

Improved offline multi-objective routing and wavelength assignment in optical networks

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Abstract Optical networks act as a backbone for coming generation high speed applications. These applications demand a very high bandwidth which can be exploited with the use of wavelength division multiplexing (WDM) technology. The issue of setting light paths for the traffic demands is routing and wavelength assignment (RWA) problem. Based on the type of traffic patterns, it can be categorized as offline or online RWA. In this paper, an effective solution to offline (static) routing and wavelength assignment is presented considering multiple objectives simultaneously. Initially, the flower pollination (FP) technique is utilized. Then the problem is extended with the parallel hybrid technique with flower pollination and intelligent water drop algorithm (FPIWDA). Further, FPIWD is hybrid in parallel with simulated annealing (SA) algorithm to propose a parallel hybrid algorithm FPIWDSA. The results obtained through extensive simulation show the superiority of FPIWD as compared to FP. Moreover, the results in terms of blocking probability with respect to wavelengths and load of FPIWDSA are more propitious than FP and FPIWD.

Keywords offline, online, flower pollination (FP), intelligent water drop (IWD), simulated annealing (SA), blocking probability, static, robustness, flexibility, heuristic, wavelength division multiplexing (WDM)

1 Introduction

With the growing popularity of the internet based multi-media applications, the requirement of high bandwidth networks is need of the day. Optical fiber can offer huge bandwidth in the range of Tb/s with the help of wavelength

division multiplexing (WDM) technology [1]. The universality of wavelength routed network increases as optical to electronic alteration and vice versa obstruct the flow of data transmission [2,3]. WDM technology and switching methods tend to increase the transmission capacity and flaccidity of optical networks [4,5]. The large bandwidth of optical networks can be spliced into the number of high speed channels with distinct wavelengths [6]. In WDM networks, users contact through all optical channels which are named as light paths. If there are no wavelength converters equipped at the nodes of the network, then each link comprising the light path must be allocated with the identical wavelength. This constraint is wavelength continuity constraint [7]. In case, if the nodes are provided with the potential of wavelength conversion, then wavelength continuity constraint can be reclined so as to optimize the blocking probability [8]. For cost effective communication over the network, the count of couplers, multiplexers, demultiplexers, amplifiers used between the end nodes should be minimum [4]. In wavelength routed networks, the routing and wavelength assignment (RWA) problem is to choose the route and allocate wavelength to every link. RWA can be differentiated as static or dynamic depending on the type of traffic demands [9,10]. For the set of predefined traffic, created light paths stay for a long time. And for dynamic traffic, a light path is created and then torn off after some time as the traffic changes and a new light path is created depending on the traffic at a particular instance [11].

The RWA problem had been addressed for optimizing various objectives in literature. In Ref. [12], two link disjoint routing methods had been presented which provided proper utilization of resources in WDM networks. In Ref. [6], a fixed alternate routing technique in which the different possible paths between the end nodes had been arranged according to their load was presented. The nodes did not exhibit the potency of wavelength

conversion. This technique outfits the fixed alternate routing in context of the blocking probability. In Ref. [4], performance analysis of different topologies (i.e., bus, star, ring and tree) had been carried out. The count of users supported were evaluated taking under consideration the output power and signal quality. Results deduced that tree topology proved to be optimum in the context of the number of users handled using the minimum count of optical amplifiers. In Ref. [13], waveband switching routing algorithm had been demonstrated to reduce the ports count in the optical cross connect of WDM networks. In Ref. [14], a variable weight routing and wavelength assignment algorithm was suggested in which weight was proportional to the congestion in the network. The results proved that the proposed algorithm helped in reducing the blocking probability and number of wavelengths. In Ref. [15], a solution to the static RWA problem was presented based on linear programming (LP) relaxation formation. The proposed algorithm improved the wavelength utilization and blocking probability. In Ref. [16], a hybrid technique comprising genetic algorithm and minimum degree first fit was presented for solving multi-objective static RWA. The fast non-dominated sorting genetic algorithm was utilized for looking for non-dominated solutions. The results showed that, the suggested algorithm increased the count of successful demands routed and reduced the wavelength count. In Ref. [17], the multi-objective integer linear programming based approach was formulated which maximized the throughput, link usage and minimized the resource usage in WDM networks. In Ref. [18], a hybrid WDM ring tree configuration had been proposed which exhibits the potential of proper bandwidth utilization and enhanced user capacity. It also possesses tremendous optical node density relative to the packet switched optical network.

Many heuristic techniques had been utilized for routing and wavelength assignment for online traffic requests, like genetic algorithm in Ref. [19], ant colony optimization in Refs. [20–24], artificial bee colony optimization in Ref. [25], chaotic particle swarm optimization in Ref. [26] and the differential evolution in Ref. [27]. In addition to this, recently evolved heuristic algorithms, like wind driven optimization [28], flower pollination (FP) [29], simulated annealing (SA) [30] and intelligent water drop (IWD) method [31], have been appropriately applied in various engineering fields. In this paper, an efficient solution to multi-objective static routing and wavelength assignment is presented utilizing three heuristic algorithms. First, FP algorithm is utilized. Then, parallel hybrid of flower pollination and intelligent water drop algorithm (FPIWDA) is proposed. Further, the parallel hybrid of flower pollination, intelligent water drop and simulated annealing algorithm (FPIWDSA) is applied. The proposed model simultaneously maximizes the traffic load, minimizes the blocking probability and number of wavelengths used.

The remainder of the paper is arranged as follows. First, it includes the research methodology, and various design objectives considered for the traffic problem in optical networks. Further, it defines the significance of the techniques being used in the proposed research. The results of current work are elaborated further. Finally, the last section summarizes the overall conclusion of the research work.

2 Research methodology

In this research work, static traffic is considered on two test networks one with 14 nodes and another with 20 nodes. In this model, nodes exhibit the capability of wavelength conversion which can help in reducing the blocking probability. The connection requests arrive at the network with Poisson distribution which possess the exponential holding time. The distance between the end nodes is calculated for all the possible paths between the nodes for which connection demand is scheduled. Then, the shortest path is opted for routing the traffic. Each link is assigned with the weight which is used to calculate the shortest trail between the end nodes. For particular traffic, wavelength is assigned on every link formed by the intermediate nodes of the selected path using the first fit method. If no wavelength is available, then the requested connection is blocked. The traffic load is considered in the Erlangs in the range of 10 to 16 Erlangs. The blocking probability is calculated with wavelength conversion capability available at intermediate nodes. MATLAB programming was used to simulate the network.

2.1 Objective functions

In this research work, $G(N, E)$ represents a network with N interconnected nodes and E links. W_1 represents the total wavelengths allocated to the particular network, W_{tr} represents the wavelengths required for transmission between the end nodes, and M represents the total number of connection demands where R_m represents the successfully routed demands on a particular link. W_f denotes the free wavelengths available.

2.1.1 Traffic load (X_1)

It is the overall number of connection demands successfully routed over the network.

$$X_1 = \sum_{m \in M} R_m. \quad (1)$$

2.1.2 Number of wavelengths (X_2)

It is the total count of wavelengths needed for routing the requested connections between source and destination.

Less the value of X_2 , more wavelengths will be free for communication between end users.

$$X_2 = \sum_{i,o \in N} W_{tr}. \quad (2)$$

2.1.3 Blocking probability (X_3)

If all the wavelengths assigned to the network are busy, then there will not be any free wavelength available which can be allocated to connection demands. This results in blocking of that particular traffic demand. The average blocking probability is measured as

$$X_3 = Bp_{avg} = \frac{\text{number of connection requests blocked}}{\text{total number of connection requests}}. \quad (3)$$

According to Erlang-B formula, the blocking probability on the link with Y load on the link and W_{tr} wavelengths can be represented in Ref. [32].

$$P(Y, W_{tr}) = \frac{\frac{Y^{W_{tr}}}{W_{tr}!}}{\sum_{i=0}^{W_{tr}} \frac{Y^i}{i!}}.$$

The fitness function is calculated as below:

$$X = \min(X_1 - X_2 - X_3). \quad (4)$$

Here, fitness function comprises three objectives in which traffic load is to be maximized, the blocking probability and number of wavelengths utilized are to be minimized. To minimize particular objective means to maximize the negative of same, so the negative sign is considered with the objectives to be minimized. Here, the decision variable is the blocking probability w.r.t load and number of wavelengths. The blocking probability is to be minimized while using minimal number of wavelengths, so minimization of fitness function is considered. Moreover, the blocking probability has been evaluated w.r.t the number of connection requests and optimized by using hybrids FPIWD and FPIWDSA as compared to FP and shortest path first fit routing.

3 Heuristic techniques used

3.1 Flower pollination algorithm

This algorithm was presented by Yang in 2012 [29]. It can be successfully used for global optimization and nonlinear problems. Pollination can be represented by two ways: biotic and abiotic. Biotic pollination is the one in which insects, animals act as pollinators. Whereas, in abiotic there are no pollinators used in fact, wind, diffusion in

water act as pollinators.

Two significant categories of pollination are self-pollination and cross pollination. Pollen of equivalent plant or flower act as pollinator in self-pollination. And pollen of distinct flower yields in cross pollination.

However, cross pollination and biotic pollinator is a global pollination in which pollens follow levy flights. A biotic pollination is a form of local pollination.

Flower constancy gives the similarity index of flowers undergoing pollination. During pollination, pollinators like insects will carry the flower pollens, and these pollens can travel through the considerable distance as the insects can fly and move to the more considerable distance. This will lead to the felicitous results. Mathematically, global pollination can be represented by the first rule plus flower constancy, i.e., given as below:

$$S_i^{t+1} = S_i^t + L(S_i^t - k_*). \quad (5)$$

Here, S_i^t is the pollen i , k_* is the existent finest solution and L is the step size of insects which follow levy flights.

The mathematical representation of the local pollination can be shown as below:

$$S_i^{t+1} = S_i^t + \epsilon(S_j^t - S_k^t). \quad (6)$$

Here, S_j^t and S_k^t are considered as the pollens from the disparate flowers from the similar plant species and ϵ is taken from uniform distribution (0,1) [29,33].

3.2 Intelligent water drop method

If predetermined traffic demands are given, selecting the routes and wavelengths for the links in WDM networks can be accomplished using the intelligent water drop (IWD) method [34]. IWD is the nature inspired swarm heuristic proposed by Hosseini in 2007 [35]. This algorithm follows the natural behavior of the water drops flowing through the layers of lakes, rivers or seas. It starts accumulating a little chunk of soil along with it. The velocity of water particles is inversely proportional to the present soil. So, the water drop with less soil will have more velocity. This is the most important part of the overall algorithm as it influences the process of making opinion to find the fittest solution [31,34]. Steps for the IWD algorithm are as below [31]:

1) Initialize the velocity parameters a_{ve} , b_{ve} , c_{ve} , the soil parameters a_{so} , b_{so} , c_{so} , and the local soil (β_n) and global soil updating parameters. After this, initialize the dynamic parameters.

2) Place the IWDs at the outset of the end node acting as a source.

3) Visited node by each water drop is updated in the list of node just visited.

4) For every IWD at the node ' j ', selection for the next

node 'k' will be dependent on the selection probability. It is inversely proportional to the total hunk of the soil at the link's edge. Also the next node should not be present in the list of node just visited.

5) Next, when the IWD is traversing from one node 'j' to the node 'k', then velocity will get updated according to the below formula:

$$\text{Velo}_{\text{IWD}}(t+1) = \text{Velo}_{\text{IWD}}(t) + \frac{a_{\text{ve}}}{b_{\text{ve}} + c_{\text{ve}} \cdot \text{soil}^2(j,k)}, \quad (7)$$

where $\text{Velo}_{\text{IWD}}(t+1)$ represents the new velocity of IWD.

6) Next is to calculate the change in soil. For that the below formula must be used:

$$\Delta\text{soil}(j,k) = \frac{a_{\text{so}}}{b_{\text{so}} + c_{\text{so}} \cdot \text{time}^2(j,k; \text{Velo}_{\text{IWD}}(t+1))}, \quad (8)$$

such that

$$\text{time}(j,k; \text{Velo}_{\text{IWD}}(t+1)) = \frac{\text{TUD}(k)}{\text{Velo}_{\text{IWD}}(t+1)},$$

where $\text{TUD}(k)$ is the heuristic technique undesirability.

7) Now, amend the $\text{soil}(j,k)$ of the route between node j and k and soil_{IWD} (update the soil that the IWD carries), by using the below formula:

$$\text{soil}(j,k) = (1 - \beta_n) \cdot \text{soil}(j,k) - \beta_n \cdot \Delta\text{soil}(j,k), \quad (9)$$

$$\text{soil}_{\text{IWD}} = \text{soil}_{\text{IWD}} + \Delta\text{soil}(j,k). \quad (10)$$

8) Find the best solution for particular iteration (T^{ibest}).

9) Change the soil on the paths that form T^{ibest} and update the total best solution (T^{Tbest}) if $T^{\text{Tbest}} > T^{\text{ibest}}$.

10) Move to step 2 if the cessation criterion is not met, i.e., the maximum number of iterations not reached.

3.3 Simulated annealing

Simulated annealing (SA) is a heuristic approach used in large space for extensive optimization and was proposed to deal with the problem of traveling salesman in 1983 [30]. The key factors of this technique involves the simplicity, robustness and good efficiency in solving complex optimization problems [36]. Annealing is defined as the process of heating metals, crystal or glass aggressively till its melting point is reached and then keep it still at that particular temperature. Then again cooling the alloy at slow pace such that it takes the form of compact crystalline arrangement. This overall simulation is referred as the SA [30]. Steps involved in the complete process are listed below [30,36].

1) Initialize, the maximum number of iterations (iter_{max}), the initial temperature (T_i) and size of the problem.

2) Initialize the current solution and let it be S_p , and at this instant S_p is assumed to be the best solution.

3) Repeat this procedure and generate S_f from S_p .

4) Check for various conditions:

If $f(S_f) \leq f(S_p)$, then $S_p = S_f$

Else if $e^{\frac{f(S_p) - f(S_f)}{T_k}} > \text{random}[0,1]$, then $S_p = S_f$.

5) Now, determine the control parameter.

6) The probability can be calculated by using below expression:

$$P_a\{\text{keep } S_f\} = \{1 \text{ if } f(S_f) \leq f(S_p)\}$$

$$\text{elseif } \left\{ \exp\left(\frac{f(S_p) - f(S_f)}{T_k}\right) \right\}.$$

3.4 Flowcharts of hybrid techniques used

In this research work, two hybrids using heuristic techniques are proposed. First one is the hybrid of flower pollination algorithm and an intelligent water drop method (FPIWD) which operate in parallel. The best solution of both the algorithms is compared and the finest value is selected accordingly. The second hybrid is comprised of three heuristic techniques working in parallel, in addition to FPIWD, the simulated annealing algorithm is used (FPIWDSA). In both hybrids presented, parallel hybrid techniques are implemented, i.e., value of the current best of the algorithms are compared and then the best is selected. This increases the chances of getting the best optimal value at the particular iteration.

The flowcharts of both the hybrids are presented in Figs. 1 and 2.

4 Results and comparison

The shortest path routing and the first fit wavelength assignment was utilized and based on this, only the shortest available path will be selected for communication between the source and destination. This will increase the maximum allowed users on the network as with the short path, the transmission will be done in less time and more users can use the channel for further transmission required.

Global optimization can be achieved by using FP. FP algorithm exhibits good local and global searching capability due to which pollinators explore the search space extensively [29]. In addition to this, FP algorithm is a simple technique with good flexibility, convergence rate and have less parameters to tune [33,37]. In this model, initially independent FP is utilized for multi-objective routing and wavelength assignment problem so as to maximize the traffic load, minimize the number of wavelengths used and to minimize the blocking probability simultaneously. Experimentation is performed on both the test networks. In literature, FP is hybrid with SA [38] so as to reach the global best rapidly, so the idea to hybrid FP

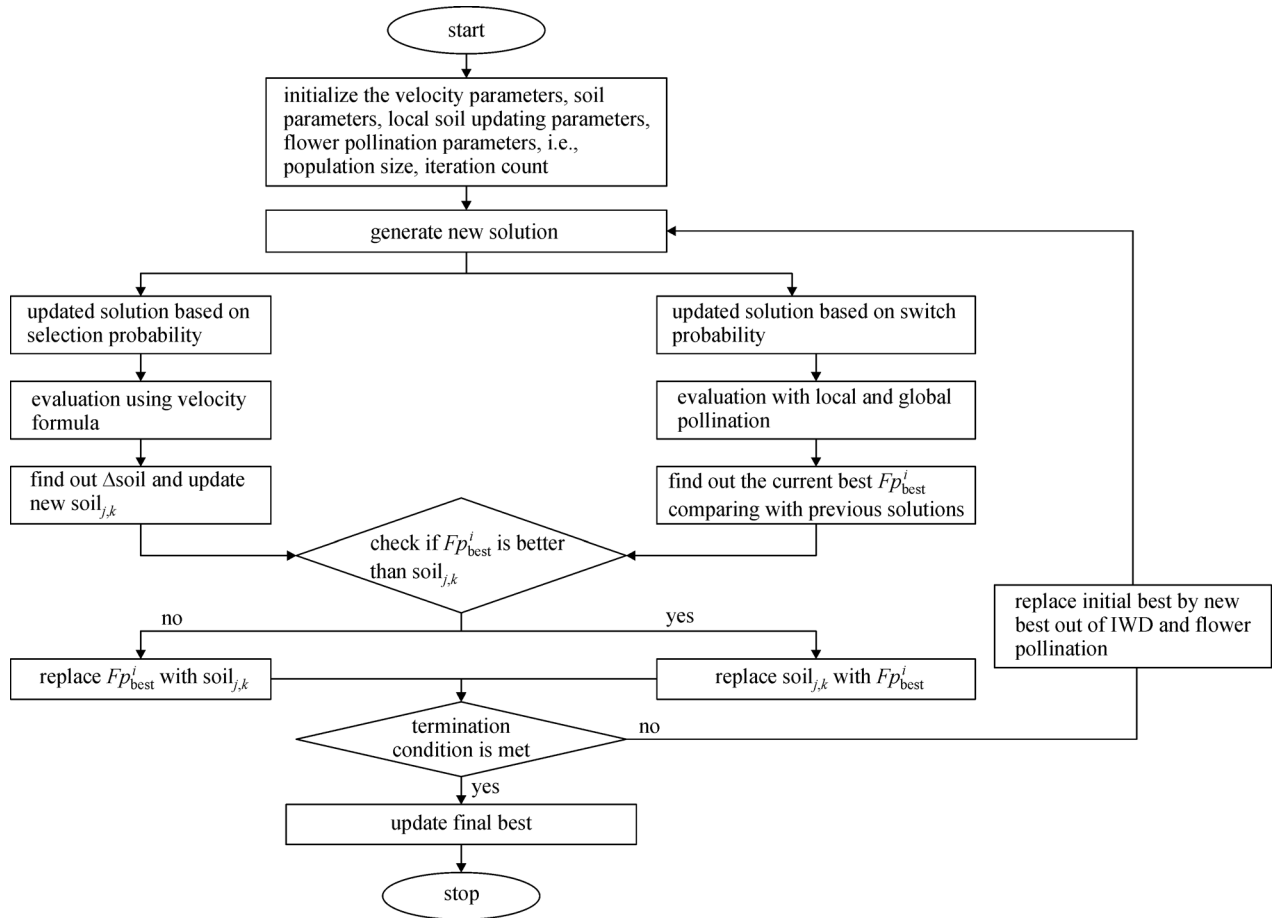


Fig. 1 Flowcharts of hybrid FPIWD algorithm

with other technique is implemented in this work.

To improve the performance, FPIWD is proposed and parameters are evaluated to check the effectiveness of FPIWD. IWD method is more efficient in searching the solution in time [39]. SA leading features are its flexibility [40], robustness, ability to find the good solution and easy to code nonlinear problems [41]. To take advantage of the SA, it is used in parallel with hybrid of FP and IWD to form FPIWDSA to optimize the performance of the optical networks further.

In the model suggested, initially FP is applied on both 20 nodes and 14 nodes network. The number of iterations considered are 2000 and switching probability is taken to be 0.8. The number of pollens considered for 20 nodes network and for 14 nodes network are 20 and 14 in count respectively. The results tabulated in Table 1 to 7 are obtained by performing the simulations for 15 runs. For the validation of the results, standard deviation values are obtained for every parameter evaluated which results in very low value. It indicates that values of the blocking probability and the fitness in every simulation run are almost similar. Table 1 shows the average and standard deviation for the blocking probability w.r.t wavelength and

the minimum fitness value with FP algorithm.

For the first hybrid proposed, i.e., FPIWD, the local soil updating parameter is considered to be 0.1, the initial soil value = 400, initial velocity = 50 and the initial path set value is taken 1000. Tables 2 and 3 show the average and standard deviation values for the blocking probability w.r.t load with FP and FPIWD algorithm for both the test networks.

The average and standard deviation values for the blocking probability obtained w.r.t wavelength variation for both 20 nodes network and for 14 nodes network are shown in Table 4 along with values of the average and standard deviation for minimum fitness value obtained with FP and FPIWD.

The second hybrid proposed FPIWDSA comprises the FP, IWD algorithm and SA algorithm operating in parallel. For SA initial temperature is taken 1.0 and the final cooling temperature is considered to be e^{-10} . Where the Boltzmann constant K is unity, cooling factor is taken to be 0.5 and normalized energy is taken to be e^{-2} .

Tables 5 and 6 show the mean and standard deviation values for the blocking probability w.r.t load obtained for both the test networks using FPIWDSA.

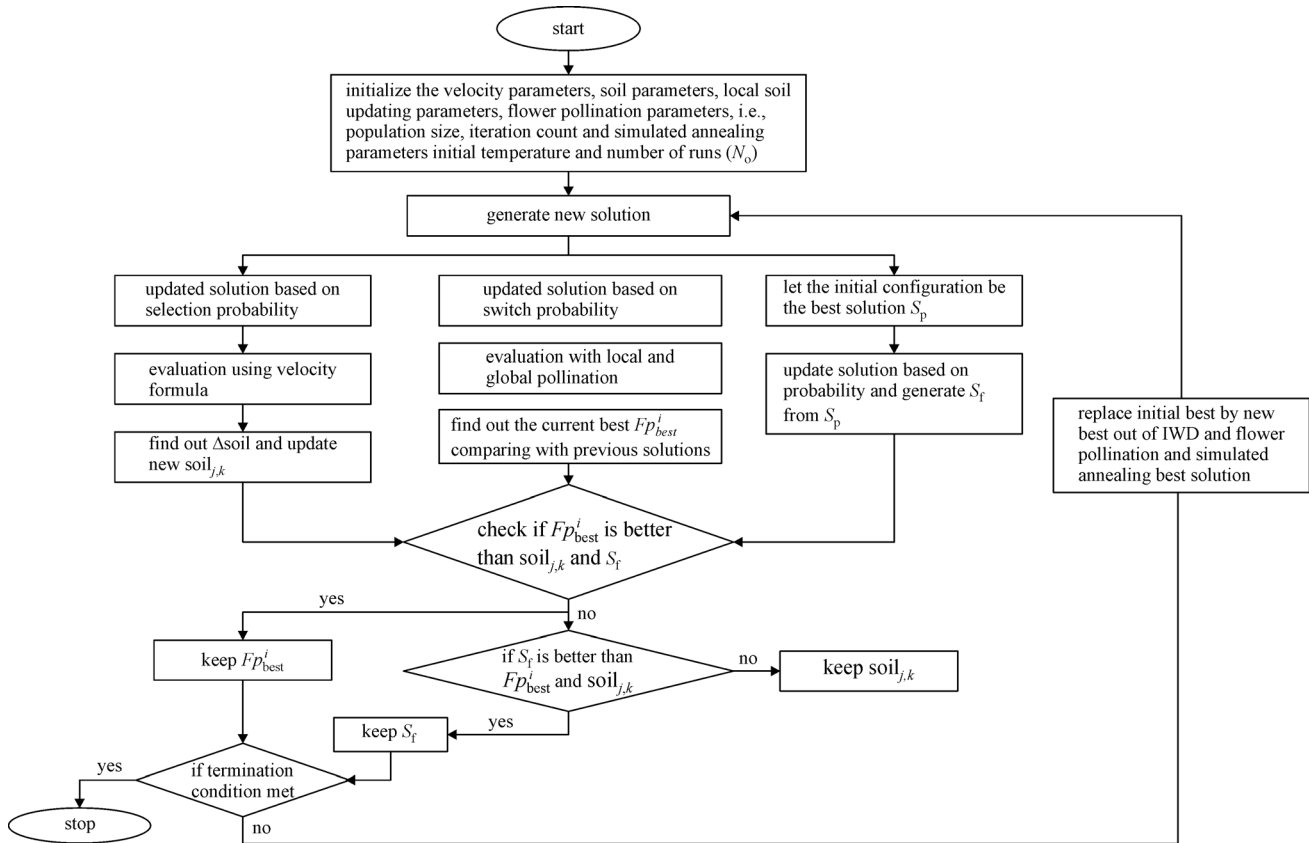


Fig. 2 Flowchart of hybrid FPIWDSA algorithm

Table 1 Blocking probability w.r.t wavelength and minimum fitness using flower pollination.

	average (%) / stdev (%)	
	20 nodes network	14 nodes network
B.P w.r.t wavelength	79.88 / 0.55	72.87 / 0.53
f_{min}	-107.3 / 0.31	-98.5 / 0.49

Notes: f_{min} means minimum fitness, stdev means the standard deviation value, B.P means the blocking probability

Table 2 Optimum variables obtained with FPIWD for 20 nodes network

B.P w.r.t load (FP)	average (%) / stdev (%)	B.P w.r.t load (FPIWD)
50.53 / 1.2		35.6 / 0.24
80.58 / 2.6		38.95 / 0.14
94.24 / 0.72		39.65 / 0.03
96.93 / 0.51		39.86 / 0.02

Notes: stdev means the standard deviation value, B.P means the blocking probability

Table 3 Optimum variables obtained with FPIWD for 14 nodes network

average (%) / stdev (%)	
B.P w.r.t load (FP)	B.P w.r.t load (FPIWD)
38.22 / 2.19	26.97 / 0.27
70.94 / 1.6	28.96 / 0.049
88.45 / 0.89	29.39 / 0.019
94.84 / 0.43	29.52 / 0.016

Notes: stdev means the standard deviation value, B.P means the blocking probability

Table 4 Average blocking probability w.r.t wavelength for both the test networks

average (%) / stdev (%)		
	20 nodes network	14 nodes network
B.P w.r.t wavelength (FP)	80.5 / 0.66	73.04 / 0.88
B.P w.r.t wavelength (FPIWD)	50.5 / 1.13	41.93 / 0.091
f_{\min}	-172 / 0.6	-153.3 / 0.77

Notes: f_{\min} means minimum fitness, stdev means the standard deviation value, B.P means the blocking probability

Table 5 Optimum variables obtained with FPIWDSA for 20 nodes network

average (%) / stdev (%)		
B.P w.r.t load (FP)	B.P w.r.t load (FPIWD)	B.P w.r.t load (FPIWDSA)
51.65 / 2.2	35.77 / 0.37	1 / 0
81.18 / 1.6	38.95 / 0.144	9.5 / 0.8
94.28 / 0.7	39.66 / 0.026	12.6 / 1.46
96.91 / 0.48	39.84 / 0.022	39.6 / 0.037

Notes: stdev means the standard deviation value, B.P means the blocking probability

Table 6 Optimum variables obtained with FPIWDSA for 14 nodes network

average (%) / stdev (%)		
B.P w.r.t load (FP)	B.P w.r.t load (FPIWD)	B.P w.r.t load (FPIWDSA)
39.54 / 1.59	27.16 / 0.18	0 / 0
68.94 / 2.43	28.862 / 0.13	28.9 / 0.066
87.91 / 0.91	29.377 / 0.017	29.377 / 0.017
94.47 / 0.63	29.52 / 0.021	29.52 / 0.021

Notes: stdev means the standard deviation value, B.P means the blocking probability

Table 7 Average blocking probability w.r.t wavelength and minimum fitness with FPIWDSA

average (%) / stdev (%)		
	20 nodes network	14 nodes network
B.P w.r.t wavelength (FP)	80.8 / 1.3	72.7 / 0.72
B.P w.r.t wavelength (FPIWD)	50.2 / 0.13	41.8 / 0.117
B.P w.r.t wavelength (FPIWDSA)	34.8 / 0.15	33.02 / 0.071
f_{\min}	-172.4 / 0.9	-152.9 / 0.7

Notes: f_{\min} means minimum fitness, stdev means the standard deviation value, B.P means the blocking probability

The average and standard deviation values for the blocking probability w.r.t wavelengths and minimum fitness obtained with FPIWDSA are tabulated in Table 7.

The load is considered in Erlang units. We considered the load ranging from 10 to 16 (i.e., 10,12,14,16 Erlangs per link) for the proposed solution. The blocking probability w.r.t the number of connection request for different load Erlangs per link is evaluated initially with the shortest path routing and the first fit wavelength assignment (SPFF) method and then with independent FP. Further the same is enhanced using the hybrids, i.e., FPIWD, FPIWDSA.

probability w.r.t to the number of connection requests for different Erlangs per link for 20 nodes network and 14 node network. From the graphs, it can be deduced that as there is increase in connection requests, the blocking probability will also be exaggerated. The results obtained for 20 nodes network showed that using FP independently optimized the blocking probability relative to SPFF algorithm. Also, the parallel hybrid FPIWD outfits FP in terms of the blocking probability for the larger number of connection requests. The hybrid FPIWDSA showed promising results only for 16 Erlangs load compared to the parallel hybrid of FPIWD and that also for lesser number of connection requests whereas, at the larger

Figures 3 and 4 represent the variation of blocking

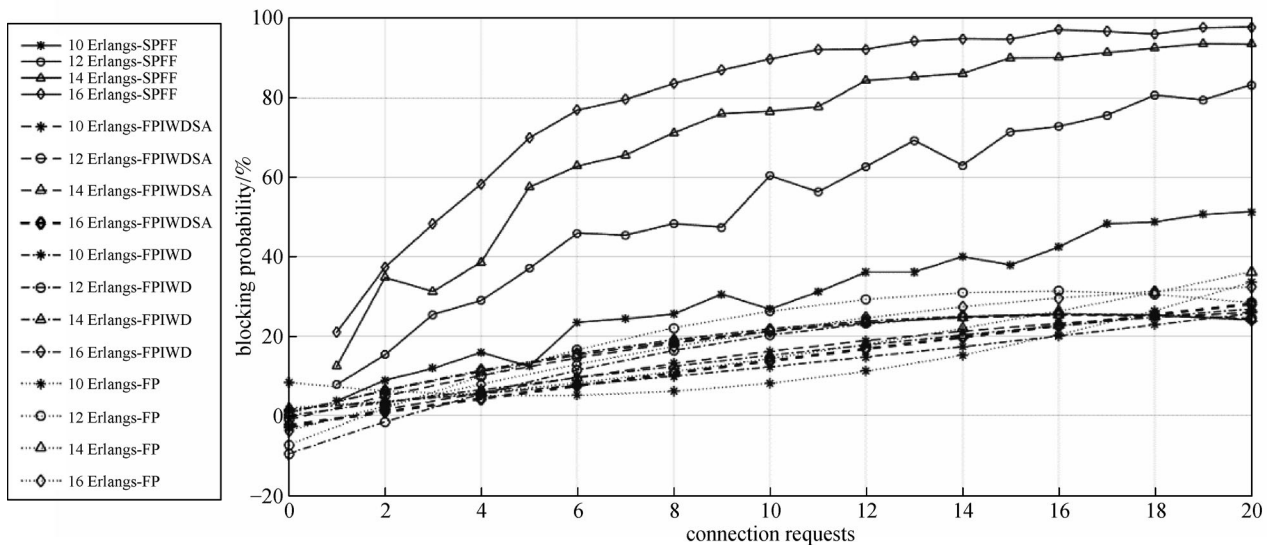


Fig. 3 Blocking probability for different Erlangs load per link w.r.t connection requests with shortest path first fit algorithm, FP, FPIWD and FPIWDSA for 20 nodes network

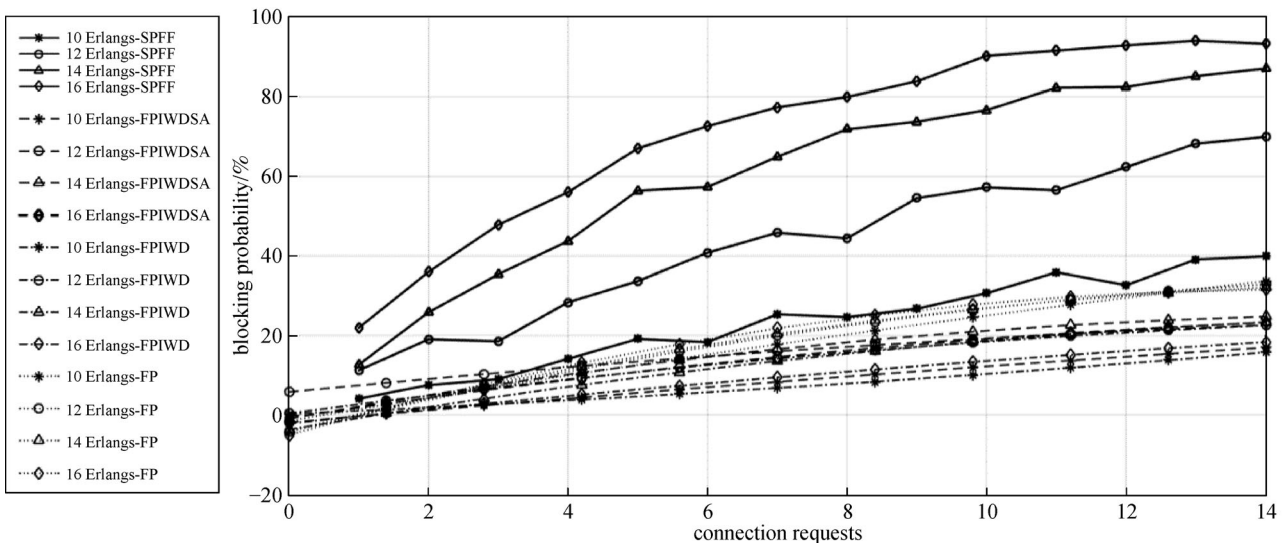


Fig. 4 Blocking probability for different Erlangs load per link w.r.t connection requests with shortest path first fit algorithm, FP, FPIWD and FPIWDSA for 14 nodes network

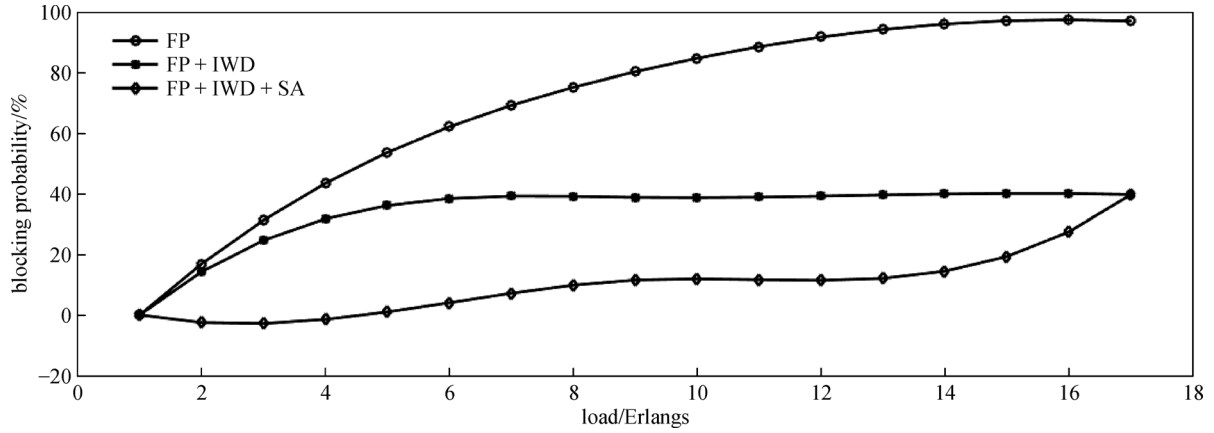


Fig. 5 Blocking probability w.r.t load with all algorithms for 20 nodes network

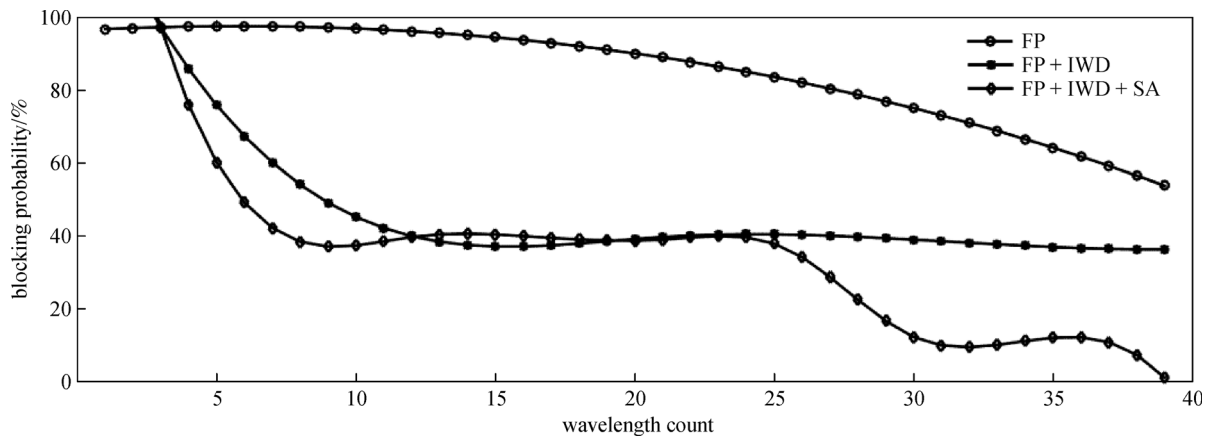


Fig. 6 Blocking probability w.r.t wavelength count with all algorithms for 20 nodes network

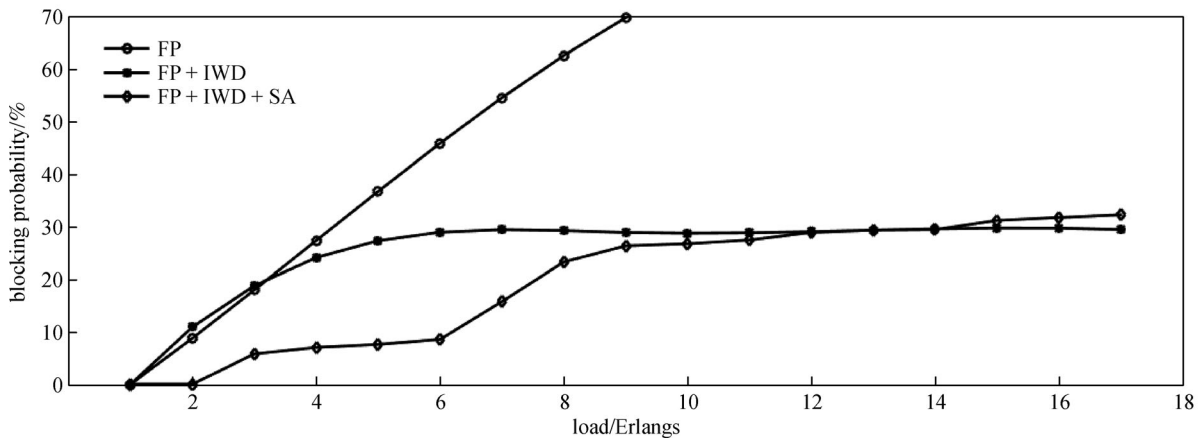


Fig. 7 Blocking probability w.r.t load with all algorithms for 14 nodes network

number of connection requests, the blocking probability obtained with both the hybrids (FPIWD and FPIWDSA) was found to be almost the same. However, the results

showed that both the hybrids improve the blocking probability w.r.t increase in the connection requests for different range of Erlang per link as compared to

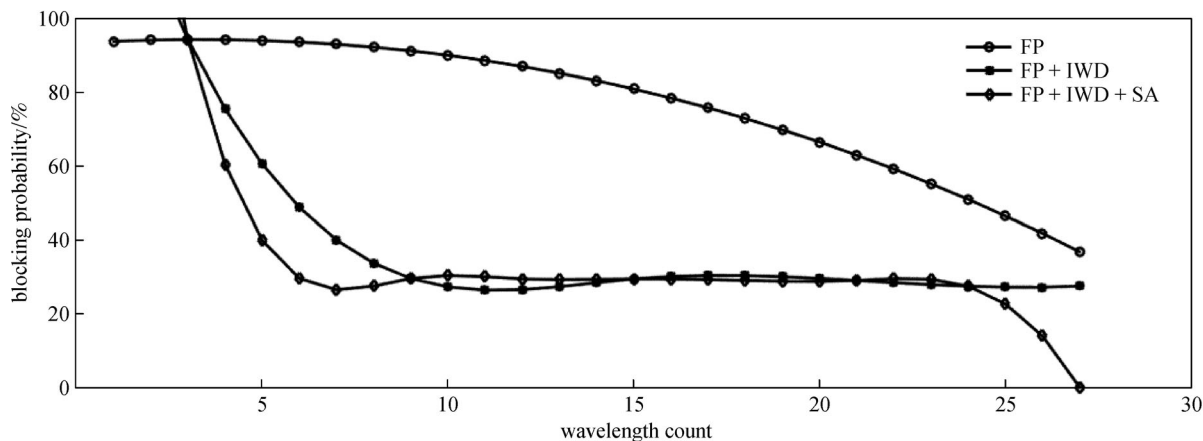


Fig. 8 Blocking probability w.r.t wavelength count with all algorithms for 14 nodes network

independent FP. Moreover, hybrid FPIWDSA can be a better solution than FPIWD at higher load, i.e., 16 Erlangs.

From Fig. 4, it is clear that in 14 nodes network, the parallel hybrid FPIWD enhances the blocking probability for different Erlang per link as compared to FPIWDSA. Whereas both the hybrids provide better solution than using FP independently to optimize the blocking probability.

Figures 5 and 6 represent the variation of the blocking probability w.r.t increasing load and wavelengths for 20 nodes network. Figures 7 and 8 represent the variation of the blocking probability w.r.t increasing load and wavelengths for 14 nodes network. With the increase in load, the blocking probability also increases, but as the wavelength count increases then blocking probability decreases. The blocking probability is optimized for hybrid FPIWD as compared to FP which is further improved with the hybrid of FPIWDSA. Hence, from results conclusion can be drawn that parallel hybrid of FP, IWD algorithm and SA act as optimizer and provides better solution for minimizing the blocking that incurred in optical WDM networks with respect to load and wavelength count as compared to using independent FP.

5 Conclusion

This paper presents an efficient solution for creating light paths using static traffic in WDM optical networks. In this work, two parallel hybrids FPIWD and FPIWDSA are proposed for the optimization multi-objective problem. The idea of using parallel hybrid is to incorporate and use the best of features of all three algorithms in optimizing the performance metrics of WDM networks, i.e., blocking probability, load and number of wavelengths. Assessment of blocking probability for different values of Erlang load per link with respect to the number of connection requests is performed using the proposed algorithms. Comparing

the results with individual FP algorithm, both the hybrid algorithms enhance the performance metrics of WDM optical networks. Comparative analysis of the blocking probability the defined number of wavelengths and the offered load is also done. The results indicate that the hybrid FPIWD outfits independent FP and hybrid FPIWDSA provides even much more appropriate solution as compared to the hybrid of FP and IWD.

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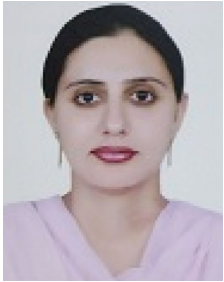
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