Optimization of area traffic control parameter using a GA

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Abstract

In this paper, we propose a method for optimizing common cycle length and offsets among signal control parameters in area traffic control of a grid street network using a genetic algorithm. The gene of each offset is expressed by three bits, and that of a common cycle length by six bits. Each individual (a candidate of solution) is evaluated based on the weighted sum of delay time and stop percentage using CORSIM simulator in TSIS traffic integration software. The results of simulation experiments for regular and irregular grid street networks show that the optimal solutions obtained by the proposed method are better than theoretical ones based on a linear model in traffic signal control.

1 Introduction

Increasing number of vehicles in use generates serious problems such as traffic accidents and congestion. It is deeply desired that automobile traffic safety and smooth traffic flow are realized by appropriate traffic light control. There are three types of traffic light control: independent control handling a single signal, coordinated control in which two or more signals on a arterial road work in association with each other, and area traffic control which is a two dimensional version of coordinated control. Especially, large effects can be expected in coordinated control and area traffic control if they are optimized.

The object of this study is to improve the performance in area traffic control. Among the parameters of area traffic control, common cycle length, splits, and offsets, we focus attention on the common cycle length and offsets. The decision of common cycle length and offsets is considered as a combinatorial problem. If the number of intersections increases, the number of combinations becomes huge, and it is difficult to find an optimal solution. Hisai and Sakai [1] proposed analytical method for optimizing the offsets of signals on a grid street network. The time cost of the method is small but it is difficult to optimize them globally. Therefore, we have to solve the problem by some heuristic method. Abu-Levdeh and Benekohal [2] examined several genetic algorithms (GAs) applied to the optimization of traffic control parameters. GA is metaheuristics applied in versatile as a methodology for optimization, adaptation, and learning. Their target system in experiments was a signalized arterial road. In this paper, we propose a method for optimizing common cycle length and offsets among signal control parameters in area traffic control of a grid street network using a GA.

2 Area traffic control

Coordinated control is an approach to manipulating two or more signals on an arterial road in association with each other. Area traffic control (ATC) is a method by which a traffic signal group placed on a street network spreading two-dimensionally is controlled concentratedly. It can be considered as a two-dimensional version of coordinated control. Common cycle length and offsets are particular parameters of area traffic control. Common cycle length is a total time to complete one cycle in common with all signals. Offset is the delay from the start of the green phase of a reference signal to that of the signal concerned. According to the manual of JSTE [3], if round trip time T of a link in overall speed V is multiple integer of cycle length C, that is,

$$T = \frac{2D}{V} = nC, \tag{1}$$

vehicle delay time can be minimal. In the equation of (1), D is the link length. In the method adopted by present Japan, a region to be controlled by ATC is manually divided into several blocks based on the amount of traffic flow for every traffic situation considered. The control parameters are decided in every block and they are integreted. For a traffic situation, a set of control parameters corresponding with the situation is chosen from among the several sets of them obtained in advance and applied. However, because the frequent renewal of the several sets of them is difficult in this system, the system can not deal with unexpected traffic situations immediately. And, it is difficult to automate such work. So, we aim at optimizing ATC parameters of all signals in the region of interest by a heuristic method. In this study, we limit street networks to grid ones as the simplest case, and propose an optimization method of the control parameters.

3 Applying a GA to ATC

In this study, a combinatorial optimization problem of the set of control parameters, the common cycle length and offsets, is considered for a grid street network which consists of the streets of L rows and R columns and the intersections of $L \times R$. Each intersection points is called a 'signal' and each connecting street between two adjacent intersections is called a 'link'. Using the traffic micro simulator CORSIM, we simulate the street network with the sets of control parameters represented by viable solutions generated by a GA. Evaluating the results of the simulations, we use the output data of CORSIM; Vt (Vehicle Trips :the number of vehicles that have been discharged from the link), Tt (Total Time : total time on the link for all vehicles), Dt (Delay Time : the time that vehicles are delayed if they cannot travel at the free flow speed), Sp (StopPercentage : the ratio of the number of vehicles that have stopped at least once on the link to the total link trips) where the link means unidirectional one. We calculate a performance index (PI) as follow:

$$PI = \sum_{n=1}^{N} \left\{ \frac{\mathrm{Dt}_n}{\mathrm{Tt}_n} \times \frac{\mathrm{Vt}_n}{\mathrm{Td}} + K \times \mathrm{Sp}_n \times \frac{\mathrm{Vt}_n}{\mathrm{Td}} \right\} \qquad (2)$$

where K is the weight coefficient of Sp, Td is the simulation time, and N is the number of unidirectional links, $N = 2L(R-1) + 2(L-1)R$. The PI is the weighted sum of delay and stop. So, the smaller the PI the better the evaluation.

This optimization is carried out by a GA. GA is a metaheuristics applied in versatile as a methodology for optimization, adaptation and learning. The coding method of the GA is as follows. A chromosome for the GA consists of 30 bits as shown in Figure 1, where an offset is represented by a 3-bit binary number, and common cycle length is represented by a 6-bit binary number. Each intersection is numbered as shown in Figure 1. Actual offset values represented by 3-bit binary numbers I_k are taken as center values of equally divided 8 intervals between 0 and a common cycle length C, as shown in Figure 2. Actual common cycle length $C(MIN \leq C \leq MAX)$ represented by a 6-bit binary number I_N is ranging from 40 to 150 seconds, and obtained as

$$C = MIN + \frac{MAX - MIN}{2^6 - 1} I_N. \qquad (3)$$

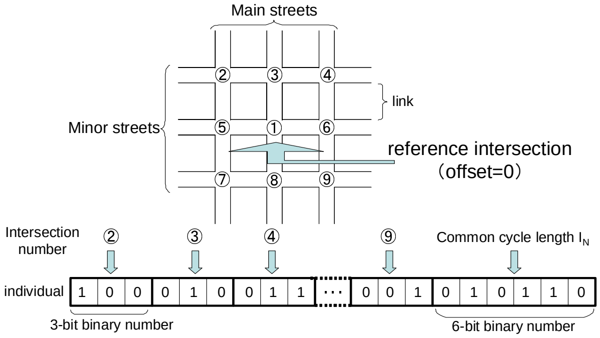

Figure 1: Coding method of cycle length and offsets

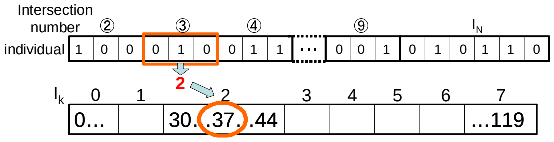

Figure 2: Calculating method of offsets

The fundamental algorithm of the GA is expressed in the following. First, M individuals (the initial population) are generated using uniform random numbers. All individuals of the current generation are evaluated by the fitness F defined by the inverse number of PI as

$$F = \frac{1}{PI}. \qquad (4)$$

Secondly, the operations based on genetic rules are applied to them for the construction of the next generation. As the genetic rules, we adopt elitism, and apply crossover and mutation to the individuals selected by roulette. Elitism is a mechanism that protects the chromosomes of most-highly-fit population from the genetic operations. In experiments, the top of the individuals becomes elite. Crossover is the main mechanism of the GA which expects the more-highly-fit children than their parents. For crossover, $M/2$ pairs of parents with permitted duplication are chosen from

M individuals based on the roulette selection at the probability proportional to the F value. From $M/2$ pairs of parents, their copies are made as M children, and one-point crossover is applied for the children in the probability of 1.0, and the last child is exchanged for elite. The mutation inverts a randomly chosen bit among 30 bits in each chromosome according to the probability of 0.1. The set of offsets with most highly fitness at the last (Tth) generation is made to be the best solution. Considering the calculation efficiency, the GA optimizes the offset of each intersection in the resolution of 3 bits. Then, we apply a coarse-to-fine approach to raise the resolution of the offset. In the first stage, the interval between 0 and C is coarsely divided into 8 segments, each offset is represented by the segment number 0 to 7 which corresponds to the 3-bit binary number, and the offset of all signals are optimized by the GA. In the second stage, for each offset the interval is diminished by one quarter, its center is set to the center of the segment obtained in first stage, and the same procedure as the first stage is carried out. After the third stage performed as same as the second one, each offset can be obtained at the accuracy of $1/4 \times 1/4 \times 1/8 = 0.78\%$ in the interval between 0 and C. Whereas, the common cycle length C is optimized in the first stage, and it is fixed in the second and third ones.

4 Results of simulation experiments

4.1 Regular grid network

First, we compare the solution of a linear model with that of the proposed method under the situation where the actual traffic condition is simplified. That is, the street network is made to be the regular grid one with 3 columns of main streets and 3 lines of minor ones and having 9 intersections and 24 unidirectional links (12 bidirectional links) of equal length D = 1000[ft]. In the GA, the size of population is made to be 50 individuals and the number of generations to be 30. Traffic and signal conditions of the simulator CORSIM is set as follows.

- Free flow speed : 27[ml/h]
- traffic flow : (main street) 0.35[vehicles/s]
  (minor street) 0.20[vehicles/s]
- phase probability : 0.50
- right and left turn : no turn
- yellow time : 3[s]
- all red time : 2[s]

The reference signal of the grid network is made to be the center one and its offset to be 0. In the linear model, the offset of each signal connected to the reference one by the link is calculated by D/V, where V is the free flow speed. The offset of each of the rest of 4 signals are calculated by adding D/V for the vertical link to the offset of the signal connected by the link. And the common cycle length in the linear model is equal to the round trip time T of a link according to the equation (1).

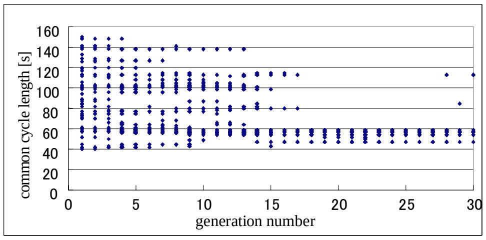

Figure 3: Distribution of the common cycle length as a function of generation in the first stage of the GA (regular grid network)

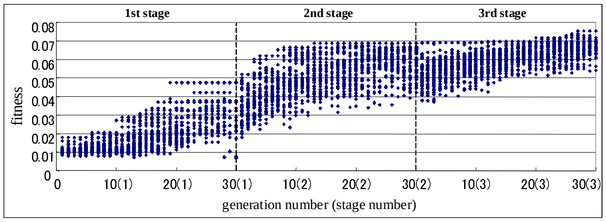

Figure 4: Distribution of the fitness value of each individual as a function of generation (regular grid network)

Table 1: The best solution of the GA and the linear model (regular grid network)

	cycle length	offsets of ①to ⑨									fitness
GA	57[s]	0	2	31	1	28	28	1	31	1	0.0754
linear model	50[s]	0	0	25	0	25	25	0	25	0	0.0279

As experimental results, Figure 3 shows the distribution of the common cycle length as a function of generation in the first stage of the GA. Figure 4 shows the distribution of the fitness value of each individual as a function of generation. Table 1 shows the best solution of the GA and the linear model.

4.2 Irregular grid network

Next, we examine the linear model and the proposed method under more actual situation than the above. That is, the street network is made to be the irregular grid one with 3 columns of main roads and 3 lines of minor ones and having 9 intersections and 24 unidirectional links (12 bidirectional links) of unequal length as shown in Figure 5.

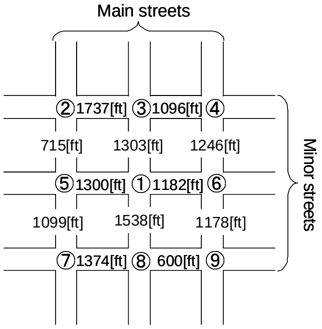

Figure 5: The setting of the link lengths

The parameters of the GA and the traffic and signal conditions of CORSIM are same as the above experiments. The reference signal and its offset are set as same as the above. In the linear model, the offset of each signal is also calculated as same manner as the above. And the common cycle length in the linear model is equal to the average of the round trip times of all links.

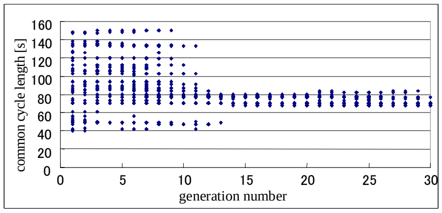

Figure 6: Distribution of the common cycle length as a function of generation in the first stage of the GA (irregular grid network)

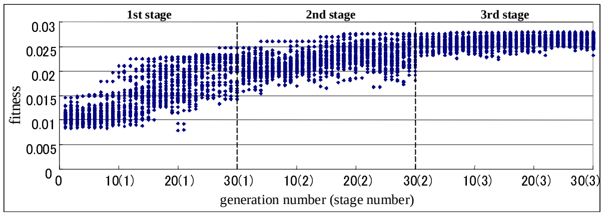

Figure 7: Distribution of the fitness value of each individual as a function of generation (irregular grid network)

As experimental results, Figure 6 shows the distribution of the common cycle length as a function of generation in the first stage of the GA. Figure 7 shows the distribution of the fitness value of each individual as a function of generation. Table 2 shows the best solution of the GA and the linear model.

Table 2: The best solution of the GA and the linear model (irregular grid network)

	cycle length	offsets of ①to ⑨									fitness
GA	70[s]	0	15	43	12	35	45	69	30	10	0.0279
linear model	61[s]	0	51	33	0	33	30	0	39	60	0.0196

5 Discussion

In Tables 1 and 2, the fitness values of the optimal parameters obtained by the GA are higher than those by the linear model on the regular and irregular grid street networks. Figures 3 and 6 show the convergence to constant values of the common cycle length in the course of generation. In Figures 4 and 7, we can see that the fitness values become high and converge, in the course of generation. And, the effect of the coarse to fine approach of the 3 stage GA can be seen. After all, on both of the regular and irregular grid street networks the availability of the proposed method is confirmed.

6 Conclusion

In this paper, we propose an optimization method for common cycle length and offsets among signal control parameters in area traffic control of a grid street network using a GA. As future work, we intend to investigate the goodness of the proposed method by comparing it with the other methods, and to apply other metaheuristics such as ant colony optimization in order to raise the efficiency of the proposed method.

References

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