Dynamic Traffic Controller Based on Traffic History and Density

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Abstract –**This paper studies two algorithms for allocating green duration and compares them in terms of vehicles average waiting time. The first algorithm, the contribution of the study, is assigning variable green light duration for each edge depending on the recorded traffic history and instant vehicles density. While the second algorithm, which is the ordinary traffic light system, assigns equal and fixed duration for each edge. The two algorithms are studied, implemented and simulated by using SUMO traffic simulator.**

Key words: ***Light traffic, traffic density, traffic history, ITS, adaptive traffic light.***

I. Introduction

The traffic light (TL) problem is a common issue which has been addressed in various aspects in countless studies. As the number of vehicles increases the problem exacerbates and the vehicle waiting time becomes longer and longer. The problem became very common issue in congested cities especially when the traffic load is not distributed equally among TL edges. The ordinary TL controller treats all edges equally regardless of the instant congestion. As a consequence the edges with less density are assigned green-light duration (GLD) more than they need while the congested edge is assigned green duration less than the sufficient time that lessens traffic jam. Several studies tackled the problem in different angles. The majority of them proposed solutions via replacing the fixed green-light-duration TL system (FGTLS) by a dynamic green-light-duration TL system (DGTLS). In this paper DGTLS is presented differently where the traffic history factor is introduced in a dissimilar way along with traffic density in all edges including traffic entering and leaving TL junction. The mathematical model of DGTLS for calculating GLD is derived in a way that dynamically changes for all edges and at the same time the summation of GLD of all edges is fixed at a predefined constant value. GLD of a specific edge depends mainly on three dynamic factors: instant density of entering traffic, instant density of leaving traffic of the other edges and traffic percentages history of that edge. I implemented and tested both algorithms, FGTLS and DGTLS, on SUMO software [5] using Python as a programming language. The experiment has been conducted on different scenarios for different traffic densities. The main two traffic scenarios were little-bias traffic and large-bias traffic. Biasing traffic was carried out by making traffic density at some edges larger than the others. In contrast the evenly distributed traffic, no-bias traffic, has not been considered as both algorithms act similarly.

II. Related work

DGTLSs or demand-actuated traffic systems have been studied and addressed by different methodologies. The used methods in the literature vary according to used hardware technologies, measured parameters and implemented software algorithms. In [1] only two parameters were observed, the leaving traffic density and the entering traffic density. They have been measured by utilizing four sensors. The first sensor is to capture the entering traffic density while the other three are to acquire the leaving traffic densities. The Measured values in [1] for the leaving traffic density were only two discrete values, either full traffic or no traffic. The computed GLD can have five possible numbers depending on the sensor reading. Another technology, inductive loop, is utilized in [2] in order to obtain the entering traffic. The algorithm of computing GLD in [2] was so simple that it may lead to assign one of the edges small GLD which might not be enough to let the vehicles pass across the junction. Moreover, different approach was introduced by [3]. This approach measures each vehicle travel time at a specific link to compute the optimal value of GLD of that link. Traffic history is presented in [4] to estimate the value of GLD. In my research the history traffic, entering traffic density and leaving traffic density all together play a key role to dynamically compute GLD using the coming mathematical model.

III. Mathematical Model

The derivation of the mathematical model of DGTLS comes from the relationship of the traffic movements and vehicle waiting time. Obviously as traffic density increases at a specific TL edge, the waiting time increases. To reduce the waiting time, the value of GLD at that edge needs to be larger. From this intuitive relationship I can say GLD and entering traffic density D are in direct relationship. For simplicity I assumed both are in directly proportional linear relationship.

$$GLD \quad \alpha \quad D \tag{1}$$

Similarly the leaving traffic density p and GLD are in reverse relationship. The reason behind this kind of relationship is to reduce GLD value when the density at the leaving edge is so high that no place for all vehicles at entering edge to move out to the leaving edge. The amount of GLD reduction depends on the value of p. GLD and p are assumed to be in inversely proportional liner relationship.

$$GLD \quad \alpha \quad \frac{1}{p} \tag{2}$$

The third main dynamic factor considered is the traffic history (H). H represents the summary of traffic at certain hour at specific edge. It can be measured by different hardware designs. H at each edge is divided into three directions: Forward, Left, and Right. H_F represents the percentage of vehicles at certain hour in the history that passes forward. H_R depicts the proportion of vehicles which turns right; similarly for H_L. By using traffic history it is possible to predict the direction of the instant vehicles density and in turns evaluates appropriate GLD. E.g. if H_r is high and p_r is low, this means high density of traffic turns right and the reception edge (right edge) can handle most of it (because the reception edge has low density p_r). Therefore GLD needs to have a large value. It can be inferred that GLD and H are directly proportional.

$$GLD \quad \alpha \quad H \tag{3}$$

Traffic history and leaving density are related. Both together form a consolidated factor In GLD calculation. From (1), (2), and (3) the following mathematical formulas are formed.

$$GLD \quad = \quad \alpha D + (1-\alpha)\frac{H}{p} \tag{4}$$

$$0 \le \alpha \le 1 \tag{5}$$

The factor α in (4) and (5) is a weight factor that gives significance for both terms of the equation. The larger the value of α is, the more weight given to entering traffic density is. When α is equal to 1, this means GLD calculation depends completely on leaving traffic density and thus traffic history and entering density are discarded.

Eq. (4) is computing GLD for one edge, where D and H are obtained from that edge. Since there is more than an edge at a traffic light junction and their summation is set to a fixed value (TT), two factors are introduced β and γ as depicted in (6).

$$GLD_i \quad = \quad \left[\frac{\alpha}{\beta}D_i + \frac{(1-\alpha)}{\gamma}\frac{H_{ij}}{p_j}\right]TT \tag{6}$$

The two parameters β and γ are proportional factors utilized to ensure the summation of GLD of the four edges is TT as shown in (7). The subscript *i* denotes the index of the entering edge while the subscript *j* depicts the index of the leaving edge as illustrated in Fig. 1.

$$TT = \sum_{i=1}^{N} GLD_i \tag{7}$$

The proportional factors guarantee that D, H, and p do not exceed 1 and respect the inequalities (8) and (9). N in (7) indicates the number of edges at a traffic light. $MAX(H_{ij}/p_j)$ in (11) denotes the maximum proportion of traffic history to leaving density among three directions for edge i.

$$0 \le \frac{\alpha}{\beta_i} D_i \le 1 \tag{8}$$

$$0 \le \frac{(1-\alpha)}{\gamma_i}\frac{H_{ij}}{p_j} \le 1 \tag{9}$$

$$\beta = \sum_{i=1}^{N} D_i \tag{10}$$

$$\gamma = \sum_{i=1}^{N}\left(\sum_{\substack{j=1 \\ j\neq i}}^{N} MAX\left(\frac{H_{ij}}{p_j}\right)\right) \tag{11}$$

GLD can be any value between 0 and TT. Eq. (6) can result in assigning so small value that it is not sufficient either for pedestrians or vehicles to pass across. Hence another constant need to be added to ensure minimum time MT for GLD. The final formula for GLD is shown in (12).

$$GLD_i = \left[\frac{\alpha D_i}{\sum_{j=1}^{N} D_j} + \frac{(1-\alpha)}{\gamma}\frac{H_{iM}}{p_j}\right](TT - N \times MT) + MT \tag{12}$$

IV. Simulation

The Mathematical model was implemented and tested in SUMO program, a program used for traffic simulation. The vehicle movements were simulated by Poisson distribution. The experiment has been conducted several times with different traffic scenarios. The traffic was generated randomly each time the experiment is repeated. Two measurements were collected from the experiment for each time of running the simulation, the average

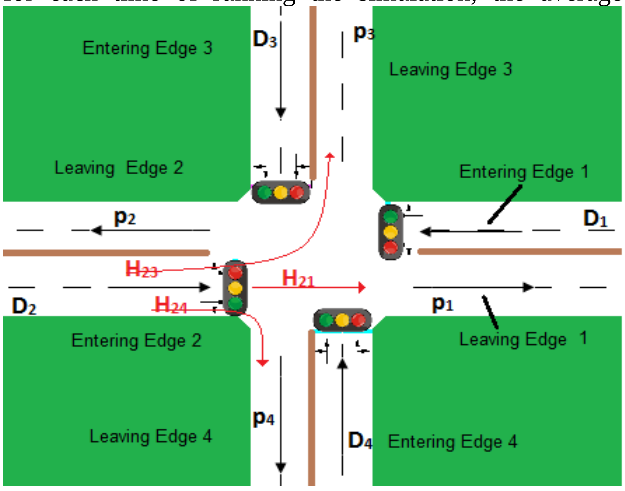


Figure 1. Traffic light with used terminologies

waiting time and traffic density. The waiting time is the duration at which the vehicle's speed is less than 0.1 m/h. The traffic density is computed as shown in (13).

$$D = \frac{N \times AveL}{EL \times NL} \tag{13}$$

Eq. (13) produces a number ranged between zero and one. N represents the number of vehicle on an edge. This can be counted by using sensors. AveL denotes the average length of vehicles and it can be estimated by using the traffic history. EL is an edge or a road length. NL designates the number of lanes within the edge. All of the factors are constants and preset except for N which needs extra HW implementation to compute it.

In order to test both algorithms, DGTLS and FGTLS, two traffic scenarios, Little-Bias and Large-Bias traffic, were generated.

A. *Little-Bias Traffic*

Traffic was generated in the simulation randomly and follows Poisson distribution. The traffic density in the roads was not equal. Certain edges have little preferences over the others. The simulation has been done for different values of α with various traffic densities for DGTLS. Fig. 2 illustrates the average waiting time for the three values. Assigning α with value of 0.4 outperforms the algorithms with α=0.5 or 0.7 in terms of average waiting time. This outperformance appears clearly when the traffic density is low. The gap starts decaying till the three curves converge at high traffic density of 0.54. Since α is the weighting factor between D and H, thus α value of 0.4 gives more significance to H than to D. In contrast α values of 0.5 and 0.7 confer D equal and more weight respectively.

Fig. 3 illuminates the average waiting time for both algorithms FGTLS and DGTLS in Little-Bias scenario. Average waiting time for DGTLS is less than FGTLS for traffic density. The gap between two curves keeps almost fixed except when D = 0.2 the gap reaches its peak. It is obvious that using dynamic assignment of green light duration lessens traffic jam considerably.

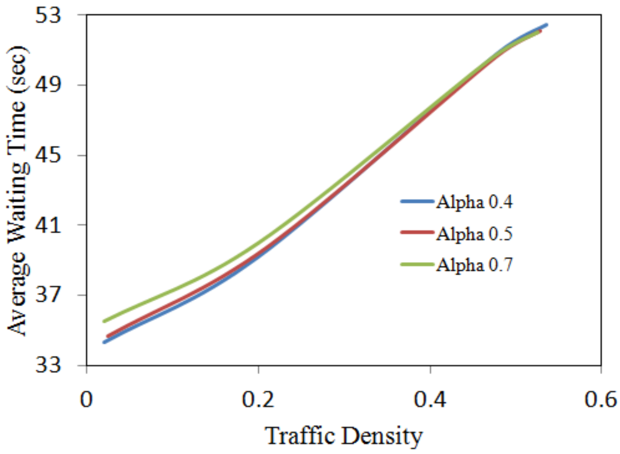


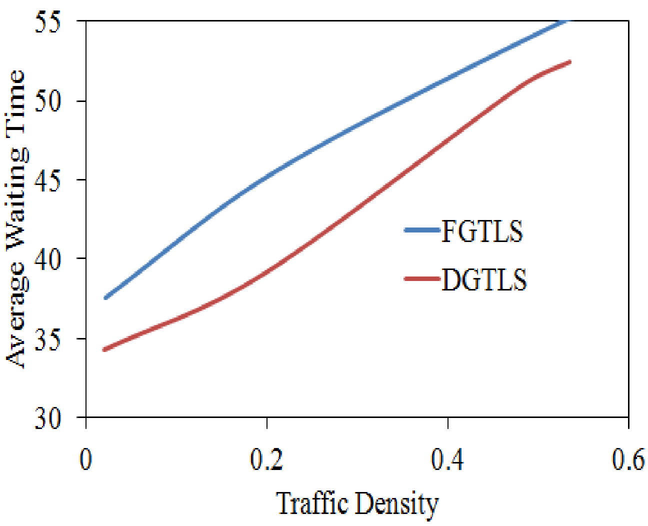
Figure 2. The average vehicle waiting time vs traffic density for three values of α for little-bias DGTLS algorithm.

B. *Large-Bias Traffic*

Dynamic traffic controller is powerful at the situation where the traffic is not distributed evenly. Balanced traffic among TL edges dose need a variable GLD. Most of TL junctions suffering from jams need a controller to assign long GLD at the edges that have congestions. In this simulation another scenario was implemented which is Large-Bias traffic. The vehicles trips were generated to pass along some edges much more than the other edges. The experiments have been conducted enough number of times to obtain sufficient confidence of the results.

The value of TT was set to 120. The number of edges was 4 as shown in Fig. 5. In the no-bias traffic scenarios each edge is given GLD of 30 seconds.

Fig. 4 illustrates the comparison between FGTLS and DGTLS in large-Bias traffic. The average waiting time of DGTLS curve is almost a double of FGTLS when the number of loaded vehicles into roads network ranges between 290 and 900 vehicles. The gap between two curves continue rising till reach its peak when the number



of loaded vehicles is around 2300.

Figure 3. Indicates the performance of FGTLS and DGTLS in terms of vehicle waiting time for Little-Bias scenario.

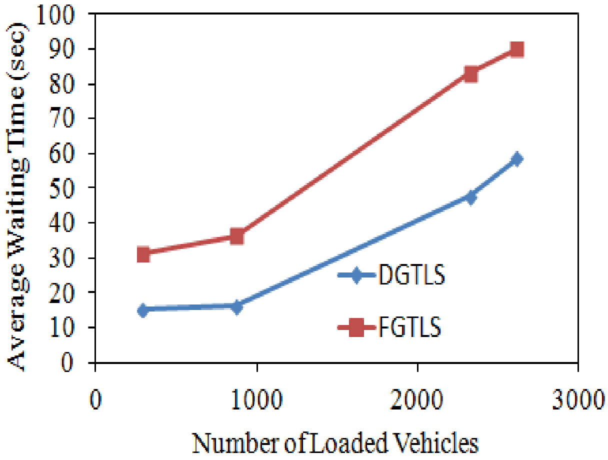


Figure 4. Shows the average waiting time for FGTLS and DGTLS in large-bias scenario

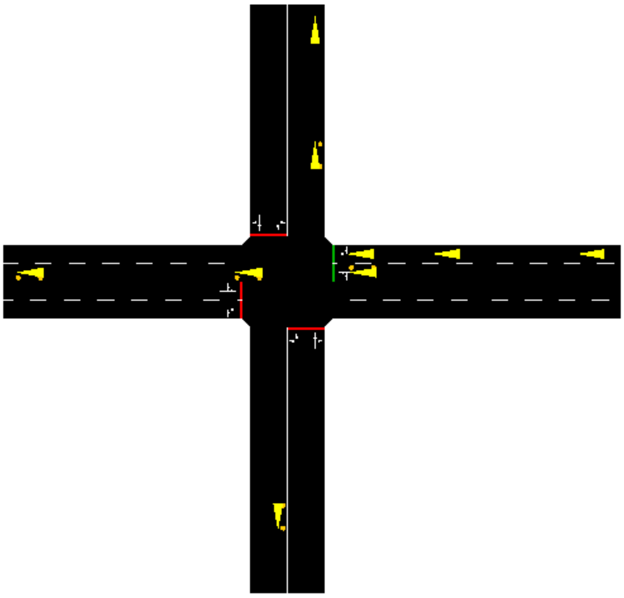


Figure 5. Illustrates the snapshot f the road network used in SUMO

V. DGTLS Algorithm

The algorithm presented in Table 1 was simulated and implemented in SUMO simulator, the algorithm was tested on the road maps shown in Fig. 5.

TABLE 1. SHOWS THE DGTLS ALGORITHM

Algorithm Name : DGTLS
BEGIN
DO
TT=120
MT=5
LIGHT_STATUS={“GRRR”,”RGRR”,”RRGR”,”RRRG”}
READ FROM SENSORS (D1,D2,D3,D4)
READ FROM SENSORS (P1,P2,P3,P4)
READ FROM DATABASE (H_{12},H_{13},H_{14},H_{21},H_{23},H_{24})
READ FROM DATABASE (H_{31},H_{32},H_{34},H_{41},H_{42},H_{43})
// USING EQUATION 12
COMPUTE (GLD[1],GLD[2],GLD[3],GLD[4])
GR=1
DO
GLD[GR]=GLD[GR]-1
OUTPUT LIGHT_STATUS[GR]
TT= TT -1
IF GLD[GR] = 0 **THEN**
GR = GR + 1
IF GR = 5 **THEN**
GR = 1
ENDIF
ENDIF
WHILE TT >= 0
WHILE TRUE
END

VI. Summary And Futurwork

DGTLS solves the problem of traffic light congestion especially when the traffic is congested on one of the traffic light edges. The experiments show the excellence of DGTLS over FGTLS in terms of average waiting time and traffic density. For future work the mathematical model can be modified to include new parameters such as roads states either under maintenance or emergency blocking. In addition the model parameters can be optimized using heuristic techniques.

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Biographies

Mohamed Ahmed T Elgalhud was born in ASCOT /UK, on July 6, 1981. He received Bsc degree in Computer Engineering from University of Tripoli in 2003. He got Msc degree in Computer Engineering from Northeastern University in USA in 2010. He is currently a lecturer in Department of Computer Engineering at University of Tripoli/Libya.