Contextualized Traffic Controlling At Isolated Urban Intersection

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ABSTRACT

This paper proposes a novel traffic control concept: **contextualized traffic controlling** at an isolated intersection. In this traffic control system, the traffic control command is sent to each vehicle individually based on its corresponding information that is provided by new information and wireless communication systems embedded in vehicles. In other word, traffic command is contextualized on the measurement of vehicles' state. Vehicle is allowed to pass through an intersection while the right-of-way is received. Hence, there is no traditional traffic light planned by the city. The intersection traffic control becomes to determine the best access order to the intersection (the passing sequence) for vehicles based on their information. In this paper, the objective of traffic control is to increase the throughput (or to evacuate all vehicles as soon as possible). Two scenarios are proposed for this traffic control system, i.e. in first scenario where vehicles' passing sequence is decided by a center controller and in the second scenario where vehicles negotiate with each other according to a predefined protocol to define the access sequence. The proposed control system is compared to an adaptive traffic controller and a traffic control system that is based on completely autonomous vehicles.

Keywords: Wireless Communication System, Traffic Control, Car-to-Car Communication, Car-to-Infrastructure Communication and Autonomous Vehicles

1. INTRODUCTION

Recent interest in the application of wireless communication, i.e. car-to-car communication, car-to-infrastructure communications and GPS for improving driving condition has received much attention. Several works have come forth, like car platooning to improve traffic highway capacity [1], intelligent Co-operative Systems [2] make drivers benefit the real-time traffic information to plan better their journeys. Besides, the automotive industries (Ford, BMW, Volvo, Honda etc. [3]) have involved in the exploring of the safety technology on witness the development of wireless communication.

It is known to all that the intersections are mainly in the core of congestions. Efficient traffic control systems at the intersections are in favor of enhancing the performance of urban traffic networks. However, a relative small amount of work has concentrated in the field of the traffic controlling at intersection based on wireless communication. That encourages us to explorer a new traffic control system [4]. For the sake of distinguishing our traffic system from the traffic controlling systems currently used, we recall at first the process of evolution of the existing systems. The description in detail of our system is presented in the next section.

Over the past half-century, a great deal of traffic control strategies concerning isolated intersections have emerged and been widely used. From the earlier work of Webster [5] to the recently work [6-11], control algorithms have achieved the great success in reducing the average delay of vehicles or in improving the traffic throughput. It is noted that the common elements in most of these investigations are to optimize the phase sequences and the phase duration (the green time) for each conflict movement. Since the early 1980s, the decision process has been improved to respond to changing traffic conditions. Adaptive traffic control systems have been used. In these systems, the traffic load is continuously measured by magnetic loop detectors or by cameras [12].

In this last decade, the use of wireless technologies with positioning systems to improve the traffic safety and efficiency in cities received a great attention. Indeed, wireless technologies offer a tremendous potential for reinforcing the link between the vehicles (the drivers), the traffic environment and the control system. More precisely, the rich exchanging of information between the three actors of the traffic system allows making them more reactive for facing undesirable situations or dangerous cases.

Such a technological potential encourages the perspective of the use of wireless technology to improve traffic conditions at intersections. Several possibilities are offered to enhance traffic signalization at intersections. Indeed, measurements of traffic can be achieved by car-to-infrastructure communications. In such a way, the controller is continuously aware of the number of vehicles at the intersection, their positions and their speeds [13]. Hence, the traffic control algorithms can be based on new data [14], such as the number of vehicles at the intersection or the speed of vehicles.

Moreover, the car-to-car communication and the car-to-infrastructure communication allow the onboard signalization. This not only sustains the respect of the red light but also opens new ways to control the traffic. More precisely, instead of optimizing the phase durations, the traffic control

protocol optimizes the sequences of vehicles that will cross the intersection. As a result, the controller decides which vehicles are authorized to pass through the intersection or vehicles negotiate with each other to define the pass sequence. In the remainder of the paper, such a way of controlling the traffic will be called **contextualized traffic control**.

To the best of our knowledge, the paper of Kurt and Peter [15-16] is the first one that introduces a particular case of a contextualized traffic control at intersections by using another appellation. The control involves the car-to-infrastructure communication but no car-to-car communication. Hence, the controller is the only one responsible for distributing the right-of-ways. The control is based on a reservation-based system where vehicles "call ahead" to the controller and request space-time in the intersections [16]. Nevertheless, the system requires autonomous vehicles with a very precise positioning system and a very strict speed control. Hence, the whole system is called: "autonomous intersection". However, our system [4] do not need such so binding technological requirements. More precisely, no autonomous vehicle is needed to personalize the vehicle accesses at intersections, even if the proposed algorithms adapt to the autonomous vehicles.

Several papers that use the wireless communication for controlling the traffic at intersections were witnessed a significant increase of the simulated traffic throughputs. Since the wireless technology allows a wide range of possibilities for controlling the traffic, it is necessary to precise the context of the use. In this paper, we use the contextualized traffic control in order to evacuate vehicles as soon as possible. However, as is well known to all, the complexity of the traffic is a primary obstacle to finding microscopic optimal solutions. Hence, in order to approach the optimal solutions and to define the required data, this paper uses a mathematical model of a simple isolated intersection based on the timed Petri net [17]. The latter represents in a simple way the most admitted assumptions in the traffic engineering for controlling the intersections. Solutions are then applied to the simulation of a realistic intersection in order to discuss and to validate the results.

This paper is organized as follows. We begin with a thorough description of the contextualized traffic control concept and give a picture of the studied system. Then we present the control strategies for an isolated intersection. Finally the paper discusses the results of simulations before concluding.

2. SYSTEM DESCRIPTION

Definition of System
The contextualized traffic control is defined as follows: the traffic control system manages traffic at intersections by deciding explicitly the sequences of passing order of vehicles. Each vehicle is dealt individually. It is at least informed about its right-of-way by means of the onboard signalization and informs the others (vehicle or infrastructure) about its arrival time, its time distance to the vehicle in front, its movement (can be required) and its departure time. Hence, it does not require roadside signalization.

The distinction between the adaptive control [7, 11] and the contextualized traffic control is subtle because both control systems are based on continuous measures of the traffic load.

Moreover, the difference between a timed green light and the right-of-way given to the driver is not obvious without explanations. Thus, we draw the reader attention to the following facts. In the case of a timed green light, some vehicles can go faster to reach the green or slowly to miss it. In the contextualized control, the right-of-ways are addressed to vehicles and only vehicles with the right-of-way can cross the intersection. Unlike the adaptive control systems that optimize the sequence and durations of phases (the green light given to non-conflicting movements) or decide whether or not the phase is still kept for another period of time, the contextualized traffic control decides precisely which vehicle is authorized to cross the intersection and informs only these authorized vehicles. As a result of this control, the problem of dilemma zone is avoided [18].

Proposed Scenarios
Since there are only right-of-ways that are distributed to vehicles or are managed between vehicles, two scenarios are possible: centralized and decentralized. The first one assumes that there is a center controller that distributes right-of-ways to vehicles. The second one gives more autonomy to vehicles by making them participate to the distribution of right-of-ways and/or to the creation of right-of-ways.

For the first scenario (Fig. 1), the center controller has a pre-defined control range (illustrated as the white dashed lines). It is responsible for deciding the passing sequence for vehicles in this control range. The control process is described as follows:

As a vehicle goes into the control range, a device near the boundary of the control range impels this vehicle to communicate with the corresponding center controller. Vehicle informs the center controller its information, e.g. speed, acceleration, position and so on. According to such information, the time when a vehicle arrives at the stop line of intersection (arrival time) is predicted. Then the center controller calculates the optimal passing sequence for all vehicles in the control range for the sake of evacuating them as soon as possible. Once a vehicle leaves intersection, it informs the center controller the depart time to ensure the security.
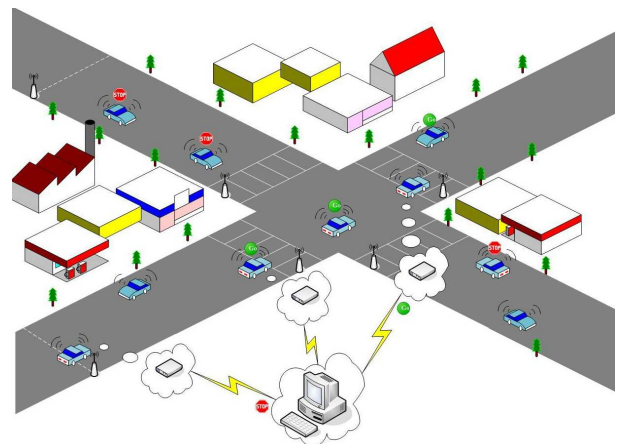

Fig. 1. Centralized traffic control based on a center controller

There are three points that we would like to emphasize:
1) We do not refer to the process of predicting the arrival time, since quite a lot of researchers have successfully exploited this field [19]. Besides, predicting the arrival

time is not the core of this paper.

2) The control range of the center controller is not explicitly indicated. Because on the one hand, the control range depends on the communication scope of wireless device; on the other hand, the algorithm that we proposed is fast enough to deal with a large number of vehicles in a very short time (more than 100 vehicles in each lane in less than 1 second).

3) The objective of traffic control is to evacuate vehicles as soon as possible (minimizing the evacuation time). Since if approaching vehicles are evacuated as soon as possible, the congestion will be avoided. The evacuation time is inversely proportional to the measure of throughput. Indeed this measure is related to other fundamental measure, e.g. the average vehicle delay, the average queue size. We will show the relation in the section of simulation.
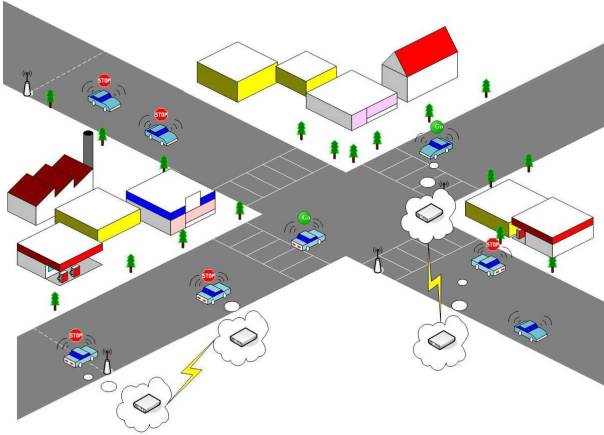

Fig. 2. Decentralized traffic control based on car-to-car communication

For the second scenario (see Fig.2), the passing sequence are negotiated by vehicles according to a predefined protocol. There is also a control range for an intersection (illustrated as the white dashed lines). Only vehicles in this control range communicate with each other. The process of control is presented in the following:

As a vehicle goes into the control range of the intersection, a device near the boundary of the control range impel this vehicle to communicate with the vehicle in front. If no vehicle in front, it communicates with the vehicle in another lane to negotiate the passing order. As a vehicle leaves intersection, it informs other vehicles. The detail of the protocol will be discussed in section 3.

Technique points
In considering of security, it is assumed that two successive vehicles in the same movement are spaced at least by a time space d when they pass through intersection. This security time distance is decided by the minimum driver reaction time and the mechanical and hydraulic systems of vehicle to respond. Considerable amount of research has dedicated to the analyse of the safe inter vehicle spacing [20]. Normally, $d \approx 2$ seconds.

With regard to two successive vehicles of conflicting movements, a minimum time space s must be held. s corresponds to the average time for passing through intersection plus a small amount time to ensure the security. Practically, s

depends on the statistic of vehicles average speed crossing intersection and the layout of intersection. Obviously, $d < s$.

The measures of d and s are predefined in the traffic control system.

3. TRAFFIC CONTROL STRATEGIES

Intersection Configuration
The intersection under consideration in this paper is an isolate simple 4-ways intersection with four through lanes, labeled as L_1, L_2, L_3 and L_4 (see Fig. 3). We would like to remind readers that the main objectives of this paper are exploring a new traffic control concept and providing the corresponding theoretical basis for it. Therefore, only a simple intersection model is considered. However, the control strategies mentioned in this paper may be applied to any complicated intersection layout.
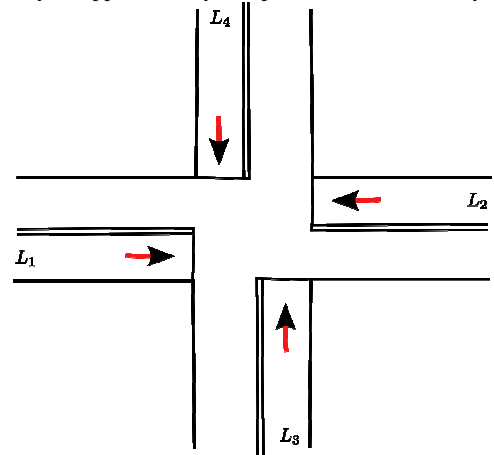

Fig. 3. Schematic of an isolated 4-ways intersection

Suppose that there are two conflicting movements to be served in this intersection, i.e. the movements from lanes L_1, L_2 and the movements from lanes L_3, L_4. Vehicles arrive at two lanes randomly and move freely. Whereas vehicle overtake is forbidden in each lane. Hence, vehicles in the same lane cross intersection in the order of First In First Out (FIFO). Besides, two successive vehicles in the same lane are spaced at least by a time space d to ensure the security. Two vehicles of two conflicting movements are spaced by a time space s.

The control strategy for the centralized control
Since the intersection is the critical resource shared by the approaching vehicles, the optimal passing sequence will reduce driver's travel time and improve traffic throughput. That coincides with the idea of single machine scheduling [21]: a schedule is for each job an allocation of one or more time intervals to one machine. The jobs are arranged so that one or many performance measures may be optimized.

Hence, we treat the traffic control problem from the point of view of machine scheduling. Precisely, the intersection can be modeled as a single machine and vehicles are modeled as the jobs. The objective is to minimize the start time of the last processed job in the schedule sequence. The control problem is formulated as $1_p \left| r_j, chain(d), s_f = s, F \right| S_{max}$ and a forward dynamic programming algorithm is developed for solving it

[22].

The control strategy for the decentralized control

Based on the timed Petri model proposed in [17], a property of the optimal passing sequence is found [23]. This property informs us that it is better to give the right-of-way to the vehicles with small temporal distance.

We give the following protocol:
1) A new vehicle goes into the control range does not obtain the right-of-way;
2) If it is close to the vehicle in front (the distance to the front vehicle equals to the minimum security time distance d), it obtains the right-of-way as long as the vehicle in front has it. In other words, if a vehicle obtains the right-of-way, its followers (distance $< d$) pass intersection together without interruption;
3) For the vehicle without the right-of-way: it communicates with the vehicles in the conflict movements to negotiate the passing order: the closest one obtains the right-of-way;

We note that this communication protocol does not need much time in computation. Indeed, vehicles cannot wait for searching information about all vehicles in the intersection before computing the time of their access.

4. SIMULATIONS

In this section, simulations have been performed to verify the new traffic control concept. In the process of simulation, we do not adopt any known traffic simulation software, e.g. VISSIM [24], AIMSUN [25] or Paramics [26]. Since these software can not provide us the appropriate simulation environment. More precisely, they do not allow the vehicles controlled individually. That urges us to develop a simulation environment that adapts to our system. In the simulator, the car-following model [27] is applied. The arrivals of vehicles obey Poisson distribution.

The intersection described in Fig.1 is investigated under different traffic condition. The control range is 100 m long at each lane. A value of 1800 vehicles/hour (0.5 vehicle/second) is set as the maximum traffic load (flow rate). Security time distance d is 2 s that accords with the value of maximum traffic load. Security time distance s is taken to 5 s. For each data point an average is take over three separate simulations. Each simulation runs 60 minutes of traffic flow.

In our previous works [28], we compare our system with the fixed-time controller which is popularly used even now. The experiments prove that the former improves significantly traffic situation. In this paper we conduct the simulation to the comparison in the adaptive traffic control system [29] and the reservation-based system [15] for autonomous vehicles. As quoted early, the reservation-based system is a particular case of a contextualized traffic control. In this system, the intersection is divided into a grid of $n \times n$ tiles. At each time step, a vehicle occupies a tile. In this way, it allows vehicles from the conflicting movement to pass intersection as long as they do not occupy the identical tile at the same time. Certainly, the system requires autonomous vehicles with an extremely precise positioning system and a very strict speed control.

Fig.4 shows the evacuation time at different sums of flow rates.

This measure is inversely proportional to the measure of throughput. The results show that the contextualized control performs better than the adaptive controller and even than the reservation-based system at very low traffic volumes (< 0.3 veh/s).

Let us now push further our investigation. On the one hand, the evacuation time is not the only criterion to evaluate the quality of a traffic control strategy. On the other hand, this criterion influences other criteria such as average vehicle delay and average queue size. Hence, we make simulations according to other criteria which are presented in Fig. 5 and Fig.6. Again, the proposed systems perform better than the adaptive controller. Whereas, the reservation-based system shows an overwhelming advantage in reducing the average waiting time and the average queue length. It should be noted that the reservation-based system is a very idea control system. Despite it maximizes the use of space of the intersection; it considers neither the safe distance between two vehicles in the non conflicting movements nor in the conflicting movements. Both factors are quite important to the safety of drivers.
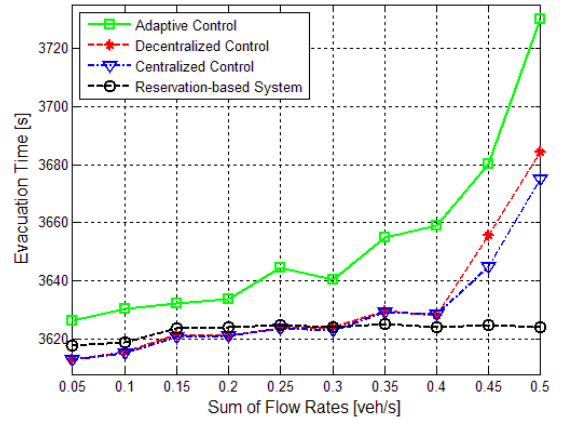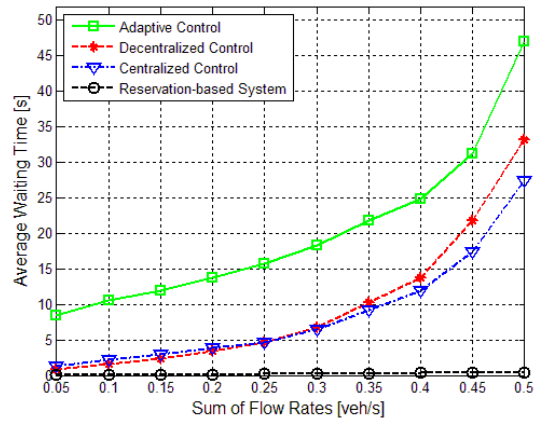

Fig.4. Evacuation time
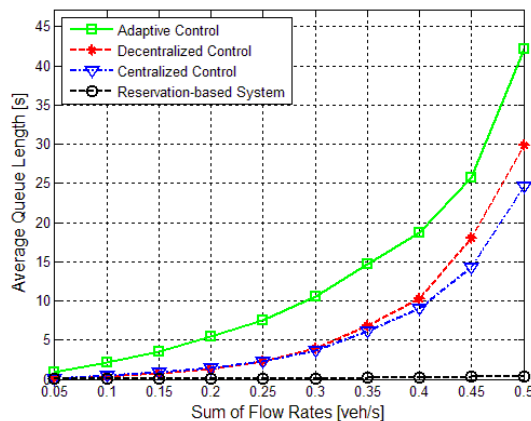

Fig.5. Average vehicle delay

Fig. 6. Average queue size

5. CONCLUSION

This paper introduces a theoretical approach—contextualized traffic control which is based on new information and wireless communication devices to control the traffic at intersections. This new traffic control system is capable of controlling traffic individually. Two scenarios are proposed and the corresponding algorithms are developed. Simulation results show that the proposed system performs better than the adaptive controller that is popularly used at present and even better than reservation-based system at very low traffic volumes. In addition, the proposed system has the potential to be applied to intersection with more complicated layout. Especially for the first scenario (vehicles' passing sequence is decided by a center controller). For the second scenario, it needs more explorations in the future. Besides, we will provide more validation data not just limit on the simulation environment developed by ourselves.

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