TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 9, September 2014, pp. 6699 ~ 6710
DOI: 10.11591/telkomnika.v12i9.6036

Bee Inspired Zonal Vehicle Routing Algorithm in Urban Traffic

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Abstract

Dynamic Route Guidance System, which can provide the drivers with the optimal routes, is one of the most efficient solutions to the traffic jam. This paper presents a bee inspired zonal vehicle routing algorithm to provide a reasonable and effective optimal route for the Dynamic Route Guidance System. Firstly, the proposed algorithm divided the whole traffic network into different traffic guidance zone based on Shapley value game. Then, real time traffic data was collected in each traffic guidance zone by inter-vehicle and vehicle-to-infrastructure communications. Ultimately, the proposal simulated the bee foraging phenomenon in the biological system to synchronously compute the optimal routes in each traffic guidance zone. The simulation results show that the algorithm has higher computation efficiency under the precondition of providing the global optimal route.

Keywords: *bee inspired, traffic guidance zone, optimal route, dynamic route guidance system.*

1. Introduction

In recent years, the constantly accelerating of urbanization and motorization progress of modern city leads to vehicular number increasing year by year. The urban traffic faces unprecedented pressure, and the traffic jam occurs more and more often, which incurs the traffic accident, energy waste, and environmental pollution that has become the most social focus. Intelligent Transportation System (ITS) is an effective approach to solve urban traffic congestion, ensure traffic safety, and improve transportation efficiency. Dynamic Route Guidance System (DRGS), as an important part in ITS, can provide reliable guidance information, plan optimal travel path, avoid congestion region, and balance network traffic load by real time traffic data acquisition and dynamic traffic information processing. The DRGS can utilize the network capacity adequately to realize the optimization of urban road network management and control.

In the traditional static route guidance system the index of route choice model is generally distance, that is calculating the shortest path. The most commonly methods are Dijkstra, A*, Floyd, and so on. These algorithms have advantages and disadvantages. The Dijkstra algorithm can calculate the optimal solution of the shortest path, however its ergodic node number is excessive so as to reduce its efficiency. It is suitable for small network, but its efficiency drops when the network becomes large. The Floyd algorithm encodes simply, and it can calculate the shortest path between any two nodes. Its efficiency is higher than Dijkstra algorithm in dense diagram, but the same as Dijkstra algorithm, it is not suitable for large network and huge data computation because of its high time complexity.

Since the road network becomes more and more complex, and the traffic congestion becomes more and more common, the real time variation of congestion information is highly nonlinear and mutability. The Traditional static route guidance system has not been fully considered the interference of traffic jam to the guidance system, and the guidance efficiency decreases as the nonlinear and mutable congestion information can be reflected in the model. Hence, the dynamic route guidance system with the index such as time, cost, fuel consumption, becomes mainstream. The route choice model generally calculates the shortest path with the time index in DRGS. Well-known methods are D*, tabu search algorithm, ant colony optimization, and simulated annealing algorithm, etc. For the enlargement of urban road

Received March 30, 2014; Revised June 25, 2014; Accepted July 20, 2014

network and the increase of node number, the search region and the calculation quantity of these algorithms increase, resulting in the large computation time and low efficiency, which cannot meet the real time requirement in DRGS. Researchers presented many algorithms to improve the optimal route searching performance in complex road network with decreasing searching scales, such as restricted search area algorithm [1], and hierarchical search area algorithm [2], etc. These algorithms can improve the vehicle routing efficiency to a certain extent, but they are easily leading to a local optimal route due to the limitation of search area. Even the hierarchical search area algorithm often leads the vehicle into the backbone layer, which not only misses the global optimal route, but also results in congestion, and even congestion transfer or causing new congestion.

For this purpose, this paper presents a zonal vehicle routing algorithm to decrease the space complexity of route calculating. Meanwhile, this algorithm employs the bee inspired strategy to improve the efficiency of route finding. Simulation in an actual network is given, and the results show that on the basis of ensuring the global optimal route, the proposal performs better efficiency in route computation.

2. Bee Nature and Bee Colony Optimization

Social insects such as ants and bees have a kind of instinct called group intelligence, which can make the group highly coordinated, and complete complicated and intelligent behavior. The worker bees bring the nectar back to their nets and exchange the nectar information with their companion through specific dance called “8 Dance” in order to attract other bees follow them to realize the optimization of group foraging behavior. The dance form is closely relevant to the harvest, such as duration, angle, rhythm, which can express the yield on the visited flowers. The yield can be regarded as the function with the independent variable of honey quality, quantity, and distance. The other bees observed the “8 Dance” and followed with a certain probability, that is, to forage to the position that the dance indicated. The following probability is positive correlation to the intensity of the dance, consequently to the previous foraging yield of the dancer. The bee swarm can form the optimization of extraction of the honey source through this self-organization mode.

This process can be introduced to solve the optimization problem, which is called bee colony algorithm [3]. The bee colony is a bionic algorithm based on the self-organization model and swarm intelligence of bee swarm in the nature. A bee population consists of three kinds of bees: the employed bee, the onlookers, and the scouts. At the very beginning, half of the colony is the employed bee, and the other is the onlooker. The swarm intelligence of foraging is achieved by the communication and cooperation among different kinds of bees. The source is introduced in the model to represent all possible solutions. The progress of foraging is the process of searching for the optimal solution. The basic behavior of bee is to search, to evaluate, and to abandon the source. The value of the source is indicated by the yield function. The yield function is a judgment, which determines the optimization direction. The process of solving the optimal solution is the process of searching high yield source. Therefore, the overall goal is to solve the optimal solution of the yield function. The employed bees correspond to their searching source, in other word the source is the target of the employed bees. The onlookers obtain the yield information from the employed bees in the dance region. The probability of source selection is proportional to the honey quantity, namely the yield of source. When the yield of source is relatively low, it will be abandoned. Meanwhile, the corresponding employed bee to this source will become a scout. The scouts randomly search the new source near the old source so as to jump out of local optimal boundary.

Karaboga successfully applied the artificial bee colony (ABC) algorithm to numerical optimization in 2005 [4], and proposed a systematic ABC algorithm, which is simple and robust with the superiority in numerical optimization of unrestraint problem. In 2006, Karaboga and Basturk utilized the ABC to solve restrained numerical optimization [5], and obtained a good effect.

In combinatorial optimization, Chin et al. utilized bee colony algorithm to solve workshop scheduling problem [6], and they solved the travelling salesman problem by using bee colony optimization in 2008 [7]. Alok et al. successfully found the minimum spanning tree with leaf constraint in a certain undirected weighted graph by using ABC algorithm [8]. Kou et al. applied the ABC algorithm to solve the TSP problem [9], and put forward the improvements of the parameters, which performed good effect. Hu et al. realized the application of ABC algorithm in the path planning problem in welding engineering [10].

3. Traffic Guidance Zone Partition

3.1. Definition of Traffic Guidance Zone

A complete road network consists of vast road sections and intersections. The object of traffic control zone is intersection. However the traffic guidance zone prefers road section, with the parameters such as traffic flow, occupancy, and saturation etc. The urban road network is abstracted as a connected directed graph, where the nodes indicate the intersections, and the edges indicate the road sections. The attachments form a network topology structure, which can be expressed as follows:

$$S = \{R, A\} \tag{1}$$

Where $R=\{r_1, r_2, \ldots, r_n\}$ indicates the set of road sections, and n is the number of road sections; $A=\{a_1, a_2, \ldots, a_n\}$ indicates the set of attribute of R, that is $a_i=\{a_{i1}, a_{i2}, \ldots, a_{ip}\}$ represents the set of all attributes of road section r_i, such as traffic flow, travel time, average speed, saturation, and occupancy, and p is the number of attributes. Because the dimensions of all the attributes are different, normalization must be done before data processing.

Traffic guidance zone is defined as a large network, which divides the entire road network into different regions according to the traffic characteristics like traffic flow, flow direction, saturation, and occupancy etc. When the traffic flow guidance and vehicle routing occur, optimal path search is parallelly implemented in each traffic guidance zone separately. These relatively independent zones are the traffic guidance zones, noted as $u(o_{ik}, G_i)$, which are the non-null subsets of entire road network $S=\{R, A\}$.

3.2. Optimization Goal Analysis

Traffic zone is a set of adjacent road section series, in which the nodes have high traffic similarity to each other. Meanwhile, the road section quantities of different traffic zones are as balanced as possible, and each road section only belongs to one traffic zone. Therefore, the optimization goal of traffic guidance zone partition and its constraints can be expressed as follows:

$$\left.\begin{array}{l} G = (G_1, G_2, \cdots, G_t) \\ G_i = (o_{i1}, o_{i2}, \cdots, o_{iN_i}) \\ u(o_{ik}, G_i) = \max(u(o_{ik}, G_1), u(o_{ik}, G_2), \\ \qquad \cdots, u(o_{ik}, G_i), \cdots, u(o_{ik}, G_t)) \\ \begin{cases} Sim(G_i) \geq \delta_{sim}, N_i \geq \mu_{num} \\ \quad \forall o_{ij} \in G, \sum_{1}^{t} x_{kj} = 1 \end{cases} \end{array}\right\} \tag{2}$$

Where G indicates the set of zones and t represents the zone number. o_{i1}, $o_{i2}, \ldots, o_{iNt}$ are the road sections of Zone i, and N_i is the road section number in Zone i. $u(o_{ik}, G_i)$ is the correlation between o_{ik} and Zone i, which is determined by both the distance-position factors and the traffic similarity. δ_{sim} is the minimum similarity threshold, and μ_{num} is the minimum road section number threshold. x_{kj} is the attribution of road section j to Zone k, that is, when road section j belongs to Zone k, x_{kj} is equal to 1, otherwise is 0.

3.3. Model Establishment

Define the game G as the process of road section partition according to the traffic zone core. The three elements of the game process are:

(1) The game participant set: $i \in N$, where $N=\{1, 2, \ldots, n\}$ is the road sections in the network;

(2) Strategy for each participant: σ_i={σ_{i1}, σ_{i2},…, σ_{it}}∈∑, is the finite mixed strategy. ∑ is the space of all participants' mixed strategies. σ_{ij}=(1,2,…,t) is the probability of road section i to join t traffic zones. The value of σ_{ij} is related to the distance between the road section and the gravity center of the traffic zone, which can be expressed in Equation (3):

$$\sigma_{ij} = \frac{\frac{1}{d_{ij}}}{\sum_{j=1}^{t} \frac{1}{d_{ij}}}, \qquad \sum_{j=1}^{t} \sigma_{ij} = 1 \tag{3}$$

Where d_{ij} is the Euclidean distance between road section i and the gravity center of traffic zone j.

The bigger the distance between the road section and the traffic zone is, the smaller the probability of the road section joins the traffic zone core. The road section joins the nearest traffic zone core to form the traffic zone with the maximum probability.

(3) The expected profit of participant set: u_{ij}={u_{i1}, u_{i2}, u_{it}} is composed by the profit when the participants take strategies from the strategy space. Each road section takes the traffic characteristic similarity with the traffic zone which it might join in as the game profit, such as Equation (4) shows:

$$\begin{aligned} u_{ij} &= [sim(o_i, c_j)]\sigma_{ij} \\ &= [\max dif - dif(o_i, c_j)]\sigma_{ij} \\ &= [\max_{1\le j\le t} dif(o_i, c_j) - \sum_{k=1}^{r} \left| p_{ik} - \overline{p}_{jk} \right|]\sigma_{ij} \end{aligned} \tag{4}$$

Where $\overline{p}_{jk}$ indicates the average attribute value of each road section in the traffic zone core j.

3.4. Game Partition Algorithm Realization

In a round of the game, each game participant (player, here refers to road section) pursuits its own maximum profit relevant to divided zones according to the knowledge related to all the zones, namely the traffic similarity and probably joined zone strategy combination. The strategies of all participants consist of a strategy combination. The Nash equilibrium of traffic zone partition refers to such a strategy combination: After iterations, any player obtains the maximum profit under the existing strategy, that is, the player earns more in the current zone than other zones, and the profit of the whole network won't reduce because of player's seeking for the maximum profit.

Shapley value is a mathematical method to solve the problem of profit distribution of n-player with cooperative strategy [11]. When n individuals are engaged in an activity with economic profit, each individual can obtain certain profit. But when n individuals constitute alliance, the alliance gross profit is bigger than the sum of the independent profits of n individuals. Each cooperative form with different combinations of several individuals corresponds to a certain profit. When the activity with economic profit is non-confrontational, the increase of player number in the cooperation cannot cause the profit reduction. So, the cooperation of all the n individuals brings the maximum profit. The biggest advantage of Shapley value is that its principle and results are fair and easily accessible by each player. The Shapley value method is a scheme of the maximum profit distribution, which is defined as follows [12]:

Set I={1,2,…,n}, and if any subset of I, which represents any combination of n players, corresponds to a real valued function $v(s)$, satisfies:

$$v(\Phi) = 0 \tag{5}$$

$$v(s_1 \cup s_2) \ge v(s_1) + v(s_2), s_1 \cap s_2 = \Phi \tag{6}$$

[*I*, *v*] represents the n-player cooperation strategy, and *v* indicates the characteristic function of the countermeasure, where *v*(*s*) is the profit of subset *S*.

x_i represents the profit that player *i* obtains from *v*(*I*). In cooperation *I*, the cooperative strategy distribution is represented by $x=(x_1, x_2,\ldots,x_n)$. The cooperation must satisfy the conditions as follows:

$$\sum_{i-1}^{n} x_i = v(i), i = 1,2,\cdots,n \tag{7}$$

$$x_i \geq v(i), i = 1,2,\cdots,n \tag{8}$$

$\phi_i(v)$ represents the profit distribution of player *i* in cooperative game [*I*, *v*]. The Shapley value of the profit distribution of each player in cooperation [*I*, *v*] can be described as follows:

$$\Phi(v) = (\phi_1(v), \phi_2(v), \cdots, \phi_n(v)), \tag{9}$$

$$\Phi_i(v) = \sum_{s \in S_i} w(|s|) \cdot [v(s) - v(s \setminus i)], i = 1,2,\cdots,n \tag{10}$$

$$w(|s|) = \frac{(n-|s|)!(|s|-1)!}{n!} \tag{11}$$

Where s_i indicates all the subsets which contains player *i* in set *I*, and |*s*| represents the factor number in subset *s*. *w*(|s|) is the weighted factor, while *v*(*s*) is the profit of subset *s*. [*v*(*s*)-*v*(*s**i*)] represents the incremental profit after player *i* joins the subset *s*. *n*! indicates the combination of all subsets. The Shapley value does not deal with all these combinations, however it only deals with all the players when player *i* doesn't join subset *S* and have joined subset *S*, namely the (*s*-1)!*(*n*-*s*)! interesting sequences. The above two expressions combine the weighted factor [(*s*-1)!*(*n*-*s*)!]/*n*!, which distributes a fair marginal contribution to each interesting alliance. Calculate the accumulative sum of subset *S* where player *i* exists repeatedly. The final result represents all possible alliance assigned value of play *i* which is equal to the expected marginal contribution or incremental value.

The Shapley value method pays more attention to the efficiency of road section profit and the profit of road section partition, rather than only the distribution principle of road section occupancy in traffic zones. The algorithm not only avoids the situation that road section size decides the zone region, and also prompts the internal relation so as to improve their inner resource utilization ratio and the entire network resource utilization ratio by seeking for cooperation with adjacent zones actively. These advantages fully embody the fair, balance, and global optimal characteristic of Shapley value, which is good for the implementation of zonal route guidance system.

The Shapley value-based traffic guidance zone partition algorithm can be described as follows:

Step 1: Set the direction of traffic flow based on the original *S* of guidance route, and choose the road section attributes where *S* is the center of the diffraction to compute the game;

Step 2: According to the similarity threshold and node number threshold, choose the traffic zone core;

Step 3: According to the maximum expected profit principle, make the road sections join the corresponding traffic zone core to form traffic zones. Let the zone contenting *S* be the Zone *k*, and the adjacent zone be Zone *k*+1, and so on;

Step 4: In the first round of game, according to the average attribute value and the distance to the gravity coordinate of each traffic guidance zone, calculate the expected profit of each node to every traffic guidance zone u_{ij}, and let u_{max}=max{u_{ij}}. The computation data of Zone *k* is the real time data, while the data of Zone *k*+1 is the predicted data at the moment *k*+1, and so on.

Step 5: When the expected profit of the node to the located zone $u_0<u_{max}$, choose the maximum expected profit zone to join in, and re-calculate the average attribute value and gravity coordinates of the new traffic guidance zone and the Shapley value of each node.

Step 6: Enter the next round of game, and re-cluster the node according to the expected profit of each node. When the Shapley value is maximum, namely the game equilibrium, the traffic guidance zones are divided;

Step 7: When the next period of real time data acquiring comes, if *S* is still in Zone *k*, repeat step 4 to step 6, otherwise repeat step 2 to step 6.

4. Route Choice Model

4.1. Optimization Index Analysis

Dynamic Route Guidance System realizes the vehicle routing by using rolling cycle way [13]. The mathematical model of the shortest path problem usually adopts the graph theory knowledge to describe urban traffic road network topology. The specific model can be described as follows:

$$\min \sum_{i=S}^{E} \sum_{\substack{j=S \\ i\neq j}}^{E} Z_{i,j}^{(k)} I_{i,j} \tag{12}$$

s.t.

$$I_{i,j} = \begin{cases} 0, & (i,j) \notin R(S,E), \\ 1, & (i,j) \in R(S,E). \end{cases} \tag{13}$$

Where *i* and *j* indicate the vertex of the directed graph, namely the intersections of urban road network, and (*i*, *j*) indicate the edge of the directed graph, that is, the road section between intersection *i* and intersection *j* in the real road network. $Z_{i,j}(k)$ represents the road resistance at moment *k*, which is sum of the travel time in road section (*i*, *j*) and intersection delay (the average vehicle delay in the adjacent entrance lanes of intersection *i* and intersection *j*) at moment *k*. *S* and *E* indicate the original and destination respectively, and *R*(*S*, *E*) represents the acyclic path set from *S* to *E*.

The optimal route from *S* to *E* is the solution which satisfies the Eq.(12) and its constraints Equation (13).

4.2. Model Establishment

The whole network is divided into different traffic zones, and every traffic zone contains two kinds of nodes: inner nodes and border nodes. The inner nodes maintain the optimal route table to the other nodes in the same zone, while the border nodes maintain the optimal route table to the other border nodes in adjacent zones.

In section 1, bees are distinguished into three kinds: the employed bees, the onlookers, and the scouts. The employed bees collect the information, while the onlookers wait in the beehive to observe the fellow’s dance, and the scouts search for food source randomly. The number of the employed bees is equal to that of the onlookers, noted as *BN*, and the same as that of the food source (*SN*). Therefore, the solution set composes *SN* D-dimensional vectors, and the ist solution can be expressed as $x_i=(x_{i1}, x_{i2}, \ldots, x_{iD})$, where i=1, 2, …, *SN*. The pollen quantity of food source corresponds to the quality of the solution, namely the fitness value.

Initially, generate the initial solution set *P* (*G*=0) randomly, and evaluate its fitness value. After the initialization, the employed bees, the onlookers, and the scouts are circularly searching for the optimal solution, here standing for the optimal route. The employed bees amend the position relying on the local information in their memory, and test the fitness value of new position. If the fitness value is higher than the previous one, the employed bees remember the new solution instead of the old one, otherwise still hold the old one. After a round of search process, bees share the fitness value and position information with the onlookers in the dance region. The onlookers evaluate all the fitness value information from the employed bees, and select the food source according to the probability of the fitness value. Like the employed bees, the onlookers also amend the position relying on the local information in their memory, and test the fitness value of new position. If the fitness value is higher than the previous one, they drop the old one. An artificial onlooker select the food source according to the probability of food source quality as follows:

$$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \tag{14}$$

Where, fit_i indicates the fitness value of food source position.

The algorithm uses the following expression to create a competition position of an old position.

$$v_{ij} = x_{ij} + rand\ (-1,1)\left(x_{ij} - x_{kj}\right) \tag{15}$$

Where the index k is randomly selected, and $k \in \{1, 2, \ldots, BN\}$, $j \in \{1, 2, \ldots, D\}$. Although k is randomly decided, it must be different to i. rand(-1,1) is the random number in the region [-1, 1], which decides the adjacent food source creation of x_i. This correction represents the comparison of adjacent food source in bee visual, namely the neighborhood search process.

The food sources abandoned by the bees are replaced by new food source which the scouts find. If a position cannot be amended by a preset cycle number called “limit”, the abandoned food source will be replaced by the new food source found by the scouts with the assumption that this food source is abandoned. The operation is realized by the following equation:

$$x_j = \min_j + rand(0,1)(\max_j - \min_j) \tag{16}$$

This update equation represents the global search strategy. The maintenance of the scouts makes the algorithm a better global search ability so as to avoid the bee swarm falling into local minima.

After the establishment of every competitor’s position v_i, evaluate them and compare them with x_i. If the new food source is better, abandon the old, otherwise keep the old, that is, select the food source between the old and the current in greedy selection mechanism.

4.3. Zonal Guidance Procedure

When travelers have a route guidance demand, choose the original and destination, divide the traffic guidance zone based on Shapley value, and search the optimal route in each traffic zone by using bee inspired algorithm. The route guidance original located Zone k adopts the real-time data at the moment k to calculate the optimal route in the zone. Define the adjacent zone of S located Zone k as Zone k+1, and calculate the optimal route in Zone k+1 by using predicted data at the moment k+1, and so on. All the marginal road sections of traffic zones compose the interval network to provide the connection of segmented optimal route in traffic zones. The implementation of the algorithm is as follows:

Step 1: Set the traffic direction based on route guidance original S as benchmark, and select the traffic attribute of diffraction direction of the original to compute the game;

Step 2: Adopt Shapley value-based game theory to divide the traffic zone;

Step 3: Calculate the optimal route in each traffic zone by using parallel computing. Here only calculate the S located Zone i and the adjacent Zone k+1, Zone k+2, until the E located Zone $k+i$;

Step 4: Calculate the optimal route of the interval network to connect the optimal route in each traffic zone so as to form the optimal route from S to E;

Step 5: If S enters a Zone k+1, repeat Step 2 to Step 4 to re-divide the traffic zone and update the optimal route.

5. Simulation and Analysis

Take part of an urban road network as an example, which covers about 15 square kilometers, and contains 184 road sections, including 10 one-way sections and 155 two-way sections. Treat the road sections as nodes, so that the actual road network and the abstract road network are shown in Figure 1 and Figure 2 respectively. Establish the road network topology in VISSIM, and acquire the traffic parameters of all the road sections through simulation. The real-time data is collected every 5minutes, and the predicted data is obtained by using RBF neural network [14].

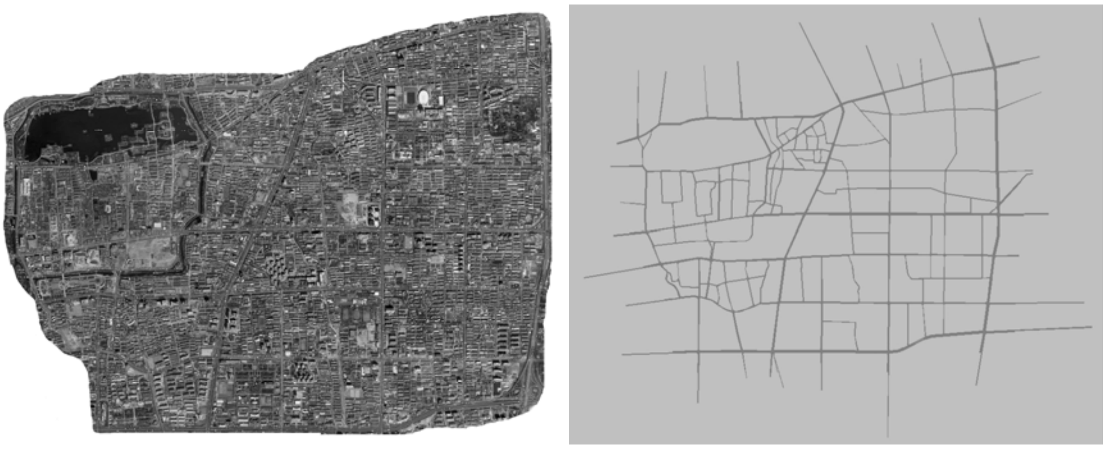

Figure 1. Actual Road Network and its Topology Architecture

Divide the whole network into traffic zones by using Shapley value-based game theory. After limited iterations, the game gets convergence and equilibrium, thus the traffic zones are determined as shown in Figure 3.

Figure 2. Abstraction of Road Sections of Actual Road Network

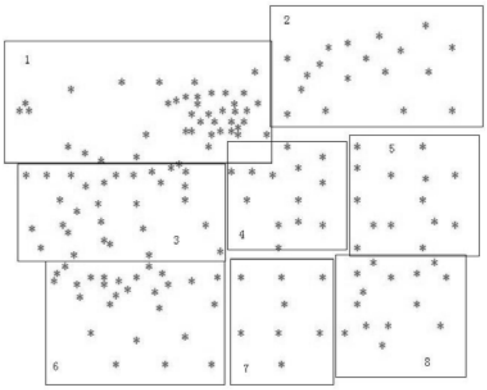

Figure 3. Traffic Zone Partition Based on the Shapley Value

Choose part results of zonal and non-zonal optimal routes from a mass of optimal routes search results as shown in Table 1, one of which from original 1392 to destination 1225 is shown in Figure 4 (in bold).

Figure 4 shows that the zonal optimal route and non-zonal optimal route from Node 1392 to Node. Table 1 lists that the zonal optimal routes are consistent with the non-zonal ones. Therefore, the algorithm can provide global optimal route after partition of the whole network into different traffic zones, and cannot make the optimal route search into local optimum due to decentralize the route search region into each traffic zone. On the basis of global optimal route guarantee, the optimal route search process after zone partition adopts parallel computing for optimal route calculation in each traffic zone synchronously. Furthermore, the algorithm doesn’t search relatively far zones from the zones that original and destination located so as to decrease the ergodic node quantity and reduce the computing complexity. Table 1 lists that the calculation time of zonal vehicle routing algorithm is less than 1 second, which is five time less than the non-zonal algorithm. Consequently, the zonal vehicle routing algorithm increases the routing efficiency, and shortens the calculation time.

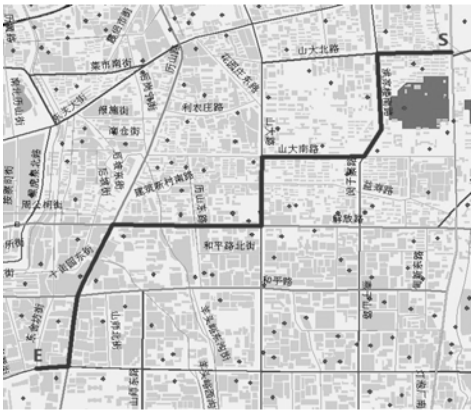

Figure 4. The Optimal Route of Zonal Vehicle Routing Algorithm

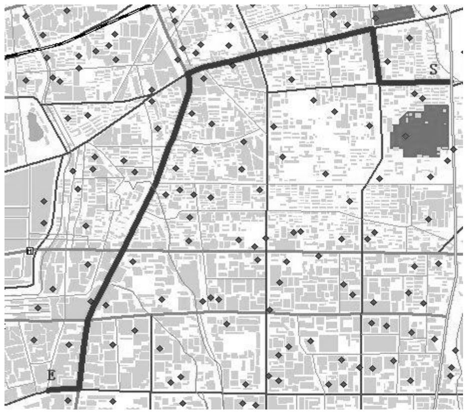

Figure 5. The Optimal Route of Hierarchical Algorithm

Dividing the entire network into different traffic zones can not only reduce the ergodic node quantity, computing complexity, and calculation time so as increase the search efficiency and real-time performance, but it also can provide a global optimal route. Consequently, the traffic zone partition can ensure the premise of accuracy and improve the efficiency and performance of DRGS. Furthermore, the traffic zone partition can also optimize the data collection and processing in vehicle-infrastructure cooperative real-time acquisition so as to provide convenient and effective data for the DRGS to enhance its performance.

Table 1. Results of Optimal Routes Compared with Non-zonal Algorithm

Original	Destination	Zonal vehicle routing		Non-zonal vehicle routing	
S	E	Node No.	Cal. time	Node No.	Cal. time
1392	1225	73	832ms	202	4827ms
Route	1392→1361→1359→1360→1355→1354→1318→1258→1232→1225				
1420	1212	104	916ms	238	5383ms
Route	1420→1415→1360→1355→1354→1318→1258→1232→1225→1212				
1093	1353	115	985ms	259	5195ms
Route	1093→1097→1142→1140→1156→1155→1182→1181→1201→1217→1223→1233→1234→1240→1258 →1232→1253→1289→1316→1322→1356→1350→1353				
1105	1314	101	875ms	239	4967ms
Route	1105→1114→1169→1212→1225→1232→1258→1276→1315→1314				
1304	1387	26	812ms	136	4662ms
Route	1304→1346→1359→1360→1355→1354→1398→1397→1369→1356→1350→1367→1386→1387				
989	1407	43	907ms	236	5217ms
Route	989→1017→1026→1041→1075→1108→1127→1131→1148→1168→1213→1232→1253→1289→1316 →1322→1356→1369→1397→1407				

To compare with hierarchical vehicle routing algorithm, the urban network is divided into two layers. The trunk roads compose the backbone layer as shown in Figure 1 (bold lines), and the other roads surrounded the trunk roads constitute the branch layers. In hierarchical vehicle routing algorithm, search the optimal route from the original and the destination to the backbone layer respectively, and the optimal route on the backbone to connect the original and the destination to generate the optimal route from original to destination. The optimal route results of the hierarchical and zonal vehicle routing algorithms are shown in Table 2, and the optimal route from 1392 to 1225 of hierarchical algorithm is shown in Figure 5 (in bold).

Table 2. Results of Optimal Routes Compared with Hierarchical Algorithm

Original	Destination	Zonal vehicle routing			Hierarchical vehicle routing		
S	E	Node No.	Cal. time	Trav.	Node No.	Cal. time	Trav.
1392	1225	73	832ms	18.2min	56	437ms	25.7min
RouteZ		1392→1361→1359→1360→1355→1354→1318→1258→1232→1225					
RouteH		1392→1361→1418→1419→1388→1345→1319→1311→1304→1302→1299→1276→1258→1232→1225(different from RouteZ)					
1420	1212	104	916ms	19.4min	73	519ms	32.2min
RouteZ		1420→1415→1360→1355→1354→1318→1258→1232→1225→1212					
RouteH		1420→1415→1410→1411→1398→1354→1318→1258→1232→1225→1212（different from RouteZ）					
1105	1314	101	875ms	13.7min	85	492ms	13.7min
RouteZ		1105→1114→1169→1212→1225→1232→1258→1276→1315→1314					
RouteH		The same with RouteZ					
1304	1387	26	812ms	22.5min	62	467ms	40.8min
RouteZ		1304→1346→1359→1360→1355→1354→1398→1397→1369→1356→1350→1367→1386→1387					
RouteH		1304→1302→1299→1276→1258→1232→1225→1212→1286→1308→1324→1334→1353→1370→1387 (different from RouteZ)					
1407	989	43	907ms	14.6min	76	485ms	35.9min
RouteZ		1407→1397→1369→1356→1322→1316→1289→1253→1232→1213→1168→1148→1131→1127→1108→1075→1041→1026→1017→989					
RouteH		1407→1409→1411→1398→1354→1318→1258→1240→1234→1219→1215→1188→1178→1173→1151→1136→1116→1095→1089→1072→1063→1048→1031→1017→989(different from RouteZ)					

Due to the characteristic of hierarchical vehicle routing algorithm, it provides an optimal route with less ergodic node quantity and shorter calculation time than zonal vehicle routing algorithm. However, most optimal routes of hierarchical algorithm have longer travel time than that of the zonal algorithm. The reason is that the aim of hierarchical search is to shrink the search region into the trunk layer so as to optimize the calculation time. Although the traffic capacity of backbone layer is higher than that of the branch layer, the travel time, occupancy, or saturation of backbone layer is better than that of the branch layer. Therefore, the optimal route of hierarchical algorithm is easy to lost in local optimum. On the other hand, due to the backbone layer only consists of the trunk roads, if there are plenty of routing demands at the same time, the backbone layer will become congested, which cannot solve the traffic jam, but bring further new congestion in contrary. Therefore, compared with hierarchical algorithm, the zonal algorithm can provide a global optimal route with appropriate calculation time sacrifice.

Select couples of originals and destinations, and verify the search efficiency of bee inspired algorithm compared with ant colony algorithm and D* algorithm. The optimal route results given by the above algorithms are shown in Table 3 and Table 4.

Table 3. Results of Optimal Routes Compared with Ant Colony & D* Algorithm

Org.	Dest.	Zonal vehicle routing			Ant colony vehicle routing			D* vehicle routing		
S	E	Node No.	Cal. time	Trav.	Node No.	Cal. time	Trav.	Node No.	Cal. time	Trav.
1392	1225	73	832ms	18.2min	85	1263ms	18.2min	137	3792ms	18.2min
1420	1212	104	916ms	19.4min	127	1419ms	27.1min	196	3942ms	19.4min
1105	1314	101	875ms	13.7min	132	1463ms	13.7min	217	4049ms	13.7min
1304	1387	26	812ms	22.5min	44	1184ms	32.5min	82	3563ms	22.5min
1407	989	43	907ms	14.6min	69	1231ms	14.6min	115	3631ms	14.6min

Table 4. Optimal routes compared with ant colony & D* algorithm

Org. S	Dest. E	Zonal vehicle routing RouteZ	Ant colony vehicle routing RouteA	D* vehicle routing RouteD
1392	1225			
RouteZ		1392→1361→1359→1360→1355→1354→1318→1258→1232→1225		
RouteA		The same with RouteZ		
RouteD		The same with RouteZ		
1420	1212			
RouteZ		1420→1415→1360→1355→1354→1318→1258→1232→1225→1212		
RouteA		1420→1415→1360→1355→1354→1357→1356→1350→1353→1334→1324→1308→1286→1212(different from RouteZ)		
RouteD		The same with RouteZ		
1105	1314			
RouteZ		1105→1114→1169→1212→1225→1232→1258→1276→1315→1314		
RouteA		1105→1114→1169→1212→1225→1232→1258→1276→1315→1314(same as RouteZ)		
Routed		1105→1114→1169→1212→1225→1232→1258→1276→1315→1314(same as RouteZ)		
1304	1387			
RouteZ		1304→1346→1359→1360→1355→1354→1398→1397→1369→1356→1350→1367→1386→1387		
RouteA		1304→1346→1359→1360→1355→1354→1357→1356→1350→1353→1370→1387(different from RouteZ)		
RouteD		The same with RouteZ		
1407	989			
RouteZ		1407→1397→1369→1356→1322→1316→1289→1253→1232→1213→1168→1148→1131→1127→1108→1075→1041→1026→1017→989		
RouteA		The same with RouteZ		
RouteD		The same with RouteZ		

Compared with the ant colony algorithm and D* algorithm, the proposed bee inspired algorithm provide a global optimal route with less ergodic node quantity and faster calculation time. Hence, the bee inspired algorithm can provide accurate and fast global optimal route.

6. Conclusion

This paper presents a zonal bee inspired vehicle routing algorithm, which divides the road network based on Shapley value by using the traffic information acquired through inter-vehicle communication firstly, and then adopts parallel computing to calculate the optimal routes in each traffic guidance zone based on bee inspired algorithm to obtain the optimal route from the original to the destination. Simulation results show that the zonal bee inspired vehicle routing algorithm can decrease the computation complexity to improve the real-time performance of DRGS under the premise of global optimal route guarantee.

The traffic information is easy to obtain under the vehicle-infrastructure cooperative condition. Dividing the whole road network into different traffic zones makes the traffic information collection and processing high timeliness. The Shapley value-based traffic guidance zone partition not only reduces the traffic information interactive region so as to speed up the real-time performance of traffic information collection and processing, but also reduces the route search region to decrease the computation complexity and calculation time cost.

The bee inspired vehicle routing algorithm in traffic guidance zone is simple to realize, and it is not easy to fall into local optimal solution compared with other swarm optimization algorithms. Thus, the algorithm can provide an accurate and efficient global optimal route. However, the disadvantage of the algorithm is that it needs to adjust several parameters. So, improvements should be put forward to obtain better computational efficiency in future research.

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