IMPROVED BUTTERFLY OPTIMIZATION ALGORITHM USING LOCAL SEARCH OPERATOR FOR CAPACITATED VEHICLE ROUTING PROBLEM

P. PRIYADHARSHINI[1], K. PRAKASHRAJ [2], S. PADMAPRIYA[3]

[1,2,3]*Final Year B.Tech, Dept of Information Technology, Pondicherry Engineering College, Puducherry, India*

---***---

Abstract - *The aim of the project is to improve Butterfly Optimization Algorithm (**BOA**) which is a Meta Heuristic Algorithm based on food foraging behavior of butterfly. To improve the performance of BOA on Capacitated Vehicle Routing Problem (CVRP) by introducing Local Search Operator. This work will be tested by using the fisher instances of various sizes.*

Key Words: **Butterfly optimization algorithm (BOA), Nature inspired Metaheuristic, Capacitated Vehicle Routing Problem (CVRP), Local Search Operator.**

1. INTRODUCTION

1.1 BUTTERFLY OPTIMIZATION ALGORITHM

Real world problems are intricate as they are multidimensional in nature that encourages computer scientists to develop better and efficient problem-solving methods. Nature-inspired metaheuristics exhibit better performances than that of traditional approaches. Till date, researchers have bestowed and experimented with numerous nature-inspired metaheuristic algorithms to handle various search issues. Butterfly optimization algorithm [1] that mimics food search, to solve global optimization problems.

Butterfly Optimization Algorithm (BOA) is mainly inspired by the food foraging behavior of the butterflies. The behavior of butterflies can be described as their cooperative movement toward the food source position. The butterflies receive/sense and analyze the smell in the air to determine the potential direction of a food source belongs to Nature-inspired optimization algorithms. It is basically inspired by the food foraging behavior of butterflies. In BOA, these butterflies are used as search agents to perform optimization.

In BOA, a butterfly is able to generate fragrance with some intensity. This fragrance is further correlated with fitness of the butterfly. This means that whenever a butterfly moves from one position to other particular position in the search space, its fitness will vary accordingly. Now, the fragrance which is sensed by butterflies is propagated over distance to all other butterflies in the region. The propagated fragrance is sensed by butterflies and a collective social knowledge network is formed. Whenever a butterfly senses fragrance from the best butterfly in the search space, it takes a step towards the best butterfly and this phase is termed as ***global search*** phase of BOA. In the second scenario, whenever a butterfly is not able to sense fragrance of any other butterfly in the search space, it will take random steps and this phase is termed as ***local search*** phase in BOA.

1.2 BUTTERFLY

In the Linnaean system [3] of Animal Kingdom, butterflies lie in the class of Lepidoptera. There are more than 18,000 species of butterflies across the world. The reason of their survival for so many million years lies in their senses (Saccheri et al. 1998). Butterflies use their sense of smell, sight, taste, touch and hearing to find food and mating partner. These senses are also helpful in migrating from one place to another, escaping from predator and laying eggs inappropriate places. Among all these senses, smell is the most important sense which helps butterfly to find food, usually nectar, even from long distance (BlairandLauner1997).

In order to find the source of nectar, butterflies use sense receptors which are used to smell and these receptors are scattered over butterfly's body parts like antennae, legs ,palps, etc. These receptors are actually nerve cells on butterfly's body surface and are called chemoreceptors (Pollard and Yates 1994). These chemoreceptors guide the butterfly to find the best mating partner in order to continue a strong genetic line. A male butterfly is able to identify the female through her pheromone which are scent secretions emitted by the female butterfly to cause specific reactions. A butterfly will generate fragrance with some intensity which is correlated with its fitness, i.e., as a butterfly moves from one location to another, its fitness will vary accordingly. The fragrance will propagate over distance and other butterflies can sense it and this is how the butterflies can share its personal information with other butterflies and form a collective social knowledge network.

1.3 FRAGRANCE

In BOA, each fragrance has its own different scent and personal touch. It is one of the main characteristics that distinguishes BOA from other metaheuristics. In order to understand how fragrance is calculated in BOA, first we need to understand, how a modality like smell, sound, light, temperature, etc. is processed by a stimulus. . The whole concept of sensing and processing the modality is based on three important terms viz. sensory modality (c), stimulus intensity (I) and power exponent (a).

1.4 MOVEMENT OF BUTTERFLIES

To demonstrate the above discussions in terms of a search algorithm, the above characteristics of butterflies are idealized as follows:

1. All butterflies are supposed to emit some fragrance which enables the butterflies to attract each other.
2. Every butterfly will move randomly or toward the best butterfly emitting more fragrance.
3. The stimulus intensity of a butterfly is affected or determined by the landscape of the objective function.

2. CAPACITATED VEHICLE ROUTING PROBLEM

Capacitated Vehicle Routing Problem [2] is a NP-Hard problem. It is a Vehicle Routing Problem (VRP) in which the optimal set of routes taken by the vehicles is determined under capacity constraint. CVRP is formally defined as an undirected graph G = (V, E) where V = $\{v_0,v_1,...,v_n\}$ is a vertex set and E = $\{(v_i,v_j) \mid v_i,v_j \in V,\ i < j\}$ is an edge set. The depot is represented by vertex v_0, which uses m independent delivery vehicles, with identical delivery capacity D, to service demands d_i from n cities or customers, i = 1,2,...,n, represented by the set of n vertices $\{v_1,...,v_n\}$. A non-negative cost (distance) matrix C = (c_{ij}) between customers v_i and v_j is defined on E. A solution for the CVRP would be a partition $P_1,P_2,...,P_m$ of V representing the routes of the vehicles, each route $P_i = \{v_{i0},v_{i1},...,v_{ik+1}\}$, where $v_{ij} \in V$ and $v_{i0} = v_{ik+1} = 0$ (0 denotes the depot), satisfying $\sum_{v_{ij}\in P_i} d_j \le D$.

The cost of the problem solution is the sum of the costs of its routes P_i, defined by the following equation 1.

$$Cost=\sum_{i=1}^{m} Cost(P_i)=\sum_{j=0}^{k} c_{j,j+1} \qquad (1)$$

The CVRP involves determining a set of maximum m routes with minimum total cost, such that each route starts and ends at the depot and each customer is visited exactly once by exactly one vehicle, subject to the restriction that the total demand of any route does not exceed D. To solve CVRP, the distance matrix is generated using the Euclidean distance formula for two vertices.

CVRP has been solved using many metaheuristic algorithms, BOA which has good exploitation property exhibits foraging behavior is a recently invented algorithm which produces better solutions with a reasonable amount of time. Implementation of BOA and CVRP is carried out with the intention of producing optimal solutions by making use of both exploitation and exploration.

3. LOCAL SEARCH OPERATORS

Local Search Operators will improve the Meta heuristic algorithms. In this, we are going to apply intra route operators for CVRP in BOA to improve the performance.

Move operator is an intra-route operator of local search operators which is used to move a node randomly from its current position to a new random position.

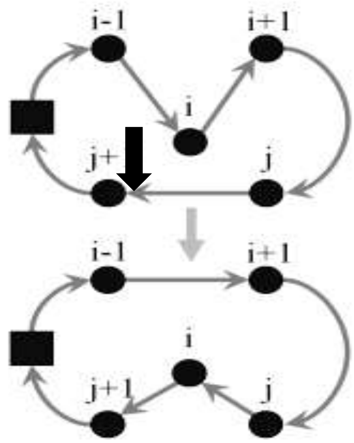

Fig: 1. Illustration of Local Search Move Operator

Swap operator is an intra-route operator of local search operators which is used for selecting two positions randomly along with the individual and swaps the contents.

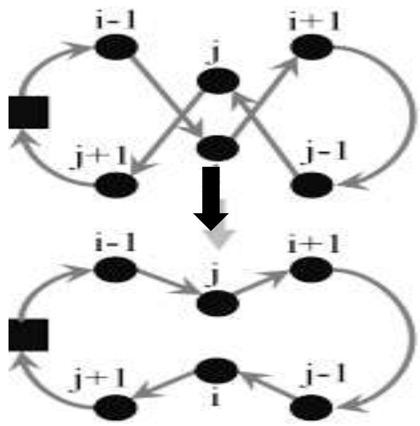

Fig: 2. Illustration of Local Search Swap Operators

Inversion operator is also intra-route operator of local search operators which inverses a subsequence between two customers in route.

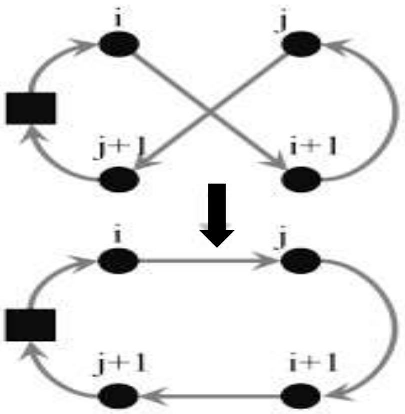

Fig: 3. Illustration of Local Search Inversion Operator

4. EXSISTING WORK

The main strength of BOA lies in its mechanism to modulate fragrance in the algorithm. The basic concept of sensing is dependent on three vital parameters such as

a) Sensory modality (**c**),

b) Stimulus intensity (**I**), and

c) Power exponent (**a**).

Sensory modality defines the method by which the form of energy is measured and processed by the sensors. Different modalities senses can be smell, sound, light, temperature or pressure, etc., and in BOA, it is fragrance. In BOA, many butterflies emit fragrance at the same time, it is their sensory modality which allows butterflies to sense and differentiate these fragrances from each other. "**I**" is a actual stimulus intensity which is correlated with the fitness of the butterfly/solution (i.e., a butterfly with higher fragrance or greater fitness value attracts other butterflies in that region).

The parameter "**a**" allows response compression, i.e., as the stimulus gets stronger, insects become increasingly less sensitive to the stimulus changes.

The natural phenomenon of butterflies is based on two imperative issues:

- Variation of " **I** ", and
- Formulation of " **f** ".

For simplicity, in BOA, "**I**" of a butterfly is associated with the encoded objective function. However, "**f**" is relative (i.e., it should be sensed by other butterflies), and therefore, considering these concepts, in BOA, the fragrance is formulated as a function of the physical intensity of stimulus as follows:

$$\mathbf{f = cI^a}$$

Where, **f** is the perceived magnitude of fragrance, i.e., how stronger the fragrance is perceived by i^{th} butterfly.

c is the sensory modality **I** is the stimulus intensity and

a is the power exponent dependent on modality, which accounts degree of absorption.

5. PROBLEM DEFINITION

To develop an Improved Butterfly Optimization Algorithm using Intra route local search Swap operator for finding out optimized solution for the Capacitated Vehicle Routing Problem.

6. OUTLINE OF THE PROPOSED WORK

Capacitated Vehicle Routing Problem is a well-known NP Hard Combinatorial Optimization Problem. The proposed work aims at improving CVRP using Butterfly Optimization Algorithm, since it has produced optimal solutions for some engineering design problems compared to other Meta heuristic methods.

There are two important phases in the BOA; they are ***global search phase*** and ***local search phase***. In global search phase, the butterfly takes a step towards the fittest butterfly/solution vector g* which can be represented as

$$x_i^{t+1} = x_i^t + (r^2 \times g^* - x_i^t) \times f_i$$

Local search phase can be represented as

$$x_i^{t+1} = x_i^t + (r^2 \times x_j^t - x_k^t) \times f_i$$

Where x_j^t and x_k^t are jth and kth butterflies from the solution space. If x_j^t and x_k^t belongs to the same swarm and r is a random number in [0, 1] then it becomes a local random walk. Search for food and mating partner by butterflies can occur at both local and global scale. Considering physical proximity and various other factors like rain, wind, etc., search for food can have a significant fraction p in an overall mating partner or food searching activities of butterflies. So a switch probability p is used in BOA to switch between common global searches to intensive local search.

Till the stopping criteria is not matched, the iteration phase is continued. The stopping criteria can be defined in different ways like maximum CPU time used, maximum iteration number reached, the maximum number of iterations with no improvement, a particular value of error rate is reached or any other appropriate criteria. When the iteration phase is concluded, the algorithm outputs the best solution found with its best fitness. The above-mentioned three steps make up the complete algorithm of butterfly optimization algorithm and its pseudo code is explained in "Algorithm Below"

```
Objective function f(x), x=(x1, x2, ..., xdim), dim = no. of dimensions
Generate initial population of n Butterflies xi = (i=1, 2, ..., n)
Stimulus Intensity Ii at xi is determined by f(xi)
Define sensor modality c, power exponent a and switch probability p
while stopping criteria not met do
    for each butterfly bf in population do
        Calculate fragrance for bf using Eq. (1)
    end for
    Find the best bf
    for each butterfly bf in population do
        Generate a random number r from [0, 1]
        if r < p then
            Move towards best butterfly/solution using Eq. (2)
        else
            Move randomly using Eq. (3)
        end if
    end for
    Update the value of a
end while
Output the best solution found.
```

- Initialize the butterfly population, which is number of solutions.
- Initialize the value for each number solution switch probability (p), sensory modality(c), and power exponent alpha.
- Then evaluate the best solutions, among the number of solutions.
- If the best solution value is greater than the probability of initial population then it undergoes for local search solution.
- Otherwise the best solution value is lesser than the probability of the initial population then it undergoes for global search solution.
- Update the values of best solution.
- By implementing the intra local search operator (selection rule) for getting optimized solution.
- Then it undergoes for termination criteria for optimized solution.
- Then output for best solution is executed.

7. PIVOTAL RULES

Commonly used pivoting rules in the selection mechanism of Local Search Operators are best improvement and first improvement.

Best improvement

Best improvement selects in each search step the one that achieves maximal reduction of total distance. Best improvement is additionally referred to as greedy hill-climbing or discrete gradient descent.

First improvement

First improvement tries to avoid the time complexity of evaluating all possible neighbors by performing first improving step found during neighborhood search.

Worst improvement

Least improving strategy chooses the improvement that reduces total distance of the solution by a smallest amount.

8. ARCHITECTURE DIAGRAM

In this architecture diagram, we are going to incorporate the butterfly optimization algorithm on capacitated vehicle routing problem by using the local search swap operator to improve the performance of BOA.

To get the optimal solution by using the local search operator

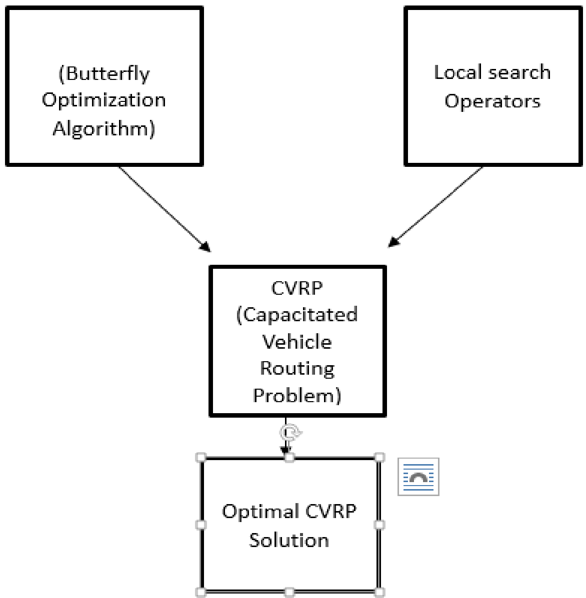

Fig: 4 Architecture diagram for BOA on CVRP using local search operator

9. COMPLEXITY INVOLVED IN PROPOSAL

- Intra route operators introduced
- Pivotal Rule introduced

The intra route operators which are added to BOA in order to get better performance.

The following pivotal rules which are employed and it will be applied for getting better solution such as best improvement and first improvement.

10. IMPLEMENTATION

The proposed method has been implemented in C++ using Visual Basic 2010 on Windows 10 Operating System and running on a machine having 4 GHz Intel Core i5 processor with 4GB RAM.

The parameter values used by the algorithms, which are given in tables 1-1 below.

Table 1 : EXPERIMENTAL SETUP

Sl..No.	Parameter	Value
1	Number of Butterflies	10
2	Number of runs	10
3	Number of iterations	1000
4	Instances	[1.5,2.5]
5	Switch Probability(p)	0.8
6	Power exponent (a)	0.1 - 0.3
7	Sensory Modality (c)	0.01

To carry out the experiments, Augerat instances have been used as the input dataset. Dataset contains number of nodes, number of vehicles and maximum capacity of each vehicle. The location coordinates of each node and the demand of each customer will also be indicated.

11. EXPERIMENTAL RESULTS

The output indicates the optimal route distance and the run and iteration at which it was obtained. The execution time taken by the algorithm is also denoted. The output shows that in most of the cases, the total distance and computing time tend to increase as the number of customers increases.

The results are tabulated and shown in Table 3.

Table 2: Obtained output

Sl.No.	Dataset Name	Best Butterfly	Run	Iteration	Best fittness (Distance)	Computation Time (in ms)
1	A-n32-k5	2	1	544	1525	0.529
2	A-n34-k5	6	9	828	1347	0.565
3	A-n36-k5	6	3	697	1527	0.739
4	A-n44-k6	5	2	817	1929	0.878
5	A-n46-k7	8	1	439	2017	0.731
6	A-n48-k7	6	5	999	2195	1.225

Experimental Output for Basic Butterfly Optimization algorithm with Capacitated Vehicle Pouting Problem

Table 3: Obtained output

Sl.No.	Dataset Name	Best Butterfly	Run	Iteration	Best fittness (Distance)	Computation Time (in ms)
1	A-n32-k5	9	6	78	929	0.78
2	A-n34-k5	2	10	834	706	0.732
3	A-n36-k5	7	8	170	881	0.761
4	A-n44-k6	2	3	459	1062	0.921
5	A-n46-k7	5	2	763	1258	0.976
6	A-n48-k7	10	4	315	1442	0.995

Experimental Output for Butterfly Optimization algorithm with capacitated vehicle routing Problem using Local Search Swap Operator.

12. CONCLUSION

Butterfly Optimization Algorithm has experimented with the intra route local search Swap operator on Capacitated Vehicle Routing Problem. BOA is based on food foraging behavior and information sharing behavior of butterflies. Hence, with the appropriate CVRP parameter settings. We applied BOA on CVRP to get the optimal solution. The performance and the improvement has been analyzed by path distance and the computation time. The result evaluated by comparing with various fisher instances.

REFERENCES

[1] Arora, S. and Singh, S., 2018. Butterfly optimization algorithm: a novel approach for global optimization. Springer Soft Computing, pp.1-20.

[2] Juraj Fosin, Tonci Carie, Edouard Ivanjko., 2014 Vehicle Routing Optimization Using Multiple Local Search Improvements.
[3] Qi et al, X., Zhu, Y. and Zhang, H., 2017. A new meta-heuristic butterfly-inspired algorithm. Journal of Computational Science, 23, pp.226-239.
[4] Wang, G.G., Deb, S. and Cui, Z., 2015. Monarch butterfly optimization. Neural Computing & Applications.

ACKNOWLEDGEMENT

We respect and thank Dr. S.Kanmani **P**rofessor, Information Technology, Pondicherry Engineering College, Puducherry**.** For providing us an opportunity to do the project work and giving us all support and guidance to complete the project. We are extremely thankful to her for providing such a nice support and guidance.