Adaptive Traffic Light Control System Using Wireless Sensors Networks

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***Abstract*—Optimization of signal control at intersection by using real time traffic collected by wireless sensors network presents an important focus of research into intelligent transportation system. Several studies have proposed adaptive algorithm road traffic which concentrates on determining green light length and sequence of the phases for each cycle in accordance with the real time traffic detected, and in order to minimize the waiting time at the intersection, these methods have chosen to give priority to the largest queue. In this paper we propose adaptive traffic light control method for an isolated intersection that considers a number of traffic factors such as traffic volume, and the waiting time. In this method we give priority to the shortest queue and we show that this method reduces waiting time.**

Keywords— smart traffic, intelligent transportation system, traffic light control, traffic congestion.

I. INTRODUCTION

Congestion at road intersections is a source of irritability, stress and fatigue for drivers, given the complicated state of the current signaling controllers, which the intelligent transportation system introduced in order to manage traffic and reduce waiting time for drivers at the intersections. The current signaling controllers assign a fixed duration for each light and for all cycles and this method is not adequate when one lane has a large number of vehicles waiting for the green light while another one in green light has only a few vehicles or else it has none, that presents a waste of energy and sources of pollution and stress for drivers. Consequently, several research works attempt to improve traffic at road intersections based on the measurement of traffic at these intersections by wireless sensors networks.

The principle of the road traffic management problem at an intersection is to know how to react in real time to the traffic change at the intersection lanes, in order to improve the control efficiency of the traffic light, reducing the waiting time for the green light and avoiding traffic congestion at the intersection.

Knowing the traffic is an essential element in real time for the operation of the road network and in particular to feed traffic management assistance systems at the intersection (base station). To do this, we use a network of wireless sensors where the role of each sensor is to collect a set of data in its environment and transmit it to a base station, which is responsible for traffic management.

In this paper, we present an adaptive traffic management algorithm that allows specifying the sequence of phases and the green light time according to the waiting time and the number of vehicles for each lane.

The document is organized as follows: after the introduction, in section 1, we present some traffic management algorithms. In section 2 we propose an adaptive algorithm to determine the sequence of phases and the time of green light. In section 3 we evaluate our method via the SUMO simulator and we demonstrate its effectiveness by comparing the results to other methods.

II. RELATED WORKS

Optimization of control signalization in isolated intersection is an important axis of research in intelligent transportation system. This contribution focuses on two essential criteria: to maximize the flow crossing the intersection during the green light and to minimize vehicles waiting time, by exploiting the data collected by the wireless sensors. The literature of this aspect of research is abundant, it explores several theoretical models: fuzzy logic [1], fluid mechanics [2], neural networks [3] and queues [4].

In [1], a method based on fuzzy logic is employed, in this method the authors present a table which define the green light time according to the numbers of vehicles waiting. For example, for an intermediate flow with a number of vehicles arrives between 5/min and 10/min, we allow duration of 20s for green light.

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The research work [5] considers a topology of two sensors in such lane which are separated by a variable distance that depends on the maximum green time. The authors, in the same paper, presented an adaptive controller which specifies the phases and their order for each cycle. This solution permits also a management of emergency vehicles.

The research work [5] proposes a light plan based on movement combinations can make simultaneously without any conflict. The authors use the same model of intersection presented in figure 1 with a topology of two sensors in such movement which are separated by a variable distance that depends on the maximum green time. In this model of intersection there are 4 lanes and 8 distinct combinations of non-conflict movements. this algorithm then selects the sequence of phases composing a cycle, according to several criteria: the presence of priority vehicles, the duration of the periods when no detection of new arrival, the cases of famine, the total waiting time and the length of the queues wait.

The model proposed in [5], however, is based on unrealistic assumptions, requiring vehicles to be of the same type and run at the same speed.

The authors, in [4], use the model of intersection presented in figure, each lane equipped by two sensors which are separated by a distance of 10 m. And they presented each lane as a M/M /1 queue model and they use the Little law that gives $W = Q_L / \lambda$ and equation 2 to calculate the queue length in each lane for a cycle.

$$Q_{L_j} = Q_{L_{(j-1)}} + \lambda G_G - \mu G_G + \lambda G_R \qquad (1)$$

where W is the waiting time, Q_L is the queue length and λ is the arrival rate of the vehicles, j represents the traffic cycle number, Q_{L_j} is the expected queue length in this cycle, $Q_{L_{(j-1)}}$ is the queue length from the previous cycle , λG_G is The arrival rate in the green phase , λG_R the arrival rate in the red phases and is considered equal to μG_R within the same cycle, μ is the departure rate.
The G the green period of one phase in seconds, and R represent the red light period in seconds and it is equal to difference between the T (Traffic cycle duration) and the green time period.
The algorithm in [4] selects at each phase the combination of non-conflicting movements whose have the largest number of vehicles, so as to minimize the average length of the intersection.
The green light time is determined in proportion to the length of the queues in the intersection.

III. PROPOSED SOLUTION

A. *Traffic modeling*

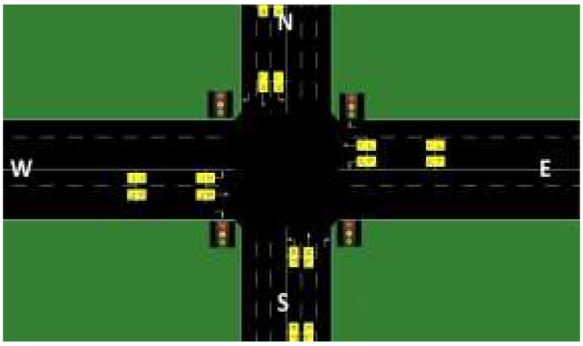


Fig. 1. Intersection model.

Our system (Fig 1) consists mainly of four directions (N, S, E, W) each of which contains two lanes (go straight and turn left). Vehicles are always allowed to turn right without restricting traffic. Traditionally, each lane was equipped with two magnetic sensors: one is located near the traffic light to count the number of departures of vehicles and the other is installed at a variable distance, which depends on the maximum time allowed for the green light, from the first sensor to detect the arrival of vehicles.

Each controller of the traffic lights defines a time called cycle which is a sequence of the phases and each of the phases presents a time of green light necessary for two movements (for example ES, EW, SN ...) which occur simultaneously.

All sensors communicate and transfer traffic information to base station which calculates the queues' lengths for each direction and its average waiting time in order to control the traffic flow.

TABLE I. THE CONFLICT DIRECTIONS MATRIX

	WN	*WE*	*SN*	*SW*	*EW*	*ES*	*NS*	*NE*
WN		1	0	0	0	1	0	0
WE	1		0	0	1	0	0	0
SN	0	0		1	0	0	1	0
SW	0	0	1		0	0	0	1
EW	0	1	0	0		1	0	0
ES	1	0	0	0	1		0	0
NS	0	0	1	0	0	0		1
NE	0	0	0	1	0	0	1	

The table 1 presents the conflict directions matrix. Each column and lane in the table demonstrate a direction in the intersection and its status if it is allowed or not. That means that all the possible movements with the number 1 can be made at the same time without creating a blocking at the intersection and the other number 0 shows that if we choose that lane direction and column direction in the same time we will have a conflict inside the intersection which increases the waiting time at the intersection.

B. Traffic light control algorithm(TACA)

In [6], we proposed a method to decrease the overall waiting time for a cycle, giving priority to the phase that has the smallest queue.

Our method has managed to decrease the overall waiting time in an intersection and during a cycle, but on the other hand, it has increased congestion which is contradictory to the main objective of the road traffic management which is to decrease waiting time and avoid congestion.

The data collected by the sensors are evaluated by a score S (equation 2) to choose the next phase that will have the green light. Two objectives are taken into consideration for the calculation of the score: the number of vehicles Q_u , Q_v and the waiting times W_u and W_v for two movements u and v which are able to cross at the same time the intersection without causing conflict. The movements are chosen respecting the conflict matrix.

If Q = 0 then S=0

$$\text{Else } S = \frac{(W_u + W_v)^{\alpha}}{(Q_u + Q_v)^{\beta}} \quad (2)$$

The values of α and β are chosen so that one objective is privileged to another, u and v are two lanes that can get the green light at the same time without conflict.
The queues' length for an instant t and for the lane k is given by (3).The first step is to collect the information received by the wireless sensors and analyze it in order to determine the lengths of the queues and their waiting times.

$$Q_j(t) = AR_j + AG_j + Q_j(t-1) - DP_j \quad (3)$$

Where:

$Q_j(t)$: The queue length for lane j and at time t

AR_j : Vehicles arriving during the red light and for the lane j.

AG_j : Vehicles arriving during green light and for the lane j.

$Q_j(t-1)$: Vehicles are remaining from the last green light.

DP_j : Number of departure during current green light.

AR , AG and DP are calculated from the information received by the two sensors.
To calculate the waiting time W there are two cases:
If there are no vehicles waiting from the last green light, the waiting time is the time of the first vehicle arrived during this red time.
If there are still vehicles from the last green light, the waiting time is the current red light time.
Equation (4) gives the waiting time value for each lane as a function of FA, time of the first vehicle arrived, RT the time of the current red light and K which is an index equal to 1 if there are vehicles of the last green light and 0 otherwise.

$$W = FA + K * RT \quad (4)$$

The green light time T_G required to serve the vehicles present on the lane of one phase.

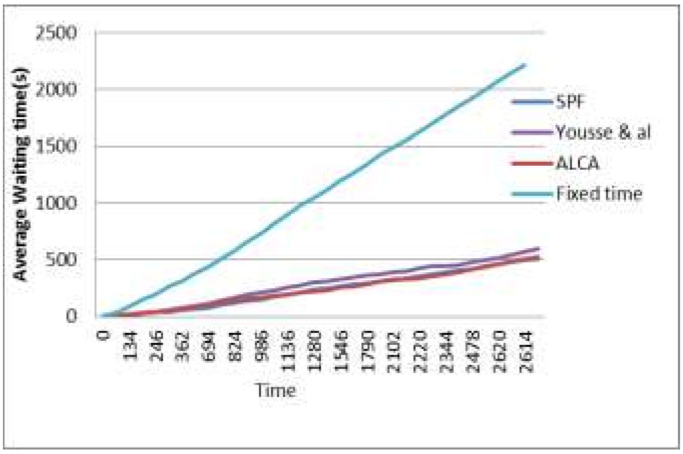
$$T_G = T_S + T_h * Q_l \quad (5)$$

With $Q_l = \max(Q_u, Q_v)$
And T_S is the average starting time of a queue, T_h is the mean time of light traversal for a vehicle, and Q_l is the vehicle size of the largest queue for the chosen phase.
The time of the green light must not exceed a maximum limit $T_{\max}$.
The maximum green light time has been the subject of severals studies. Kell and Fullterton [7] observed that $T_{\max}$ must be between 30 and 60 seconds. Lin [8] studied the relationship between $T_{\max}$ and the mean waiting time, so that T_maxis consistent even at peak times. Orcutt [9] suggested that $T_{\max}$ should be long enough to let 1.3 times the average length of the queue. Courage [10] indicated that a high $T_{\max}$ had little impact on an adaptive system if the traffic was too low. Finally, [11] and [12] proposed more modern methods in order to fix a coherent, complex $T_{\max}$ and the possible diversity of an intersection.

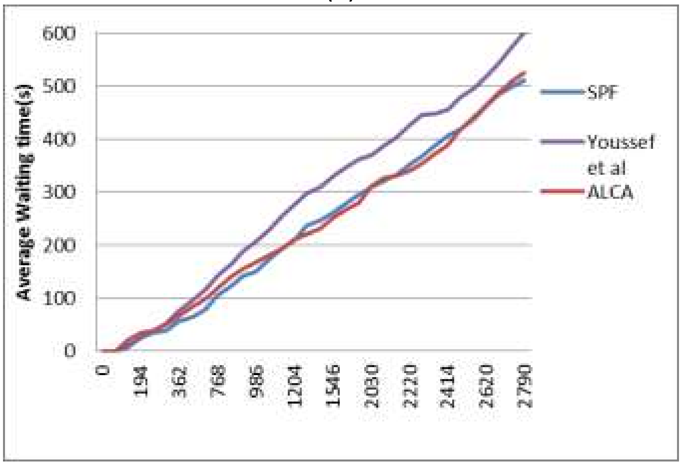
Algorithm 1: Adaptive Traffic Light Control Algorithm
Input: ARj, AGj , FA , DPj 1. if there exists a lane with green light priority then Assign green light to this phase next. 2. S={ES,EW,SW,SN,NS,NE,WE,WS} 3. Calculate W and Q for each element in S $W = FA + K * RT$; $Q_j(t) = AR_j + AG_j + Q_j(t-1) - DP_j$ 4. Calculate the Score S : $S = \frac{(W_u + W_v)^{\alpha}}{(Q_u + Q_v)^{\beta}}$ (u,v)϶ S and they can get the green light in same time If $Q_u + Q_v = 0$ then S(u,v)=0 5. Calculate max(S(i,j)) and select the lanes (u,v) wich composes the phase with max(S(i,j)) 6. Assign the next green light to this phase (u,v) 7. Calculate the green time T_G for phase (u,v) $T_G = T_S + T_h * Q_l$ If $T_G > T_{\max}$ then $T_G = T_{\max}$ 8. S=S - {uv} 9. If S={} go to step 2 , else go to step 3

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the method proposed in this manuscript and compare it with the fixed time controller [4], the Smallest Phase First (SPF) algorithm ,which gives priority to the smallest queues, and with the algorithm proposed by Youssef et al [5] which prioritizes the largest queues. For the simulation environment, we use the model of the intersection presented in figure 1.



(a)



(b)

Fig. 2. *Accumulated Average waiting time comparison between fixed-time control, Smallest Phase First control Youssef and al algorithm,and our proposed adaptive algorithm(ALCA)*

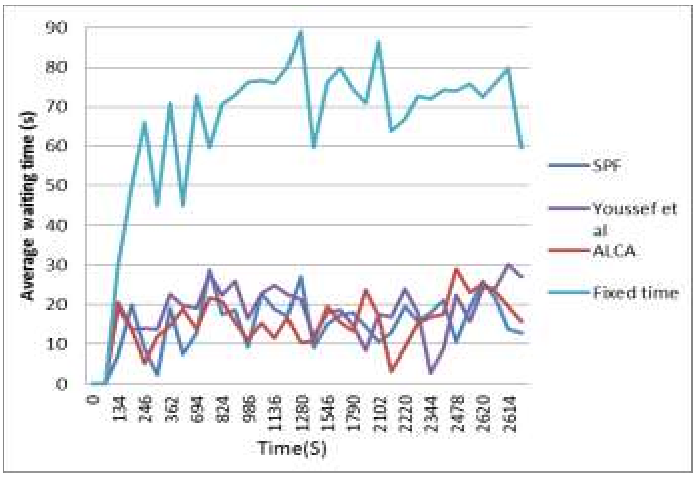
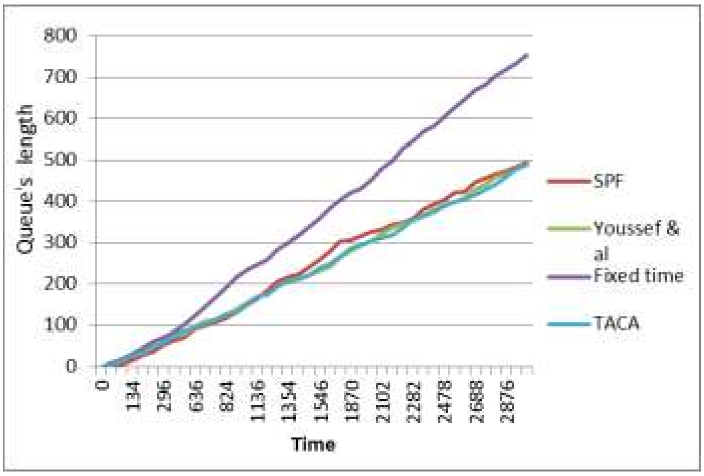
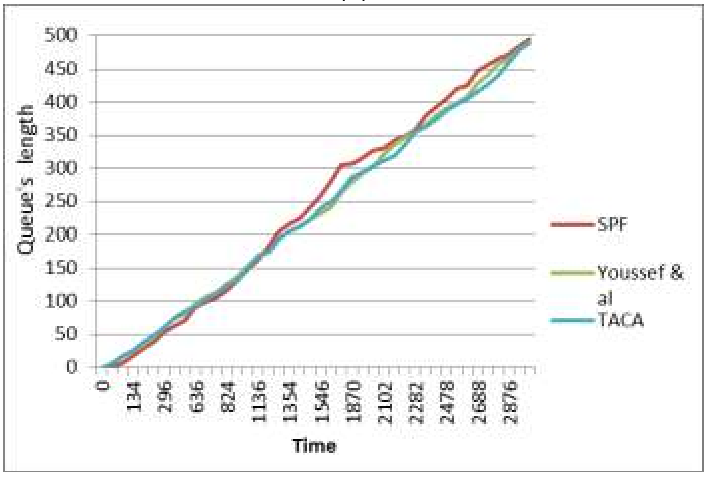


Fig. 3. *Average waiting time comparison between fixed-time control, Smallest Phase First control Youssef et al algorithm, and the proposed adaptive algorithm(ALCA)*



(a)



(b)

Fig. 4. *Accumulated queue's length comparison between fixed-time control, Smallest Phase First control , Youssef & al algorithm, and our proposed adaptive algorithm(ALCA)*

Figures 2 , 3 and 4 show, respectively, the variations of the waiting time of vehicles(Figures 2 and 3) and queuing lengths during a cycle in the simulation for the four traffic management methods presented above. Each simulation is launched for 3000s and the vehicles entering at the intersection follow the Poisson's law.

Figures 2 and 3 compares the results of simulations for the waiting time between four methods and shows that the algorithm (SPF) and our algorithm TACA give a reduced waiting time compared to that obtained by the algorithm proposed by Youssef et al, and by the fixed time controller. However, Figure 4, which shows the variation of queue lengths during the simulation, shows that the algorithm of Youssef et al and the algorithm that we propose give queues smaller than those obtained by the other methods.

The results of the simulations show that the algorithm proposed in this research work provides a significant improvement in the waiting time and the lengths of the queues compared to the results obtained by the methods of the fixed-time controller, Youssef and Al algoithm and Smallest Phase First (SPF).

CONCLUSION

In this paper, we have proposed an adaptive algorithm to control traffic light signalization at an isolated intersection and we based on two criteria: the waiting time and the queue's length. Our experimental results demonstrate that the proposed algorithm reduces the waiting time of vehicles compared to a fixed time control algorithm, an algorithm that gives priority to the small queue and another algorithm prioritizes the largest queues. . In our future research, we will try to expand to further investigate the problem of traffic control of multi-intersections.

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