order of decreasing performance values and updates the population based on best frog's position, repartition the frog group into memeplexes and progress the evolution within each memeplex until the conversion criteria are satisfied (Samuel and Rajan 2014).

4 Simulation results

The optimization algorithms have been implemented using the software MATLAB. Simulations are carried out for a 14 node network having 21 bidirectional links similar to NSFNET network topology. The fitness against the execution time for the genetic algorithm and shuffled frog leaping algorithm with 4 number of channels fand a load of 10 Erlangs is shown in Fig.4. Number of hops, holding time and cost are the paramateres included in the fitness function. The shuffled frog leaping algorithm has a better fitness compared to the genetic algorithm.

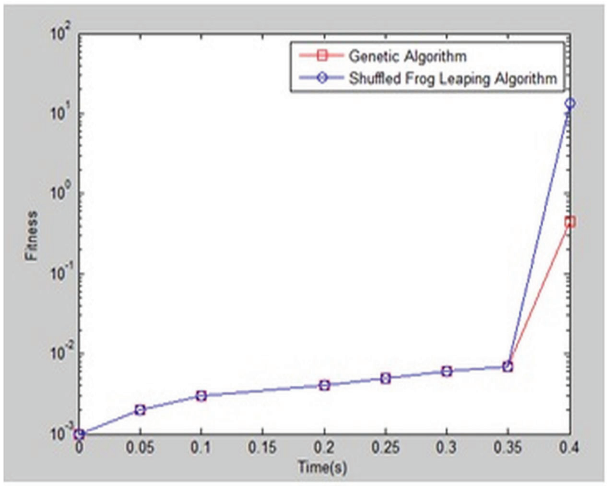

Figure 4: Fitness function of GA and SFLA

The mean blocking probability against number of generations for GA and SFLA with 4 number of channels fand a load of 10 Erlangs are shown in Fig.5 and 6 respectively. By comparing both the figures, its is clear that the blocking probability is lesser in SFLA than in GA. Among the three wavelength assignment techniques Round robin Technique has the least blocking probability.

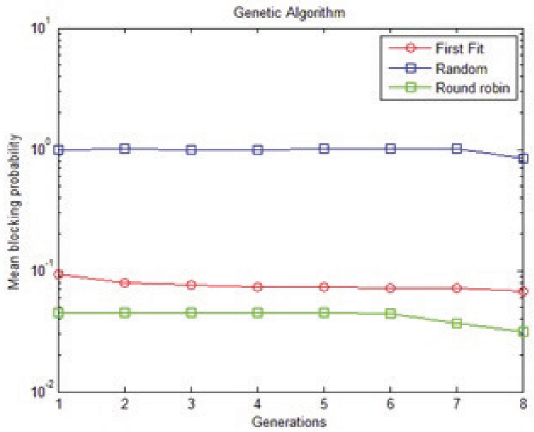

Figure 5: Mean blocking probability against number of generations using GA

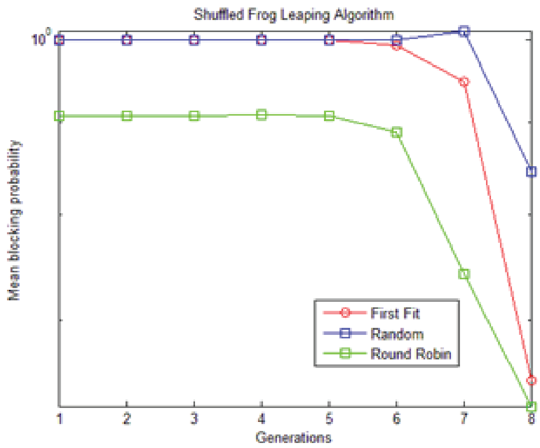

Figure 6: Mean blocking probability against number of generations using SFLA

For different wavelength assignment techniques first fit, random, round robin, wavelength ordering and FWM aware priority based wavelength assignment, the rate of convergence of genetic algorithm and shuffled frog leaping algorithm with 4 number of channels fand a load of 10 Erlangs is shown Fig.7. By randomly selecting an individual and choosing the best fitness value, the graphs are plotted. The average fitness score decreases, as the generations increase. For both GA and SFLA with different wavelength assignment techniques, the average fitness score is approximately the same. Among all the wavelength assignment techniques, FWM priority based assignment has a better average fitness score.

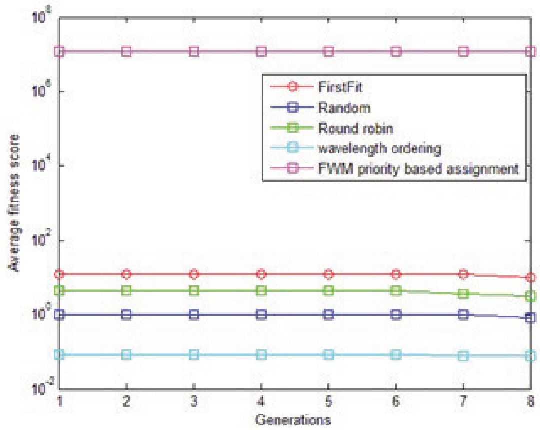

Figure 7: Average fitness score for GA and SFLA

The experimental results of mean execution time obtained for different wavelength assignment techniques First Fit, Random, Round Robin, Wavelength Ordering and FWM aware priority based wavelength assignment using GA and SFLA for various network load in Erlangs is as ahown in Table 1. The mean execution time (seconds)varies appropriately with the network loads and is observed that FWM aware priority based wavelength assignment technique requires very minimum mean execution time in both GA and SFLA algorithms for various network loads. When SFLA is compared with GA, SFLA requires minimum mean execution time for all the wavelength asignment techniques.

The imrpovements achieved in the mean execution time while using SFLA compared to GA is showm in Table 2. The experimental results are quantified using t-test to show the improvements in the proposed SFLA algorithm. The parameters t and p-value are dimensionless. The p-values obtained for all the wavelength assignment techniques are less than or equal to the level of significance value 0.05. This shows that the mean execution time is lesser for the proposed shuffled frog leaping algorithm compared to genetic algorithm.

5 Conclusions

One of the complex optimization problems in optical networks is Routing and Wavelength Assignment

Table 1: Mean Execution Time for different wavelength assignment techniques using GA and SFLA

Wavelength Assignment Techniques	Mean Execution Time for various network loads(Erlang) using GA in seconds					Mean Execution Time for various network loads(Erlang) using SFLA in seconds				
	0	0.7	2.0	3.3	4.6	0	0.7	2.0	3.3	4.6
First Fit	0.1200	0.0241	0.0537	0.1024	0.1029	0.1191	0.0232	0.0504	0.1019	0.1003
Random	0.3000	0.2462	0.2398	0.3071	0.3824	0.2987	0.2451	0.2369	0.3042	0.3736
Round Robin	0.1200	0.1543	0.1597	0.2002	0.2357	0.1198	0.1503	0.1513	0.2001	0.2227
Wavelength Ordering	0.0500	0.0049	0.0108	0.0297	0.0453	0.0490	0.0044	0.0097	0.0281	0.0404
FWM priority based Assignment	0.0050	3.873e-11	7.490e-11	2.0037e-10	3.01e-10	0.038	3.726e-11	7.329e-11	1.998e-10	2.92e-10

Table 2: T-test results showing improvements in Mean Execution Time in SFLA

Wavelength Assignment Techniques	Difference between Mean Execution Time for various network loads(Erlang) of SFLA and GA in seconds					Average in seconds	Standard Deviation in seconds	t	p-value
	0	0.7	2.0	3.3	4.6				
First Fit	0.0009	0.0009	0.0033	0.0005	0.0026	0.00164	0.001232	2.98	0.02
Random	0.0013	0.0011	0.0029	0.0029	0.0088	0.0034	0.003137	2.42	0.04
Round Robin	0.0002	0.004	0.0084	1e-04	0.013	0.00514	0.005557	2.07	0.05
Wavelength Ordering	0.001	0.0005	0.0011	0.0016	0.0049	0.00182	0.001766	2.31	0.04
FWM priority based Assignment	-0.033	1.47e-12	1.61e-12	5.7e-13	9e-12	-0.0066	0.014758	-1	-

(RWA) problem. In the proposed work, two optimization algorithms Genetic Algorithm and Shuffled Frog Leaping Algorithm are used to solve the problem. The fitness function minimizes the blocking probability, number of hops and cost. Basic wavelength assignment techniques such as first fit, random and round robin and also wavelength ordering and FWM aware priority based wavelength assignment are used to analyze the performance of the algorithms GA and SFLA.

Fitness value achieved is found to be better in SFLA compared to GA. The two optimization algorithms GA and SFLA are compared in terms of mean execution time, mean blocking probability and fitness score. The experimental results show that SFLA has better fitness score, less mean execution time and minimum mean blocking probability. Within the algorithm among various wavelength assignment techniques, FWM aware priority based wavelength assignment technique achieves better average fitness score and also less mean execution time. Time complexity of SFLA approach is lower compared to that of Genetic Algorithm and therefore some flexibility may be provided in the network design.

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