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Traffic Signal Timing Optimization for Isolated Intersections Based on Differential Evolution Bacteria Foraging Algorithm

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Abstract

Aiming at that the traffic congestion in urban often appears, the signal timing optimization model and method are researched. The signal control model is proposed considering the max throughput of intersection. The objective function of this model is to minimize the delay vehicles of a cycle time. The model has all kinds of constraint. A differential evolution bacteria foraging optimization algorithm is presented. The velocity of the traditional bacteria foraging optimization algorithm is slow. The bacterium position is revised by differential evolution in chemotaxis process to improve the convergence precision. Based on an intersection in Guangzhou City, the model is calculated and simulated through programming. As it shows, it can improve traffic capacity of intersections and especially works well in high demand.

Keywords: traffic engineering; signal timing optimization; delay vehicles; bacterial foraging; differential evolution

1. Introduction

Intersection is an important part to lead traffic. Signal timing optimization is an important measure to relieve traffic congestion and improve traffic safety. In several decades urban road network congestion

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has been a problem of most cities around the world. It is necessary that the signal timing optimization model and method under high-demand is researched. A lot of research work has been carried out on the development of signal timing optimization in urban areas. As a whole, there are two methods to realize the signal timing. One is fix time control. The other is sensor control. The Webster model and ARRB model are often used to fix time control (WEBSTER, 1996; AKCELIK, 1981).Both models are work well in low demand traffic but not well in high demand traffic. In recent years the method of sensor control is becoming highly valued. All kinds signal dynamic optimization model are found (CAO, 2010; Lo, 2004; WAN, 2007). Delay time and stops are selected as the performance index in those models. The GA is usually used to solve those models. But the methods can't achieve good control results in high demand traffic. Some scholars has been studied the over-saturated intersection signal timing. Some of them found the improved fix time model based on Webster model (PEI, 2005). Some of them adjustment phase and phase sequence to relieve intersection traffic (HE, 2010).It isn't practical.

Based on the above, the signal control model is proposed considering the max throughput of intersection. The objective function of this model is to minimize the delay vehicles of a cycle time. Meanwhile, the differential evolution bacteria foraging algorithm（DEBFA）is proposed to solve the model. The differential evolution is use to revise the bacteria position in the process of chemotax to improve the convergence precision based on BFO.

2. Signal timing optimization of isolated intersection model proposed

The signal timing optimization model of a typical Intersection with four phases and three line lanes is found in this paper.

2.1. Objective function

The performance indexes of signal control model are usually the delay time, the stop times or the two in combination. Urban road network congestion has been a problem of most cities around the world for several decades. So the performance indexes of signal timing optimization problem should pay more attention to the max throughput. In this paper the delay vehicles is selected. The fewer vehicles are delayed, the more vehicles can pass. The delay vehicles can be express by formula (1).

$$Q(k) = \sum_{k=1}^{K}\sum_{j=1}^{4}\sum_{l=1}^{3}\max\{0, \frac{Q_{jl}^{I}(k-1) + \sum_{i=1}^{I}(q_{jl}^{i}(k) - \mu_{jl}^{i} * \lambda_{jl}) * g^{i}(k)}{C(k)}\} \quad (1)$$

$$\forall i = 1,2,\cdots,I;\ j = 1,2,3,4;\ l = 1,2,3;\ k = 1,2,\cdots,K$$

In Eq. (1), $Q(k)$ are the delay vehicles in red time of unit time (vech). k is the number of cycle and K is the max. i presents the phase and I is the max. j presents direction and 1,2,3,4 respectively presents the east , west, south and north of the intersection. l presents the lane and 1,2,3,4 respectively presents the left, straight and right. $Q^{I}_{jl}(k-1)$ is the delay vehicles of each lane at the last phase of the $k-1$ cycle. $q^{i}_{jl}(k)$ is the average arrival rate of the l lane at the direction j in i phase of the k cycle(vech/s). $g^{i}(k)$ is the green time of i phase in the k cycle. $C(k)$ is the Cycle Length of k. λ_{jl} presents the Saturation flow rate of l lane at the direction j (vech/s). μ^{i}_{jl} presents the state of release of l lane at the direction j in phase i and can be express by formula (2).

$$\mu_{jl}^{i} = \begin{cases} 1 & release \\ 0 & stop \end{cases} \quad (2)$$

The objective function can be express by formula (3).

$$Z = \min\left(\sum_{k=1}^{K}\sum_{j=1}^{4}\sum_{l=1}^{3}\max\left(0, \frac{Q_{jl}^{I}(k-1) + \sum_{i=1}^{I}(q_{jl}^{i}(k) - \mu_{jl}^{i} * \lambda_{jl}) * g^{i}(k)}{C(k)}\right)\right) \tag{3}$$

2.2. Constraint condition

The delay vehicles of each lane in the first phase of the k cycle are equal to that of the last phase of the $k-1$ cycle.

$$Q_{jl}^{o}(k) = Q^{I}{}_{jl}(k-1) \tag{4}$$

The signal cycle is equal to the sum of the green time of each phase.

$$\sum_{i=1}^{I} g^{i}(k) = C(k) \tag{5}$$

The actual signal cycle must be satisfied with formula (6)

$$C_{\min} \le C(k) \le C_{\max} \tag{6}$$

where, $C_{\min}$ is the minimum long cycle; $C_{\max}$ is the maximum long cycle.

The phase time must be satisfied with formula (7).

$$g_{\min}^{i} \le g^{i}(k) \le g_{\max}^{i} \tag{7}$$

where, $g_{\min}^{i}$ is the minimum phase time of phase i ; $g_{\max}^{i}$ is the maximum phase time of phase i .

3. Differential evolution bacteria foraging algorithm

The competition and collaboration in bacterial groups are used to achieve the optimization in BFO algorithm. It can avoid local minima for complex optimization problems. However, the optimization process of traditional BFO algorithm is slow (Passino, 2002). The differential evolution is use to revise the bacteria position in the process of chemotax to improve the convergence precision based on BFO.

3.1. Encoding of bacteria

The encoding of bacteria is real-number. Each dimension of bacteria presents the green time of each phase. The length is the number of phase. It can be expressed by formula (8).

$$[g_1, g_2, \cdots g_i, \cdots g_I] \tag{8}$$

3.2. Steps of the algorithm

(1) Initial algorithm parameters

Those parameters are needed to be initialized, such as the position of bacteria, population size S , number of chemotaxis N_C , number of breeding N_{re} , migration times N_{ed} and the probability of migration P_{ed} .

(2) Chemotaxis process

i. The bacteria are tumbled and moved with unit vector.

ii. The bacteria are swum until the fitness can’t be improved.

The bacteria are tumbled and swum to update the position by the formula (9) (DAS, 2009; LIU, 2002; LIU, 2011).

$$\theta^{i}(j+1, k, l) = \theta^{i}(j, k, l) + c(i)\phi(i) \tag{9}$$

$$\phi(i) = \frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \tag{10}$$

$\theta^i(j, k, l)$ presents the bacteria i position of the j th chemotaxis, the k th reproduction and the 1th migration. $c(i)$ is the chemotaxis step. $\phi(i)$ is the direction vector of unit. $\Delta(i)$ is the random vector.

iii. Differential variation

θ_{gbest} is defined as the global optimum. θ_{1best} is the current position. P is the variation operator and is expressed by formula (11).

$$P = \theta_{r1} + F(\theta_{gbest} - \theta_{r2}) + rand(\theta_{1best} - \theta_{r3}) \tag{11}$$

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

iv. Differential cross

The differential cross is executed by formula (12) to increase the variety of population.

$$\theta_i = \begin{cases} P_i & if \quad rand < CR \quad or \quad i == irand \\ X_i & otherwise \end{cases} \tag{12}$$

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

(3) Reproductive behavior

The S/2 bacteria with worst fitness die and the S/2 bacteria with the best fitness split.

(4) Migration behavior

The bacteria with worst fitness are eliminated with probability P_{ed}.

The flow of the DEBFA algorithm is shown in Fig. 1.

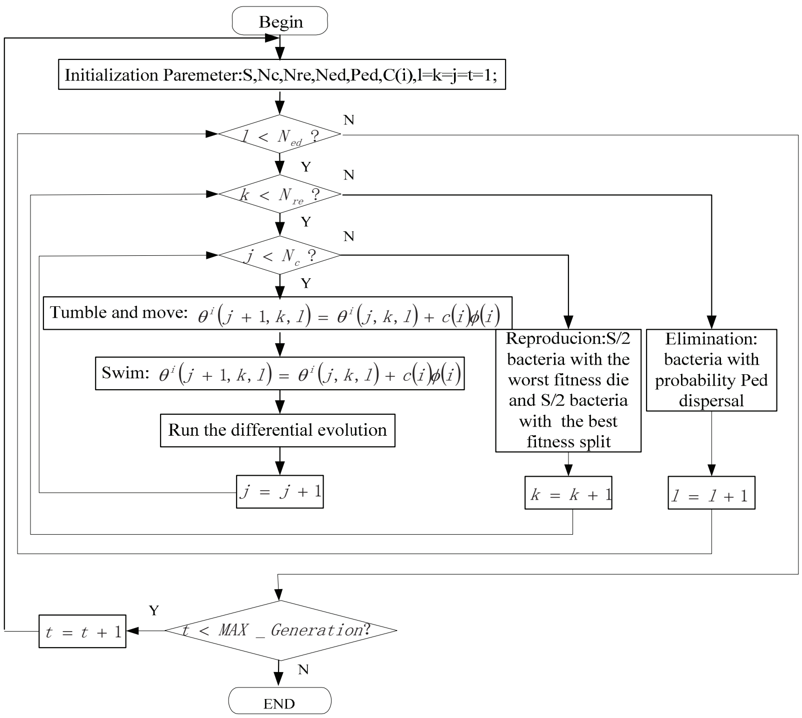

Fig. 1. Flow chart of differential evolution bacterial foraging algorithm for bus scheduling problem.

4. Simulation analysis

In order to prove the validity of this model and DEBFA, some intersection of Guangzhou is selected to simulation. This intersection has four phases. The simulative is done in matlab7.0.In simulation process the number of bacterial is equal to 50.The times of tumble N_C is equal to 100.The time of reproduce N_{re} is equal to 5.The time of elimination N_{ed} is equal to 3.The elimination probability P_{ed} 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 DEBFA algorithm and GA algorithm under low demand, medium demand and high demand. Meanwhile, the simulation is done by the fix time method. One of simulation result is shown in TABLE 1. The fitness curve of the DEBFA algorithm and the GA algorithm in high-demand are shown in Fig. 2.The total delay vehicles in 10 cycles of 10 simulation times is presented in Fig. 3. From the dates in TABLE 1 shows the validity of this model and method proposed. Under low demand three methods have no difference. It is pointed that the application effects of the model and the DEBFA algorithm proposed is much better than the other under high demand. It is found that the average delay vehicles is reduced by 28.3% than the fix time method and reduced by 5.6% than the GA algorithm. It can be seen that the fitness of the DEBFA algorithm and the GA algorithm tends gradually smooth and reach a steady value as the iteration number increased in Fig.2. But the DEBFA algorithm converges faster and can get the better solution than the GA algorithm for the signal timing optimization.

Table 1. Signal timing result and performance comparison

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	15.2	/
	GA	50	12	28	15	105	13.1	50
	DEBFA	41	10	32	12	95	12.3	38
Medium-demand	FIX TIME	38	32	45	35	150	44.5	/
	GA	45	13	59	6	123	38.9	56
	DEBFA	40	14	45	13	112	32.3	41
High-demand	FIX TIME	60	30	53	32	175	120.1	/
	GA	62	13	57	24	156	91.2	60
	DEBFA	58	20	42	25	145	86.1	45

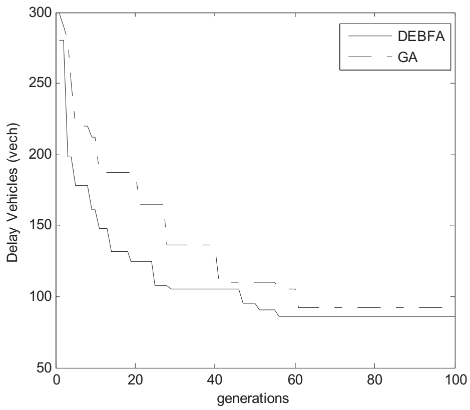

Fig. 2. Comparing the fitness curve of DEBFA and GA in high-demand

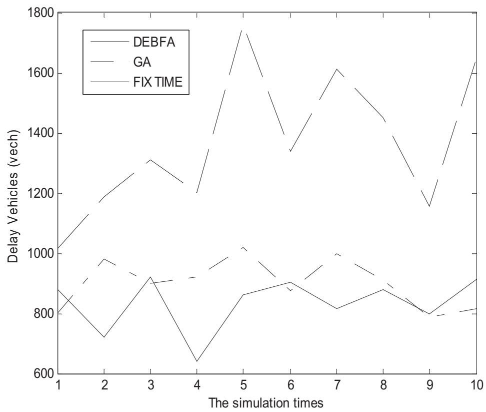

Fig. 3. Comparing the delay vehicles of three methods in high-demand

5. Conclusions

Aiming at the phenomenon that the urban intersection is often very crowd in cities, this paper proposed a signal timing optimization model and the DEBFA algorithm. 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. DEBFO is proposed to solve the Problem. Computational experiments of an intersection in Guangzhou 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.

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