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A Statistical Multiplexing Method for Traffic Signal Timing Optimization in Smart Cities

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Abstract

Urban road traffic is the heart of many problems: more recent years, this critical aspect involved every day is unfavorable to many fields, such as economics or ecology. For these reasons, the Intelligent Transportation Systems (ITS) have emerged to best optimize the expenditure of the user on often complex road networks. In this paper, after studying the backgrounds of such systems, we propose a system of control of traffic lights through the use of statistical multiplexing technique based on fixed and vehicular networks of wireless sensors. We will see that this architecture can be flexible within the framework of ITS and participate in low cost to obtain interesting results. The simulation results prove the efficiency of the traffic system in an urban area with an adaptable and dynamic traffic road, because the average waiting time of cars at the intersection is sharply dropped when the red light duration is 65 s and the green light time duration is 125 s.

Keywords: *vanet, smart city, ITS, statistical multiplexing*

1. Introduction

The urban road traffic has grown in recent years, increasing the problems caused as traffic jams, accidents, and pollution. In Moscow, for example, drivers are subjected to daily traffic jams of half past two on average. To an employer, congestion (Figure 1) means lost worker productivity, trade opportunities, delivery delays, and increased costs. To solve congestion problems is feasible not only by physically constructing new facilities and policies but also by building information technology transportation management systems.

The road traffic management is in the field of ITS, designed to provide tools and models to manage risks by reactive equipment. The implementation of such systems will have multiple objectives, including the thinning traffic incident detection, the real-time traffic monitoring, information dissemination or variables instructions to motorists and the corresponding reduction in pollution and noise. Many traffic light systems operate on a timing mechanism that changes the lights after a given interval.

Figure 1. Complex scenario of traffic promoting congestion

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An intelligent traffic light system senses the presence or absence of vehicles and reacts accordingly. The idea behind intelligent traffic systems is that drivers will not spend unnecessary time waiting for the traffic lights to change. An intelligent traffic system detects traffic in many different ways [1]. The older system uses weight as a trigger mechanism [2]. Current traffic systems react to motion to trigger the light changes. Once the infrared object detector picks up the presence of a car, a switch causes the lights to change. In order to accomplish this, algorithms are used to govern the actions of the traffic system. While there are many different programming languages today, some programming concepts are universal in Boolean Logic.

In this paper, therefore, we propose a traffic light controlling that can cope with the traffic congestion appropriately. Based on the statistical multiplexing method, it uses as an input variable a degree of traffic congestion of upper roads, which vehicles on a crossroad are to proceed to. We compared and analyzed the fixed traffic signal controller and the proposed system by using the delay time and the proportion of passed vehicles to entered vehicles. As a result of comparison, the proposed controller showed more enhanced performance than the fixed traffic signal controller.

2. Related Works

Due to the importance of the ITS topics, several works was focused on this field and area. Authors in [3], discuss how optimal and suboptimal traffic light switching schemes with possible variation of cycle as a function of time. Binbin Zhou & al [4] propose an adaptive traffic light control algorithm to adjust the sequence and length of traffic lights in accordance with the real time traffic detected. Their algorithm considers a number of traffic factors such as traffic volume, waiting time, vehicle density to determine green light sequence and the optimal green light length. In [5], authors used Wireless Sensor Network (WSN) as a tool to instrument and control traffic signals roadways, and a traffic controller to control the operation of the traffic infrastructure. Malik & al [6], proposed an architecture system which is classified into three layers; the wireless sensor network, the localized traffic flow model policy, and the higher level coordination of the traffic lights agents that manages its intersection by controlling its traffic lights. Holger.p & al [7], presents an organic approach to traffic light control in urban areas that exhibits adaptation and learning capabilities, allowing traffic lights to autonomously react on changing traffic conditions.

3. The Traffic Signal System

There are usually two different modes adopted by most nations on the planet: fixed time and dynamic control. Let’s take them one a time and see the differences. A fixed time traffic light control system is that boring and old-fashioned way in which traffic lights are configured to turn on the green color after a given period of time, usually around 30 seconds, but this may very well vary depending on traffic values and region. The fixed time traffic light control systems relied on an electro-mechanical signal controller, it’s a less complicated controller with components that can move, but also with dial timers to be able to keep a specific color for a given period of time. Dynamic traffic light control systems are more appropriate for the crowded traffic we’re facing every morning, as they have been developed specifically to be able to adapt their settings to traffic conditions. In case you’re driving at a rush hour and you’re seeing green all the way from office to home, you’re in luck: dynamic signals have turned all traffic lights to green to maintain traffic flow. As compared to fixed time control systems, the foundation of a dynamic system is actually a detector, which is nothing more than a simple device that communicates with the traffic light and informs it about traffic conditions in real time. This time, the traffic light can not only adjust timing, but also solve traffic jams by turning red as soon as an intersection gets stuck with cars.There are two different types of detectors (Figure 2), embedded into the road surface and mounted above the road.

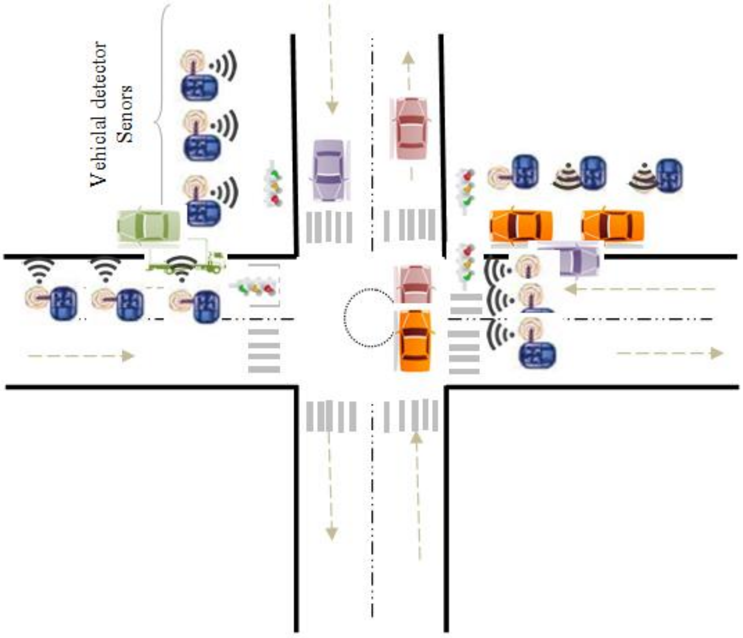

Figure 2. Basic concept of Smart Traffic Light Controller

4. Statistical Multiplexing

Statistical multiplexing dynamically allocates bandwidth to each channel on an as-needed basis. This is in contrast to time-division multiplexing (TDM) techniques, in which quiet devices use up a portion of the multiplexed data stream, filling it with empty packets. Statistical multiplexing allocates bandwidth only to channels that are currently transmitting. It packages the data from the active channels into packets and dynamically feeds them into the output channel, usually on a FIFO (first in, first out) basis, but it's also able to allocate extra bandwidth to specific input channels.

4.1. The Scalar Conservation Law

A scalar conservation law [8] in one space dimension is a first order partial differential equation of the form:

$$u_t + f(u)_x = 0 \tag{1}$$

Here $u = u(t,x)$ is called the conserved quantity, while f is the flux.

The variable t denotes time, while x is the one-dimensional space variable.

Equations of this type often describe transport phenomena. Integrating (1) over a given interval [a, b] one obtains:

$$\frac{d}{dt}\int_a^b u(t,x)dx = \int_a^b u_t(t,x)dx = -\int_a^b f(u(t,x))_x dx$$
$$= f(u(t,a)) - f(u(t,b)) = [inflow\ at\ a] - [outflow\ at\ b]$$

In other words, the quantity u is neither created nor destroyed: the total amount of u containedinside any given interval [a, b] can change only due to the flow of u across boundary points (Figure 3).

Using the chain rule, (1) can be written in the quasi linear form:

$$u_t + a(u)u_x = 0, \tag{2}$$

Where $a = f'$ is the derivative of f. For smooth solutions, the two Equation (1) and (2) are entirely equivalent. However, if u has a jump at a point ε , the left hand side of (2) will contain the product of a discontinuous function $a(u)$ with the distributional derivative u_x , which in this case contains a Dirac mass at the point ε. In general, such a product is not well defined. Hence (2) is meaningful only within a class of continuous functions. On the other hand, working with the equation in divergence form (1) allows us to consider discontinuous solutions as well, interpreted in distributional sense.

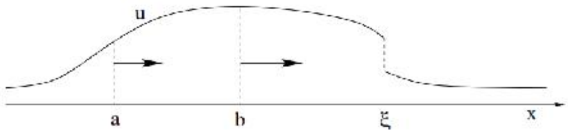

Figure 3. Flow across two points

A function $u = u(t,x)$ will be called a weak solution of (1) provided that:

$$\iint\{u\emptyset_t + f(u)\emptyset_x\}dxdt = 0 \tag{3}$$

For every continuously differentiable function with compact support $\emptyset \in C_c^1$.
Notice that (1.3) is meaningful as soon as both u and f(u) are locally integrable in the t-x plane.

4.2. The Conservation Law Application in the Traffic flow

Let $\rho(t,x)$ be the density of cars on roads near to the intersecting at the point x at time t. For example, u may be the number of cars per meter (fig. 4). In first approximation, we shall assume that ρ is continuous and that the velocity v of the cars depends only on their density:

$$v = v(\rho), \text{with } dv / d\rho < 0$$

Given any two points a, b on the highway, the number of cars between a and b therefore varies according to the law:

$$\begin{aligned}
&\int_a^b \rho_t(t,x)dx = \frac{d}{dt}\int_a^b \rho(t,x)dx = \\
&= [\mathit{inflow\ at\ a}] - [\mathit{outflow\ at\ b}] \\
&= v(\rho(t,a)) \bullet \rho(t,a) - v(\rho(t,b)) \bullet \rho(t,b) \\
&= -\int_a^b [v(\rho)\,\rho]_x\, dx
\end{aligned} \tag{4}$$

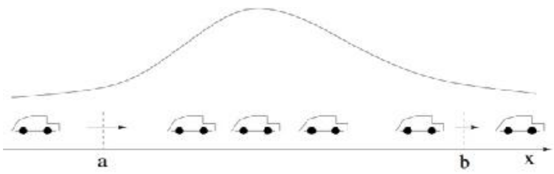

Figure 4. The density of cars can be described by a conservation law

Since (1.4) holds for all a, b, this leads to the conservation law $\rho_t + [v(\rho)\,\rho]_x = 0$, where ρ is the conserved quantity and $f(\rho) = v(\rho)\rho$ is the flux function.

5. Algorithm

The proposed algorithm is designed to manage the traffic cycle which can be changed dynamically by giving priority to vehicles in the less dense road to facilitate the efficient traffic control at certain junction. This algorithm is based on the statistical information using the conservation law of vehicles in the four road parts and using a hierarchical wireless sensor network (Figure 5). This also can be extended to multiple crossroads control.

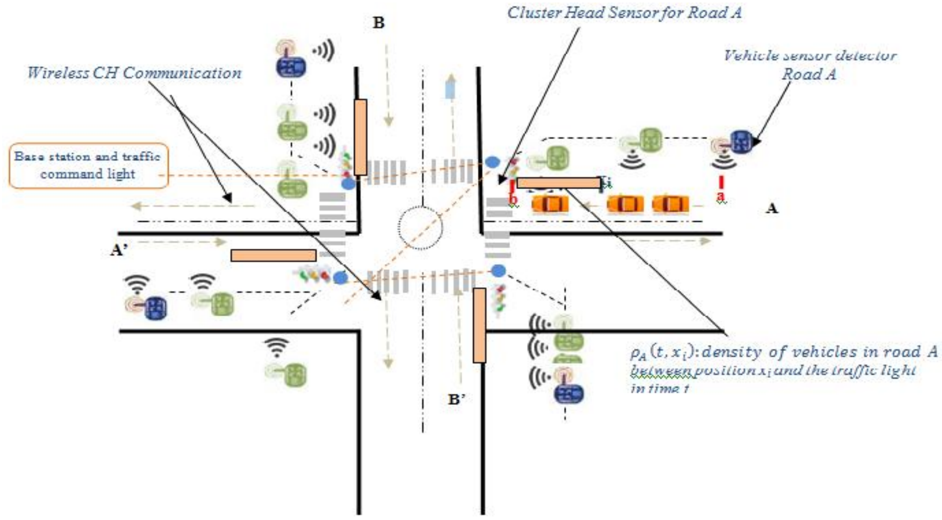

Figure 5. Illustration of proposed algorithm method

The traffic controller algorithm is defined as follow:

Let *N_A , $N_{A'}$, N_B,$N_{B'}$, numbers of vehicles, respectively, in roads A,A',B and B'*
$\rho_j(t,x_i)$ density of car at time t and position x_i in road j Where j= {A,A',B,B'}
mean_delay'(i,j): the mean time of evacuation from roads (A,A') or (B,B')
min_time_evacuation :minimum time of evacuation from a road (for yellow light)
$k = \{A,B\}$

Do
Sensors road's Start detecting vehicles
Achieving accounted values to de CH
Computing min (sum(N_A,$N_{A'}$),sum(N_B,$N_{B'}$))
Computing $\rho_j(t,x_i)$ for every value of j at time t
mean_delay(k,k')= $\rho_k(t,x_i)$ (in secondes)
If sum(N_A,$N_{A'}$)> sum(N_B,$N_{B'}$)
Then mean_delay(B,B')= mean_delay(B,B')/2
Else mean_delay(A,A')= mean_delay(A,A')/2
End if.
If sum($\rho_A(t,x_i)$, $\rho_{A'}(t,x_i)$)>= sum($\rho_B(t,x_i)$, $\rho_{B'}(t,x_i)$)
Then
*(B_light and B'_light): G until delay=($\rho_B(t,x_i)$ +$\rho_{B'}(t,x_i)$)*mean_delay_(B,B')*
*(A_light and A'_light): R until delay=($\rho_B(t,x_i)$ +$\rho_B(t,x_i)$))*mean_delay(B,B')+min_time_evacuation*
(B_light and B'_light):Y until delay= min_time_evacuation
*(A_light and A'_light): G until delay=($\rho_A(t,x_i)$ +$\rho_{A'}(t,x_i)$) *mean_delay(A,A')*
*(B_light and B'_light): R until delay=($\rho_A(t,x_i)$ +$\rho_{A'}(t,x_i)$) *mean_delay(A,A')+min_time_evacuation*
(A_light and A'_light):Y until delay= min_time_evacuation
Else
*(A_light and A'_light): G until delay=($\rho_A(t,x_i)$ +$\rho_{A'}(t,x_i)$)*mean_delay(A,A')*
*(B_light and B'_light): R until delay=($\rho_A(t,x_i)$ +$\rho_{A'}(t,x_i)$) *mean_delay(A,A')+min_time_evacuation*
(A_light and A'_light):Y until delay= mean_time_evacuation
*(B_light and B'_light): G until delay=($\rho_B(t,x_i)$ +$\rho_{B'}(t,x_i)$)*mean_delay(B,B')*
*(A_light and A'_light): R until delay= ($\rho_B(t,x_i)$ +$\rho_B(t,x_i)$) *mean_delay(B,B')+min_time_evacuation*
(B_light and B'_light):Y until delay= min_time_evacuation
End if.
Loop.

In this algorithm, we proposed a dynamic traffic light commutation based on the conservation law and the density of road and the incremental values of vehicles given by sensor detector. The basic idea is to reduce traffic by giving priority to the least dense route to evacuate the smaller number vehicle, before opening the way to the highest road in term of vehicles. On one hand, this solution is based on the law of conservation and the density function, and on the other hand, by using the number of vehicles provided by the sensors to solve the problem higher density road proceeding to the reduction of time of the other side road traffic in to the half mean time of evacuation.

6. Simulations and Results

Measurement of an actual Traffic light is expensive and infeasible. Therefore, the evaluation technique is simulation; we have used sumo simulator dedicated for VANET simulations. To perform the proposed algorithm, the used simulation scenario consists of 120 nodes in an area of 500x500m^2 created with random movement and generation. The traffic is introduced into the sumo network and map generator for 60m/s as maximum speed of vehicles. The algorithm was applied for 11 cycles of light variation depending on the traffic in roads A and B. The maximum density is 30 vehicles per road side. To evaluate the proposed algorithm, we used two metrics; the density of road and the waiting time in every road.

For a random generation of vehicles in both roads (Figure 6), we can observe the variation of low conservation in the 4 sides of the roads A and B from *Xi* to the traffic light position.

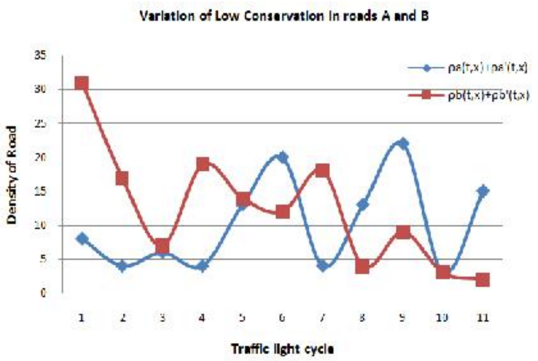

Figure 6. Density of Road A and B based on low conservation

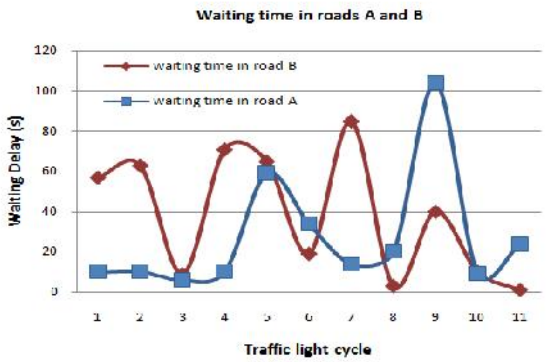

Figure 7. Waiting time in red light for roads A and B

As described in Figure 7, the waiting time in both roads A and B is varying and depends on the density of road. The waiting time can attend values less then 20s and equal in some situations like values according to 3, 5and10.Because of this, the vehicles circulation well be dynamic and helps to reduce congestion in urban environment.

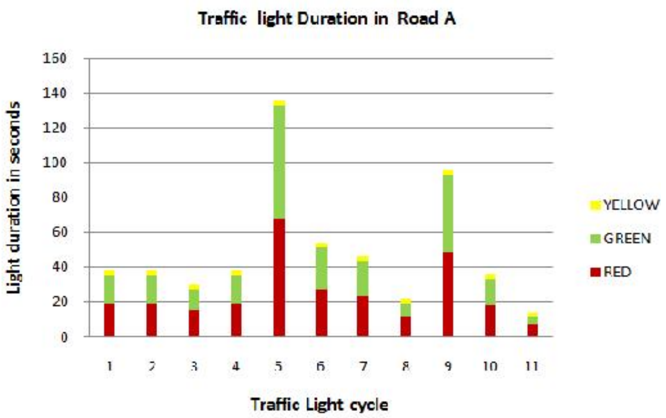

Figure 8. Light duration for every cycle in road A

In other hand, Figure 8 shows that the light duration varies depending on the density of road $\rho_k(t, x_i)$ (here, k=A) and comes dynamic with an addition of the minimum time of road evacuation (*min_time_evacuation*).

7. Conclusion

In this paper, we have shown an intelligent traffic light system, including a Statistical Multiplexing Method algorithm. This algorithm is based on the conservation law and the density of road taking into account the incremental values of vehicles given by sensor detector. We implemented several algorithms by varying the density of roads in term of number of vehicles, and evaluating the variation of density and waiting time versus several traffic light cycles. The evaluation of given results justify the relevance of our proposed algorithm for a dynamic management of traffic road light to avoid the congestion and promote a flexible circulation in the urban environment known by the high density of vehicles. This can be a rich infrastructure for a possible combination with VANET technologies, and to be adapted to the future smart city considered as one of the biggest challenges in intelligent transportation system (ITS).

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