Using Swarm Intelligence for solving NP-Hard Problems

Saman M. Almufti

Department of Computer Science, College of Computer & Information Technology, Nawroz University, Duhok, Iraq

ABSTRACT

Swarm Intelligence algorithms are computational intelligence algorithms inspired from the collective behavior of real swarms such as ant colony, fish school, bee colony, bat swarm, and other swarms in the nature. Swarm Intelligence algorithms are used to obtain the optimal solution for NP-Hard problems that are strongly believed that their optimal solution cannot be found in an optimal bounded time. Travels Salesman Problem (TSP) is an NP-Hard problem in which a salesman wants to visit all cities and return to the start city in an optimal time. This article applies most efficient heuristic based Swarm Intelligence algorithms which are Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), Bat algorithm (BA), and Ant Colony Optimization (ACO) algorithm to find a best solution for TSP which is one of the most well-known NP-Hard problems in computational optimization. Results are given for different TSP problems comparing the best tours founds by BA, ABC, PSO and ACO.

KEY WORDS: Swarm Intelligence, NP-Hard problem, Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), Bat algorithm (BA), and Ant Colony Algorithm (ACO)

1. INTRODUCTION

Swarm Intelligence algorithms are computational intelligence techniques studies the collective behavior in decentralized systems (Almufti, 2015). Such systems are made up of a population of simple individual's agents interacting locally with each other and with the environment around themselves (Almufti, 2015). This paper focuses on the comparative analysis of most successful methods of optimization techniques inspired by Swarm Intelligence (SI): Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO), Bat Colony Optimization (BA), and Artificial Bee Colony (ABC) for solving one of the most well-known NP-Hard problems which is called Travels Salesman Problem (TSP) (Almufti, 2015) , (Andrej Kazakov, 2009).

2. OVERVIEW OF SWARM INTELLIGENCE ALGORITHMS

Swarm intelligence(SI),which is an artificial intelligence (AI) field, is concerned with the designing of intelligent interactive multi-agent systems that cooperate to gather to achieve a specific goal. Swarm intelligence is defined by Dorigo M as "The emergent collective intelligence of groups of simple agents"(Li, Y.: 2010). Swarm-based algorithms are inspired from behaviors of some social living beings (insects, animal, and bacteria's) in the nature, such as ants, birds, bats, bees, termites, and fishes. The most remarkable features of swarm systems are Self-organization and decentralized control that naturally leads to an emergent behavior in the colony. Emergent behavior is an interactive property that emerges a local interaction among all system components (agents) and it is not possible to be achieved alone by any agent in the system (Almufti, 2015). In computer science there are many algorithms that are designed as an inspiration of real collective behavior systems in the nature, swarm intelligence algorithms includes Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), Artificial Immune System, Bat algorithm, Bacterial Foraging, Stochastic diffusion search, Glowworm Swarm Optimization, Gravitational search algorithm, Cat Swarm Optimization, and other optimization algorithms (Almufti, 2015).

Swarm intelligence works on two basic principles: self-

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Corresponding author's e-mail: Saman.almofty@gmail.com

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organization and stigmergy (e.g., Fig. 1).

1. Self-organization: This can be characterized by three parameters like structure, multi stability and state transitions. In swarms, interpreted the self-organization through four characteristics: (i) positive feedback,(ii) negative feedback, (iii) fluctuations, and (iv) multiple interactions.

2. Stigmergy: It means stimulation by work. Stigmergy is based on three principles:(i) work as a behavioral response to the environmental state; (ii) an environment that serves as a work state memory(iii)work that does not depend on specific agents.

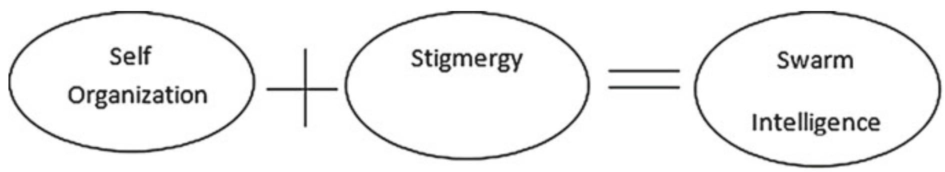

Figure 1: Swarm intelligence basic principles

Ant Colony Optimization (ACO) is a population based optimization algorithm developed by Marco Dorigo as an inspiration of the behavior of ants in finding the optimal way (best path) between their nest and a food source (Almufti,2015). The Bat algorithm is a natural inspired metaheuristic algorithm for global optimization problems (Shi YH, Eberhart RC, 1998). It was inspired by the echolocation behavior of microbats, with varying pulse rates of emission and loudness (Shi YH, Eberhart RC, 1998), (Yang, X.-S. 2010). The Bat algorithm (BA) was developed by the scientist (Yang, X.-S. 2010). Artificial bee colony algorithm (ABC) is a natural inspired metaheuristic optimization algorithm based on the intelligent foraging behavior of honey bee swarm, proposed by the scientist Karaboga for solving combinatorial optimization problems (Marco Dorigo, Thomas Stu, 2004). Particle Swarm Optimization (PSO) is a population based optimization algorithm developed by Eberhart and Kennedy as an inspired by bird flocks' behavior when searching for food (Altringham J. D., Bats, 1996). The travel salesman problem (TSP) which is an NP-hard problem that is impossible to find the optimal tour with in an optimal time has been studied extensively over the past several decades. In this paper ACO and PSO are used to find the solution of TSP (Altringham J. D., Bats, 1996).

3. NP-HARD PROBLEM

Non-deterministic Polynomial-time hard (NP-hard) problems are those problems that are impossible to obtain their optimal solution within a polynomial bounded computation time (Karaboga D. 2007). Generally the methods for solving real-life optimization problems are belonging to one the following categories: complete approach or approximate approach. Complete approach requires exponential time (long execution time) for solving NP-hard problems; on the other hand the approximate approaches are divided in to two search approaches, population-based search and single-based search. Both population-based search and single-based search are focusing on obtaining a relatively good solution in a relatively less time (short execution time) instead of finding an optimal solution which is not easy to compute and have a long execution time (Karaboga D. 2010). Using exact algorithms for NP-hard problems are not preferable, because they takes unbounded (long) time to execute, for this reason researches often use approximates methods, which tries to obtain a near optimal solution for NP-hard problems in a significantly short bounded time (Kennedy J., Eberhart R. 1995).

4. INTRODUCTION TO TRAVELLING SALESMAN PROBLEM (TSP)

Traveling Salesman Problem (TSP) was first proposed by the scientist K. Menger in 1932. Since then, it has been a case of study to many researchers. It is one of the well-known intensively studied problems in optimization and evaluations problems and is used as a benchmark for many optimization methods (Basic J. 2012), (Dorigo M., Maniezzo V., A. 1996).

TSP is an NP-hard problem in combinatorial optimization (Almufti, 2015). The travelling salesman trays to visit all stations (cities) in a map and return to the start station (city) without visiting any station (city) twice, the best tour is the shortest tour among all possible tours (Dorigo M., Maniezzo V., A. 1996). The length of the optimal tour of TSP problems can be found as shown below.

$$optimal\ tour = d_{p(n)\,p(1)} + \left(\sum_{i=1}^{n-1} d_{p(i)\,p(i+1)}\right)$$

Where p is a probability list of cities with minimum distance between city (p_i and p_{i+1}) (Almufti, 2015).

5. PARTICLE SWARM OPTIMIZATION (PSO)

The Particle Swarm Optimization (PSO) algorithm concept roots from the social behavior of organisms such as fishing schooling bird flocking, it was first introduced by (Kennedy and Eberhart in 1995), (Hochbaum, S. 1997) and is widely used to solve computational problems. PSO particles cooperate between themselves as one group to achieve their goal efficiently and effectively. PSO simulates this social behavior as an optimization tool to solve some optimization problems and NP-Hard problems such as Travelling Salesman Problem (TSP) (Almufti, 2015). PSO pseudo code is shown below in (algorithm 1):

Begin
Parameter settings and initialization of swarm.
Evaluate fitness and locate the leader (i.e., initialize pbest and gbest).
I=0 //I= Iteration count
While (the stopping criterion is not met, say, I < Imax)
For
For each particle
Update velocity (flight) and position.
Evaluate fitness
Update pbest
End For
Update leader (i.e., gbest)
I++
End While
End

6. BAT ALGORITHM (BA)

Bat algorithm (BA) is a population based metaheuristic algorithm proposed by Yang in 2010 for solving continuous optimization problems (Yang, X.-S. 2010). The basic BA algorithm is bio-inspired metaheuristic on the bio-sonar or echolocation characteristics of bats. In nature, bats release ultrasonic waves to the environment around it for the purposes of hunting or navigation. After the emission of these waves, it receives the echoes of the waves, and based on the received echo they locate themselves and identify obstacles in their ways and preys. Furthermore, each agent in swarm is capable of finding the most “nutritious" areas or moving towards a previous best location found by the swarm (Shi YH, Eberhart RC, 1998). Bat algorithm has showed grate efficiency in finding solution in continuous optimization problems (Yang, X.-S. 2010). This article, have adapted BA for to find solutions for travelling salesman problem (TSP), which is one of NP-hard problem in combinatorial optimization (Shi YH, Eberhart RC, 1998). BA pseudo code is shown below in (Algorithm 2):

Algorithm 2: Pseudocode of the basic BA:
Define the objective function f(x);
Initialize the bat population X = x1, x2, …, xn,
for each bat xi in the population do
Initialize the pulse rate ri, velocity vi and loudness Ai;
Define the pulse frequency fi at xi;
end
repeat
for each bat xi in the population do
Generate new solutions through Equations 1, 2 and 3;
if rand>ri then
Select one solution among the best ones;
Generate a local solution around the best one;
end
if rand<Ai and f(xi)<f(x_) then
Accept the new solution;
Increase ri and reduce Ai;
end
end
until termination criterion not reached;

Rank the bats and return the current best bat of the population;

Equations for Generating new solutions

$$f_i = f_{min} + (f_{min} - f_{max})\beta \tag{1}$$

$$v_i^t = v_i^{t-1} + [x_i^{t-1} - x_*] f_i \tag{2}$$

$$x_i^t = x_i^{t-1} + v_i^t \tag{3}$$

7. ARTIFICIAL BEE COLONY (ABC)

Artificial Bee Colony (ABC) is one of the most recent swarm intelligence algorithms. It was proposed by Dervis Karaboga in 2005 for solving multi-dimensional and multi-modal optimization problems. (Marco Dorigo, Thomas Stu, 2004). ABC algorithm is inspired from the intelligent, interactive and foraging behavior of real honey bees in searching for food sources “nectar”, and announcing other bees in the nest about the information of food source (Rao RS, Narasimham SVL, 2008), (Reinelt, 1991). In the bees nest each agent store the information of the previously visited food source area in her memory and searches for a new better food source, if the nectar (fitness) of the new solution (food source) is greater than the previous one, then the agents bee forgets the old source and store the information of the new source.

In order to apply ABC to TSP problem, a food source corresponds to a feasible tour. Also, the nectar amounts of a food source represent the quality of the solution tour. Firstly, a random set of food sources are generated by agents’ bees. Then, the nectar (fitness) of the visited food sources are calculated as an objective function. As a result, the quality of the initial solutions is evaluated (Sahni, S. & Gonzalez, 1976). ABC pseudo code is shown below in (algorithm 3):

Algorithm 3: Pseudocode of the basic ABC:
Initialization: Generate the initial population z, = 1, 2,..., SN
Evaluate the fitness (f,) of the population
cycle = 1;
REPEAT
FOR each employed bee { Produce new solution Calculate the value f1
Apply greedy selection process }
Calculate the probability values pi for the solutions zi
FOR each onlooker bee
Select a solution z, depending on p,
Produce new solution Calculate f,

Apply greedy selection }
IF an abandoned solution for the scout exists,
HEN replace it with a new solution at random
Memorize the best solution so far
cycle++;
UNTIL cycle = MCN

8. ANT COLONY OPTIMIZATION (ACO)

The Ant Colony Optimization (ACO) is a heuristic algorithm inspired from the behavior of real ant in finding the shortest way to a source of food (Bonabeau E, Dorigo M, Theraulaz G. 1999). Naturally, ants in a swarm are indirectly communicates by an odorous chemical substance that ants may deposit and smell called pheromone trails. In a swarm, each ant which represent an agent in a collection randomly, laying down a pheromone trail in its way to a food source, if any agent founds a food, it return to the nest by smelling pheromone trail, in case of increase of pheromone in any path all the other agents follow that path (Andrej Kazakov, 2009).

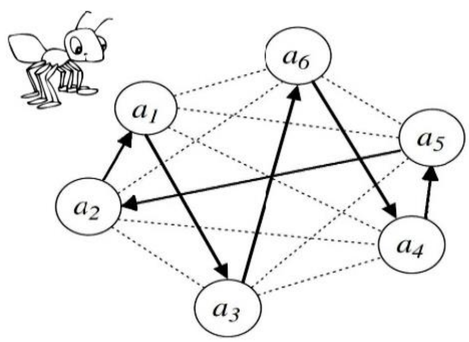

Figure 2: ACO in TSP

In this article, ACO is adapted to find solution for TSP problem (fig: 2), in a graph first each agent of colony use the pheromone trail to choose a nearest station to its current station, the process continues by adding stations one by one until it complete TSP tour by visiting all stations and back to the starting station. ACO update the pheromone trail after each agent complete its tour Blum, C. (2005). ACO pseudo code is shown below in (algorithm 4):

Algorithm 4: Pseudocode of the basic ACO:
Initialize
Loop
Each ant is positioned on a starting node
Loop
Each ant applies a state transition rule to incrementally build a solution and a local pheromone updating rule
Until all ants have built a complete solution
A global pheromone updating rule is applied
Until end condition

9. RESULTS

This section presents the performance of adapting BA, ABC, ACO and PSO. To verify the validity of the proposed algorithms, some instances from the TSPLIB library (Karaboga D, Basturk B. 2007), are selected for simulations. The experiments have been performed on a PC with 2 GHz processor and 8 GB RAM memory running MATLAB R2015b in windows 10. Each instance is run for 100 times.

Table 1 shows the results of applying Particle Swarm Optimization (PSO) algorithm, Artificial Bee Colony (ABC) algorithm, Bat algorithm (BA), and Ant Colony Optimization (ACO) algorithm on five different TSP problem from TSPLIB which are ranged between 50 and 80 cities, the table include optimal solutions of the chosen problems, best solution founded by the applied algorithms, and the error for each used algorithm.

The error rate are calculated by using the following equation (4) (Almufti, 2015), (Basic J. 2012):

$$Error = ((Bsol - Opt) / Opt) \times 100\% . \quad (4)$$

Table1: TSP solutions using BA, ABC, ACO, and PSO algorithms.

TSP problem	Optimal Solution	PSO Bsol	Error	ACO Bsol	Error	ABC Bsol	Error	BA Bsol	error
EIL51	426	427	0.23%	426	0%	428	0.47%	430	0.93%
berlin52	7542	7542	0%	7657	1.52%	7544	0.03%	7542	0%
st70	675	675	0%	675	0%	677	0.3%	675	0%
EIL76	538	546	1.49%	543	0.92%	545	1.30%	538	0%
PR76	108159	108280	0.12%	108159	0%	108159	0%	108159	0%
			PSO Error ∑=1.84		**ACO Error** ∑=2.44		**ABC Error** ∑=2.10		**BA Error** ∑=0.93

10. CONCLUSIONS

According to the results in table 1 and from measuring the error percentage of each proposed algorithms that have been used to find solutions for five different TSP problems ranged between 50 and 80 cities, its conclude, that using Bat algorithm (BA) is the best algorithm between the four proposed algorithms for finding the solution for TSP.

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