ADAPTIVE TRAFFIC LIGHT CONTROL SYSTEM USING AD HOC VEHICULAR COMMUNICATIONS NETWORK

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În această lucrare, considerăm o arteră rutieră urbană şi studiem problema controlului adaptiv al semafoarelor, utilizând informații de trafic în timp real. Fluxul de trafic în ariile urbane depinde de comportamentul şoferilor, de modul de control al traficului şi de factorii de mediu. Pe baza acestui context şi datorită creşterii anuale a numărului de vehicule în ariile urbane, autorii s-au orientat spre găsirea unor soluții pentru a utiliza infrastructura curentă la o capacitate maximă. Fiecre intersecție este controlată prin intermediul volumului de vehicule, tipul acestora şi de recomandările cooperative ale intersecțiilor învecinate. Lucrarea prezintă o nouă strategie de control al traficului, îmbunătățită prin analiza dintre comportamentul de conducere şi circulația vehiculelor individuale sau a coloanei de vehicule. Autorii vor modela această dependență cu ajutorul programului MATLAB.

In this paper, we consider an urban arterial road and investigate the problem of adaptive traffic light control using real-time traffic information. The urban traffic flow depends on the driver behaviour, and also, it is influenced by traffic control and environmental factors. On the basis of this context and the increase, year by year, of the number of vehicles in urban areas, the authors are focused on finding solutions to use the current road infrastructure in an intensive manner. Every intersection is controlled by its own traffic volume, vehicles type and its neighboring intersections cooperative recommendations. The paper presents a new adaptive traffic light control strategy which is improved by the results of analyzing the relation between drivers behavior and the movement of the vehicles or groups of vehicles. The authors will model this dependency using MATLAB.

Keywords: adaptive systems, traffic control, green-wave, offset, simulations

1. Introduction

Traffic congestion is a crucial problem in the urban road network, normally caused by an inadequate usage of road capacity [12]. In urban areas, optimum traffic has a great influence on traffic flow optimization [1].

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Urban traffic control strategies are based on lights controllers. An intersection is managed by a controller in charge of several red lights. The management is based on phases, cycles, split vectors and coordination between the controllers of the different intersections on the road network.

One strategy for optimum control and traffic management is the coordination of traffic lights to create green waves [19]. Currently, there exist different strategies to calculate green waves. The main purpose of these techniques is to reduce the number of stops and minimize the travel times in trips.

Various approaches are based on purely mathematical optimum solution of the difference between phases at the downstream crossroads, using the distance between two crossroads of traffic light and average speed of the section.

In [21] the classic model approach to calculate green waves is exposed. The model is based on the distance between links, the section free flow speed and the phases of the traffic control plan.

Therefore a lot of work in network transport and traffic research is currently under development and the authors are focused on finding solutions to use the current road infrastructure in an intensive manner [17].

In [1] an optimization of traffic signal to calculate green waves is developed using cyclically expanded networks. The purpose of this study is to minimize the travel times of all road user considering jointly the optimum traffic signalization and the traffic assignment in each intersection. It is based on a time expanded network providing a realistic implementation of traffic signals.

In [2] a bi-directional green wave strategy based on inverse green light optimization is presented. The goal of this study is to eliminate the stops of cars running in the opposite directions by improving the time (or speed) of going through the road section.

Other strategies are based on genetic algorithms, fuzzy logic [18], or neural network approaches. In [3] is presented a bi-directional green wave control strategy to solve the coordinated control issues of urban traffic trunk. The goal of this control strategy is to achieve the zero stop of the up-run or down-run vehicles on the trunk and make the vehicle average delay time smaller. The whole control structure was divided into the coordination layer and the control layer. The first layer calculates optimum public cycle time, up-run and down-run offset, and the control layer adjusts the splits of each intersection on the trunk at the end of each cycle. The cycle time is adjusted by one fuzzy neural network arithmetic according to the traffic flow saturation degree of the key intersection on trunk. The offset are calculated by the up-run speeds or the down-run speeds. The variable splits of each intersection are based on historical and real-time traffic information.

Paper [4] describes how to compute the optimum extension time that will add to the fixed time control system in an isolated intersection with respect to the situation of its backward and forward neighbors based on fuzzy logic. The implemented intelligent traffic system has the capacity of mimicking the human intelligence for controlling traffic light.

Other approaches are based on the multi-agent paradigm. Multi-agent systems are composed by intelligent agents able to develop independent actions and to develop task in a cooperative way to solve complex systems. Thus, the characteristics of multi-agent technology made it useful to develop intelligent transport systems.

In [22, 23] we presented two different multi-agent system to optimize signal control and traffic flows using agents and fuzzy logic. In [24], a test-bed based agent system is presented using Petri nets for road traffic management.

These systems provide different approaches to improve urban traffic flows. However, all analyzed systems do not take in account the drivers behaviors. Several research on this issue demonstrated a dependency between the different classes of vehicles (in terms of behavior), constrains imposed by road infrastructure and traffic congestions [6].

Traffic flows depends on the vehicles behavior (based on the driver comportment) and, furthermore, it is influenced by traffic measures, and various environmental factors like weather situations.

The main problem to take into account the vehicles behavior is the difficulty to monitor the different vehicle's behavior in road network. Currently, the use of the new technologies in the traffic domain has made possible to improve the process of traffic monitoring. One example of these improvements is the Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications [20].

V2V and V2I support the creation of Vehicular Ad-Hoc Networks (VANET). VANET is a highly promising technology for providing solutions to current road congestion problems. In [7], [8] the fundaments of VANET technology are exposed. Using VANET to monitor traffic status it is possible to determine the different traffic user behavior.

The purpose of this paper is to analyze an intelligent traffic green-wave control system, taking into account drivers behavior. The proposed solution improves the existing ones because it combines two methods: a) the mathematical approach solution and b) the fuzzy logic. Furthermore, the proposed system takes into consideration new parameters like weather, vehicle type and road events.

The system is structured in a set of: road sections, intersections, sub-network monitoring systems, base station and vehicles. The road sections and the intersections model the urban road network, the sub network monitoring systems develop the data collection tasks, and the data processing and data analyzing are performed by VANET system agents, The paper is organized as follows: In section 2 the proposed model is exposed. The third section deals with the experimentation methods and results. Finally, in section 4 some conclusions are presented.

2. Proposed model

Overview

According to our problem, we assume that all the roads under consideration are two-way roads, each side of them has three lanes; the required information level and data acquisition are provided by Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) wireless/wired communications technologies [7], [8]. We also assume that V2X system connected with a network of sensors will provide us an accurate information about the number and the vehicles type in queue, the drivers' behavior on sections between two intersections (speed, number of vehicles on lane), while the system has an knowledge database for information infrastructure (road section length, lines' number and speeding).

The proposed model for the adaptive traffic light control system is shown in Fig. 1, in which the urban intersections are shown by letters: i, $i+1 \ldots i+n$. The ad hoc domain (VANET) is composed of vehicles equipped with OBUs (on-board units) and stationary units along the road RSUs (road-side units). Components of our proposed model and their functions are briefly summarized below [8].

On-board Units (OBUs)

On-Board Units are responsible for car to car and car to infrastructure communications. An OBU is equipped with at least a single short range wireless communications network device. The network device is used to send, receive and forward data in ad hoc domain [11].

Road-side Units (RSUs)

A Road-Side Unit is a physical device located at fixed positions along roads (and highways), or at dedicated locations (gas station, parking places, restaurants etc). An RSU is equipped with at least a network device for short range wireless communications radio technology. The main function of RSU are extending the communication range of an ad-hoc network, possibly running safety applications, possibly providing Internet connection to OBUs, possibly cooperating with other RSUs in forwarding or in distributing safety information etc [11].

Traffic Light Controller (TLC)

The traffic Light Controller has the function to adaptive calculate the cycle length and effective green time corresponding to each phase traffic light. We suppose that TLC can wireless/wired communicate with OBUs, RSUs, and other adjacent TLC, and takes into account the physical presence of vehicles, and queue length of vehicles for deciding signal timing. It also takes into account the predictive travel time and driver's behavior to calculate the order of the phases and the offset between traffic signals at adjacent intersections [7], [8].

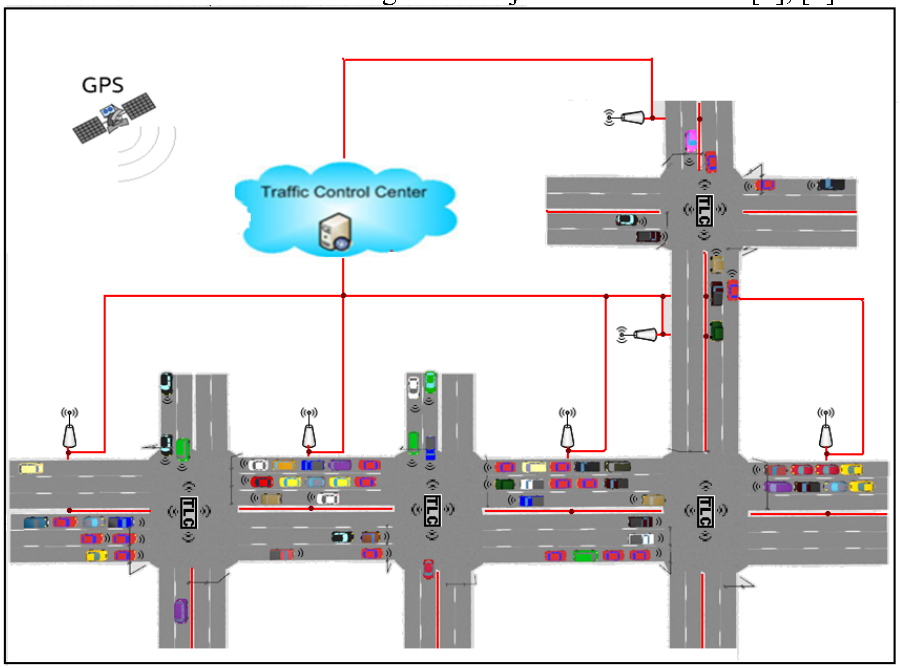

Fig. 1. The propose model for adaptive traffic light control system.

Traffic Control Center (TCC)

Traffic Control Center serves as the focal point for the management of the transportation system in urban area. It integrates data from a variety of different sensor sources and provides a means for operators to manage traffic and inform the public from a centralized point. TCC directly communicates with RSUs and TLCs, and examines data traffic information to identify potential traffic problems, and then develop strategies to address the problems. TCC often serves as the central media contact point for any urban road related problems [7], [8].

OBUs and RSUs can be seen as nodes of an ad hoc network. As a result, RSUs may allow OBUs to access the infrastructure. The main objectives of V2V/V2I communication are automatic and fast transmission between vehicles and between vehicles and road side units. The ad hoc V2V communications enable the cooperation of vehicles by linking individual information distributed between multiple vehicles. Constantly, the system is collecting data and predicting traffic congestion on roadways throughout a large region. The traffic light controller uses information collected by OBUs and RSUs to automatically calculate the green time for each traffic light phases and the green wave offset for a wide range of cooperative intersections. In order to predict the green wave offset, we assume that the system monitors the action of the drivers, the position and the behavior of all other nearby vehicles. The effect of this approach is less stops on roadways resulting in increased traffic flow for equipped vehicles, as we can see in the following sections.

3. Experimentation methods and results

In this chapter, we will concentrate on optimizing the offset between consecutive traffic signals and we will explain the way we adjust the offset time depending on driver's behavior. Additionally, to implement a correct green wave strategy, we assume that all intersections will work together and they will choose a common cycle, while all others parameters are fixed. Thus, we are going to choose the maximum length of the correlated intersections cycle time.

The performance of traffic signal green-wave strategy can be measured by average delay travel and the number of stops. Other measures of performance, like preferences for public transport and pedestrians, are not taken into consideration in this paper. Thus, we are looking for a green-wave strategy for the main route, without affecting traffic on the secondary routes. In this case it is very important the way we establish the cycle length and the offset between the phases of two adjacent intersections.

Cycle Length

One approach to determin cycle lengths for isolated pre-timed location is based on Webster's equation for minimum delay cycle lengths. Assume that the adjusted saturation flow rate is equal to 1800 vph, which corresponds to a headway equal to 1.00 [9].

$$C = \frac{(1.5 \cdot LT) + 5}{1 - \sum_{i=1}^{M} z_i} \tag{1}$$

where: C – traffic light cycle length; LT – Lost Time per cycle in seconds;

$\sum_{i=1}^{M} z_i$ - is degree of saturation for Phase I; M – number of the traffic light phases

z_i= Observed Flow/Adjusted Saturation Flow Rate;

Since traffic flow is composed by different vehicles, the volume is expressed as the number of equivalent vehicles per time unit. For each vehicle type, an equivalent number of cars can be determined, on the basis of the fact that various vehicles need different time to pass through the intersection. Table 1 presents the equivalent vehicles units for each type of vehicle [12] [13], adjusted for our arterial urban roads, when going straight or turning.

Table 1.

Equivalent number of passenger cars

Vehicle Type	Straight (pcu/s)	Turning(pcu/s)
Car	1	1
Bus	1.7	2
Heavy truck	1.7	2

Green Time Distribution

The distribution of the green time for a pre-timed signal should be proportional to the critical lane volumes on each phase [9]:

$$G = C - \sum_{i=1}^{M} \left(Y_i - LT_i \right) \tag{2}$$

where: G – net green time; Y_i - Yellow time per the phase *i* in seconds;

LT_i - Lost time per phase *i* in seconds;

For an arterial road of "*n*" intersections, we choose the maximum cycle length;

$$C = \max \left\{ C_1, C_2, \ldots, C_n \right\}, \tag{3}$$

Offset optimization is the essential analysis in our chosen model. In the literature we can find different approaches of the signal coordination problem, but all of them have in common the offset optimization problem. Generally, in literature is suggested that the offset time can be calculated with:

$$\tau_{i,i+1} = \frac{l_s}{v_m}, \tag{4}$$

where: l_s - length of road segment; v_m - average speed of vehicles (on the road segment);

Offset Adjustment

For our approach we propose the algorithm below for the offset calculation:

$$\tau_{adjust} = t_{i,i+1} - t_d, \tag{5}$$

$t_{i,i+1}$ – travel time of vehicles between intersection *i* and intersection *i+1;*

t_d – time of queue vehicles discharge of intersection *i+1;*

$$t_{i,i+1} = \frac{l_s}{v_{\max}} \cdot k_i, \tag{6}$$

k_i - offset adjustment constant. $v_{\max}$ - admitted maximum speed;

According to the degree of influence for each parameter, the adjusted offset is calculated as below.

$$k_i = \sum_{i=1}^{n} x_i , \tag{7}$$

n –being the number of offset parameters.

The offset parameters are: weather (x_1), vehicle type (x_2), and road events (x_3). On this line, traffic measures made by authors in Bucharest showed that weather conditions (e.g. rain, fog, snow, etc), influence the driver behavior, reducing the average speed up to 20 km/h. Heavy vehicles (e.g. buses, trunks etc) need more time to accelerate and also use a lower speed. For this type of vehicles, the average speed is reduced with 10 or 15 km/h compared to the normal speed of the cars. Therefore, considering the number of the lanes and heavy vehicles on the road section, we can remark that the type of the vehicle can influence the average speed with 15 km/h. Minor events (e.g. minor accidents that occupies only one lane, the existence of the emergency vehicles etc), can influence the average speed with 10 km/h. For example, suppose that we have one road section with two lanes. If an accident occurs on the first lane, the vehicles that were using this lane will try to pass on the free lane. So, the number of the vehicles will increase in one lane and the necessary time of the last vehicle to pass through the intersection will increase also. Implicitly, the average speed of the vehicles will decrease (compared with the initial average speed of the referred lane).

The three parameters presented above are very flexible, and the average speed can vary from a region to another, or from a city to another one, even if the parameters were measured in the same conditions.

For illustration and the easiness of the calculations, in Table 2 we considered one ideal case, in which the above mentioned parameters can influence the average speed, decreasing it with 30 km/h of the admitted maximum speed value (60 km/h). We didn't consider the major events, case in which the traffic could be completely blocked (average speed < 30 km/h), situation when there would be no need to adjust the offset time.

Table 2.

The dependence between average speed and different type of parameters

No. Crt.	Weather (x_1)	Vehicle type (x_2)	Events (x_3)	Speed ($v_{i,i+1}$)
1	Good weather conditions	cars	No events	60 km/h
2	Adverse weather conditions	Cars plus buses which are occupying two lanes	Minor events	50 km/h
3	Severe weather conditions	Cars plus busses and heavy trunks which are occupying all the three lanes		40 km/h
4	-	-	Major events	>40km/h

$$t_d = SLT + h \cdot N + t_{vm} \ , \tag{8}$$

$$\tau_{adjust} = \frac{l_s}{v_m} \cdot k_i - (SLT + h \cdot N + t_{vm}) \ , \tag{9}$$

where: t_d - delay time; SLT – Start Up Lost Time [s]; t_{vm} – time unit to reach the average speed [s]; N –number of vehicles [veh/lane]; h – headway factor [s]; $v_{i,i+1}$ - speed of the road section;

Evaluation of offset algorithm

In the final of our study, we have developed a fuzzy logic program [14 – 16], to automatically calculate the offset coefficient (k_i), depending on the hazardous features (weather, vehicle type, minor events). To determine these coefficients we suggest the following hypothesis: we suppose that driver behavior depends on the chosen parameters (weather, vehicle type, minor events). In this case, we set the offset coefficient (k_i) according to relation (6), where $\tau_{i,i+1}$ is calculated according to relation (4) and the average speed proposed in *Table 3*. Then, the offset coefficients (x_i) will be calculated according to the following relations:

$$\begin{cases} k_i \in [1,2] \\ k_i = x_1 + x_2 + x_3 \\ x_1 = 2 \cdot x_3 ;\ x_2 = 1.5 \cdot x_3 \end{cases} \tag{10}$$

From (10) results that $x_1 \in [0.44; 0.9], x_2 \in [0.33; 0.65]; x_3 \in [0.23; 0.45]$. In *Table 3* are presented the parameters and the coefficient values, calculated according to the average speed we have proposed for analysis.

Table 3.

The offset parameters and coefficient calculation

Average Speed [km/h]	k_i	x_1	x_2	x_3
60	1	0.23	0.26	0.67
45	1.5	0.67	0.5	0.33
30	2	0.9	0.66	0.44
>30	>2	-	-	>0.45

Thus, we consider the "k_i" coefficient as a triangular fuzzy function [5], for which the associated values of 30 km/h, 45 km/h and 60 km/h average speeds are known. In each experiment, we have varied the inputs and we have analyzed the offset value. For any x_i parameters value, the function (k_i), will be automatically determined by interpolation using fuzzy logic, offered by Matlab program in Fig. 2 [10].

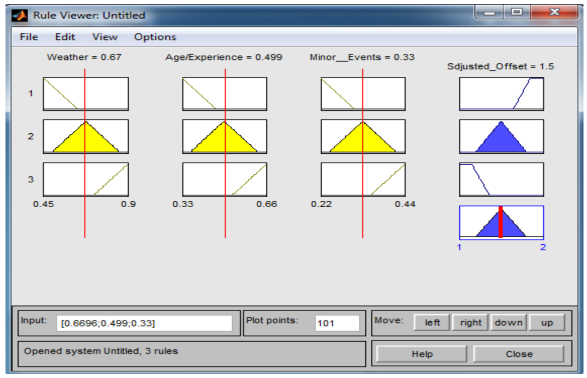

Fig. 2. Input/output values of the fuzzy logic model in Matlab.

In *Table 4* the initial traffic data conditions that we took into account for our analyses are listed. As one can see, we have used only three adjacent intersections for simulation, enough to highlight our approach. Although the Cycle Length, Brut Green Time and initial offset were calculated according formulae presented above in relations (1) and (2), we considered them as part of initial conditions.

Table 4.

The initial traffic data conditions

Inters No.	Distance [m]	Speeding [km/h]	W-E Volume [vph]	N-S Volume [vph]	SLT [s]	Cycle Length [s]	W-E Green Time [s]	$\tau_{i,i+1}$ [s]
i	-	-	800	500	5	72	39	-
i+1	380	60	450	300	5	35	15	8
i+2	290	60	900	500	5	80	45	9.4

Simulations showed that for an inadequate offset calculation, more than 50% of vehicle will receive red light before passing through the artery road, and this automatically increases the travel delay. Of course, it is difficult to reach the limit case of our approach (30 km/h), but this cannot be omitted. In our approach we didn't consider the major events (accident that takes more lanes, average speed < 30 km/h), because in this case, the control light cannot improve the traffic flow. As one can see, *Table 5* presents results obtained during the testing.

Table 5.

The experimental results

Common Cycle [s]	Average Speed [km/h]	τ_{adjust} i,i+1 [s]	τ_{adjust} i+1,i+2 [s]	Stop Number ($\tau_{i,i+1}$)	Stop Number (τ_{adjust})
80	60	17	30	1	1
80	45	21	37	up to 2	1
80	30	32	56	up to 3	1
80	>30	-	-	-	-

4. Conclusions

In this paper we have proposed a new adaptive traffic light system and a new traffic light green-wave control algorithm that takes into account the driver's behavior. The innovations include the introduction of new parameters (weather, vehicle type, minor events), designed to improve the method for calculating the green wave. According to our approach, it is clear that in this case traffic flow will be improved by reducing stop number and each car's delay. To calculate the offset adjustment constant, we have used a fuzzy logic simulator, while the remaining results are simply mathematical calculations. The main advantage of using a fuzzy logic model is the simplicity of the approach. This is because the fuzzy logic can better capture human expertise through manual adjustment of membership functions. Simulations have shown that using fuzzy systems, we can have satisfactory results even with a small quantity of information.

The next steps especially focus on the improvement our algorithm by taking in account others parameters like driver fatigue, or time of day (in terms of behavior), for adjusted offset constant. An improvement of the algorithm will lead to better performance of the green wave control system, and the existing resources of the road and traffic light can be fully used.

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