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Cooperative Traffic Control based on the Artificial Bee Colony

Jinjian Li, Mahjoub Dridi, And Abdellah El-Moudni

ABSTRACT
This paper studies the traffic control problem in an isolated intersection without traffic lights and phase, because the right-of-way is distributed to each vehicle individually based on connection of the Vehicle-to-Infrastructure (V2I), and the compatible streams are dynamically combined according to the arrival vehicles in each traffic flows. The control objective in the proposed algorithm is to minimize the time delay, which is defined as the difference between the travel time in real state and that in free flow state. In order to realize this target, a cooperative control structure with a two-way communications is proposed. First of all, once the vehicle enters the communication zone, it sends its information to the intersection. Then the passing sequence is optimized in the intersection with the heuristic algorithm of the Artificial Bee Colony, based on the arrival interval of the vehicles. At last, each vehicle plans its speed profile to meet the received passing sequence by V2I. The simulation results show that each vehicle can finish the entire travel trip with a near free flow speed in the proposed method.
Index Terms: Time Delay, Artificial Bee Colony, V2I, Communication, Intersection. F 1

I. INTRODUCTION

THE traffic congestion is one of the most serious problems in our daily life. The intersection is one of the main places where this problem occurs. Therefore various traffic control methods have been developed to improve this problem. Among these method, there are two main types of methods: the conventional traffic control method and the intelligent traffic systems (ITS). The most important examples of the former are the fixed time control (FC) [1] and the adaptive signal control [2]. The shortcoming of FC is that its parameters is fixed according to the historical traffic data. As a result, when the traffic flows change heavily, Its performance is worse than expected. In order to improve this problem, the adaptive signal control is developed by dynamically adjusting the parameters based on the traffic information sent by the sensors. But it can't capture the precise movement of each vehicle. In addition, both methods have the limit value in the parameters, leading to fact that the green time in each phase can't be used absolutely. Such as, on the one hand, some vehicles wait before the red right, on the other hand, the green time is distributed to the lane without vehicle. This situation is very common in the evening. The intelligent traffic systems is a new traffic control method developed with the development of technology. It establishes the communication between vehicles and traffic control based on the vehicle-to-infrastructure (V2I) and infrastructure-to-vehicle (I2V), to improve the traffic control efficiency. Therefore, the vehicle can exchange the information with the intersection. However, many researchers only apply one-way information in their traffic control methods. For example, on the one hand, some researchers only apply the information from the vehicle to intersection to improve the traffic performance. The author Fei Yan [3] decreases the evacuation time by the Branch and Bound method. The author Jia Wu [4] reduces the final passing time by the Dynamic Programming. Both papers can diminish each vehicle's stop time based on its fixed arrival time in the intersection. On the other hand, some researchers only make use of the information from the intersection to the vehicle in their traffic control method. These papers try to reduce the stop time by changing vehicle's speed profile according to the fixed traffic control schedule. Such as the Green Light Optimal Speed Advisory (GLOSA) proposed in the papers [5] [6]. The GLOSA can help the vehicle to avoid the stop before the intersection by adjusting its profile before arriving at the intersection. There are other similar works , like Eco-driving systems [7] [8] [9] and driver assistance system [10]. Therefore, in this paper, a new traffic control method that combines the best features of the previous two types of approaches is presented. In other words, the proposed method considers a twoway communications between vehicles and intersection to improve the efficiency and reduce the time delay.

The proposed method in the paper is based on the following assumptions:
1) All vehicles are autonomous. Then they can accurately execute the given orders.
2) The time delay in the communication process isn't considered.
3) There is not the traffic lights at the intersection.

4) The right-of-way is allocated to each vehicle. Each vehicle can only pass the intersection in its right-of-way.
5) In each lane, the overtaking is interdicted, which means that the regulation of First-In-First-Out (FIFO) is imposed.

The paper is organized as follows: Section I surveys the background and the literatures of traffic control methods. Section II describes an isolated intersection model without traffic light and phase. Section III presents a new cooperative traffic control method based on a two-ways communications. Section IV shows the simulation results and the comparison with other methods. The last section concludes this work and proposes the future researches.

$$ET3^{a}_{(j,l,p)} = \max \begin{cases} ET3^{f}_{(j,l,p)},\ ET3^{a}_{(j',l',p')} + HW & l' = l,\ j = j'+1,\ p' < p \\ ET3^{f}_{(j,l,p)},\ ET3^{a}_{(j',l',p')} + TT3^{a}_{(j',l',p')} & l' \bigcirc l,\ p' < p\ (l' \in [1,8]) \end{cases} \quad (1)$$

II. PROBLEM MODEL

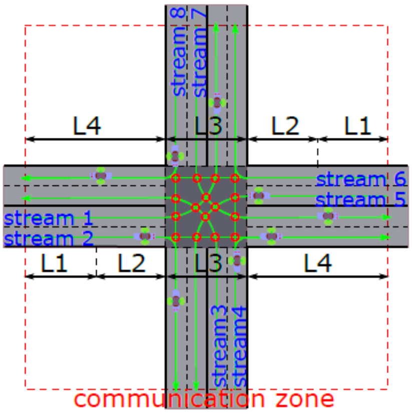

Fig. 1. An isolated intersection model

The Figure 1 shows an isolated intersection to be studied in this paper (Notations are defined in the Tab.1). There are four approaches in this intersection. Each approach contains two input streams. A stream means a part of arrival flow of vehicle and includes one or two trajectories. One trajectory is a path employed by a traffic stream to pass through the intersection. Based on the trajectory, there are two relations between the streams: compatible and incompatible. The former means that their trajectories do not cross in the intersection, as a result, the vehicles from these streams can pass the intersection at the same time. And vice versa. Therefore, in this paper, the safety constraints are summarized in the Formula (1). A vehicle is not allowed to start to pass the intersection until that all the previous vehicles in the given passing sequence from the incompatible streams have completely passed the intersection. This is one of the safety constraints for the vehicles in the time of starting to pass the intersection. Another constraint is the minimal headway for the vehicles in the same steam. The last one is the minimal arrival time $ET3^{f}$ for vehicles to arrive at the intersection by respecting the maximal road allowed speed. The figure 1 and the table 2 illustrate all the pairs of incompatible streams, in which the crossing points between the trajectories are marked as red circle, such as, the notation IOI' means that the streams I and I' are incompatible.

For each vehicle, its time delay $TD_{(j;l;p)}$ is defined as the time difference between its actual travel time and free-flow travel time. Then, the optimal function can be achieved and shown in the Eq. (3). Its objective to find a passing sequence, which is constituted by the vehicles' entrance time in the intersection ET3, to minimize the total time delay for all the new vehicles, based on the safety

TABLE 1: Definitions of the Notations

Notations	Definitions
l	The index of entrance lane, $l \in [1,8]$
N_l	The number of new vehicle on the lane l.
(j,l,p)	***Subscript***. The j^{th} vehicle on lane l locates in the p^{th} position in the passing sequence, $j \in [1,N_l]$.
a, f	***Superscripts***, the actual value and the free-flow value, respectively.
s	The s^{th} section of the communication zone, $s \in [1,4]$.
ETs	The entrance time to the s^{th} section.
EVs	The entrance velocity to the s^{th} section.
TTs, TT	The travel time in the s^{th} section. The travel time in all the sections: $TT = \sum_{s=1}^{4} TTs$.
TD	The time delays for the entire trip.
HW	The headway between two successive vehicles on the same lane.
Ls	The length in the s^{th} section.
T_{sim}	The total simulation time.
$Amax, Dmax$	The maximal acceleration and deceleration for each vehicle.
$Vmax, Vmin$	The maximal and minimal speed on the road.
Vr	The proposal speed in the second segment based on the passing sequence received.
EBS	The size of the employed bees.
OBS	The size of the onlooker bees.
max_cycle	The maximal simulation cycles.
$limit$	The number of continuous cycle that does not improve the fitness in the same food source.

constraints in the Eq. (1).

$$TD_{(j,l,p)} = TT^{a}_{(j,l,p)} - TT^{f}_{(j,l,p)} \quad (2)$$

$$min\{\sum_{l=1}^{8}\sum_{j=0}^{N_1} TD_{(j,l,p)}\} \quad (3)$$

In order to solve the optimal problem, each trajectory is divided into four segments in the communication zone, which is prescribed by dashed square in the Fig. 1. In each segment, the vehicle has different performance, such as the manipulation or the communication process with the control center. Here, a example is explained based on the straight trajectory in the stream 2 in the Fig. 1:

The first segment L1. It is supposed that each vehicle keeps the maximal speed Vmax before entering the communication zone and locates in the suitable stream for its destination (no lane change in the intersection). Once it enters this segment, it is marked as new vehicle and send its entrance time ET0 and minimal arrival time in the intersection ET3f to the control center. Then it keeps Vmax till arriving at the second segment and waits for the passing sequence from the control center.

- The second segment L2. Once a new vehicle arrives at this segments from any input streams, a new optimal process (NOP) is activated. A NOP means that the control center makes an optimization of the passing sequence in the intersection for all the new vehicles in the first segment, in other words, the new vehicles in the first segment is the scope of each optimization process, instead of that in the whole communication zone before the intersection (L1 and L2), like paper [4]. This framework can produce the following benefits: 1) the calculation time is reduced by taking a smaller number of vehicle in each optimization process; 2) after receiving the passing sequence, each new vehicle is marked as old and adjusts it speed profile in the second segment based on the given information to improve the traffic efficiency in the intersection.
- The third segment L3. In this segment, each vehicle accelerates to or keeps the maximal road speed to minimize the passing time in the intersection.
- The fourth segment L4. The vehicle's operation in this segment is similar to that in the third segment.

In general, in order to get the minimal time delays, the communication protocol between control center and vehicles are a twoway communications: the former optimizes each passing sequence based on the running information of each new vehicle, the latter adjusts its speed profile to meet the given passing sequence. The performance of the vehicle's speed is: the vehicle accelerates to or keeps the maximal speed in L1, L3 and L4; the vehicle optimizes its operation in L2 according to the given passing sequence. The figure 2 illustrates the above processes.

III. THE PROPOSED ALGORITHM

This section presents the detailed design of the proposed algorithm. Each intersection is one of the main collision zones in the transportation network, which restricts the improvement of traffic efficiency. However this problem can be solved by getting an optimal passing sequence ET3a based on the safety constraint in the Eq. (1) in the intersection without traffic light, where each vehicle is considered independently. First of all, taking into account the safety constraint, the ET3f , ET3a and TT3a should be calculated for each vehicle, which is resented detailedly in the sub-section 3.1. After these information is calculated and sent to the control center, it optimizes the passing sequence by

TABLE 2: All the pairs of incompatible streams

streams	1	2	3	4	5	6	7	8
1			○			○	○	○
2			○	○	○			○
3	○	○			○			○
4		○			○	○	○	
5		○	○	○			○	
6	○			○			○	○
7	○			○	○	○		
8	○	○	○			○		

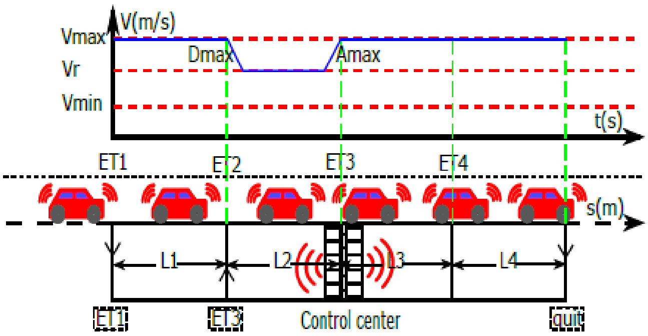

Fig. 2. A two-way communication procedures between vehicles and control center

the Artificial Bee Colony(ABC) algorithm, as shown in the subsection 3.2. At last, each vehicle plans its speed to meet the given passing sequence, as the sub-section 3.3 shows. At the end of this section, the complete lgorithm process is concluded.

3.1 Information from vehicle to control center

In order to calculate the variables of $ET3^f$, ET3a and $TT3^a$ for each vehicle, the relationships among them should be introduced firstly. The variable of $ET3^f$ is the lower limit of $ET3^a$, because it is impossible for the vehicles to arrive at the intersection before the time $ET3^f$. The relationship between ET3a and $TT3^a$ is connected by the intermediary $EV3^a$. From the time $ET3^a$ in each vehicle, there a value range (0, Vmax) for its EV3. Among this range, the maximal one should be chosen as $EV3^a$. Because the higher EV3, the smaller time needed by vehicle to accelerate to Vmax in the intersection. As a result, the TT3 is smaller. Therefore, the $TT3^a$ depends on the $EV3^a$, which is controlled by $ET3^a$.

3.1.1 The curve of relationship between $ET3^a$ and $EV3^a$

This curve of relationship is divided into four segments, according to the threshold limit value (TLV) of EV3a (TLV = fVmax; Vmin; 0g), because in each segment, the method of calculating EV3a is different. Each TLV orresponds to the difference key point of $ET3^a$ (KP = fKP1; KP2; KP3g). For the L2, it should be long enough for the vehicle to decelerate to the Vmin from Vmax and accelerate to the Vmax from Vmin. This rule is for the reason of readability, because the method of calculating speed profile is similar when the L2 isn't long enough.

$$L_2 \geq (V_{min}^2 - V_{max}^2)/(2D_{max}) + (V_{max}^2 - V_{min}^2)/(2A_{max}) \qquad (16)$$

Next, the different methods for calculating KP = fKP1; KP2; KP3g are presented detailedly.

KP1—TLV (Vmax): The KP1 expresses the maximal time when the vehicle can arrive at the intersection with Vmax. In other words, it is impossible for the vehicle to arrive at the intersection with the speed Vmax after the time KP1. The vehicle control strategies for getting KP1 are given as the followings: firstly, the vehicle decelerates to Vmin with Dmax; secondly, it keeps in Vmin; finally, it accelerates to Vmax with Amax. KP2—TLV (Vmin): The KP2 means the maximal time of arriving at intersection with Vmin for a vehicle. That is to say, it is impossible for the vehicle to arrive at the intersection with a speed more than Vmin after KP2. The vehicle control strategies for achieving KP2 are shown by the processes: first of all, the

$$KP1 = ET2 + (V_{min} - V_{max})/D_{max} + (V_{max} - V_{min})/A_{max} + (L2 - (V_{min}^2 - V_{max}^2)/(2D_{max}) - (V_{max}^2 - V_{min}^2)/(2A_{max}))/V_{min} \qquad (5)$$

$$KP2 = ET2 + (V_{min} - V_{max})/D_{max} + (L2 - (V_{min}^2 - V_{max}^2)/(2D_{max}))/V_{min} \qquad (6)$$

$$KP3 = ET2 - V_{max}/D_{max} + (L2 + V_{max}^2/(2D_{max}))/V_{min} \qquad (7)$$

$$EV3 = Vmin + \sqrt{Amax((Vmax - Vmin)^2/Dmax + 2(L2 - VminTT2))} \qquad (8)$$

$$EV3 = Vmin - \sqrt{(Vmax - Vmin)^2 + 2Dmax(L2 - VminTT2))} \qquad (9)$$

$$TT3 = \begin{cases} (Vmax - EV3)/Amax + \\ (L3_i - (Vmax^2 - EV3^2)/(2Amax))/Vmax & : L3_i \geq MD \\ (-EV3 + \sqrt{EV3^2 + 2AmaxL3_i})/Amax & : L3_i < MD \end{cases} \qquad (14)$$

$$TT4 = \begin{cases} L4/V_{max} & : L3_i \geq MD \\ (V_{max} - EV3 - TT3 * Amax)/Amax + \\ (L3_i - (Vmax^2 - (EV3 + TT3 * Amax)^2)/(2Amax))/Vmax & : L3_i < MD \end{cases} \qquad (15)$$

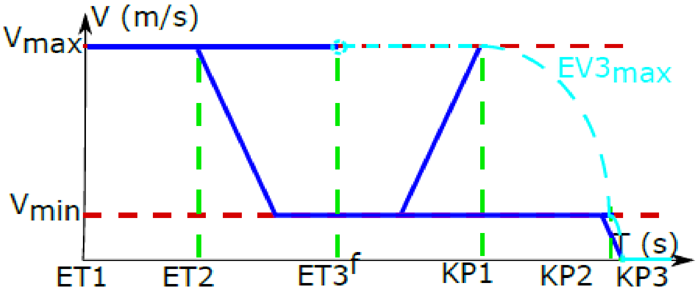

Fig. 3. The curve of relationship between ET3a and EV3a

vehicle decelerates to Vmin with Dmax; then it keeps this speed till arriving at the intersection. KP3—TLV (0): The KP3 presents the time, after which the vehicle should stops before the intersection. The vehicle control strategies of obtaining KP3 are as followings: first of all, the vehicle decelerates to Vmin with Dmax; then it keeps Vmin; finally, it decelerates to stop before the intersection with Dmax. After the above three key points have been calculated, the $EV3^a$ in each segment is calculated. Therefore, the cure of relationship between the $EV3^a$ and $ET3^a$ is shown in Fig. 3 and summarized in Tab.3.

TABLE 3
Cure of relationship between $EV3^a$ and $ET3^a$

Segment of $ET3^a$	Range of $EV3^a$	Formula of $EV3^a$
$[ET3^f, KP1]$	$Vmax$	$Vmax$
$(KP1, KP2]$	$[Vmin, Vmax)$	Eq. (8)
$(KP2, KP3)$	$(0, Vmin]$	Eq. (9)
$[KP3, \infty)$	0	0

3.1.2 The curve of relationship between $EV3^a$ and $TT3^a$

There are two factors affecting the $TT3^a$. One is the different length for the vehicle to pass the intersection L3i (i=r; s; l), which depends on the operation of vehicle in the intersection, i.e., going straight, turning right or left. It limits the travel length for the vehicle in the third segment in calculating $TT3^a$. The Figure 4 and equations (10-12) show an example for the streams 1 and 2 from the approach west. It is similar for the others streams to calculate the L3i.

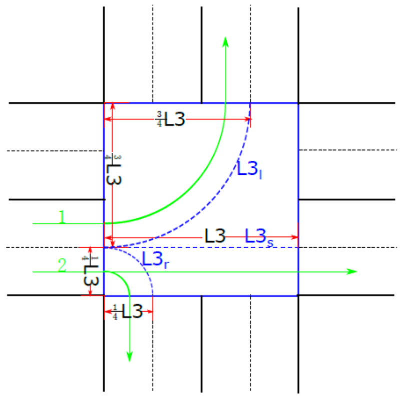

Fig. 4. Different length of passing the intersection

$$L3_r = \pi L3/8 \qquad (10)$$

$$L3_s = L3 \qquad (11)$$

$$L3_l = 3\pi L3/8 \qquad (12)$$

Another factor is the $EV3^a$. It determines the entrance speed in the third segment for calculating $TT3^a$. First of all, the length MD should be calculated, which means the minimal distance needed by the vehicle to accelerate to Vmax from $EV3^a$ with Amax. If the L3i is long enough for the vehicle to accelerate to Vmax, firstly, it accelerates to Vmax in L3i. Then it keeps Vmax to finish the rest of travel. Otherwise, it should keep the acceleration in L3i and a part of L4 till the speed of Vmax, then it keeps Vmax to finish the

$$MD = (Vmax^2 - EV3^2)/(2Amax) \quad (13)$$

3.2 Optimization in control center to get the passing sequence based on the vehicles' information

The Artificial Bee Colony (ABC) algorithm was proposed by the author Karaboga [11] according to the foraging behaviour of honey bees. It is applied to find the optimal passing sequence (food source) in this paper.

3.2.1 Code of the food source

Taking into account the feature without overtaking at the same stream, we take the stream number of each vehicle as the basic unit in the sequence, instead of each vehicle' identity, to avoid the infeasible sequence in the iteration process, as shown in the Eq. (16). For example, the vehicle veh1 is before the vehicle veh2 from the same stream 1, and the vehicle veh3 comes from the stream 3. Then, S = (3;1;1), one of the feasible sequences, means is the following passing sequence: veh3, veh1 and veh2.

$$S = (l_i), \quad i \in [0, \sum_{j=0}^{N_1}]; \quad l_i \in [1, 8]. \quad (16)$$

3.2.2 Swap operator process

The swap operator (SO) is a method to generate a new food source based on the existing one for a discrete problem [12]. For example, swap operator $SO\ (j, h)$ means the exchange of position between l_j and l_h. Then a new source S' is generated by $S' = S + SO$. For the same example in the foregoing sub-section, based on the SO (1,2), a new source is get: $S' = (3, 1, 1) + (1, 2) = (1, 3, 1)$. A swap sequence SS ($SS = (SO_1, SO_2, \ldots SO_n)$), means a group of the swap operators $SO_i (i \in n)$. Then, $S' = S + SS = ((S + SO_i) + SO_2) + \ldots SO_n$.

3.2.3 ABC process

This sub-section presents the details of applying the ABC to get the optimal passing sequence.

- Initialization, including the variables of limit, cycle, max cycle, EBS, f ood source, OBS, and so on.
- Each employed bee evolves a new f ood source based on its old one with a random SS. Then the new food source is evaluated with the Eq. (3). If it is better than the old one, it is chosen as the new source by this bee. Otherwise, it is abandoned, and the trail of old source plus one, which records the unimproved cycle in this source.
- Each onlooker bee selects a f ood source from the employed bees by the roulette wheel rule. Then this chosen source is evolved to get a new one with a random SS. After, the evaluation of the new one is done, and is compared with the old one. If the new one is better than the old one, it is chosen as the new source by this bee. Otherwise, it is abandoned, and the trail for the old source plus one.
- If a source's trail is greater than the limit, this source is abandoned. A scout is sent to find a random source to replace the old one. If there are several sources whose trail is greater than the limit at the same cycle, a source is selected randomly. Because in each cycle, only one scout bee is sent.
- The cycle plus one. If it reaches the maximal number of cycle max cycle, the iteration stops. Otherwise, this process goes to second step.

3.3 Plan of the vehicle speed profile according to the given passing sequence

After the passing sequence is acquired in the section 3.1, with the V2I communication, each vehicle gets its $ET3^a$. Then the pair ($ET3^a$, $EV3^a$) is obtained, as shown in the Tab.3. There may be countless speed profiles satisfying this pair in the second segment, among which, the one with maximal Vr is get by the Eq. (17), as the Fig. 2 shows

$$Vr = (-b \pm \sqrt{b^2 - 4ac})/(2a) \quad (17)$$

$$a = Dmax - Amax$$

$$b = 2(AmaxDmaxTT2 + AmaxVmax - DmaxVmax$$

$$c = Vmax^2(Dmax - Amax) - 2AmaxDmaxL2$$

IV. SIMULATION RESULTS ANALYSIS

The simulation system is coded by C++ and run on a desktop computer with four 2.6 Ghz Intel processors. In each entrance stream, the generation of the new vehicles is assumed to obey the Poisson Distribution, which accurately represents the actual traffic system [13], [14], [15]. Each vehicle' initial speed is Vmax. The other parameters are shown in Tab. 4.

4.1 The comparison with Dynamic Programming

First of all, the simulation results are compared with the Dynamic Programming (DP) to verify the performance of ABC based on the same model, because the ABC is an approach algorithm and DP is an exact method. This comparison lies in two factors: the average calculation time (cal time) and control performance in different traffic volume. On the one hand, the figure 5 shows the calculation time between ABC and DP. The cal time of DP raises more rapidly than that of ABC. In the traffic volume 500 veh=h=stream, The cal time of DP is almost six times of ABC. On the other hand, the figure 6 presents the time delay of these two methods. This result is similar between them. Therefore the proposed ABC can achieve a near optimal solution with a smaller cal time satisfying the need of real-time comparing with the DP.

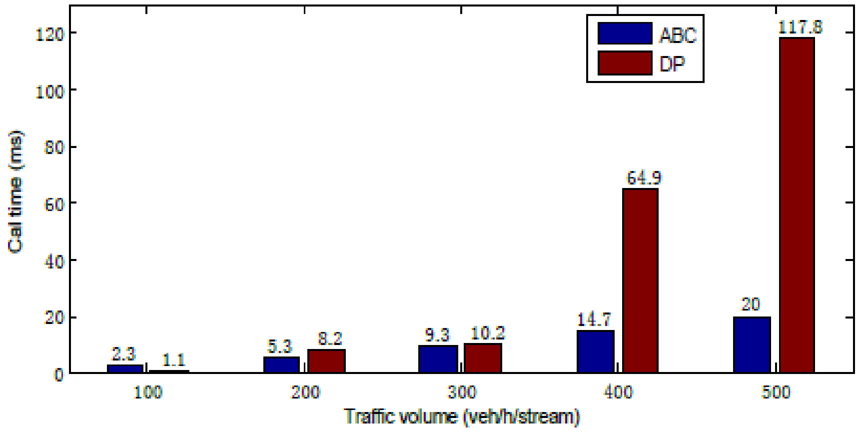

Fig. 5. Cal time between ABC and DP in the different traffic volume

The results are compared with papers [4] [5] to evaluate the performance of the proposed algorithm in the traffic volume 100 veh=h=stream, as shown in Table.5. Both paper [4] and the proposed method attempt to improve the traffic efficiency by optimizing the passing sequence in the intersection. For the item of EV3, it always equals to zero in

TABLE 4
Simulation parameters

$V_{max}\ (m/s)$	$V_{min}\ (m/s)$	$A_{max}\ (m/s^2)$	$D_{max}\ (m/s^2)$	$T_{sim}\ (s)$
14	4	2	-2	1800
$L_1\ (m)$	$L_2\ (m)$	$L_3\ (m)$	$L_4\ (m)$	$HW\ (s)$
100	200	10	300	1
$limit$	max_cycle	EBS	OBS	$t_{step}\ (s)$
3	$5\sum_{l=1}^{8} N_l$	$\sum_{l=1}^{8} N_l$	$\sum_{l=1}^{8} N_l$	0.1

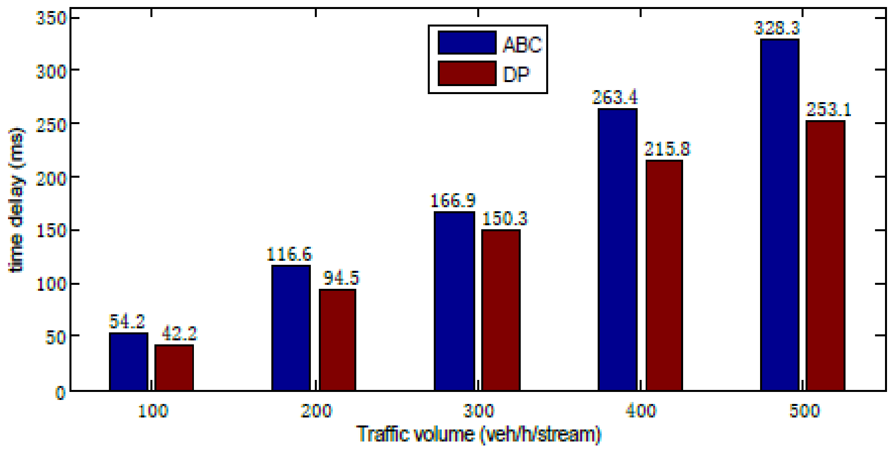

Fig. 6. Time delay between ABC and DP in the different traffic volume

TABLE 5
Simulation results

	proposed method	paper [4]	paper [5]
EV3 (m/s)	11.2	0	3.29
TT3 (s)	0.75	2.87	2.18
stop time(s)	0	6.39	16.01
time delay(s)	0.0542	6.41	33.41
cal time(ms)	2.3	44	0

the paper [4], because its model assumes that all the vehicle stop before the intersection in a fixed arrival time. As a result, when the vehicle starts to pass the intersection, its speed is always zero. On the contrary, the roposed method optimizes the passing sequence based on the arrival time range of each vehicle to get a higher EV3. Owing to the preceding reason, each vehicle can avoid the stop before the intersection and be evacuated more rapidly than that in paper [4], as proved by the items stop time and TT3. Therefore, the proposed method can save 99.15% of time delay comparing with paper [4]. When the time delay is smaller, the

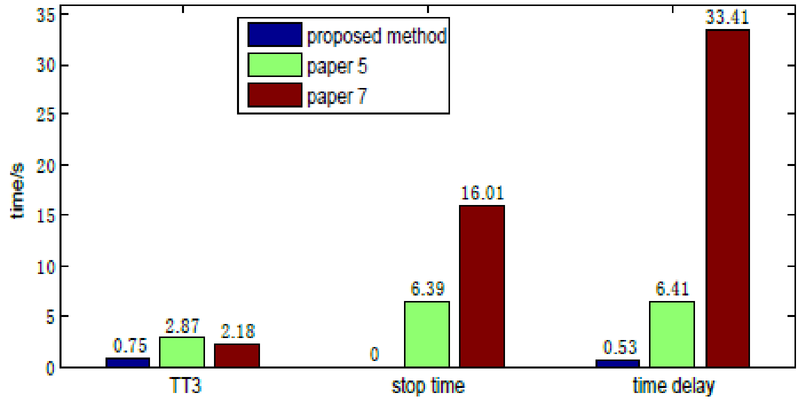

Fig. 7. Simulation results

real speed profile is closer to free speed profile. Moreover, the proposed method takes the vehicles in the first segment as the optimal range, instead of the entire communication zone before the intersection, like paper [4]. As a result, the complexity of optimization is decreased, which is proved by the cal time of TD. Therefore, the proposed method is better than paper [4] in the major criteria.

Both the paper [5] and the proposed method can deduce the stops time by optimizing the speed profile for each vehicle before entering the intersection, but the paper [5] does not optimize the traffic control. For the stop time, it is smaller in the proposed method than that in the paper [5], because the proposed method dynamically groups the compatible streams based on the different vehicle arrival, and allocates the time-of-way precisely to each vehicle, instead of setting the fixed phase, green time, and phase sequence. Therefore, the proposed method has a higher average value of EV3 than that in the paper [5], due to that it always tries to find a maximal entrance speed based on a given allowed time of entering the intersection, rather than just finding one possible speed. As a result, the evacuation time in the intersection is smaller in the proposed method. Therefore it can save 99.84% of time delay comparing with paper [5].

V. CONCLUSION

In this paper, a new traffic control algorithm based on the Artificial Bee Colony (ABC) in an isolation intersection is proposed. The traffic model in this paper is a two-way communications: the control center receives the information from vehicles to optimize the passing sequence by the ABC; the vehicles plan their speed to meet the given sequence. Therefore the proposed combines the advantages of papers [4] [5] to achieve a higher traffic efficiency, without sacrificing the demand of real-time. In the future, the isolated intersection should be extended to a multi-intersections by considering the relations between the neighbor intersections. The distribution of traffic flow in different intersections will be researched also.

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