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Survey and Implementation of Intersection Management:

Intersection Management for Autonomous Vehicles using iCACC

Abstract

Recently more automated vehicle's techniques have been invited, so we can anticipate that there will be more automated vehicle on the road in future. So it may need smarter intersection management not like now. This paper presents a new optimize algorithm using CACC concept to avoid collisions and minimize intersection delay.

Our contributions:

- **We read 1 paper [117 citations] and summarize it in this report.**
- **We implement 1 algorithm and demonstrate the results.**
- **We propose an approach to solve the probable issues in paper and outperform existing approaches.**

Percentage of survey and implementation in the project:

- **Survey: 50%**
- **Implementation: 50%**

Introduction

Automated vehicle has been studied for decades to reduce car crash and make car move more safely, smoothly and rapid, so there are many vehicle assistant systems were invited like collision avoidance, lane-departure warning and automated parking etc. But now we're talking more about conversation of vehicles, we want a system that can let vehicle communication with each other about the situation that other vehicle faces of, then the vehicle can do more preparation earlier, so it may be more efficiency and safety. This is what CACC do now, CACC use others vehicle's information and the sensing data that detected by itself to determine what the speed that vehicle need to change to, so it can decrease the gap with the front vehicle make transportation more efficiency.

And this paper we survey think that maybe we can use CACC's concept of using other vehicles information to determine it next movement to find out what time I leave the stop line and go through the intersection block is the most safety and won't get crash with other vehicle that is sharing the same conflict point with our lane.

So in this paper, we're talking about two target that iCACC system want to do, first is safety, we don't want any vehicle crash in intersection block; second is small delay time, we want every vehicle can pass the intersection block as fast as it can.

Formulation

In this part, we're going to show the formulation and constraints in the proposed paper we selected. Later on, we'll show our modification on it.

1. Road setting

   For simply to explain the theorem we first define our road below:

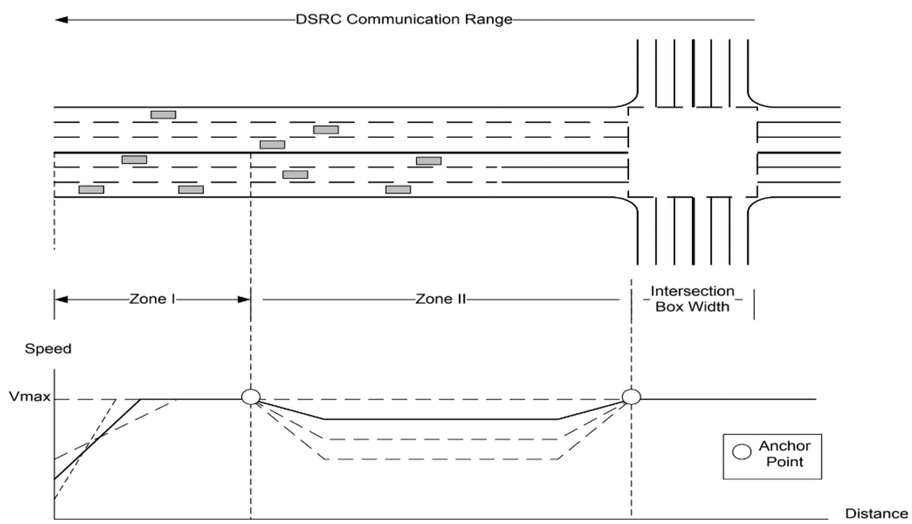

Figure 1: The different zones of the optimization process in the iCACC tool

First, every lane only has one direction, it can't share direction with other lanes. And every car can't change the lane when they came into Zone 1. In Zone 1 the car will accelerate to the max speed of the road, next they will meet the first anchor point. At this point iCACC system will give you the time to pass stop line. After first anchor point the vehicle is in Zone 2, in here vehicle will change their speed to comply the time given by system. In the end of Zone 2 they are coming another anchor point we also call stop line, at this point vehicle will be in maximum speed of the road and prepare for passing the intersection block.

2. Constraints in the original paper

   Before diving into the constraints, there are some important variables to show.

OT_i = The optimum arrival time for vehicle i at the stop line. (estimated by running the vehicle at V_{max} = 35 miles/hr in Zone 2)
D_i = The time difference between the optimum time (OT) and the actual time (AT). (In other words, the delaying period for each vehicle)
l_{im} = 1 if vehicle i enters into IB from lane m and 0 otherwise (binary variable)
c_{mn} = 1 if vehicle i from lane m has conflict point with vehicles from lane n and 0 otherwise (binary variable)
τ_{mn} = Travel time from the stop-line of lane m entering into IB (intersection) to the conflict point of lane n.
Δ_τ = Time interval of a vehicle occupying the conflict point (safty period shall be kept in intersection)
H_{min} = The minimum headway between vehicles in the same lane.
Ω_0 = Set of vehicles that entered into the system before current time step (vehicles which are already scheduled)
Ω_1 = Set of vehicles that enter the system at current time. (vehicles to be scheduled)
Ω = Set of vehicles in the system at the current time step. (Ω= Ω_0+ Ω_1)

$$Min : \sum_{i=1}^{\Omega^1} D_i \tag{1}$$

Subject to:

$$(OT_i + D_i) - (OT_j + D_j) \geq H_{\min}(l_{im} l_{jm}); \quad i \neq j, \forall i, j \in \Omega, \forall m \in \Psi \tag{2}$$

$$\left|(OT_i + D_i + \tau_{mn}) - (OT_k + D_k + \tau_{nm})\right| \geq \Delta\tau(l_{im} l_{kn} c_{mn}); \ i \neq k, \forall i, k \in \Omega^1, \forall m, n \in \Psi \tag{3}$$

$$(OT_i + D_i + \tau_{mn}) \geq \max\left[(OT_f + D_f + \tau_{mn}), (OT_p + D_p + \tau_{nm})\right]; \forall i \in \Omega^1, \forall f, p \in \Omega^0, \forall m, n \in \Psi \tag{4}$$

$$D_i \geq 0; \quad \forall i \in \Omega \tag{5}$$

a. The objective: minimize the average delay for incoming vehicles.
b. Vehicles shall keep a minimum headway with its frontal vehicle in the same lane.
c. If there is any mutual conflict point between the vehicles that is going to be scheduled (Ω_1), they should keep a safety period in intersection. (Since all the vehicles run at fixed speed in intersection, we can formulate the constraint like this)
d. This constraint says that the incoming vehicles (Ω_1) couldn't arrive the conflict point before any other vehicles that have been scheduled (Ω_0). However, we found this constraint has duplicated property and a probable issue.
    i. Duplicated property: constraint (2) would guarantee that the incoming vehicles won't go beyond any other vehicles.
    ii. A probable issue: constraint (3) ensures that a safety period among the incoming vehicles (Ω_1) in intersection, however, this constraint doesn't ensure that a safty period between set Ω_1 and set Ω_0.Our modification to solve these issues is shown in part 3 of this section.
e. Positive delaying period. (No exceeding the speed limit)

3. Our modification

$$Min : \sum_{i=1}^{\Omega^1} D_i \tag{1}$$

Subject to:

$$(OT_i + D_i) - (OT_j + D_j) \geq H_{\min}(l_{im} l_{jm}); \quad i \neq j, \forall i, j \in \Omega, \forall m \in \Psi \tag{2}$$

$$\left|(OT_i + D_i + \tau_{mn}) - (OT_k + D_k + \tau_{nm})\right| \geq \Delta\tau(l_{im} l_{kn} c_{mn}); \quad i \neq k, \forall i \in \Omega^1, \forall k \in \Omega \ , \forall m, n \in \Psi \tag{3}$$

$$D_i \geq 0; \quad \forall i \in \Omega \tag{4}$$

We made constraint (3) to solve the issues we found in the previous section. The constraint shows that for any pair of vehicles, if they have a mutual conflict point, they shall keep a safety period in intersection. Further, if there is some time interval which is not occupied for specific conflict point, there are still chances to utilize it.

Proposed approach

Apart from the method (moving horizon optimization) used in proposed paper, we choose to use SUMO and adopt "Simulated Annealing" in optimization of finding a feasible solution (scheduling). Through this part, we're going to show the optimization in our implementation.

The most important part in "Simulated Annealing" is "Neighbor Choosing". Fig. 2 is a simple illustration of the solution space, imagine we're going to schedule for 3 incoming vehicles and the grayed areas state to be a solution with collision (infeasible). At the left inner corner (close to origin) in Fig. 2, there are lots of gray areas and it shows that the delay period for the 3 vehicles is too short and too close to each other. Although there are still lots of feasible solution, most of the solutions increase the total delay time a lot.

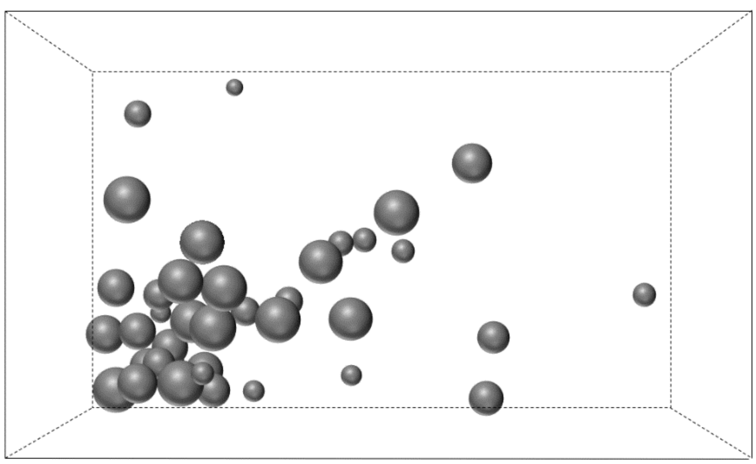

Figure 2: solution space of time that vehicles pass the intersection

Furthermore, with more incoming vehicles, we'll have more gray areas in our multidimensional solution space. Therefore, instead of choosing a random point in solution space at once, we choose to assign random delay time for each incoming vehicle sequentially. With this method:

- Going to next step (assignment of random delay time) if it fulfills the constraints.
- Fairness is still maintained, the first vehicle in assignment may be assigned with a longer delay time.

For the result of implementation, we’ll cover it in the next part.

Experimental Result

Firstly, we make some setting for paper’s experiment. Each lane width is 3.5 meter and speed limit of the road is 35 mph (approximately 16 m/s). A fixed turn-percentage of 0.2:0.6:0.2 of we used for left: through: right. The optimization paper use is moving horizon optimization. And the statistic below is compare with the traditional intersection management.

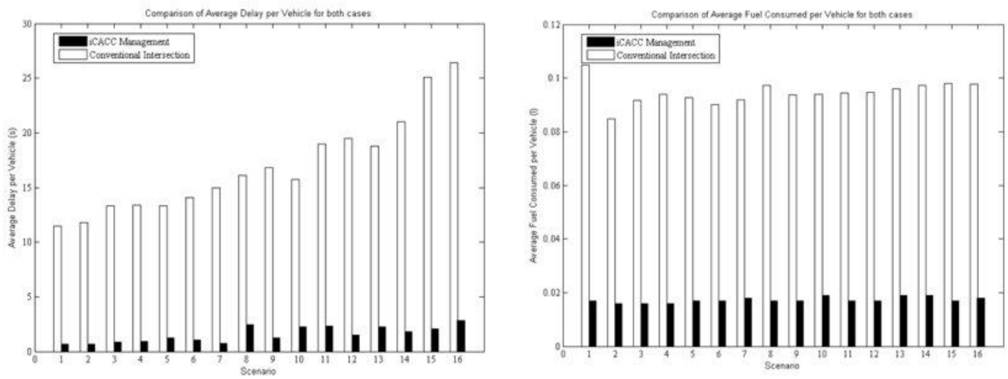

Figure 3: The comparison with traditional intersection management of delay time and fuel consumption

Scenario	Major Volume (vph/approach)	Minor Volume (vph/approach)	iCACC Case		Signal Case	
			Average Delay per vehicle (s)	Average Fuel per vehicle (l)	Average Delay per vehicle (s)	Average Fuel per vehicle (l)
1	500	250	0.6518	0.0167	11.500	0.105
2	600	300	0.6410	0.0159	11.800	0.085
3	700	350	0.8477	0.0160	13.300	0.092
4	800	400	0.9438	0.0162	13.400	0.094
5	900	450	1.2528	0.0167	13.300	0.093
6	1000	500	1.0520	0.0168	14.100	0.090
7	1100	550	0.7106	0.0182	15.000	0.092
8	1200	600	2.4354	0.0169	16.100	0.097
9	1300	650	1.2250	0.0175	16.800	0.094
8	1400	700	2.2338	0.0188	15.700	0.094
11	1500	750	2.3125	0.0172	19.000	0.094
12	1600	800	1.4795	0.0174	19.500	0.095
13	1700	850	2.2407	0.0186	18.800	0.096
14	1800	900	1.8062	0.0190	21.000	0.097
15	1900	950	2.0369	0.0170	25.100	0.098
16	2000	1000	2.8600	0.0185	26.400	0.098

Table 1: The value of Fig. 3

White block means traditional intersection management and the black block is iCACC. From Fig. 3 we can apparently notice that iCACC is more efficiently than the traditional one. Plotted value are showing in Tab. 1.

In our implement(The code in on GitHub: https://github.com/StevenChiu2018/Intersection-Management) we use the same lane width with the paper. And the maximum speed of road is 15 m/s (approximately 33.554 mph). Fixed turn-percentage is the same as the paper. We adopt “Simulated Annealing” in the optimization part in implementation. Below is our result compare with the paper.

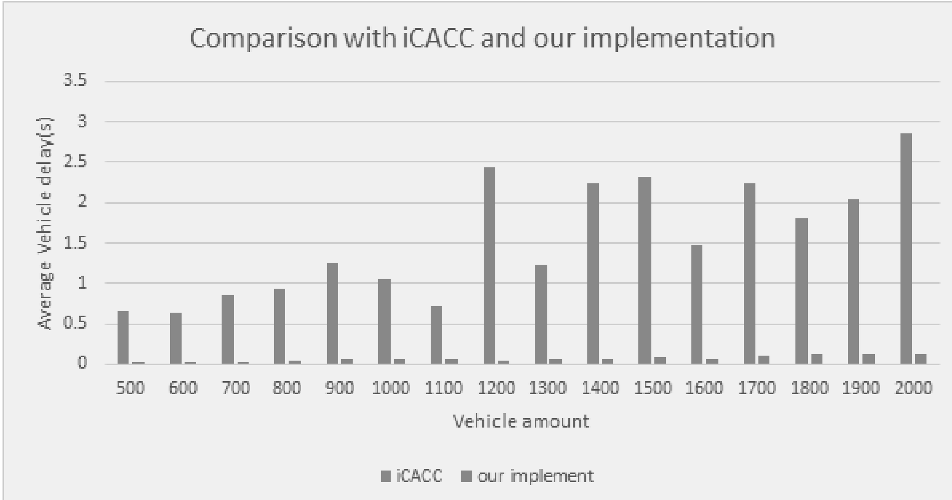

Figure 4: The comparison with iCACC of delay time

vehicle amount	iCACC	our implement
500	0.6518	0.0253
600	0.641	0.0258
700	0.8477	0.0314
800	0.9438	0.0362
900	1.2528	0.063
1000	1.052	0.0574
1100	0.7106	0.057
1200	2.4354	0.0512
1300	1.225	0.0614
1400	2.2338	0.0749
1500	2.3125	0.0921
1600	1.4795	0.0749
1700	2.2407	0.0976
1800	1.8062	0.1197
1900	2.0369	0.1248
2000	2.86	0.1176

Table 2: The value of Fig. 4

The consequence from the Fig. 4 and the plotted value in Tab. 2 we can notice that our modification can work and is better than iCACC.

Also we add more vehicle into the intersection and the result is in Fig. 5 and plotted value is in Tab. 3.

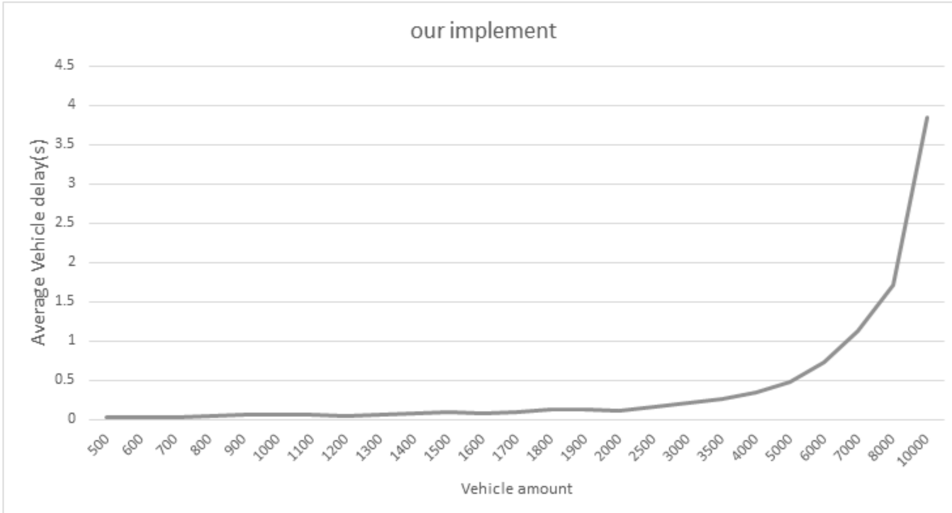

Figure 5: The average vehicle delay time of more vehicle amount

vehicle amount	our implement
500	0.0253
600	0.0258
700	0.0314
800	0.0362
900	0.063
1000	0.0574
1100	0.057
1200	0.0512
1300	0.0614
1400	0.0749
1500	0.0921
1600	0.0749
1700	0.0976
1800	0.1197
1900	0.1248
2000	0.1176
2500	0.1608
3000	0.2106
3500	0.266
4000	0.3488
5000	0.4733
6000	0.7341
7000	1.1281
8000	1.7045
10000	3.8483

Table 3: The value of Fig. 5

Conclusion

We can anticipate that there will be many automated vehicles in future, so we may need a smarter intersection management to give more efficiency to the automated vehicle. And this paper using CACC to do the intersection management because it concept is similar with intersection management do, like no crashing and communication between vehicles, so it’s maybe can be used in intersection management that this paper describe it.

During our implementation, we were confused with some constraints and we thought that there is more space of progress in minimizing average delay time. Hence, we modify the constraints and simulate it on SUMO. Consequently, we find it is more efficient then the method in paper. Indeed, we think that our modification would contribute to minimize the average delay, but we haven't thought that it would outperform the result in paper a lot.

Potential contribution to outperform the result in paper:

- Modification in constraints.
- Minimum gap between vehicles: 1 meter with frontal vehicle and 1 meter between vehicles with mutual conflict point in intersection.

Reference

1. Ismail H. Zohdy, Raj Kishore Kamalanathsharma, Hesham Rakha, Member, IEEE, "Intersection Management for Autonomous Vehicles using iCACC", 2012 15th International IEEE Conference on Intelligent Transportation Systems