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VANETs overview, advanced traffic light control*

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Abstract

At the present time the research of Vehicular Ad Hoc Networks is very actual. This paradigm can be used for various purposes such as traffic safety, crash avoidance, route planning, Internet access, etc. The main problems in this area are security of the VANETs, setting up topology and data routing, data delivery and communication protocols, route planning and its privacy. Several routing methods are used in VANETs, such as Live traffic map, Route Information sharing, Shortest Path, etc. Efficiencies of these methods were compared using SUMO traffic simulator. To estimate efficiency of each method the following criteria are used: total travel time, waiting time. For the optimization of route planning a central server is required. There are several problems in this area, such as network topology modeling, the central server load balancing and reduction. Very important aspects of using VANETs are security and privacy. We need to provide secure data exchange between traffic participants and the central server. We also have to enable route sharing without breaking privacy of drivers. In this paper we will focus on the advanced controlling of traffic lights using VANETs. The different situations were simulated on SUMO traffic simulator: simple traffic light, traffic light with separate light for turning, traffic light connected to VANET. There are two different kinds of information, which are shared in VANETs - position sharing and route sharing. We simulated and compared these two cases in different circumstances.

Keywords: VANET, Traffic control, route sharing, live traffic map, advanced traffic lights, SUMO

1. Introduction

Vehicular ad hoc networks (VANETs) are a subgroup of mobile ad hoc networks

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(MANETs) with the distinguishing property that the nodes are vehicles. Main purpose of VANETs is to build a vehicular communication system to enable ‘quick’ and ‘cost-efficient’ transmission of data for passenger’s safety and comfort [1].

Vehicles in VANETs are able to share its position, speed, route, etc. This information is used for various applications such as traffic safety, route planning, media and traffic light control [2]. Traffic safety is one of the most important applications of VANETs. When cars in a city are able to communicate, its onboard system can warn driver about a car in the blind zone or obstruction on the road such as ice, road maintenance or accident. Another important application is route planning. Modern routing systems are using maps and statistical data about traffic jams on the roads. VANETs allow building live traffic map of the city, which contains real, current data about traffic jams, accidents and obstruction on the road. Using this information routing is much more efficient.

This communication performed by using direct inter-vehicle communications. The main concept of IVC is Local Dangerous Warnings, which use the following algorithms: data collection, individual situation analysis, information dissemination, cooperative situation analysis, relevance evaluation, situation prediction, situation indication [3].

Vehicles in VANETs can communicate with traffic lights. Traffic lights in VANETs can work as advanced and adjust their behavior based on the current traffic density. In this paper we will focus on the traffic lights analysis and comparison of different transition models.

2. Mathematical Background

Let ϱ_1 be green light duration for the first road, ϱ_2 be green light duration for the second road and Δ - delay time. The delay time for the car includes yellow light time and the time between car budge and reaching full speed (see Fig. 1). With Δ we can simplify our model, since no need for detailed computation during acceleration period, but we may assume full speed of the vehicles if they are moving.

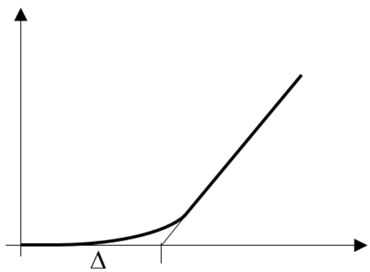

Figure 1: Vehicle acceleration

Let $f(x) = a_1 x$ be the function which determines the number of vehicles in the queue on the first road and let $g(x) = a_2 x$ be the function which determines the number of vehicles in the queue on the second road, where a_1 and a_2 are density coefficients. Furthermore, let $c(x) = cx$ be the function of the number of vehicles passing the crossroad, which determine number of cars left the crossroad since the beginning of green light, c is the crossroad capacity coefficient.

In this model, we do not consider turning, but the overall capacity of the crossroad. Green light period can be divided into several traffic light transition steps. The general behavior of the vehicles will be the same.

We use deterministic model and assume the distances between vehicles are the same. In stochastic approach some error term appears, but the significance is low.

In every second a_1 vehicles arrive on the first road, a_2 on the second road and $c$vehicles leave the crossroad during green light. For static traffic lights ϱ_1, ϱ_2, Δ and c are constant.

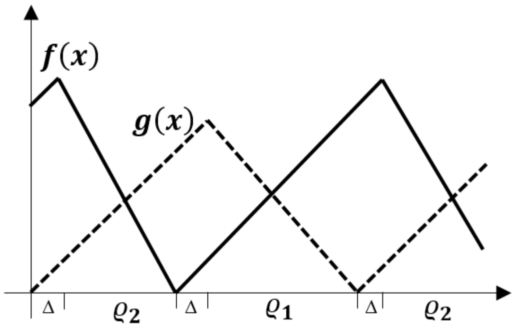

Figure 2: Vehicle number changing during cycle

Let us define bounds for the static traffic light. Maximal traffic light capacity can be reached if the amount or cars arrived to the crossroad during complete period is equal to the number of car left the crossroad during green light:

$$\begin{cases} a_1(\varrho_1 + \varrho_2 + 2\Delta) = \varrho_2 c \\ a_2(\varrho_1 + \varrho_2 + 2\Delta) = \varrho_1 c \end{cases}$$

We can find the optimal traffic light duration: $\varrho_1 = \frac{a_2(\varrho_2+2\Delta)}{c-a_2}$, $\varrho_2 = \frac{2\Delta a_1(a_2+1)}{c(c-a_1-a_2)}$. Obviously, traffic jam will appear if:

$$\begin{cases} a_1(\varrho_1 + \varrho_2 + 2\Delta) > \varrho_2 c \\ a_2(\varrho_1 + \varrho_2 + 2\Delta) > \varrho_1 c \end{cases}$$

Since a_1 and a_2 are not necessarily constant, for the efficient traffic light behavior we need to find ϱ_1, ϱ_2 for maximal a_1 and a_2.

Let us consider that new cycle starts when green light switch to yellow.

The waiting time for a car in one cycle can be calculated by the following expression: $\nu_i(x) = \max\{G_i - \left(1 - \frac{a_i}{c}\right)x\}$, where G_i is the cumulative non-green

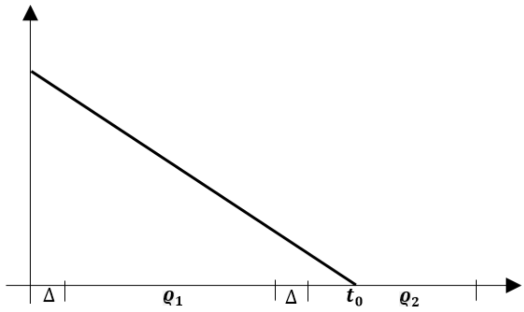

Figure 3: Vehicle waiting time

time $\varrho_{3-i} + 2\Delta$, x is the time of car arrival and $i = \{1, 2\}$. Since $\nu_i(x)$ is linear, the average waiting time is $\frac{G_i}{2}$ in the optimal case.

If the number of cars in the queue is less than crossroad capacity, then since $\mathbf{t_0}$ waiting time of the new vehicles will be 0 and average waiting time is $\frac{G_i \cdot t_0}{2 \cdot (\varrho_1 + \varrho_2 + 2\Delta)}$.

In case of advanced traffic light we are able to adjust $\varrho_1$and ϱ_2, so the traffic light efficiently will be higher.

3. Simulation

It is simple to develop mathematical model for one crossroad, but to build it for the whole city is much harder because of TL synchronization issues. Another way to estimate efficiency of the proposed traffic lights control model is to simulate traffic flow. SUMO – open source, highly portable microscopic and continuous road traffic simulation package designed to handle large road networks [4]. We simulated crossroads with three lanes on each directions and one traffic light.

Input parameters are the network description, vehicles routes, vehicles number. Output data is the departure and arrival time, trip duration and waiting time for each vehicle.

We compared two traffic light transition models – round and opposite (see Fig. 4).

Traffic light with "Round" transition model on every step allows vehicles from one direction to go any direction. "Opposite" model is more complicated. On the first step, it allows vehicles going from two opposite directions to go straight and to turn right; on the next step, it allows them to go left. For each model, we consider two cases: static and advanced traffic lights. Static traffic light is not able to change behavior during the simulation. Advanced traffic light is able to receive data about the number of vehicles on each lane and to adjust its behavior.

Before comparison of these models, we need to answer the following questions.

- What static TL duration is optimal?

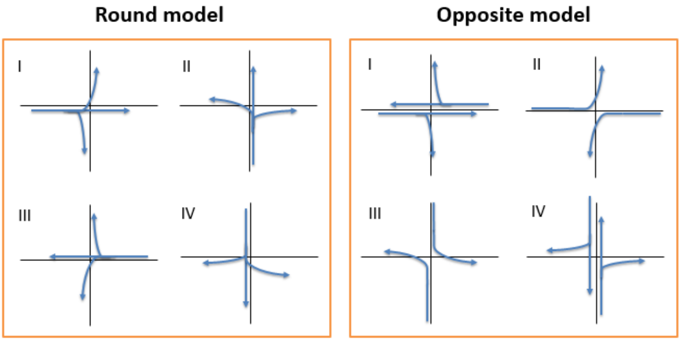

Figure 4: Traffic light transition models

- How advanced TL should adjust its behavior?

To answer the first question we made several simulations with constant density. We used Poisson distribution for the generation of vehicle routes. For different vehicle launching probability, the optimal traffic light duration was different. However, in real world the density of the traffic is not constant. We made simulations where the density function was not constant but periodic and tried to find optimal traffic light duration. However, mean trip duration was worse than for the constant density case. That means that static traffic light is not optimal and its efficiency may be enhanced.

It is obvious that the green light duration of advanced traffic lights should depend on number of vehicles and can be defined by the expression$\gamma = kN$, where N is the number of vehicles in the queue and k is some coefficient of crossroad throughput. By simulation we found that optimal coefficient value for the current case is 2.5

We have made simulations and measured maximal and mean trip duration and entropy. Trip duration is the period from vehicle starting until its leaving the simulation. It includes waiting time in queue. Entropy is $H\left(x\right) = \sum p(i) \cdot \log_2 p(i)$. In addition, maximal and mean waiting time were measured. By comparing these parameters, we can estimate which transition model is better.

4. Results

We used Poisson distribution for vehicles generation. In every second we generated random number $n = \{0, 1\}$ and for each lane we checked if $n < \frac{1}{11} + \frac{\sin\left(\frac{x}{318}\right)}{21}$. So the probability of launching vehicle on the lane was $p = \{0.04; 0.14\}$. The $\sin(x)$ function allows us to include waves into our simulation. Since the simulation duration was one hour – 3600 seconds, we choose the waving function period 2000 seconds to observe 1.5 period (see Fig. 5).

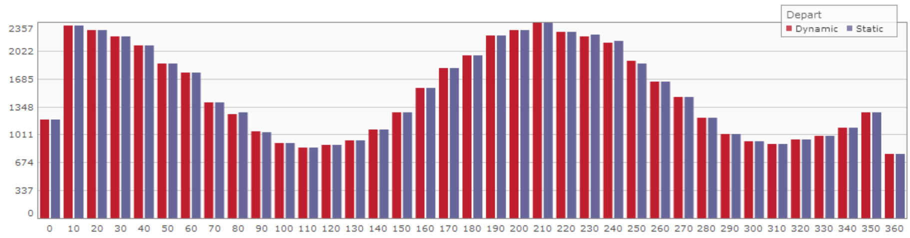

Figure 5: Number of launched vehicles during simulation

We made 20 simulations with different random seed for each case and built charts based on simulations results. X-axis is the trip duration in seconds. Y-axis is the number of vehicles with corresponding trip duration.

Round model

Using Advanced traffic light allow to reduce maximal trip duration by 32,75% (**497.00**, 739.00) and mean trip duration by 42,1% (**297.92**, 172.51).

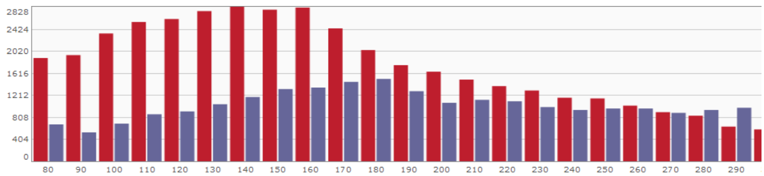

Figure 6: Round model: advanced vs static traffic light

Opposite model

Using Advanced traffic light allow to reduce maximal trip duration by 16,5% (**582.00, 697.00)** and mean trip duration by 15,88% (**252.81**, 212.91)

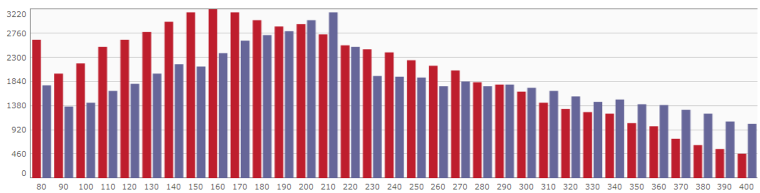

Figure 7: Opposite model: advanced vs static traffic light

Static traffic light

Using Opposite model allow to reduce maximal trip duration by 23,41% (**566.00**, 739.00) and mean trip duration by 28,48% (**297.92**, 213.08)

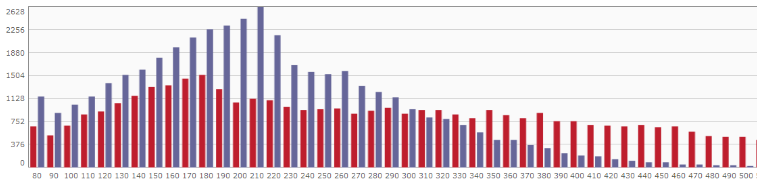

Figure 8: Static traffic light: round vs opposite model

Advanced traffic light

Using Round model allow to reduce maximal trip duration by 14,6% (582.00, 497.00) and mean trip duration by 18,98% (**212.91**, 172.51)

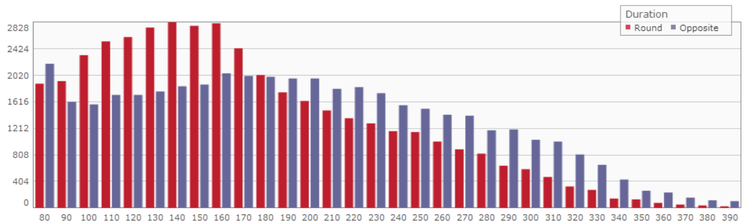

Figure 9: Advanced traffic light: round vs opposite model

5. Summary

VANETs have various applications, such as traffic safety improvement, route planning optimization, traffic lights control, etc. VANET is a strong tool for the traffic light optimization, too. Advanced traffic lights may increase crossroad capacity by 42%. For the different traffic scenarios, different transition models should be used. If the traffic is not balanced, the round model with advanced traffic light is recommended.

As a future work, we will consider the extension of the simulation on large traffic light network, research of efficient advanced traffic lights chain inside the network, protocols design for data exchange between vehicles and city infrastructure.

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