Iranian Journal of Science & Technology, Transaction B, Engineering, Vol. 32, No. B2, pp 167-173
Printed in The Islamic Republic of Iran, 2008

"Research Note"

DESIGN OF A NEW URBAN TRAFFIC CONTROL SYSTEM USING MODIFIED ANT COLONY OPTIMIZATION APPROACH*

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Abstract– This paper proposes a new ant colony based optimizer to improve the traffic flow in a city. For this reason, a new structure of urban traffic control system has been introduced, which uses an ant colony optimizer as its main part. To study the performance of such system, we simulated the ACO based system as an adaptive path planner. Results show a very good optimization of path length and path traffic. To apply ACO on this problem we have changed the original version of ACO and the modified algorithm can be used for other applications such as designing intelligent data routers, intelligent data mining, etc.

Keywords– Urban traffic control, ant colony optimization, swarm intelligence, combinational optimization, path planning

1. INTRODUCTION

Urban traffic, which is defined as the congestion of cars in an area, is now one of the most important problems challenging many engineers to represent a method to control it [1-5]. Through the last decade, developments in communications and information technologies have improved the classical traffic control methods toward more modern and intelligent ones. Although most of these methods only optimize the timing of traffic signals to represent a smooth flow of traffic, intelligent traffic control systems introduce other operators such as Ramp Metering Systems (RMS), Variable Message Signs (VMS), License Plate Recognition (LPR), Electronic Toll Collection (ETC), Advanced Traveler Information Systems (ATIS), etc. to decrease travel time [6]. Many engineers have tried to introduce an optimal traffic control method. As traffic control is a combinational optimization problem [4], the early methods represented for this problem were based on classical optimization [7]. Although these methods are exact, they are usually based on complicated mathematical computations, and may end in solving complicated systems of integral equations. Heuristic methods of combinational optimization can find optimal solutions faster in which the solving process is limited to some simple computations, but the computation time in these methods will grow exponentially when the problem dimensions grow [4]. Meta-heuristic optimization methods are usually faster than heuristic methods and the computation time is almost linearly related to the dimensions of the problem [8]. Modern traffic control systems, such as SCATS, SCOOTS, TRANSYT and UTSC, are adaptive traffic control approaches used in many cities all over the world [1, 9, 10 and 11]. All of these methods use information from traffic sensors to control the timing of traffic light networks [12].

As an advanced control system, we have introduced a new structure for a traffic control system. Because of the capabilities of the Ant Colony Optimization (ACO) approach, in comparison with other

*Received by the editors November 13, 2006; final revised form November 21, 2007.
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meta-heuristic optimization methods [8], the main part of the traffic control system uses an ACO based path planner. We have considered the traffic control problem as a case of a path planning problem and solved this problem with ACO. According to the theory of urban traffic [13], we defined six different levels to model the traffic flow in each link connecting two junctions, level A to F, in which level F defines the most congested mode and level A the lightest mode, while the other levels scale this interval linearly. In our proposed method, the traffic control system will guide drivers from their source to the desired destination by optimizing the path length and the level of traffic flow acquired by traffic sensors.

This paper is organized in four sections. Section 2 describes the structure of the ACO-based traffic control system. This section compares the original version of the ACO algorithm with what we have used in this research. The following sections show the experimental results and discuss these results.

2. ACO BASED URBAN TRAFFIC CONTROL SYSTEM

Ant colony optimization algorithms are a class of meta-heuristic search algorithms that have been successfully applied for solving combinational optimization problems such as the traveling salesman problem (TSP) [14], the vehicle routing problem (VRP) [15], load balancing [16], intelligent data routing [17, 18], data mining [19], water distribution network design [20], etc. ACO algorithms are inspired from biological behaviors of real ant colonies, based on the food foraging behavior of ants. The secret behind this swarm process to forage food sources is that ants of a colony can communicate with each other through a trails network of pheromone [8]. At an initial time ants find their ways randomly to the food source. Each ant sprinkles a specific amount of pheromone to its way from the food source to the nest. After a period of time ants will go through a path with the highest level of pheromone, which is the optimum path from food to the nest because the ambient temperature have evaporated the pheromone in less used paths [14].

The new traffic control system which we call the ACO Based Urban Traffic Control System (ABUTCS), is designed to minimize the congestion time in the under control area by global management over most trips done in the area. As the new system optimizes travel time using a path with a minimum norm of traffic level and length, consequently, it will optimize the fuel consumption and air pollution.

A driver's decision-making process for choosing a path to reach the desired destination could be modeled as follows, as shown in Fig. 1: choosing a path by drivers could be affected by some parameters such as past experience local knowledge of traffic flow, public beliefs of good paths and a blind estimation of traffic density with respect to the time and date [3]. Although this process is somehow intelligent and adaptive decision-making, since the drivers' information is incomplete this process could not promise an end with an optimal path selection. This fact causes the fast growth of congested areas in a city and may increase the critical traffic level. According to this fact, a system is needed to guide drivers to a path optimized in length and crowding. Such systems could be implemented by employing any optimization method and new trends of information and communication technology.

Figure 2 shows a schematic for such systems used an ACO based path planner. A traffic data processor will receive sensor data and estimated traffic flow data of each link connecting any two junctions of the city by some predefined rates. The processor will update the traffic database with a set of logical traffic data after applying a global process over the sensor data and estimated data. An intelligent path planner will fetch the required data from the traffic database including map data, length and traffic of each link. After applying the ACO algorithm for the current set of data, an optimal path will be sent to the users.

The main part of this control system is the path planner subsystem. Considering the good results of applying ACO to TSP [8], and due to the authors' research [3, 21], ACO could be a proper method for designing the ABUTCS's path planner. Although the original version of the ACO algorithm can solve the

TSP, it does not solve our new problem and it is necessary to apply some modifications on the ACO algorithm to design and implement the intelligent path planner subsystem.

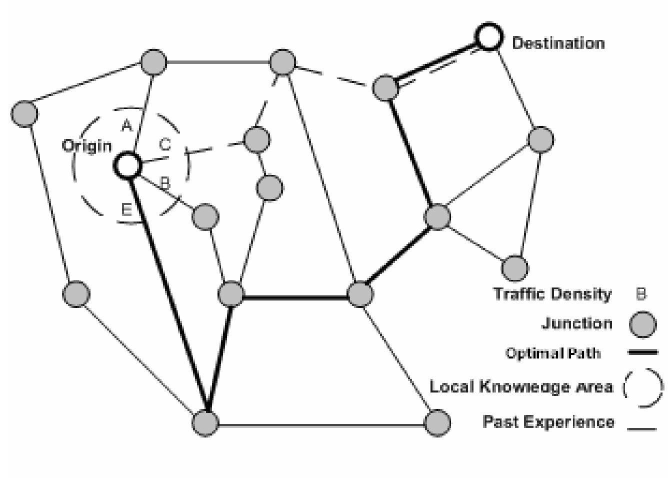

Fig. 1. Drivers decision making process model

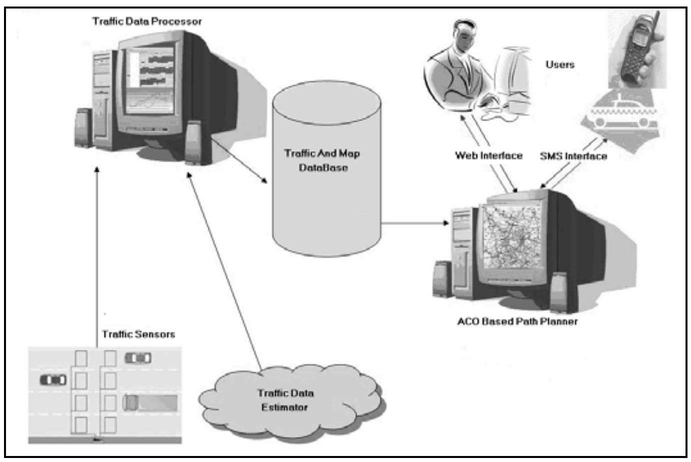

Fig. 2. A prototype designed ABUTCS schema

For TSP, an acceptable path is a path with minimum length that passes all the N cities in the problem space, and the priority of visiting cities is not a matter, but in a path planning process, an acceptable path is a path with minimum length that starts from a specific origin and ends at the desired destination. This means that TSP is a NP-Complete problem, but path planning is an NP problem [21]. By the way, for TSP a path that connects *i*th city to a *j*th one can both start from city *i*th toward city *j*th and vise versa. Nevertheless, in an urban area there are one-way and two-way links. So, going from junction *i*th to *j*th may only be possible from *i* to *j*. Besides this, in the TSP the total number of foregoing states is known and constant (equal to $n-1$). To overcome the dynamic nature of the new problem, we have added a subroutine to compute the number of foregoing links in each junction, so the dimensions of the algorithm variables can be redefined by the means of dynamic arrays in every iteration of the program.

For solving TSP the numbers of ants are equal to the number of cities, and at the initiation phase each ant is placed in one of the cities, but in the new problem all the ants start their trip from the origin junction. To reduce the sensitivity of the solutions to the number of ants we have changed the decision making probability function so that for about 10% of total program iterations, ants choose different paths with equal probability. This will result in a uniform distribution of ants in the problem space in the early steps of the solving process. Applying these changes, it is possible to set the number of ants equal to the number of nodes in this problem too.

The original version of ACO only optimizes the path length, but in this problem it is required to optimize at least two parameters of path length and path traffic. We used the norm of optimizing parameters instead of links' length to compute the visibility parameter.

Applying these modifications to the original ACO solution used for the TSP problem, we can match this solution to the urban traffic control problem. Figure 3 shows the algorithm used for the ACO-Based traffic control system.

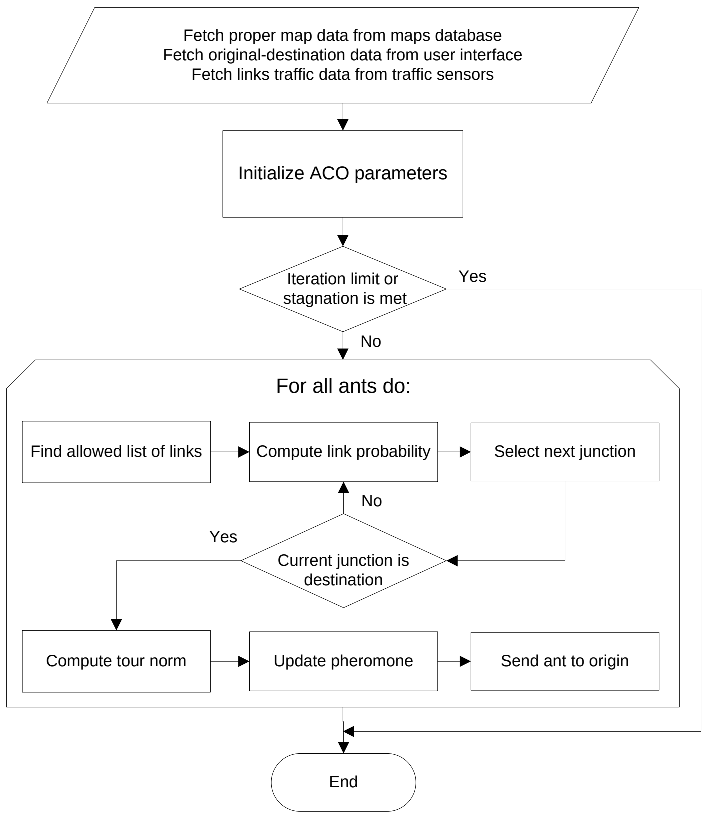

Fig. 3. Algorithm used in ACO-base traffic control

3. EXPERIMENTAL RESULTS

As mentioned in the previous section the original version of the ACO algorithm could not be used for our problem. So, some modifications, those that came in the previous section, must be applied to fit this algorithm for the traffic control problem. To benchmark the ABUTCS behavior, we have applied it to different kinds of situations in which two critical ones appeared in this section to show its performance. Each case has been tested for 10 iterations and the achieved results show that the solutions converged in 10 times of iterations.

The first case is a sample map with 40 junctions and 57 two-way links (114 links). All the links have traffic densities defined to be equal to traffic density class A (minimum traffic density), and the origin defined to be junction 1 (down left junction). The destination has been set to junction 40 (up right junction). Figure 4 indicates the optimal path, which is provided by the ABUTCS. Figure 5 shows each ant's path length through the solving process. This figure shows the convergence of the problem to the optimal path.

In another case, the ABUTCS is applied to a map of 75 junctions and 170 two-way links, Fig. 6. In this problem links are set to have different classes of traffic density. After 10 iterations of solving the process, each ant's passing length to the destination has converged to an optimum value, as Fig. 7 shows.

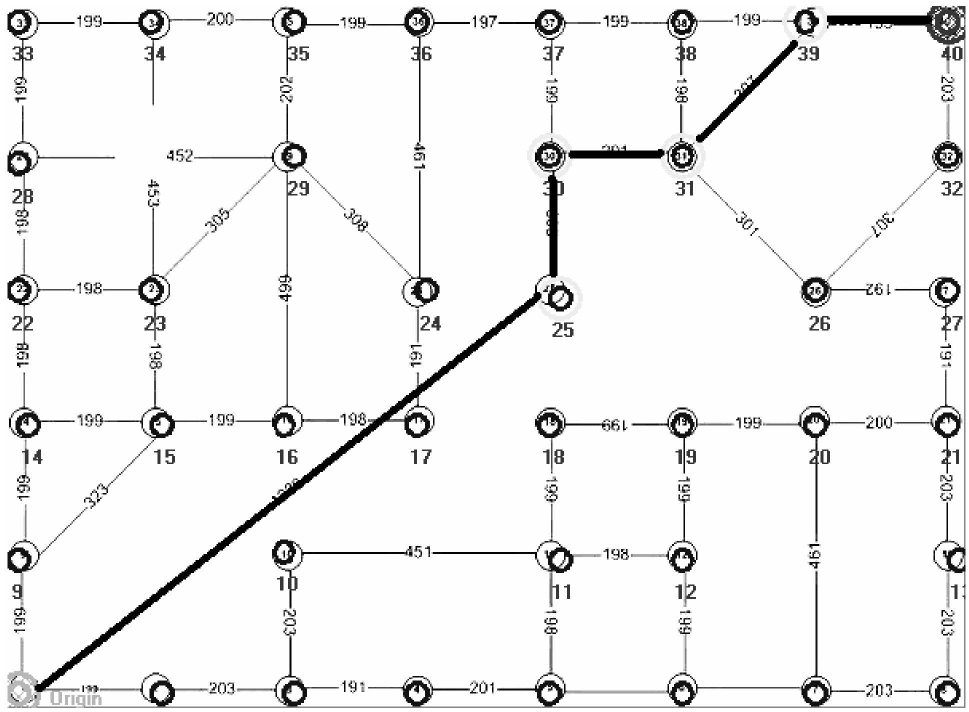

Fig. 4. Optimal path between junction 1 and 40 when all links have the same traffic density

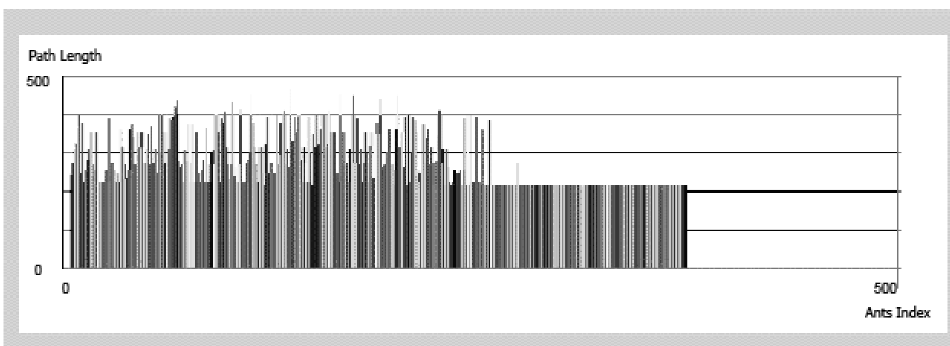

Fig. 5. Found path by each ant in first test

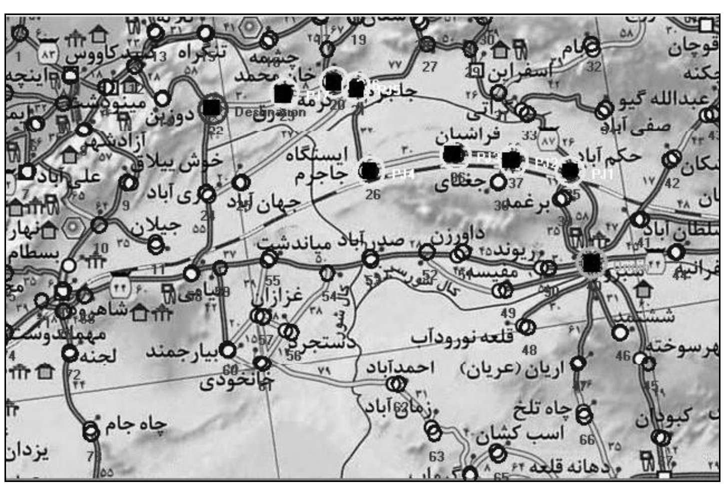

Fig. 6. Optimal path between junction 40 and 22, for a real world problem

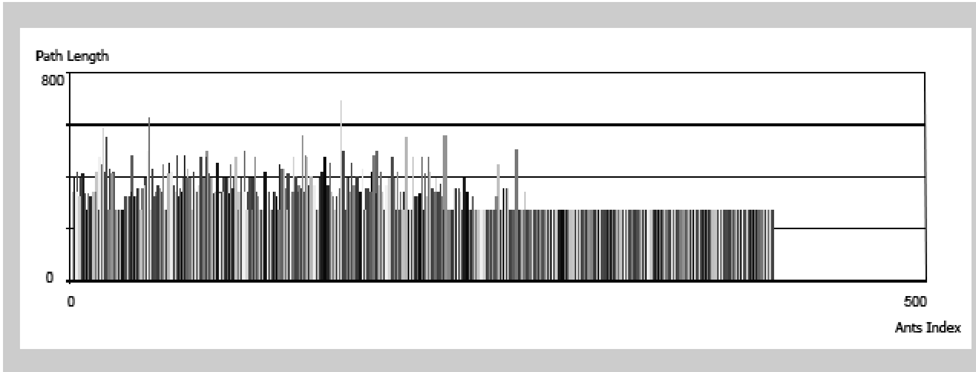

Fig. 7. Found path by each ant in a real world problem

4. CONCLUSION

This paper introduced a new urban traffic control system, which uses a modified ant colony optimization method to select the optimum path from origin to destination. This modified ACO algorithm can optimize more than one parameter, as the described system is required to optimize at least two parameters of path length and path traffic density. We discussed the simulation of this method and the required modifications we applied to the ACO algorithm to be able to optimize two parameters and also to be able to initialize the number of ants with the mentioned value. Finally, the experimental results have been presented, proving the good results of applying the modified ant colony optimizer for the main sub system of the new traffic control system.

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