Optimized Timing Parameters for Real-Time Adaptive Traffic Signal Controller

Ahmad Aljaafreh, Naeem Al-Oudat
Computer and Communication Engineering
Tafila Technical University
Tafila, Jordan
{a.aljaafreh, naeemodat}@ttu.edu.jo

***Abstract*—Traffic control and management is a major problem in many cities, especially in growing and big cities. Traffic signals solve the problem of traffic conflict on intersection by time division multiplexing. The efficiency of traffic flow through an intersection depends on the phases, sequence and the timing of the traffic signals. Due to randomness, traffic signal timing optimization is complex and blind. This paper proposes a new model for an adaptive signal controller that optimizes the phases sequence as well as the timing of the traffic signals. Then using modified job scheduling algorithms the sequence of approaches on an intersection is generated.**

Keywords–modeling and simulation; optimization; traffic signal; EDF;

I. INTRODUCTION

Traffic control and management is a major problem in many cities, especially in growing and big cities. Traffic signals solve the problem of traffic conflict on intersection by time division multiplexing. Fixed-cycle controllers are being used in all signalized intersections in many countries. The only disadvantage of the traffic signal is the delay (stop time or waiting time). The delay on an intersection is the performance measure of the efficiency of traffic signal controller. The efficiency of traffic flow through an intersection depends on the phases, sequence and the timing of the traffic signals. Adaptive signal controller controls phases, sequence and timing of the traffic signals. Optimization of traffic signal timing and sequence is a critical factor when addressing traffic congestion. Due to randomness and many other situations traffic signal timing optimization is complex and blind. The goal of this paper is to design a real time adaptive controller to optimize traffic signal timing and sequence. Traffic lights controller can be categorized to two types; the conventional fixed-time controller and the real-time adaptive controller. The fixed-time controller uses a preset cycle time based on a prior knowledge of traffic flow. The cycle time is the time of a one complete rotation including green intervals plus the change and clearance intervals through all phases. The advantage of fixed time control is the simplicity of the control where the disadvantage is that it does not adapt to variable traffic situations. Adaptive controller uses sensors input to activate a change in the cycle time and/or the phase sequence. The system detects vehicles flow and queue length using electronic sensors embedded in the pavement or through images as in [1]. A fuzzy controller is proposed in [2] to dynamically control the traffic light timings and phase sequence based on traffic density and the delay on each approach on a single intersection. Two functions based on if-rules are used to determine the next phase and whether to extend the green time of the current phase or not. Simulation results using MATLAB/ SIMULINK software show that the performance of fuzzy controller is better than fixed controller in heavy traffic conditions. A comparison between fuzzy logic controller and a fixed-time controller is done in [3]. Simulation results show that the fuzzy logic controller has better performance. An improved discrete event simulation model of traffic light control using Matlab/Simulink/SimEvents on a single Intersection is described and validated in [4]. Each intersection stream is modeled as an M/M/1 queue. Time between vehicle arrivals is modeled using exponential distribution. The number of vehicles and the average waiting time in each stream are used as the performance indices for traffic light signal control. An adaptive time control algorithm is developed in [5] to compute the red/green light duration for each traffic signal found by using the conflict directions matrix. Simulation of fuzzy traffic controller for controlling traffic flow at multilane isolated signalized intersection is presented in [6]. An intersection model consists of two lanes with different values of vehicles queue length and waiting time in each approach. The maximum values of vehicles queue length and waiting times are selected as the inputs to the fuzzy controller. The main goal of this research is prevention of traffic jam and reduction of driver waiting time. This could be achieved by optimizing the functioning of traffic signal. Traffic signal optimizing is considered one of the most effective measures to address traffic congestion [7]. However it is complex and blind due to randomness and abnormal situations [7]. In this research a discrete event simulation model will be developed, verified and validated. The model will be tested in different scenarios. Thus the objective of this paper is to determine the optimized timing parameters for traffic signal by simulation. Designing a real-time proactive adaptive control model for traffic will enhance the performance of traffic light. The rest of this paper is organized as follows. Section II gives the details of the proposed model for adaptive traffic signal controller.

978-1-4799-4922-9/14 $31.00 © 2014 IEEE
DOI 10.1109/UKSim.2014.84

Section III gives a sequence example based on the proposed sequencing algorithm. Results are discussed in Section IV. Finally paper is concluded and some directions for future work are given in Section V.

II. Adaptive Traffic Signal Controller Model

In this paper, a real-time adaptive traffic signal controller model will be designed and investigated. The model is built using Matlab/Simulink/SimEvents to optimize the controller by simulation. The inputs of the controller are the traffic rate and the queue length for each approach. The outputs are the optimal signal green time and the optimal phase sequence as in Fig. 1 below. The controller will read queue lengths for all

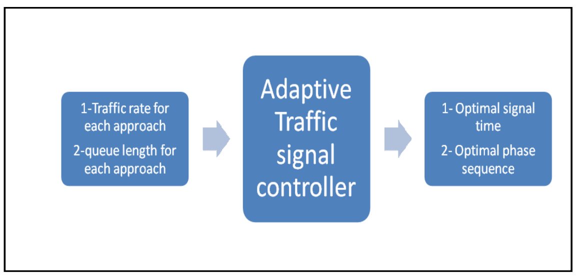

Figure 1. Block diagram for the inputs and outputs of the adaptive traffic signal controller.

phases based on the number of vehicle in the queue then the minimum green interval is computed. The minimum green time should be sufficient to clear the formed queue during the red period [8]. The controller will use a traffic flow arrivals from upstream approach to decide the optimal green time and cycle time. Then the Earliest Deadline First (EDF) scheduling algorithm is used to decide the phase sequence [9]. The controller will sample the arrival rate and calculate the optimal parameter each period of time as in Fig. 2. The

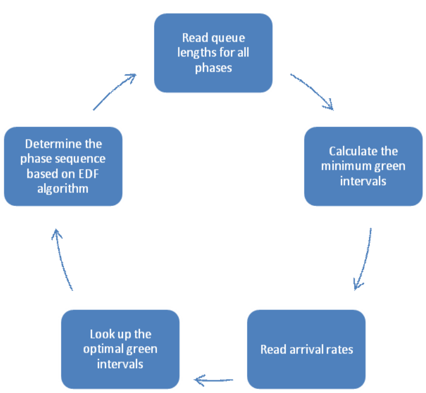

Figure 2. Flow diagram for adaptive traffic signal controller.

optimal green interval time according to the inter arrival time is shown in Fig. 3.

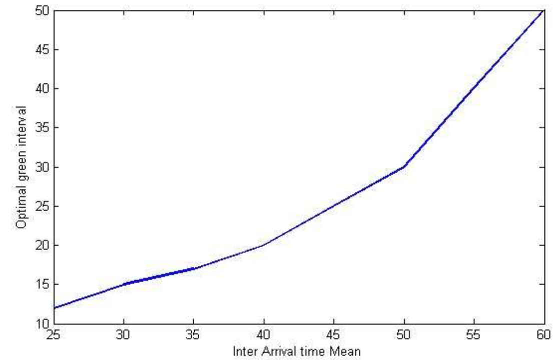

Figure 3. The relation between the mean of the inter arrival time and the optimal green time based on simulation results.

TABLE I
The Optimal Green Interval Values for Different Inter-Arrival Mean Time for Exponential Process

Inter Arrival time	Mean Optimal green interval/cycle time
25	12/68
30	15/80
35	17/88
40	20/100
45	25/120
50	30/140
55	40/180
60	50/220

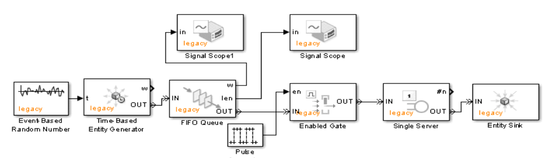

Figure 4. Simulink block diagram for a single approach.

III. Phase Sequence Example

Based on the data in the Table I above, assume an intersection with four approaches. If the traffic inter-arrival times in approach 1, 2, 3, and 4 are 25, 50, 45, and 25 seconds respectively. Then for each inter-arrival time there are an optimal green burst and an optimal cycle width. The sequence is determined for the following: approach one and four are considered as semi-periodic tasks that each one of them needs 12 seconds and repeats itself each 68 seconds. Following the same, approach two needs 30 seconds and come back after 140 seconds and approach three will be considered as a periodic task that needs 25 seconds and repeat itself each 120 seconds. Note that, it is not allowed

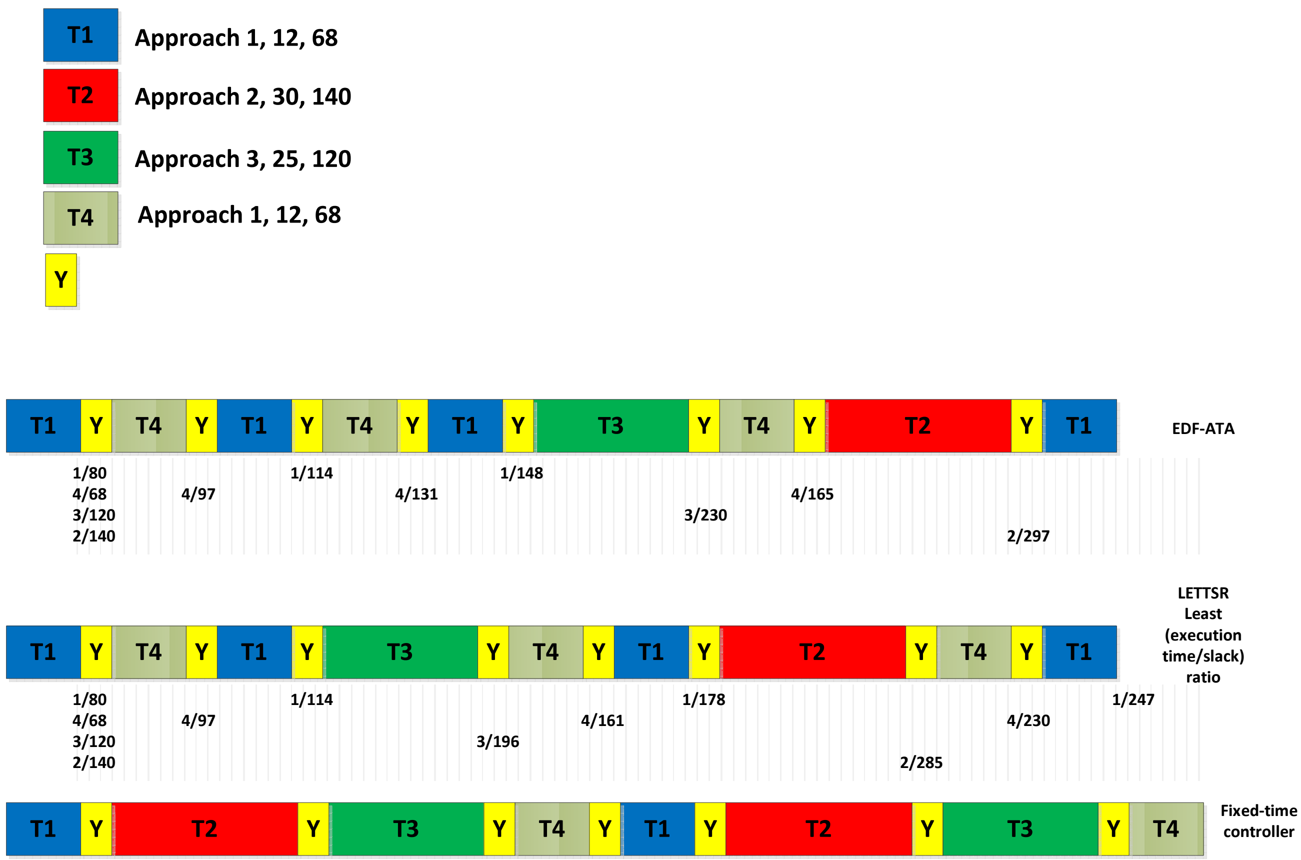

Figure 5. Sequencing of green intervals for the intersection example.

to have any idle slot whenever a car or more is waiting for traffic signal to be green. Two heuristic algorithms are proposed:

1) EDF with Always Ready Tasks (EDF-ART): when an approach green interval finishes, it is considered as ready with a deadline of its cycle plus current time.
2) Least Execution-Time To Slack Ratio (LETTSR): As in 1 task is ready once it finishes current green interval. The ratio of (time needed plus yellow time) and slack (remaining time to deadline) is calculated. Then the task (approach) with largest ratio gets its green interval. The intuition behind this is that, at any time a task which is more stressed in time should be given a highest priority.

The two algorithms are compared with the fixed time algorithm. The comparison presented next is only for a proof of concept purposes for the simple example given in Table I. See figure bellow for the three sequences obtained by EDF-ART, LETTSR and fixed-time controller algorithms. For the interval of 179 seconds shown in the figure below, one can calculate the average delay for each approach.

- For EDF-ART:
  (0(T1)+17(T4)+22(T1)+22(T4)+22(T1)+85(T3)+52(T4)+149(T2)+87(T1))/9=50.7
- For LETTSR:
  (0(T1)+17(T4)+22(T1)+51(T3)+52(T4)+52(T1)+115(T2)+57(T4)+57(T1))/9=47
- For fixed-time controller:
  (0(T1)+17(T2)+52(T3)+82(T4)+87(T1)+69(T2)+74(T3))/7=54.4

From the above calculated delays, LETTSR shows a smaller delay while fixed-time controller shows a longest delay. One should keep in mind that the two proposed algorithms are adaptive, which means that the sequence and each approach of the intersection. Sampling period of the arrival rate is in the order of minutes. It is not the case with fixed-time controller, where the sequence and green phases are kept for a time interval of days or even weeks.

IV. Results and Disscusions

A discrete event simulation model of traffic light control on a single intersection is built in this paper. The single traffic intersection model is developed in MATLAB using SIMULINK and SIMEVENTS block set as shown in Fig. 4. The optimal green time interval is determined by simulation for different traffic arrival rates as in Fig. 4. It is clear that there is an optimal green interval for each arrival rate. These values will be stored in a table to be looked up in accordance with arrival flow rates as in Table I. Each value in the second column has two values. The first is the optimal green interval. The second is the cycle time based on intersection consists of four approaches (east, west, north and south) with

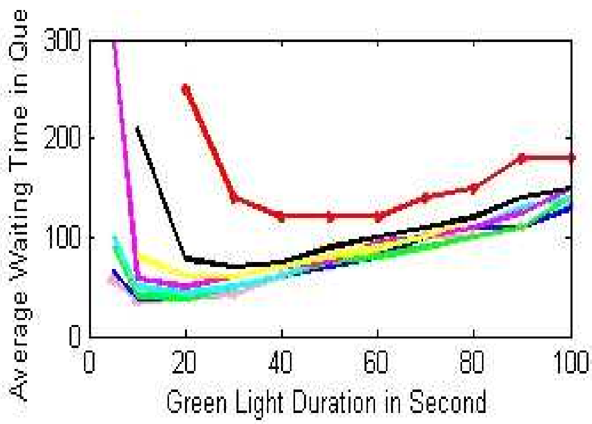

Figure 6. Simulink block diagram for a single approach.

one streams in each approach. Each optimal green interval with the cycle time is considered as a task that needs the optimal green interval time to be processed. These tasks are assumed to be periodic in accordance to cycle time. Thus EDF-algorithm schedules the sequence of phases based on relative task cycle which is also considered as its deadline.

V. Conclusions and Future Work

A model of adaptive traffic light control on a single intersection was built in this paper to optimize the green interval and phase sequence. Scheduling algorithms from computer science world was used for sequencing green intervals of different approaches on an intersection. Preliminary results showed that adaptive modeling and then sequencing of green interval outperform fixed-time controller's method currently adopted in traffic signals timings. As a future work, the problem could be formulated as a nonlinear optimization problem with minimizing total stopped delay per cycle. The results will be compared for the simulation and analytical optimization to determine the optimized timing parameters for traffic signals.

References

[1] George, Anna Merine. *FUZZY CONTROLLER FOR AN IMAGE BASED TRAFFIC SYSTEM.* IJMIE, volume 2, issue 6, 2012.

[2] Mwangi, Charles Maina, S. M. Kang'ethe, and G. N. Nyakoe. *Design and Simulation of a Fuzzy Logic Traffic Signal Controller for a Signalized Intersection.* Scientific Conference Proceedings. 2012.

[3] Center, Artificial Intelligence, and Jalan Semarak. *Intelligent traffic lights control by fuzzy logic.* Malaysian Journal of Computer Science 9.2 (1996): 29-35.

[4] Sumaryo, Sony, A. Halim, and K. Ramli. *Improved discrete event simulation model of traffic light control on a single intersection.* QiR (Quality in Research), 2013 International Conference on. IEEE, 2013.

[5] Yousef, Khalil M., Mamal N. Al-Karaki, and Ali M. Shatnawi. *Intelligent Traffic Light Flow Control System Using Wireless Sensors Networks.* J. Inf. Sci. Eng.26.3 (2010): 753-768.

[6] Soh, Azura Che, Lai Guan Rhung, and Haslina Md Sarkan. *Matlab simulation of fuzzy traffic controller for multilane isolated intersection.* International Journal on Computer Science and Engineering 2.4 (2010): 924-933.

[7] Gershenson, Carlos. *Self-organizing traffic lights.* arXiv preprint nlin/0411066(2004).

[8] Recker, Will, Xing Zheng, and Lianyu Chu. *Optimization of Control Parameters for Adaptive Traffic-Actuated Signal Control.*, 2010.

[9] C. L. Liu and J. W. Layland, *Scheduling algorithms for multiprogramming in a hard-real-time environment.* J. ACM, vol. 20, no. 1, pp. 40-61, 1973.