Performance Analysis of Artificial Bee-Colony Algorithm for Routing and Wavelength Assignment in DWDM Transport Network

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***Abstract*—Setting up lightpaths for a set of requested connection of wavelength division multiplexing (WDM) network, is by routing and assigning wavelengths to each connection. So as to minimize the use of network resources or maximize the traffic served, is called the routing and wavelength assignment (RWA) problem. A new idea based on Artificial Bee Colony (ABC) algorithm is introduced for solving RWA problem which is known to be an NP-hard problem. In the proposed ABC-RWA approach every food source represents a possible and feasible candidate lightpath between each original and destination node span in demand matrix. The situation of the food source is modified by some artificial bee in the population where the aim is to discover the places of food sources. The food source with the highest nectar value seems to be a solution which is evaluated by the fitness function. This paper proposes solutions to solve the RWA problem using artificial bee-colony algorithm in order to achieve better performance of the network connection to serve a given demand matrix of an optical network to reach RWA global solution. The work will evaluate the path length (propagation delay) for solving RWA problem with ABC algorithm in a real-world optical networks test bench to find optimal routes for connection request in demand matrix and assigning wavelength to them according to objective function and some physical and operational constraints in Dense Wavelength Division Multiplexing (DWDM) optical networks. Based on simulation with several generated traffic distribution, ABC algorithm can be used to solve routing and wavelength problem at DWDM transport network as shown that in line with iteration process the path length observed toward minimum value. The number of iteration needed to reach the fitness value depends on several parameter such as number of connection request, number of wavelength and alternative path, the distribution of generated traffic and also population size.**

Keywords—rwa; bee-colony; path length

I. INTRODUCTION

The rapid development of information technology is characterized by increasing the implementation of public access makes the need for increased data security as use of a layered coding technique and so on. This directly create a need for bandwidth continues to increase. High-speed optical transport networks used by today’s worldwide networking communications systems and applications as backbones for connecting buildings, cities and even countries across the world. Dense wavelength division multiplexing (DWDM) technology give the chances to send huge data bandwidth of fibers in optical networks by divides the bandwidth of an optical fiber into some non-overlapping channels where each of them can operate at a different wavelength [1].

DWDM optical networks is a connection-oriented network that the connection should be established before transmitting the data. In order to establish the connection in a DWDM optical network, there are two primary operation called routing and wavelength assignment (RWA). In wavelength-routed DWDM optical networks, the RWA problem is a key designing and planning issue which refers to finding routes for connection requests in demand matrix and assigning wavelengths to them according to objective function and some physical and operational constraints in optical networks [2]. The RWA problem is a crucial and complicated designing issue in optical networks which is known to be an NP-hard problem [3]. The integer linear programming (ILP) [4] models have been effectively utilized for solving RWA problem for small size optical networks, but not feasible for medium and large scale optical networks because the ILP models become more complex in consequence of increasing network size. In order to solve RWA problem for large scale optical network, many intelligent and heuristic behavior algorithms are developed by optical network researchers and engineers in literature.

The Artificial Bee Colony (ABC) algorithm was proposed by Karaboga in 2005 [5] is a population based stochastic optimization algorithm which simulates the intelligent foraging behavior of honey bee swarms for iteration based optimization problems [6]. The colony of artificial bees contains three types of bees: employed bees, onlookers and scouts bees [7]. In ABC algorithm [7], a possible solution for the optimization problem is represented by the position of a food source and the quality of solution is represented by the nectar amount of a food source which is measured by the fitness function. The number of solutions in the population is equivalent with the number of the employed bees and each employed bee should be associated to one food source.

II. RELATED WORK

The ABC has been potentially employed for some engineering optimization algorithms. Karaboga and Ozturk [8] proposed an application of ABC algorithm for data clustering on benchmark problems. Artificial Bee Colony algorithm was applied in [9] for the leaf-constrained minimum spanning tree problem and for the minimum routing cost spanning tree problem in [10]. In [11] Artificial Bee Colony algorithm was employed for small signal model parameter extraction of MESFET transistors. Artificial Bee Colony was applied for multi-objective design optimization of composite structures [12].

Recently, there are several papers found examine the RWA problem and review various routing approaches and wavelength assignment approaches. Yousef S. Kavian et al proposed routing and wavelength assignment in optical networks using Artificial Bee Colony algorithm [1]. Paper [13] and [14] described the Bee Colony method used in DWDM optical network applications. Paper [3] and [15] overviewed various routing and wavelength assignment approaches proposed in the previous literature observed those algorithms approaches individually and examined the associated research problems and challenges.

III. SIMULATION ROUTING AND WAVELENGTH ASSIGNMENT FOR DWDM TRANSPORT NETWORK USING ARTIFICIAL BEE COLONY ALGORITHM

A. Dense Wavelength Division Multiplexing

DWDM technology has important role at optical transport network technology since it has capabilities to expand bandwidth of fiber-optic channels to hundreds. So the bandwith of DWDM based optical network can be increased. DWDM typically has the capability to transport up to 80 channels (wavelengths) in what is known as the Conventional band or C band spectrum, with all 80 channels in the 1550 nm region [17]. DWDM technology has five major components [17]:

1. Multiplexer
   Multiplexer consist of wavelength converting transponder for each carried wavelength signal that convert input optical signal into electrical domain, retransmits the signal and places multiple band signal into one single fiber.
2. Repeater
   Repeater is placed approximately in every 80-100 km for re-gaining the loss of optical power, while it transverse along the optical fiber. EDFA (Erbium-doped Fiber Amplifier) is used to amplifying the signal that usually consist of several amplifying stages.
3. Optical Cross-Connect (OXC)
   Input to output port is switched by the OXC that located at nodes in order to cross-connecting a number of fiber pairs, and also support add-drop for local traffic by providing the interface into the service layer.
4. Optical Add-Drop Multiplexer
   OADM facilitates the evolution of the single wavelength point-to-point optical network to the wavelength division multiplexed networks that van selectively add and drop wavelength without using any SONET/SDH terminal equipment. The ADM is required to add new wavelengths to the network or to drop some wavelengths at their terminating points.
5. Demultiplexer
   Demultiplexer breaks the signal with multi-wavelength back into individual signals and process the signal into separate fibers to be detected by client-layer systems.

B. Routing and Wavelength Assignment

Routing and wavelength assignment problem in wavelength-routed optical networks [1] which is employed for providing intelligent ABC based solutions is described by a directed and weighted graph $G(V,E,W)$ where $V = \{v_1, v_2, \ldots, v_n\}$, is set of vertices, $E = \{e_1, e_2, \ldots, e_m\}$ is set of edges and $W = \{w_1, w_2, \ldots, w_k\}$ is set of wavelengths on each link represents the optical network topology. A set of connection requests between origin and destination node pairs (O,D) in optical networks aggregated in a demand matrix, R = {(O,D,T)|O is source, D is destination and T is the volume of traffic}, the main purpose is to establish lightpaths to serve connection requests by minimizing the number of utilized wavelengths considering physical and operational constraints. The routes are selected by network planner from a set of pre-determined K-shortest alternative paths and free wavelengths are assigned to them considering the volume of connection requests in terms of requested wavelengths and links wavelength availability information. Artificial Bee Colony model of routing and wavelength assignment problem is define by mapping the optical lightpaths into food sources. In this model, every food source represents one of the K possible and feasible paths between each node pair in the optical network. K-shortest paths between each node pair in demand matrix is assigned to a food source. The position of a food source represents a possible solution for routing problem and the nectar amount of a food source corresponds to the quality of the associated solution measured by a fitness function.

C. Artificial Bee Colony Algorithm

In the ABC algorithm [18], the artificial bees are classified into three groups: employed bees, onlooker bees and scouts. Employed bee is a bee that is currently searching for food or exploiting a food source. Onlooker bee is a bee that waiting in the hive for making decision to choose a food source. Employed bees whose food sources cannot be improved through a predetermined number of trials become scouts and their food sources are abandoned. The number of food sources is equal to the number of employed bees and also equal to the number of onlooker bees. The position of a food source represents a candidate solution of the optimization problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution. At the initialization phase, the ABC generates a randomly distributed initial population of SN solutions where each food source $x_i (i = 1,2,\ldots SN)$ is a D-dimensional vector. Each solution is produced within its limits according to the equation below:

$$x_{ij} = x_{min,j} + rand[0,1](x_{max,j} - x_{min,j}) \quad (1)$$

$i = 1,2,\ldots,SN$

$j = 1,2,\ldots,D$

$rand[0,1]$ is a function that generate an evenly distributed random number in range [0,1].

Where x_{min}^j and x_{max}^j respectively represent the minimum and the maximum of the parameter j and D is the number of optimization parameters. After initialization, the population of the solutions is subject to repeated cycles C = 1, 2, . . ., MCN, of the search processes of the employed bees, the onlooker bees and the scout bees. For each cycle, every employed bee produces new solution v_{ij} according to Eq. (2) and then evaluates its fitness fit_i.

$$v_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj}) \quad (2)$$

Where $k \in \{1,2,\ldots,SN\}$ and $j \in \{1,2,\ldots,D\}$ are randomly choosen indexes. Although k has to be different from i. ϕ_{ij} is a random number between [-1 1].

After the information is shared by the employed bees, each onlooker finds new solution v_{ij} within the neighbourhood of x_i by using Equation (2), based on probability p_i defined as :

$$p_i = \frac{fitness_i}{\sum^{SN} fitness} \quad (3)$$

Where $fitness_i$ is the fitness value of solution x_i

The value of each generated candidate solution v_{ij} that is not within the boundary of the allowed search space is updated so that it will be within this space. The fitness of each new produced candidate solution v_{ij} is compared with that of its old one. If the new solution has an equal or better fitness than the old solution, it replaces the old one in the memory. Otherwise, the old one is retained in the memory. In other words, a greedy selection mechanism is employed in the selection operation between the old and the candidate one. At the end of each search cycle, if the fitness of a solution can-not be improved and the predetermined number of trials, which is called "limit", is exhausted, then the solution will be abandoned by scout bee and a new solution is randomly searched. The new solution x_i will be generated using Equation (1).

From the above explanation, we can conclude that there are three control parameter in the ABC algorithm: The number of candidate solution which is equal to the number of employed and onlooker bees *SN*, the value of "limit" and the maximum cycle number *MCN*.

The pseudo-code of ABC Algorithm is described below :

```
1:Begin
2:Generate the initial solution $x_i$, $i = 1,2,\ldots,SN$ using Eq.(1)
3:Evaluate the fitness ($fit_i$) of the population
4:Set cycle to 1
5:Repeat
6:      For each employed bee {
              Produce new solution $v_{ij}$ using Eq.(2)
              Calculate the value $fit_i$
              Apply the greedy selection process }
7:      Calculate the probability values $p_i$ for the solution $x_i$
        by Eq.(3)
8:      For each onlooker bee {
              Select a solution $x_i$ depending on $p_i$
              Produce new solution $v_i$ by using Eq.(2)
              Calculate the value $fit_i$
              Apply the greedy selection process }
9:      If there is abandoned solution for the scout
        Then replace it with a new solution which will be
        randomly produced using Eq.(1)
10:     Memorize the best solution achieved so far
11:     cycle = cycle + 1
12:until cycle = MCN
```

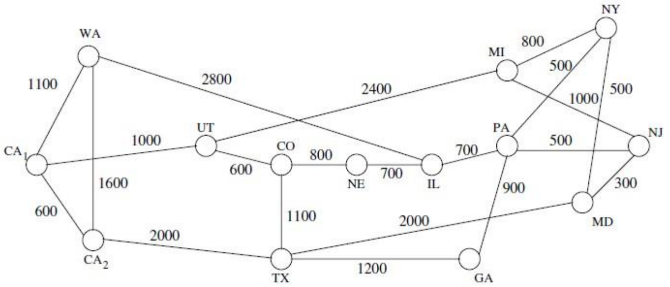


Fig 1. NSFNET Topology (Distance in km) [19]

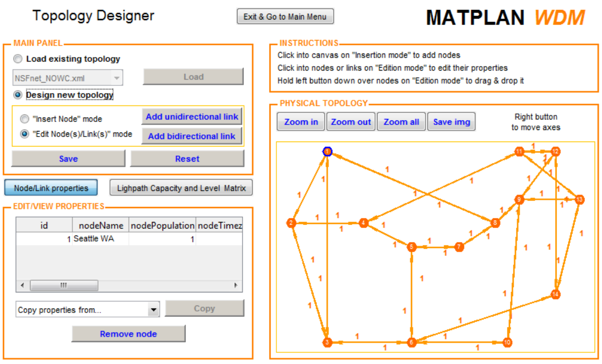
D. Simulation Scenario

In this paper, NSFNET network topology as shown at figure 3 is used to be routing and wavelength assignment test bench to be simulated to obtain best fitness value (path length) using artificial bee-colony algorithm. Once the network topology is determined, there are several parameters to be considered as simulation procedure for routing and wavelength assignment using artificial bee colony algorithm described as follows :

1. Number of nodes, is the number of nodes related to the topology used. Each node have several parameter such as node id, name, position coordinate, and the number of wavelength converter.
2. Fiber link, is the link which connecting the nodes. Each link have several parameter such as link id, origin and destination, length (in kilometer), and the number of available wavelength.
3. Traffic (connection request), is represented by the traffic Matrix (NxN) variable contains the average traffic flow offered between node pairs. The Traffic Matrix is a two-dimensional matrix with N (N: number of nodes) rows and N columns. An entry (s,d) means the average traffic flow from node 's' to node 'd', expressed in Gbps. The main diagonal is full of 0s.
4. Number of available wavelength per link is determined as the constraint of the system and set in the link parameter.

The Simulation based on MATLAB language programming in association with MATPLAN WDM [16] version 0.61 pre-developed by Prof. Pablo Pavón Mariño, for the degree of Telecommunications Engineering in the Technical University of Cartagena (Spain) to create the NSFNET backbone network topology and generating traffic for the simulation and continued by running simulation for analyze the ABC algorithm performance as iterations result :

1. Create network topology
   Network topology created using topology designer as follow :



Click into canvas on "Insertion mode" to add nodes
Click into nodes or links on "Edition mode" to edit their properties
Hold left button down over nodes on "Edition mode" to drag & drop it

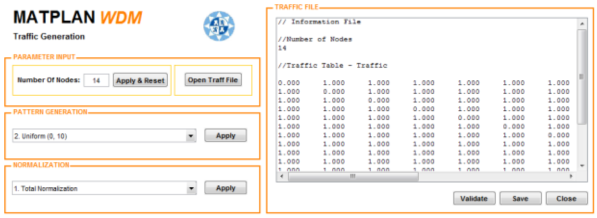
id	nodeName	nodePopulation	nodeTimez
1	Seattle WA	1	

Fig. 2. Creating Network Topology

This interface allows the user to generate a .phys file representing a network topology. Nodes are inserted into the canvas with the “Insert Node” mode activated. Links are inserted using the corresponding buttons. It is possible to insert unidirectional links or bidirectional ones. If there are nodes and links placed, their properties can be edited with the “Edit Node(s)/Link(s)” mode activated. Not all properties can be changed, i.e. “Node ID” is generated internally.

2. Generating traffic

Traffic can be generated by using traffic generator as follow :



```
// Information File

//Number of Nodes
14

//Traffic Table - Traffic

0.000    1.000    1.000    1.000    1.000    1.000    1.000
1.000    0.000    1.000    1.000    1.000    1.000    1.000
1.000    1.000    0.000    1.000    1.000    1.000    1.000
1.000    1.000    1.000    0.000    1.000    1.000    1.000
1.000    1.000    1.000    1.000    0.000    1.000    1.000
1.000    1.000    1.000    1.000    1.000    0.000    1.000
1.000    1.000    1.000    1.000    1.000    1.000    0.000
1.000    1.000    1.000    1.000    1.000    1.000    1.000
1.000    1.000    1.000    1.000    1.000    1.000    1.000
1.000    1.000    1.000    1.000    1.000    1.000    1.000
```

Fig. 3. Generating Traffic

This interface allows the user to generate a .traff file representing a traffic matrix. Traffic generator divided into several parts :

- Parameter Input
- Pattern Generation
- Normalization
- Traffic File

Traffic generation process initiates by selecting the number of nodes N in the network. With traffic matrix as follows :

$$\begin{pmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1N} \\ \gamma_{21} & \gamma_{22} & & \vdots \\ \vdots & & \ddots & \\ \gamma_{N1} & \cdots & & \gamma_{NN} \end{pmatrix}$$

where i and j are the number of nodes.

The traffic pattern defined using Pattern Generation with 5 mode available. Four of them is simple based on uniform distribution and the fifth mode allows creating a traffic matrix based on population and distance according to the model described in [20].

In this paper, a poisson random distribution also used as one of the generated traffic distribution since it is empirically found that in many circumstances the arising stochastic processes can be well approximated by a Poisson process [23]. By network users point of view, a session of messages are typically triggered by particular events. But from the network point of view, the initiations of these message are somewhat arbitrary and unpredictable. As a result, the sequence of times at which messages arrive for a given session is a random process. Moreover, the arrival process of each session has to be independent from others. The poisson process has been proved to be the most appropriate for such purpose and therefore has been considered for the simulation.

3. Setting up simulation parameter

After generating .phys and .traff file as topology and traffic generation file, the simulation process starts by loading the topology and traffic. The next step is to setting up the simulation parameters consist of number of connection request, number of alternative paths, number of wavelength per link, and maximum iteration as the maximum cycle number of ABC algorithm iteration process. In order to process initial input parameter into wavelength routed traffic possibility, there is a function that consists of a main loop divided in two parts. Firstly the algorithm tries to route as amount of traffic in the existing virtual topology as it is possible. Secondly the algorithm tries to create a new lightpath. At first, it tries to do it in order to route the maximum residual traffic flow, if this is not possible it tries with the second maximum residual traffic flow and so on. The loop ends when the algorithm cannot route a higher amount of traffic and more lightpath cannot be created.

4. Apply Artificial Bee Colony Algorithm

The simulation runs by applying ABC algorithm and observed by each iteration process to analyze the fitness value of path length. The flowchart of ABC algorithm is described using flowchart at figure 4.

Table 1. Simulation Parameters

Parameter	**Value**
Topology	NSFNET
Optimization Algorithm	Artificial Bee Colony
Number of connection request	10, 30, 50, 100
Number of alternative paths	10
Number of wavelength per link	32
Iteration	1000
Traffic Pattern	Based on population & distance, uniform and poisson random
Traffic Normalization	Total Normalization

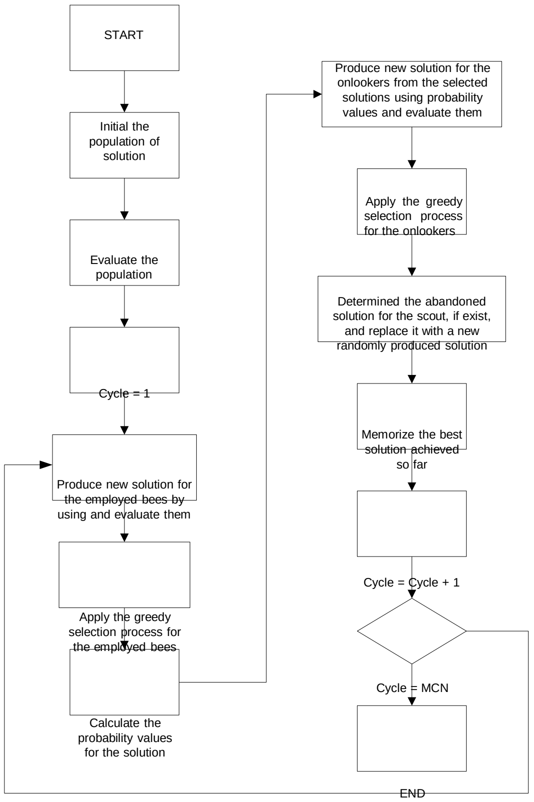


Fig. 4. Flowchart of ABC Algorithm

5. Analyze and summarize the result report
   The performance of Artificial Bee Colony algorithm is considered in a parameter of fitness value of path length. Path length optimization is indicated by minimizing the total path length for receiving connection requests. As the iteration increased, the performance of the algorithm can be obtained by analyzing the global fitness point achievement of the minimum of total path length.

IV. SIMULATION PROCESS AND OUTCOME ANALYSIS

The simulation parameter used in this paper is described as follows shown at table 1. First simulation runs with several different number of connection request to analyze the impact of connection request to the performance of ABC algorithm. Simulation process is divided in four parts with assumed that the number of connection request are 10 and 100 with the maximum iteration 1000 iterations and Poisson generated traffic. Based on the simulation result in figure 5 and 6, the number of connection request can affect directly to the performance of ABC algorithm to reach the fitness value. After running simulation using three different generated traffic distribution, for the uniform generated traffic, the simulation takes 595 iterations to reach its fitness value; for the distribution based on population and distance, the simulation takes 850 iteration to reach its fitness value; and for the poisson random generated traffic, the simulation takes 945 iterations to reach its fitness value.

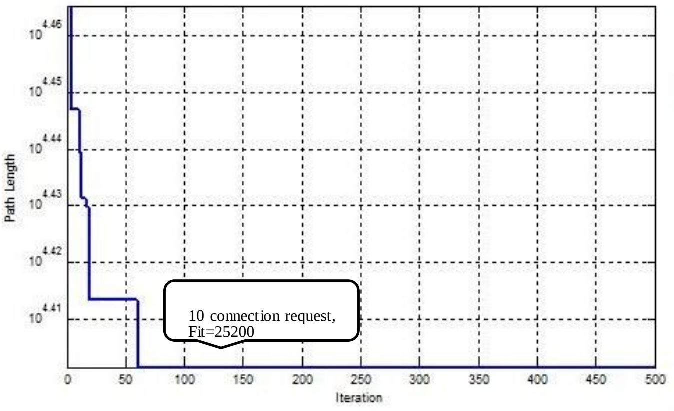


Fig. 5. Performance of ABC Algorithm with 10 Connection Requests

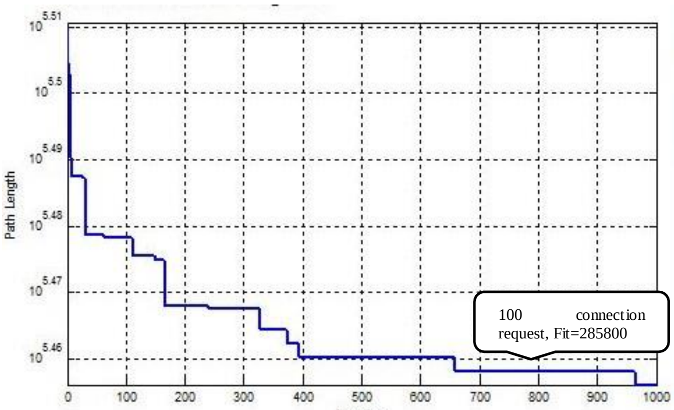


Fig. 6. Performance of ABC Algorithm with 100 Connection Requests

Since the number of connection requests increased, the number of population also increased. Increasing population size will cause initial solution data become wider and more neighborhoods data to be compared by the onlookers from each iteration. From the simulation result, captured that compared with 100 connection request, the only 10 connection can achieved fitness value with approximately 13% number of iterations.

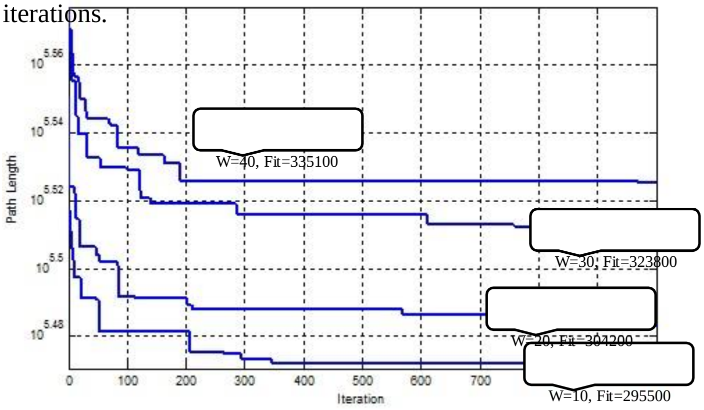


Fig. 7. Performance of ABC Algorithm on NSFNET Topology with Different Number of Wavelength

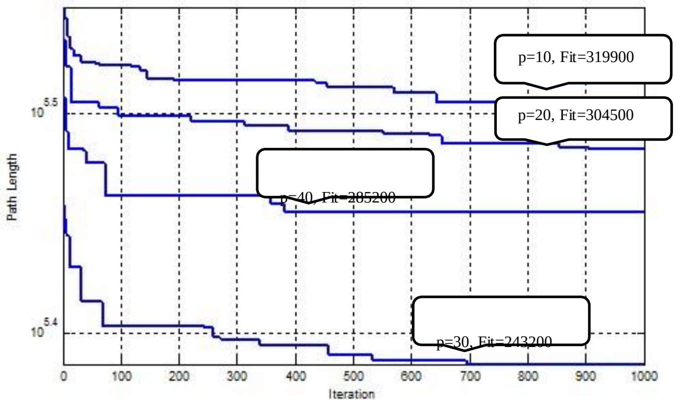


Fig. 8. Performance of ABC Algorithm on NSFNET Topology with Different Number of Alternative Path

The next simulation is to analyze the performance of ABC algorithm with several different number of alternative path and number of wavelength per link. Assumed that the number of connection request is 100 and the maximum iteration is 1000 iterations. The first part is to analyze the performance of ABC algorithm with several different number of wavelength per link as shown at figure 7. The second part is to analyze the performance of ABC with several different number of alternative paths as shown at figure 8. From the above iteration results, different fitness value of path length may occurs because of the random generated connection request. Every addition of wavelength per link or alternative path will optimize the performance of ABC algorithm to reach its fitness value. Since the number of wavelength per link is increased, the served connection request with minimum path length will generated more often without re-rerouting the traffic through another path because of number of wavelength limitation. As results, the ABC algorithm will reach fitness value with less iterations. From the simulation result, shown that with 40 number of wavelength the ABC algorithm can achieved fitness value approximately 20% number of iteration compared with 10 number of wavelength per link. As well as number of wavelength per link, since the number of alternative path increased, the upper bound of decision variable is increased. The increasing upper bound will cause the dimension of new solution finding of ABC algorithm wider per iteration, so the total iteration to find best solution or fitness value is minimized. From the simulation result, captured that with 40 number of alternative path the ABC algorithm can achieved fitness value approximately 38% number of iterations compared with 10 number of alternative path.

The performance of ABC algorithm to solve RWA with several traffic distribution also analyzed with the simulation. With assumed connection request = 100, number of alternative path = 10 and the number of wavelength each link = 32; the simulation runs for 1000 iterations with 3 different traffic distribution: Uniform (0,10), Based on population and distance of NSFNET, and Poisson random with lambda 10.

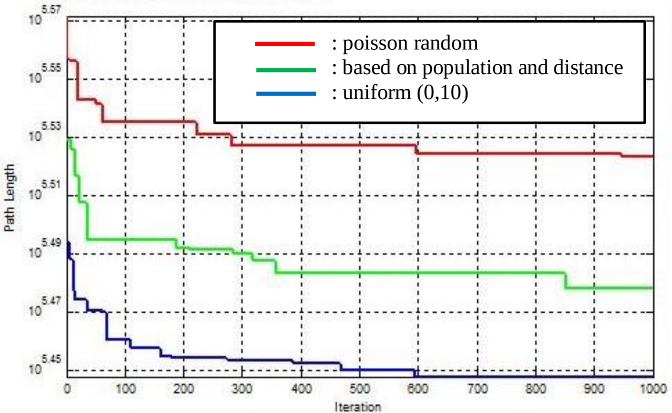


Fig. 9. Performance of ABC Algorithm with Different Traffic Distribution

The random pattern of generated traffic cause the distribution of generated connection request become more widespread, so the task of the employed bee to finding new solution within neighborhood with better fitness value will takes more iteration. From the simulation result, compared with Poisson traffic distribution, shown that the ABC algorithm can reach fitness value approximately 89% number of iterations for the based on population and distance traffic distribution and approximately 62% number of iterations for the uniform traffic distribution.

To analyze the population or colony size impact to the ABC algorithm performance, simulation runs with 2 different population size. First simulation use 50 number of population and the second use 100 number of population. With assumed connection request = 100, number of alternative path = 10 and the number of wavelength each link = 32; the simulation runs for 1500 iterations, the results shown at figure 10 and 11 below.

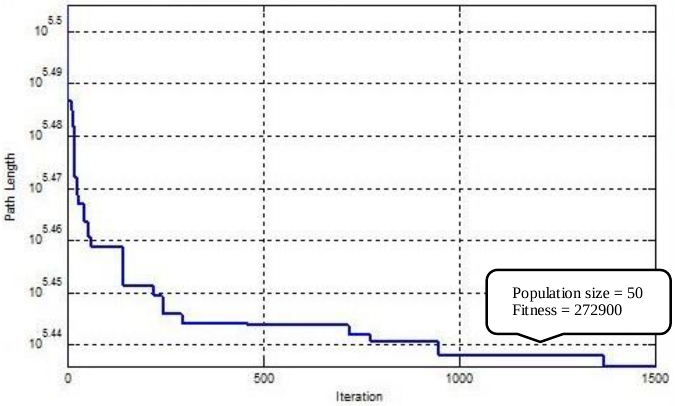


Fig. 10. Performance of ABC with Number of Population 50

The population size affects the number of iterations needed by the ABC algorithm to reach the fitness value. With 100 population size which is the same number with the number of connection requests, the ABC algorithm reach its fitness value by the iteration of about 580 iterations; But if the population size decreased by its half, the ABC algorithm need more iterations to reach its fitness value or about 1375 iterations.

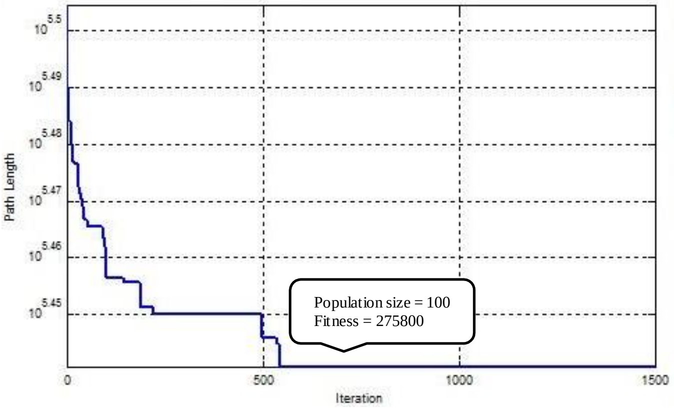


Fig. 11. Performance of ABC with Number of Population 100

With the same number of connection request, decreasing population size may reduce the number of employed bee and the onlookers in each iteration of ABC algorithm to find and compare new solution. Since reduced number of employed and onlookers used in each iteration, the ABC algorithm needs more iteration to find the best solution or reach its fitness value. From the simulation result, captured if the population size is equal with the number of connection request, the ABC algorithm can reach fitness value by approximately 42% number of iterations compared with decreased population by its half for the same number of connection requests.

V. CONCLUSION

The conclusion that achieved from the simulation result are: Artificial Bee Colony algorithm can be used to solve routing and wavelength assignment problem at DWDM transport network. In line with iteration process, the path length observed toward minimum value or global optimum value. The more number of connection request affects directly to the performance of ABC algorithm since the algorithm will need more iterations to reach the fitness value. The ABC algorithm become more effective when the number of alternative path and or number of wavelength per link is increased. From the simulation process, the increasing number of alternative path and or wavelength per link can provide better performance indicated by minimum iterations to reach its fitness value (minimum path length). The ABC algorithm can be used to solve RWA with many type of generated traffic distribution such as uniform, based on population and distance and also Poisson Random distribution. The ABC algorithm need more iterations to reach the fitness value if the population size decreased, since less number of bee for foraging new solution.

To improve the performance of ABC algorithm, we may modify the algorithm to increase the performance of algorithm to reach its fitness value with less time. In the future, this research of ABC algorithm could be extended and improved more in the future for solving RWA problem in a fault-tolerance network condition.

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