A Hybrid Mutation-based Artificial Bee Colony for Traveling Salesman Problem

Shima Sabet and Fardad Farokhi
Islamic Azad University of Central Tehran Branch, Tehran, Iran
Email: sh_sabet25@yahoo.com, f_farokhi@iauctb.ac.ir

Mohammad Shokouhifar
Shahid Beheshti University, Tehran, Iran
Email: m_shokouhifar@ieee.org

***Abstract*—Travelling Salesman Problem (TSP) belongs to the class of NP-Complete problems. It has been proved that evolutionary algorithms are effective and efficient, with respect to the traditional methods for solving NP-Complete problems like TSP, with avoidance trapping in local minima areas. Artificial Bee Colony (ABC) is a new swarm-based optimization algorithm, which inspired by the foraging behavior of honey bees. In ABC, the neighborhood search strategy is employed in order to find better solutions around the previous ones. In this paper, a hybrid mutation based mechanism is proposed to perform the neighborhood searching for the bees for the TSP. The introduced approach leads to efficiently reduce the complexity and running time of the ABC algorithm. Experimental results were carried out on the benchmarks from TSPLIB for validation. The findings imply that the proposed approach is able to achieve optimal tours very quickly.**

***Index Terms*—traveling salesman problem (TSP), artificial bee colony (ABC), mutation**

I. Introduction

Traveling salesman problem (TSP) is one of the most popular combinatorial optimization problems which is classified as a NP-Complete problem. The TSP represents the salesman who wants to visit a set of cities exactly once and finally turns back to the starting city. The objective is to determine the tour with minimum total distance. TSP is a sub-problem issue of many application domains such as network communication [1], transportation [2], scheduling problems [3], semiconductor industries and integrated circuits designs [4], and physical mapping problems [5].

In recent years many approaches have been developed to solve TSP that can be divided to exact [6] and approximate approaches [7]. Exact methods can only be used for very small size instances, and for real-world problems, researchers have to apply approximate methods that find near-optimal solutions in a reasonable time rather than an exact method that guarantees to find the optimal solution in an exponential time. The simplest exact method is to make all possible tours, and then select the optimal tour with the minimum total cost. All possible permutations of N cities are equal to $\mathrm{N}!$; however, every tour can be represented in $2\mathrm{N}$ different manner depends on the initial city and the length of tour. So the size of search space is equal to $(\mathrm{N}-1)!/2$ [7]. It is obviously that this evaluation is not possible in term of computational time even for 20 cities.

Among proposed approaches for TSP, population-based evolutionary algorithms efficiently have been developed for solve TSP. Moon et. al [8] described a genetic algorithm (GA) which is formulated by network model and used encoding scheme for TSP based on topological sort to form ordering of vertices in a directed graph. Albayrak *et al.* [9] has introduced a GA based approach for TSP with a new mutation operator as greedy sub tour mutation (GSTM). Zhao et. al [10] introduced a new method called balancing exploration and exploitation GA, aims to balance the exploitation of excellent individuals and the exploration of diverse tours using the GA. Distinct methods is published to improve GA on TSP so far, variety mutation operators were employed, such as swap [11], adjacent-change, GSTM [9], shift-change [12], exchange [13], stochastic hill climbing [14], and route mutation [15].

Ant colony optimization (ACO), is a well-known algorithm designed for TSP and has good performance. Shang et al. [16] proposed a hybrid approach which integrates ACO and association rule (AR) to solve TSP. Li *et al.* [17] presented an improved ACO, which applies a new probability selection mechanism by using Held-Karp lower bound to determine the trade-off between the influence of the heuristic information and the pheromone trails. Shi *et al.* [18] proposed a modified particle swarm optimization (PSO) algorithm which applied a crossover eliminated technique and two local search techniques. Recently, ABC algorithm was developed for solve optimization problems. Zhang suggested a novel algorithm to solve TSP so that it mixtures the route construction mechanism of the ABC algorithm with Path

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M. Shokouhifar was with the Electrical Engineering Department, Islamic Azad University of Central Tehran Branch, Tehran, Iran. He is now with the Department of Electrical and Computer Engineering, Shahid Beheshti University, Tehran, Iran (Tel: +989121944288, e-mail: m_shokouhifar@ieee.org).

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Relinking [19]. An approach called Combinatorial ABC is illustrated by Karaboga *et al.* [20], which used a mechanism for neighborhood searching based on GSTM mutation.

In this paper, a new Hybrid Mutation-based ABC algorithm (named HMABC) is proposed to quickly find an optimal tour. The rest of paper is organized as follows: In section 2, the ABC algorithm has reviewed. Section 3 presents the methodology of HMABC algorithm. In section 4, the experimental results are shown, and consequently, a conclusion is described in section 5.

II. Artificial Bee Colony Algorithm

Artificial bee colony (ABC) is a novel population-based algorithm which inspired of the intelligent foraging behavior of real honey bees swarm, proposed by Karaboga *et al.* in 2006 [21]. To solve TSP using ABC algorithm, the position of a food source represents a possible tour and the nectar amount of a food source corresponds to the quality of the tour. In ABC model, the colony consists of three groups of bees: employed bees, onlookers and scouts.

Each employed bee goes to the food source area in her memory and determines a neighbor source, and then come back to the hive and begin dance in dance area. This dance is essential for colony communication, and contains three pieces of information regarding a flower patch: the direction in which it will be found, its distance from the hive and its quality rating (fitness). Provided that the nectar amount of the new selected source is higher than the previous one, the bee memorizes the new source position and forgets the old one. Otherwise she keeps the previous position in her memory. Each onlooker watches the dances of employed bees, and makes decision to choose the food source through the shared information from the dances. Then, some employed bees which found high quality solutions, are chosen as scouts. For each scout, some employed bees are determined to search for finding new food sources in the neighborhood of the solution of the scout.

III. Methodology

A. Problem Representation

TSP can be represented as a graph $G = (V, E)$, where $V = \{1, 2, \dots, N\}$ is a set of nodes, and $E = \{\, (i, j) \mid i, j \epsilon V\}$ is the set of all connection edges between them. Each node represents a city, and each edge means the possible path between two related cities. The distance d_{ij} is associated with edge (i, j) and represents the Euclidean distance from city i to city j "Eq. (1)". The heuristic information is calculated before performing the main algorithm. So, the distances of all edges were calculated and saved.

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \qquad (1)$$

Iteratively, after construction the solutions, the qualities of the gathered solutions are evaluated by the cost function, which is calculated by sum of the Euclidean distances of the consecutive edges within the tour as "Eq. (2)". Note that the $Cost_k$ is corresponding to the bee_k.

$$Cost_k = \sum_{l=1}^{N} d_l \qquad (2)$$

B. Used Mutation Operators for Neighborhood Search

As noted above, there are variety mutation operations for TSP, such as swap, adjacent-change, route and shift-change. In this study, the Neighbor Swap (called NS), Neighbor Shift-Change (called NSC), and the proposed Neighbor-Change (called NC) operators are used in the presented hybrid mutation strategy. In NS operator, two neighbor agents of the bee are selected randomly, and then are replaced with each other. The NSC operator firstly selects two neighbor agents randomly, and then it replaces one of them with the other and shifts all remained agents between them with the same sequence. The neighborhood search by the bee using the NS and NSC operations can be seen respectively in "Fig. 1," and "Fig. 2".

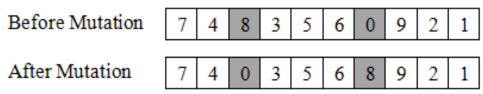


Figure 1. The NS mutation operation.

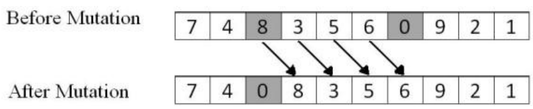


Figure 2. The NSC mutation operation.

And finally the proposed NC operator works as follow:

- One city is chosen randomly (for example the city i).
- A city must be selected in the neighborhood of the city i, and the one which has less distance, has more probability to be selected. The probability of the selected city j is computed by "Eq. (3)".
- The positions of the city i and the newly selected city are determined for the bee. So the corresponding agents in the bee are determined.
- The shift-change operator is applied to the two selected neighbor cities.

$$P_{ji} = \frac{\frac{1}{d_{ji}}}{\sum_{h}^{N} \frac{1}{d_{jh}}} \qquad (3)$$

C. Construction of Initial Solutions

To solve TSP using ABC algorithm, at the first step, a distributed initial population (food source positions) is generated. The way which is used for achieving initial solutions, was set up in a way that, it led to achieve better quality solutions than random selection. In HMABC algorithm, the initial solutions are not determined completely random. In this manner a random city is selected as initial of the tour (*e. g.* city i). Then the next cities consecutively are added to the rout, with a probability which corresponds to the inverse of their distance from city i.

D. Selection of Scout Bees by Onlookers

After all employed bees complete their search, they come back to the hive and share their information about the nectar amount of their food sources with the onlookers waiting there; so the quality of the gathered solutions are evaluated. In this step, a selection strategy is applied to choose some food source by onlookers. The probability of selecting bee_k as a scout, is computed by “Eq. (4)”. Where N_k is the amount of nectar in food source k, and $\sum_{i=1}^{N} N_k$ is the total amount of achieved nectar. In HMABC, the N_k was considered as $1/Cost_k$. The increscent in the value of μ (μ>1) leads to select the better bees. So, the onlookers play the role as an objective function to evaluate generated solutions.

$$P_k = \frac{N_k^{\mu}}{\sum_{i=1}^{N} N_i^{\mu}} \tag{4}$$

E. Equations

After selecting scout bees by onlookers, the recruitment process is performed such that some employed bees (soldiers) are assigned for each scout. The number of soldiers determined for each scout bee is determined as:

$$S_i = \beta \times (P_i / H) + \gamma \tag{5}$$

where S_i is the percentage of soldiers that are selected for the i^{th} selected scout. P_i is the preference number of the i^{th} scout bee, and H is the number of all determined scout bees. The ß and γ are two parameters that may be constant, or may change iteratively. The ß and γ determine the recruitment model. The value of γ is revealed positive. If ß=0, the number of soldiers for all scouts is determined uniformly. If ß>0, for the scout which has better quality, less number of soldiers are assigned; and if ß<0, more soldiers are considered for the better scout bee.

F. Neighborhood Search Using Hybrid Mutation Scheme

In this step, each scout bee with her assigned soldiers goes to the neighborhood area of the food source which was found by that scout. In this way, for selection of a new solution surrounding the previous one, some part of the tour will be changed a few, to find better solutions. In order to do that, the proposed hybrid mutation scheme is applied for each bee. As noted above three mutation operators are used in HMABC, which each of them has the own advantage and prevents the search path can avoid from local minima. Each soldier uses the NC operator with %50 probability, and the chances of the NS and the NSC operators are %20 and %30 respectively. As noted above, the main steps of proposed ABC-based algorithm can be summarized as follows:

Step 1: Initialization.

Step 2: Generation of initial solutions by employed bees, based on nearest neighborhood search strategy.

Step 3: Evaluation of achieved solutions.

Step 4: The global best solution found so far, is registered.

Step 5: Selection of high-quality solutions as scout bees by onlookers, and performing the recruitment process for them.

Step 6: Check the stop criterion: Stop, if the number of iterations is more than the maximum, otherwise continue.

Step 7: Search the neighborhood using the proposed hybrid mutation-based scheme.

Step 8: go to Step 3 and continue.

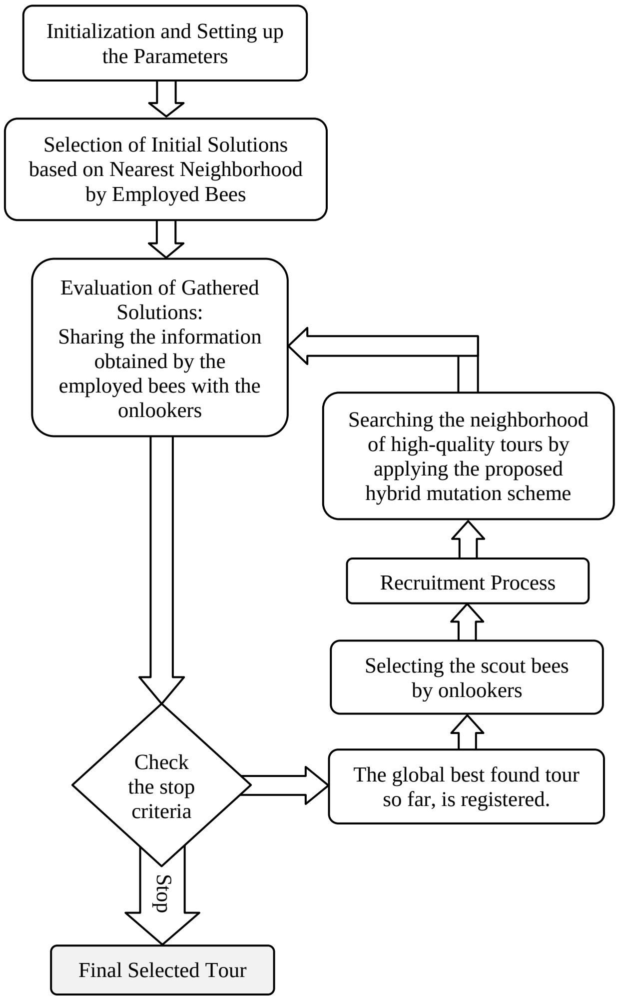


Figure 3. The overall flowchart of HMABC algorithm.

IV. Experimental Result

All of experiments tested on an Intel PC with 2.53^{GHZ} processor and 4^{MB} memory running MATLAB R2009a in windows 7. In order to evaluate the performance of HMABC algorithm, we tested it on the benchmark problems from TSPLIB [22]. For tuning the parameters, different values were tested, and the best values were considered for experiments, which can be summarized in Table I.

We compare the performance of HMABC with two ACO-based methods given in [7]. The experimental results are summarized in Table II. The first column is the problem names, the 2nd column is the optimum tour lengths. The 3th and 4th columns are the solution of the two compared algorithms, and the last column is the achieved tour lengths by proposed method. An optimum solution achieved by HMABC for Eil76, Berlin52, Eil51, and St70 problems can be seen respectively in “Fig. 4” to “Fig. 7”. And in Table III a comparison of HMABC algorithm employing the different mutation operators, is shown.

TABLE I. PARAMETER SETTING

Parameter	Value
Max Iteration	1000
Number of Employed Bees	100
Number of Scout Bees	5
Max Distance of two Neighbor agents for Mutation	N/5
Probability of NS mutation	%20
Probability of NSC mutation	%30
Probability of NC mutation	%50
μ	10
Β	-20
Γ	32
Η	5

TABLE II. COMPARISON BETWEEN BEST FOUND TOUR LENGTH

Problem	Optimal Solution	BWAS	RBAS	HMABC
Eil76	538	538	545.5	539.5
Berlin52	7542	7542	7542	7542
Eil51	426	427.9	428.1	427.2
St70	675	676.2	686,4	678.2
Rat99	1211	1213.8	1221.3	1215.3

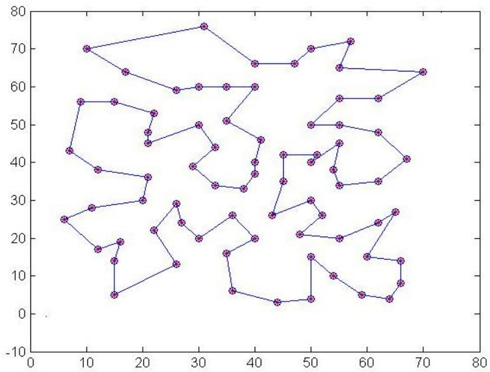
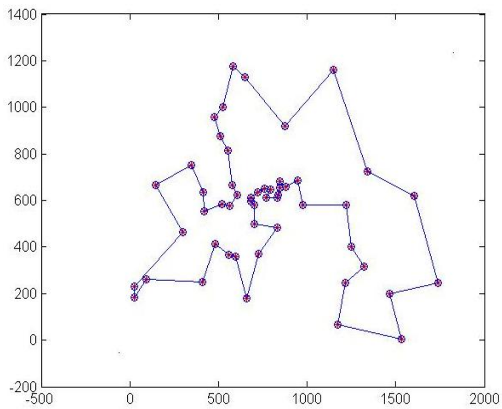


Figure 4. Note how the caption is centered in the column.



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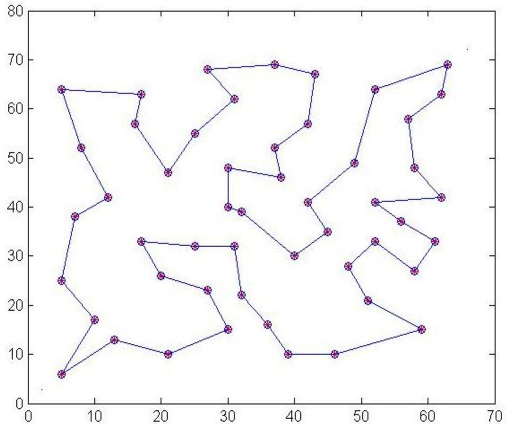

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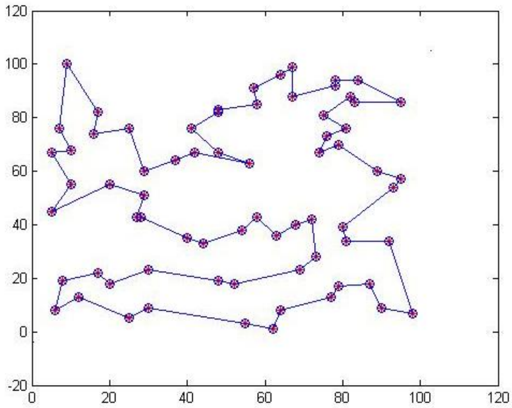

Figure 7. Note how the caption is centered in the column.

TABLE III. COMPARISON THE RESULT WITH DIFFERENT MUTATION SCHEMES, AVERAGE ON 10 RUNS

Problem	Eil51	Berlin52	Eil76
Neighbor-Swap (NS)	593	8112	655
Neighbor-Shift-Change (NSC)	482	7749	589
Neighbor-Change (NC)	477	7621	592
Proposed Hybrid Mutation	432	7553	547

V. CONCLUSION

In this paper, a novel ABC algorithm based on a hybrid mutation scheme (named HMABC algorithm) was introduced for TSP, aims to efficiently reduce the complexity of evolutionary algorithms. Proposed algorithm has a strong search capability in the graph space and can effectively find an optimal tour. Experimental results show that this approach considers both running time and solution quality as well. As a future work, the algorithm will be hybridized with ACO algorithm to find better results. Moreover the HMABC quickly achieves good performance in compare with the other evolutionary algorithms; and it is quite simple and easy to apply.

REFERENCES

[1] J. R. L. Fournier and S. Pierre, “Assigning cells to switches in mobile networks using an ant colony optimization heuristic,” *Computer Communication Conf.*, 2005, vol. 28, pp. 65-73.

[2] J. E. Bella and P. R. McMullen, "Ant colony optimization techniques for the vehicle routing problem," *Advanced Engineering Informatics Conf.*, 2004, vol. 18, pp. 41-48.

[3] D. Whitely, T. Starkweather, and F. D'Ann, "Scheduling problems and traveling salesman: The genetic edge recombination operator," in *Proc. 3rd Int. Conf. Genetic Algorithms*, 1989, pp. 133–140.

[4] S. Kirkpatrick, C. D. Gelatt Jr, and M. P. Vecchi, "Optimization by simulated annealing," *Science*, 1983, vol. 220, pp. 498–516.

[5] F. Alizadeh, R. M. Karp, L. A. Newberg, and D. K. Weisser, "Physical mapping of chromosomes: A combinatorial problem in molecular biology," in *Proc. 4th ACM-SIAM Symp. Discrete Algorithms*, 1993, pp. 52–76.

[6] T. Bektas, "The multiple traveling salesman problem:an overview of formulations and solution procedures," *Omega*, vol. 34, no. 3, pp. 209-219, 2006.

[7] A. Ugur and D. Aydin, "An interactive simulation and analysis software for solving TSP using ant colony optimization algorithm," *Advances in Engineering Software*, vol. 40, pp. 341-349, 2009

[8] C. Moon, j. Kim, G. Choi, and Y. Seo, "An efficient genetic algorithm for the traveling salesman problem with precedence constraints," *European Journal of Operational Research*, vol. 140, pp. 606–617, 2002.

[9] M. Albayrak and N. Allahverdi, "Development a new mutation operator to solve the traveling salesman problem by aid of genetic algorithms," *Expert Systems with App*, vol. 38, no. 3, pp. 1313-1320, 2011.

[10] G. Zhao, W. Luo, H. Nie, and C. Li, "A genetic algorithm balancing exploration and exploitation for the travelling salesman problem," in *Proc. Fourth International Conference on Natural Computation*, 2008, pp. 505-509.

[11] F. Samanlioglu, W. G. Ferrell jr, and M. E. Kruz, "A memetic random-key genetic algorithm for a symmetric multi-objective traveling salesman problem," *Computers & Industrial Engineering*, vol. 55, no. 2, pp. 439–449, 2008.

[12] L. N. Xing, Y. W. Chen, K. W. Yang, F. Hou, X. S. Shen, and H. P. Cai, "A hybrid approach combining an improved genetic algorithm and optimization strategies for the asymmetric traveling salesman problem," *Engineering Applications of Artificial Intelligence*, vol. 21, pp. 1370–1380, 2008.

[13] J. Majumdar and A. K. Bhunia, "Genetic algorithm for asymmetric traveling salesman problem with imprecise travel times," *Journal of Computational and Applied Mathematics*, pp. 3063-3078, 2011.

[14] K. Katayama and H. Sakamoto, "The Efficiency of Hybrid Mutation Genetic Algorithm for the Travelling Salesman Problem," *Mathematical and Computer Modelling*, vol. 31, pp. 197-203, 2000.

[15] S. M. Chen and C. Y. Chien, "Parallelized genetic ant colony systems for solving the traveling salesman problem," *Expert Systems with Applications*, vol. 38, pp. 3873-3883, 2011.

[16] G. Shang, Z. Lei, Z. Fengting, and Z. Chunxian, "Solving traveling salesman problem by ant colony optimization algorithm with association rule," *Third International Conference on Natural Computation, IEEE*, 2007.

[17] L. Li, S. Ju, and Y. Zhang, "Improved ant colony optimization for the traveling salesman problem," *International Conference on Intelligent Computation Technology and Automation*, 2008, pp. 76-80.

[18] X. H. Shi, Y. C. Liang, H. P. Lee, C. Lu, and Q. X. Wang, "Particle swarm optimization-based algorithms for TSP and generalized TSP," *Information Processing Letters*, vol. 103, no. 5, pp. 169-176, 2007.

[19] X. Zhang, Q. Bai, and X. Yun, "A new hybrid artificial bee colony algorithm for the traveling salesman problem," in *Proc. IEEE 3rd International Conference on Communication Software and Networks*, 2011, pp. 155-159.

[20] D. Karaboga and B. Gorkemli, "A combinatorial artificial bee colony algorithm for traveling salesman problem," *International Symposium on Innovations in Intelligent Systems and Applications*, 2011, pp. 50-53.

[21] D. Karaboga and B. Basturk, "A powerful and efficient algorithm for numerical function optimization: Artificial bee colony (ABC) algorithm," *Journal of global optimization*, vol. 39, no. 3, pp. 459-471, 2007.

[22] [Online]. Available: http://www.iwr.uniheidelberg.de/groups/comopt/software/TSPLIB95/TSPLIB.html

M. Shokouhifar was born in Dezfoul, Iran, in 1987. He received the MS degree in electronic engineering from Islamic Azad University of Central Tehran Branch, Tehran, Iran, in 2011. He currently is a MS student in electronic engineering in the field of analog circuit design, Shahid Beheshti University, Tehran, Iran. His research interests include: pattern recognition, image processing, fuzzy sets theory, analog and digital circuit design, wireless sensor networks, feature selection, and solving NP-complete problems by using evolutionary algorithms. He has more than 20 international journals and conference papers in the field of evolutionary algorithms. In 2010, he received the award of superior researcher from the Islamic Azad University of Central Tehran Branch. He is a student member of IEEE.

