A Signal Timing Optimization in Traffic Management using ABC Algorithm

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ABSTRACT
The ABC algorithm is a new population-based meta-heuristic approach, and it is inspired by the foraging behaviour of honeybee swarm. This study discusses Artificial Bee Colony (ABC) algorithm for finding optimal setting of traffic signals in coordinated signalized networks for given fixed set of link flows. For optimizing traffic signal timings in coordinated signalized networks, ABC with GA (ABCGA) model is developed and tested. A standard traffic model is used to estimate total network performance index (PI). The ABCGA is tested in various levels with signalized road network. Results showed that the proposed model is slightly better in signal timing optimization in terms of final values of PI when it is compared with Fixed time model, and evolutionary algorithm (EA) based model. Results also showed that the ABCGA model improves network's PI when it is compared with Fixed time and EA methods.

Keywords
Artificial Bee Colony, Genetic Algorithm, signal timings, optimization.

1. INTRODUCTION
Artificial bee colony algorithm (ABC) developed by Karaboga and further developed by Karaboga and Basturk is a nature inspired algorithm based on the intelligent foraging behaviour of honeybee swarm. The ABC algorithm describes the foraging behaviour, learning, memorizing and information sharing characteristics of honeybees. The colony of artificial bees consists of three groups of bees: Employed bees, Onlookers bees and Scouts bees [1]. The colony of the artificial bees is divided into two groups, first half of the colony consists of the employed artificial bees and the second half includes the onlooker bees.

After the invention of ABC by Karaboga, the fist conference paper introducing ABC was published in 2006 (Basturk and Karaboga). The first journal article describing ABC and evaluating its performance was presented by Karaboga and Basturk, in which the performance of ABC was compared to GA, PSO and particle swarm inspired evolutionary algorithm. In 2008, the second article presenting a performance evaluation of ABC was published by Karaboga and Basturk [1]. In 2009, a public domain web-site

(http://mf.erciyes.edu.tr/abc) dedicated to ABC was constructed. There are several source codes, written in different programming languages, of ABC and many publications about the modifications to ABC and their applications are presented in the website. The main algorithm of ABC is relatively simple and its implementation is, therefore, straightforward for solving optimization problems and ABC has been found to be very effective in the studies above, being able to produce very good results at a low computational cost. Therefore, after these initial publications many studies have been carried out on ABC.

2. WORKING PRINCIPLE OF ABC
The foraging behaviors of honeybees have recently been one of the most interesting research areas in swarm intelligence. Some approaches have been proposed to model the specific intelligent behaviours of honeybee swarms and they have been applied for solving optimization problems. Lucic and Teodorovic in [2] and Teodorovic in [3] suggested to use bee swarm intelligence aimed at solving complex problems in traffic and transportation. Teodorovic and Dell'Orco in [4] proposed the bee colony optimization to solve combinatorial problems characterized by uncertainty, as well as deterministic combinatorial problems. Teodorovic and Dell'Orco in [5] presented an application of the bee colony optimization, efficient in solving the ride-matching problem. Their results showed that proposed metaheuristic appears very promising, and indicated that the development of new models based on swarm intelligence principles could significantly contribute to the solution of a wide range of complex engineering and management problems. The Artificial Bee Colony (ABC) algorithm is a new population-based metaheuristic approach proposed by Karaboga in [6] and further developed by Karaboga and Basturk [7, 8, 9]. It is inspired by the foraging behavior of honeybee swarm. The foraging bees are classified into three categories employed, onlookers and scouts. Half of the bee colony consists of employed bees, and another half consists of onlookers. In ABC algorithm, the position of a food source represents a possible solution to the optimization problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution [10].The number of employed bees or the onlooker bees is equal to the number of solutions in the population. Employed bees are responsible for searching available food sources and gathering required information. They also pass their food information to onlooker bees. The onlookers select good food sources from those found by the employed bees to further search the foods. When the quality of the food source is not improved through a predetermined number of cycles, the food source is abandoned by its employed bee. In this case, the employed bee becomes a scout and starts to search for a new food source in the vicinity of the hive. In ABC algorithm, each cycle of the search consists of three steps. At the initialization step, the ABC algorithm generates a randomly distributed initial population as number of SN, where SN denotes the number of employed bees or onlooker bees. Each initial solution x_i $(i = 1,2,…,SN)$ is a D-dimensional vector which D is the number of decision variables of a given optimization problem. At the first step of the cycle, employed bees come into the hive and share with the bees waiting on the dance area information about nectar sources. A bee waiting on the dance area is called onlooker,

and is responsible for making decision about the choice of a food source. At the second step, an onlooker chooses a food source area depending on the nectar information distributed by the employed bees on the dance area. As the nectar amount of a food source increases, the probability of choice of that food source increases as well. The determination of a new food source is carried out by the bees based on a visual comparison process of positions of food sources. At the third step of the cycle, when a food source is abandoned by the bees, a new food source is randomly determined by a scout bee and replaces the abandoned one. These three steps are repeated until a predetermined number of cycles, called Maximum Cycle Number (MCN), is reached. An onlooker bee chooses a food source depending on the probability value, p_i , as follows:

$$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \tag{1}$$

Where fit_i is the fitness value of solution i. In this way, the employed bees exchange their information with the onlookers. In order to share the information of nectar amount of the food sources, the employed bees use a proportional selection method known as "roulette wheel selection".

In order to produce a candidate food location from the old one in population, the following equation is used.

$$v_{ij} = x_{ij} + \varphi_{ij}(x_{ij} - x_{kj}) \tag{2}$$

where v_{ij} is the candidate food position which can replace the old one in the memory and $\emptyset_{ij}$ is a random number generated in the interval $[-1,1]$. The values $k = 1,2,...,SN$ and $j = 1,2,...,D$ are randomly chosen indexes. Of course, k must be different from i, to avoid that old and new location coincide, in order to find food sources having more nectar amount than the old one. The parameter $\emptyset_{ij}$ controls the production of neighbour food sources around x_{ij}, and represents the visual comparison of two food positions carried out by a bee. If a parameter value determined using Eq. (2) exceeds the constraints of the decision variables, the parameter is set to its upper and lower boundary, depending on which constraint has been exceeded.

As mentioned above, the food source abandoned by the bees is replaced with a new food source by the scouts at the third step of the cycle. In ABC algorithm, this is simulated by generating a random location and replacing the abandoned one with it. If a location cannot be further improved in a predetermined number of cycles, then that food source is assumed to be abandoned. The value of predetermined number of cycles, called ''limit'', is an important control parameter of the algorithm. Karaboga and Akay proposed to determine this value as $SN * D$ [10]. This operation can be done using Eq. (3).

$$x_i^j = x_{min}^j + rand[0,1](x_{max}^j - x_{min}^j) \tag{3}$$

After each candidate source location v_{ij} is generated, its performance is compared with that of the old one. If the new food source has equal or better nectar than the old source, 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 as selection between the old and the candidate location.

The steps of the ABC algorithm are given as follows:

Initialize all parameters;

Repeat while Termination criteria is not meet

Step 1: Employed bee phase for computing new food sources.

Step 2: Onlooker bees phase for updating location the food sources based on their amount of nectar.

Step 3: Scout bee phase for searching new food sources in place of rejected food sources.

Step 4: Memorize the best food source identified so far.

End of while

Output: The best solution identified so far.

3. MODEL FORMULATION:
The proposed ABC GA model consists of two main parts namely ABC algorithm and GA traffic model. ABC algorithm optimizes traffic signal timings under fixed set of link flows. GA traffic model is used to compute PI, which is called objective function, for a given signal timing and staging plan in network. The network Disutility Index (DI), one of the Transport model, PI, is used as objective function. The DI is a measure of disadvantageous operation; that is stops, delay, fuel consumption, etc. The standard DI is linear combination of delay and stops. The objective function and corresponding constraints are given as: $PI = \frac{Min}{\psi, q = fixed} DI = \sum_{a \in L}[W_{d_a}.d_a(\psi) + K.W_{s_a}.S_a(\psi)]$ (4)

Subject to

$$\psi(c,\theta,\varphi) \in \Omega_0 =$$

$$\begin{cases} c_{min} \le c \le c_{max} & cycle\ time\ constraints \\ 0 \le \theta \le c & value\ offset\ constraints \\ \varphi_{min} \le \varphi \le c & green\ time\ constraints \\ \sum_{i=1}^{z}(\varphi + I)_i = c & - \end{cases} \tag{5}$$

where da is delay on link a (L set of links), w_{da} is link-specific weighting factor for delay d, K is stop penalty factor to express the importance of stops relative to delay, Sa is stop on link a, w_{sa} is link-specific weighting factor for stops S on link a, q is fixed set of link flows, ψ is signal setting parameters, c is common cycle time (sec), θ is offset time (sec), φ is green time (sec), Ω_0 is feasible region for signal timings, I is intergreen time (sec), and z is number of stages at each signalized intersection in a given road network.

The green timings can be distributed to all signal stages in a road network according to the following in order to provide the cycle time constraint.

$$\varphi_i = \varphi_{min,i} + \frac{p_i}{\sum_{k=1}^{z} p_i}(c - \sum_{k=1}^{z} I_k - \sum_{k=1}^{z} \varphi_{min,k}) \tag{6}$$
$$i = 1,2,..z$$

where φ_i is the green time (sec) for stage i, $\varphi_{min,i}$ is minimum green time (sec) for stage i, pi is generated randomly green timings (sec) for stage i, z is the number of stages and I is intergreen time (sec) between signal stages and c is the common cycle time of the network (sec).

4. ABC WITH GENETIC ALGORITHM (ABC GA)
The mutation and crossover in artificial bee colony are used to achieve the optimization in ABC GA algorithm. It can avoid local minima for complex optimization problems. However, the optimization process of traditional ABC algorithm is slow. The genetic algorithm is use to revise the nectar position in

the process of foraging to improve the convergence precision based on ABC.

4.1 Encoding of bee

The encoding of bee colony is real-number. Each dimension of employ bees presents the green time of each phase. The length is the number of phase. It can be expressed by formula (7).

$$[g_1, g_2, \dots g_i, \dots g_I] \tag{7}$$

4.2 Steps of the algorithm

4.2.1 Initial algorithm parameters

Those parameters are needed to be initialized, such as the position of nectar, population size s , number of onlookers N_c , number of scout N_{re}, migration times N_{ed} and the probability of migration P_{ed} .

4.2.2 Foraging process

i. The employee bees are tumbled and moved with unit vector.

ii. The employee bees are scout until the fitness can't be improved.

The employ bees are tumbled and scout to update the position by the formula (8)

$$\theta^i(j + 1, k, l) = \theta^i(j, k, l) + c(i)\emptyset(i) \tag{8}$$

$$\emptyset(i) = \frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \tag{9}$$

$\theta^i(j, k, l)$ presents the employ bees i position of the jth nectar, the kth reproduction and the l th migration. $c(i)$ is the cycle step. $\emptyset(i)$ is the direction vector of unit. $\Delta(i)$ is the random vector.

iii. Mutation

θ_{gbest} is defined as the global optimum. θ_{lbest} is the current position. P is the variation operator and is expressed by formula (10).

$$P = \theta_{r1} + F(\theta_{gbest} - \theta_{r2}) + rand(\theta_{lbest} - \theta_{r3}) \tag{10}$$

where, F is the zoom factor, $F \in [0.5,1]$. $\theta_{r1}, \theta_{r2}, \theta_{r3}$ are the random individual bees in the employees population.

iv. Crossover

The crossover is executed by formula (11) to increase the employee bees population.

$$\theta_i = \begin{cases} P_i \ if \ rand \ < CR \ or \ i = irand \\ X_i \qquad\qquad otherwise \end{cases} \tag{11}$$

where, CR is the cross factor. $Irand$ is the random latitude. $Rand$ is the random number, $rand \in [0,1]$.

4.2.3 Reproductive behaviour

The $S/2$ employbees with worst fitness become scout and the $S/2$ bees with the best fitness can proceed.

4.2.4 Migration behaviour

The employee bees with worst fitness are eliminated with probability P_{ed} and they become scout.

In the ABC GA, optimization steps can be given in the following way:

Step 0: Initialization. Define the user specified parameters; the number of decision variables (n) (this number is sum of the number of green times as stage numbers at each intersection, the number of offset times as intersection numbers and common cycle time), the constraints for each decision variable, the size of bee colony (SN), maximum cycle number(MCN).

Step 1: Set $t = 1$.

Step 2: Generate the random initial signal timings within the constraints of decision variables.

Step 3: Distribute to the green timings to the stages according to distribution rule as mentioned above. At this step, randomly generated green timings at Step 2 are distributed to the stages according to generated cycle time at the same step, minimum green and intergreen time.

Step 4: Get the network data and fixed set of link flows for ABC GA traffic model.

Step 5: Run ABC GA.

Step 6: Get the network PI. At this step, the PI is determined using ABC GA traffic model.

Step 7: If $t = MCN$ then terminate the algorithm; otherwise, $t = t + 1$ and go to Step 2.

5. SIMULATION ANALYSIS

In order to prove the validity of the model ABC GA, some intersection of Villupuram is selected to simulation. This intersection has four phases. The simulative is done in MATLAB7.0. In simulation process the number of employee bee is equal to 50.The times of tumble N_C is equal to 100. The time of scout produce N_{re} is equal to 5.The time of elimination N_{ed} is equal to 3.The elimination probability P_e is equal to 0.3. The green time of straight phase is between 6 and 90. The green time of left phase is between 6 and 40.The cycle is between 36 and 200. The signal timing optimization model is simulated many times by ABC GA algorithm under low demand, medium demand and high demand. Meanwhile, the simulation is done by the fixed time method. The total delay vehicles in 10 cycles of 10 simulation times is presented. It is pointed that the application effects of the model and the ABC GA proposed is much better than the other under high demand. It is found that the average delay vehicles is reduced by 25% than the fix time method and reduced by 5% than the Evolutionary algorithm. ABC GA converges faster and can get the better solution than the Evolutionary algorithm for the signal timing optimization.

Table 1. Signal Timing when Comparing Performance

Demand scenarios	The Optimization algorithm	Phase 1(s)	Phase 2(s)	Phase 3(s)	Phase 4(s)	Cycle time (s)	Average delay vehicles (vech)	Generation appearing the best fitness
Low-Demand	FIX TIME	30	26	35	25	116	16.1	−
	EA	50	12	28	15	105	14.2	55
	ABCGA	41	10	32	12	95	13.1	40
Medium-Demand	FIX TIME	38	32	45	35	150	46.2	−
	EA	45	13	59	6	123	40.4	60
	ABCGA	40	14	45	13	112	36.2	45
High-Demand	FIX TIME	60	30	53	32	175	122.2	−
	EA	62	13	57	24	156	95.1	65
	ABCGA	58	20	42	25	145	87.5	50

6. APPLICATIONS OF ABC

Since its origination, the ABC algorithm has become extraordinarily fashionable as it has less number of control parameters; it is robust and easy to apply. It is successfully applied to the problems from different application areas by many researchers. Applications of ABC algorithms listed by [11] with subject area of use. The ABC algorithm has application in field of computer science, electrical engineering, mechanical engineering and electronics engineering. Artificial bee colony algorithm applied for feature selection [12], multicast routing [13], single machine scheduling [14], balancing in assembly line [15], designing of controller [16] and to find solution of travelling salesman problem [17]. List of applications of ABC algorithm are endless, there are almost every field including engineering, science and management where ABC algorithm is in use with priority over other competitive optimization algorithm.

7. CONCLUSION

The urban intersection is often very crowd in cities, in this paper it is proposed a signal timing optimization model ABC GA. Because the throughput of the intersection is the most important under congested conditions, the delay vehicles of a cycle time are chosen as the performance indexes of model. ABC with GA is proposed to solve the Problem. Computational experiments of an intersection in Villupuram City are conducted to validate the model formulations and solution algorithms. The result of Simulation shows the validity of this model and method. It reduces the total delay vehicles and especially works well in high demand. It can improve traffic capacity of intersections. In our future work, we are planning to improve further level of optimization in a crowded cities using various optimization algorithms.

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