An Intelligent Traffic Light Scheduling Algorithm Through VANETs

Maram Bani Younes
PARADISE Research Laboratory
DIVA Strategic Research Center
University of Ottawa, Canada
Email: mbani047@uottawa.ca

Azzedine Boukerche
PARADISE Research Laboratory
DIVA Strategic Research Center
University of Ottawa, Canada
Email: boukerch@site.uottawa.ca

***Abstract*—Traffic signals are essential to guarantee safe driving at road intersections. However, they disturb and reduce the traffic fluency due to the queue delay at each traffic flow. In this work, we introduce an Intelligent Traffic Light Controlling (ITLC) algorithm. This algorithm considers the real-time traffic characteristics of each traffic flow that intends to cross the road intersection of interest, whilst scheduling the time phases of each traffic light. The introduced algorithm aims at increasing the traffic fluency by decreasing the waiting time of traveling vehicles at the signalized road intersections. Moreover, it aims to increase the number of vehicles crossing the road intersection per second. We report on the performance of ITLC and we compare ITLC to previous algorithms in this field for different simulated scenarios. From the experimental results, we infer that ITLC reduces the queuing delay and increases the traffic fluency by 25% compared to previous traffic light signal schedules. Furthermore, ITLC increases the throughput of each signalized road intersection by 30%.**

I. Introduction

Traffic lights have been utilized since 1868, to schedule and control the competing traffic flows at each road intersection using light cycle schedules. They provide safe scheduling that allows all traffic flows to share the road intersection [6]. The queuing delay at each road intersection deceases the traffic flow fluency and then decreases the traffic efficiency all over the road network. In order to enhance the performance of the traffic efficiency, several researchers have developed intelligent algorithms intending to schedule the traffic light timing [10], [11], [18]. The optimal schedule of each traffic light minimizes the delay of traveling vehicles at signalized road intersections.

Many researchers have considered the isolated traffic light intersection, where the phases of the traffic light are set according to the real-time traffic of surrounding flows [13], [14] and [15]. The traffic controlling at each traffic light is presented by the variable-sequence phasing cycle that represents the time schedule of each traffic flow which intends to pass such a road intersection [16]. Several parameters have been considered to schedule the sequence phase cycles at each intersection including: the number of vehicles, the traffic speed and the traffic volume of each flow, to mention a few. The less the average delay at each road intersection is and the higher the throughput of the road intersection is, the more efficient the scheduling algorithm becomes.

In this paper, we propose an Intelligent Traffic Light Controlling algorithm (ITLC). The introduced algorithm aims to decrease the the waiting delay time at each road intersection and to increase its throughput. The traffic flow with the largest traffic density is scheduled first, without exceeding the maximum allowable green time for that phase. We defined the area around the signalized road intersection where vehicles are ready to cross the intersection as *ready area*. The ready area is proposed to guarantee fair sharing of the road intersection without exceeding the maximum allowable green time. From the experimental results, we can infer that our proposed algorithm minimizes the queuing delay at each traffic light compared to previously proposed scheduling algorithms in this field by 25%. Moreover, a larger number of vehicles are crossing the signalized road intersection per second; larger throughput is obtained using ITLC.

The remainder of this paper is organized as follows: in Section II, we investigate the characteristics of isolated traffic lights. We discuss algorithms, mechanisms and protocols that have been previously proposed in this field in Section III. The phases of ITLC algorithm are detailed in Section IV. After that, Section V illustrates the performance evaluations of ITLC algorithm compared to other intelligent traffic light controlling mechanisms and algorithms. Finally, Section VI concludes the paper.

II. Isolated Traffic Light Intersection

Before investigating our algorithm and contribution compared to previously proposed mechanisms in this field, we present the definition and main characteristics of isolated traffic lights in this section. The isolated traffic light controls the traffic at each road intersection separately, without considering neighboring signalized intersections [6]. For example, Figure 1 illustrates a typical 4-leg road intersection; the 4-leg road intersection is shared by eight traffic flows, at any instant two of these flows can proceed simultaneously. The traffic light at such an intersection controls and schedules the sequence of the different phases while illuminating the conflict between the different traveling flows [6], [8]. At each traffic light the timing variables, including cycle length, phases, interval splits and offset parameters, are set according to the real-time traffic

978-1-4799-3784-4/14/$31.00 ©2014 IEEE

TABLE I
TRAFFIC LIGHT TIMING VARIABLE DEFINITIONS [6]

Variable	Definitions
Cycle Length	The time required for one complete sequence of signal intervals (phases).
Phase	The portion of a signal cycle allocated to any single combination of one or more traffic movements simultaneously receiving the right-of-way during one or more intervals.
Interval	A discrete portion of the signal cycle during which the signal indications (pedestrian or vehicle) remain unchanged.
Split	The percentage of a cycle length allocated to each of the various phases in a signal cycle.
Offset	The time relationship, expressed in seconds or a percent of cycle length, determined by the difference between a defined point in the coordinated green light and a system reference point.

flow characteristics [6], [7], [8]. Table I summarizes the timing variable definitions, at any signalized road intersection.

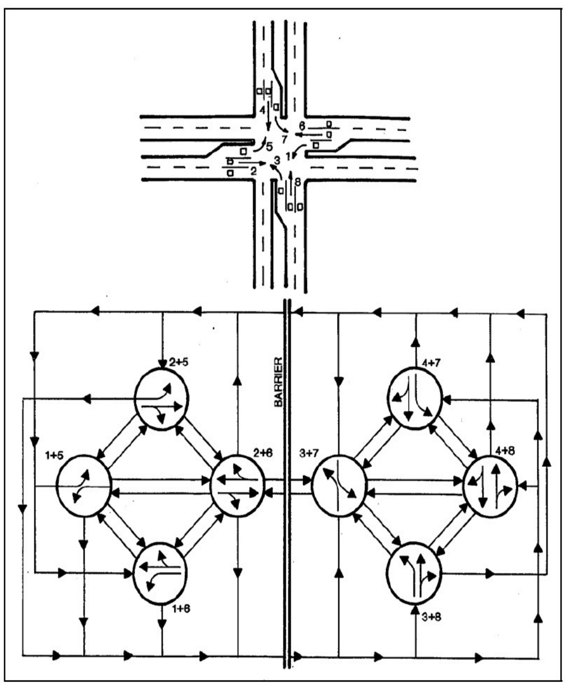

Fig. 1. Primary Phasing Options for 4-leg Intersection [6]

In general, Figure 1 illustrates all options of the primary phasing for any intersection where a variable-sequence phase or a skip-phase can be applied. In the typical controlling mechanisms (i.e., Pretimed mechanism), the cycle length, the phase length and the number and sequence of phases are set permanently for each traffic light as soon as it is installed. Engineers use statistical data for the traffic characteristics all over the area of interest to set these parameters [6], [9].

On the other hand, Traffic-Actuated Control system has been introduced to control the timing values of each phase according to the current traffic characteristics [6], [7]. Real-time detectors are required to develop semi and fully actuated control systems at each isolated traffic light. In general, the interval setting time of the green and passing intervals should be set according to mathematical operations. These operations consider the traffic speed, the capacity of the road intersection and the orderly traffic movement [7], [8], [9].

Vehicular Ad hoc technology can be thought of as real-time detectors that evaluate and report the traffic characteristics of each traffic flow at the signalized road intersection. Many adaptive and intelligent traffic scheduling algorithms have been introduced to increase the throughput of road intersections and the traffic fluency all over the area of interest [3]. In Section III, we present some previously introduced mechanisms and scheduling algorithms in this field.

III. RELATED WORK

The intelligent traffic light considers the traffic characteristics of the surrounding traffic flows, that intend to cross the road intersection [5]. Several algorithms have been introduced using Vehicular Ad-hoc Networks technology to develop an intelligent traffic light controlling algorithms [12], [19]. The communications of VANETs enable the utilization of real-time traffic characteristics of all surrounding flows. In this section, we investigate some adaptive intelligent traffic light mechanisms that have been introduced, using VANETs over the last few years.

Behrisch et al., [14] and Krajzewicz et al., [15] developed adaptive traffic signal control systems based on car-to-car communication. The traveling vehicles in these systems detect the closest incoming traffic signal so they report the traffic characteristics. The traffic density, speed, and volume, among other parameters, are considered by each intelligent traffic light for the scheduling of the next cycle phases. Behrisch et al., [14] reduces the waiting time and the queue length at each intersection. Krajzewicz et al., [15] improves the traffic fluency and shows a clear advantage over other architectures regarding cost and performance evaluations.

The V2I communications are considered in [18]. At each road intersection, an RSU is installed to gather the basic data of traveling vehicles. No communications or cooperation among these RSUs are considered in this study. Each RSU uses the phase-based strategy algorithm [6] to optimize the traffic fluency and to minimize the waiting delay time. The time is divided into five second optimization intervals.

A traffic light control algorithm that is embedded within SUMO [4] simulation is introduced in [10]. This algorithm aims to minimize the queuing delay at each intersection by using the length of the jam in front of the traffic light as an input. Each traffic light attempts to solve the detected jams with the traffic light scheduling algorithm. This algorithm looks into the incoming lanes and measures the jam lengths on each lane. If at one of these lanes, the jam becomes longer, the lane is allocated a longer time of green light to reduce the jam; same as the traffic actuated control system.

Furthermore, Webster [13] proposed a real-time traffic signal control algorithm. It utilizes VANETs to collect and aggregate real-time speed and position information of individual vehicles to optimize the control of traffic lights at each road intersection. The paper formulates the traffic signal as a job scheduling problem, where each job corresponds a platoon of vehicles. An on-line algorithm (OAF) has been developed to minimize the delay across the intersection by scheduling the optimal sequence of several phases at each traffic light. The first come first serve principle is then applied to schedule the competing platoon in each flow. Mathematical analysis and simulation implementation have been used to prove the correctness and benefits of the introduced algorithm over pre-timed and actuated scheduling algorithms.

As early explained, the less the average delay waiting time at each road intersection and the higher the throughput of each road intersection are, the more efficient the algorithm becomes. In this work, we aim to introduce an intelligent traffic signal controlling algorithm (ITLC) that considers the real-time traffic evaluation of each road intersection. This algorithm provides an improvement over previously proposed algorithms in this field. In our algorithm, we schedule the phases time of the traffic light cycle where the maximum density in the ready area is crossing first during the green time of this phase. The details of the proposed ITLC and its performance evaluations are introduced in Section IV and Section V accordingly.

IV. An Intelligent Scheduling Algorithm for an Isolated Traffic Light

Here, we introduce a traffic light scheduling algorithm that considers the real-time traffic characteristics of the surrounding road segments at each signalized road intersection. In our work, we consider the typical four-leg road intersection, illustrated in Figure 1. In the proposed algorithm, the traffic intersection is seen as a shared processor among eight flows of traffic. Vehicles arrive at the road intersection at different estimated times, so each flow of traffic can be seen as a set of successive processes. Each process contains one or more vehicles that travel through the road intersection during the green phase of the traffic light. We determine the size of each process based on the number of vehicles located in the ready area during the data gathering phase (i.e., traffic density of each traffic flow).

The ready area is a virtual defined area around each road intersection. Figure 2 illustrates an example of a ready area. The boundaries of each ready area are set based on the maximum allowable green time of the traffic light for each traffic flow. The ready area guarantee a fair share of the road intersection among the competing traffic flows. The ready area aims also to split the successive processes on each flow of traffic. Each traveling vehicle and located traffic light are assumed to be equipped with a wireless transceiver and GPS tools. The intelligent traffic lights at each isolated intersection periodically broadcast the boundaries of the ready area. Thus, the traveling vehicles becomes aware if they are located inside the ready area boundaries or not, and in which flow they are located based on their current potions. Traveling vehicles located inside the the ready area boundaries should report the real-time traffic characteristics of each traffic flow to the located intelligent traffic light.

Each vehicle over the road periodically broadcasts the basic traveling data (i.e., location, speed, direction, destination, etc). Vehicles receive the basic traffic data of surrounding vehicles. Based on the location of each sender vehicle the receiver vehicle decide if they are located on the same traffic flow (i.e., same process) or not. The traffic density (d_i), traffic speed (s_i), and estimated traveling time (t_i) are computed for each traffic flow inside the ready area according to [2]. For each traffic flow, the vehicle that is located closest to the traffic light reporting the traffic characteristics of such a flow to the intelligent traffic light.

The period of time (T) required by all vehicles in any process to pass the traffic light, is computed by using Equation 1.

$$T = \alpha + \frac{F_d}{S_{tf}} \tag{1}$$

In this equation α is a constant that accounts for the startup delay of the very first vehicle in each set of vehicles, gathered in one process, the best value of α should be set empirically; and, F_d is the distance between the furthest vehicle in the process and the traffic light at the road intersection. The distance from the traffic light to the boundary of the ready area (L_{ra}) is set based on the traffic speed of each traffic flow (S_{tf}). The time T should not exceed the maximum allowable green time of the traffic light. In other words, all vehicles, located in the ready area during the data gathering phase, should be able to pass the traffic intersection before the maximum green time.

For the 4-leg intersection with eight competing flows of traffic, eight options of double thread executions are illegible for each phase of the timing cycle. These phase including: P_{15} (1+5), P_{25} (2+5), P_{16} (1+6), P_{26} (2+6), P_{37} (3+7), P_{47} (4+7), P_{38} (3+8), and P_{48} (4+8), as illustrated in Figure 1. In

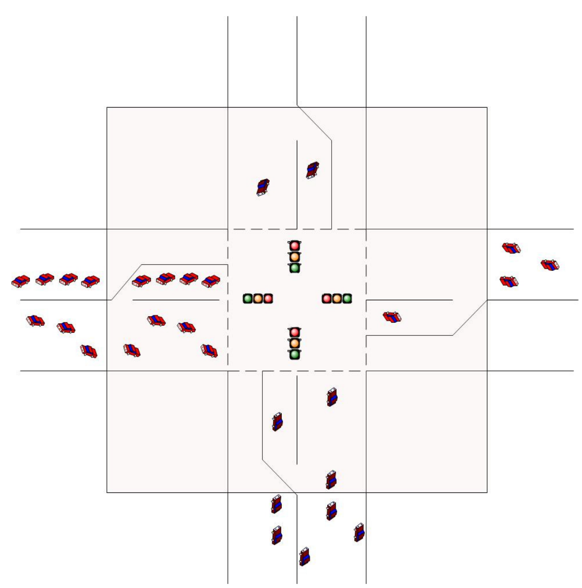

Fig. 2. Ready Area Around the Traffic Light

the proposed algorithm, the scheduling of all traffic flows start with the largest density ($Max(d_i)$) first. The assigned time to each phase based on the distance between the road intersection and furthest vehicle in each process. Algorithm 1 illustrates systematically the sequence phases of the scheduling algorithm. As soon as a traffic flow cross the road intersection, the traffic density and estimated traveling time of such a flow are set by 0. The intelligent traffic light iteratively schedule the competing flows choosing the largest density first until the density of all traffic flows are 0's. Then the traffic light executes the algorithm again for the recent reported traffic characteristics of all traffic the inside the ready area.

Algorithm 1: Intelligent Traffic Light Scheduling Algorithm

Data: TL : Traffic Light; RA: ready area; d_i : The traffic density of the traffic flow i inside RA; t_i: the required time for all vehicles inside RA, at the traffic flow i to cross the traffic intersection.

compute d_i and t_i of all traffic flows inside RA;
while *d_i of any of the traffic flows at $TL > 0$* **do**
  let j the traffic flow with the maximum traffic density (d_j);
  let $i1$ and $i2$ the traffic flows that can cross the traffic intersection simultaneously with the traffic flow (j) ;
  if $d_{i1} > d_{i2}$ **then**
    P_{ji1} = schedule (j, $i1$);
    $d_j = 0.0$; $d_{i1} = 0.0$;
    $t_j = 0.0$; $t_{i1} = 0.0$;
  else
    P_{ji2} = schedule (j, $i2$);
    $d_j = 0.0$; $d_{i2} = 0.0$;
    $t_j = 0.0$; $t_{i2} = 0.0$;
  end
  Adjust the t_k of all other traffic flows inside the ready area;
end

In each traffic light cycle, four phases of the eight candidate phases are selected to allow all flows of traffic to proceed. ITLC is expected to increase the throughput of the road intersection and decreasing the queuing delay time of traveling vehicles. This is due to less number of vehicles waiting at each competing traffic flow for the first phase. Moreover, the scheduled time is adjusted for each traffic flow after each green phase, thus for the next coming phases vehicles on the waiting flow need to wait fewer time. The time is adjusted based on the estimated current location of the furthest vehicle in each traffic flow. The current location of such a vehicle can be estimated based on the last reported location and the traffic speed of the traffic flow. In the case the estimated location of the furthest vehicle is approaching the road intersection, this means all detecting vehicles inside the ready area on this flow are waiting on the road intersection at this scenario. Thus, the green time of the traffic flow set main based on the number of traveling vehicle in front of the furthest vehicles.

Algorithm 2: Schedule Function

INPUT: traffic flows i and j
if $t_i > t_j$ **then**
  return t_i
else
  return t_j
end

As aforementioned in each scheduled phase two traffic flows are set pass the road intersection simultaneously (e.g., P_{15} (1+5) or P_{15} (2+5)). The green time set for the phase using the largest estimated traveling times between the two proceeding traffic flows in the scheduled phase. Algorithm 2 illustrates the time scheduling function of each phase systematically.

V. Performance Evaluation

In this section, we evaluate the performance of our proposed algorithm (ITLC). We have used SUMO [4] to generate several experimental scenarios. In these scenarios, traveling vehicles aim to pass through a road intersection that is controlled by an intelligent isolated traffic light. A different number of vehicles have been generated for each scenario, to study the effect of traffic density.

We have compared the performance of ITLC to a previous adaptive traffic signal control mechanism (OAF) [13]. The latter mechanism (i.e., OAF) claimed a better performance against the VANET-enabled vehicle-actuated control, VANET-enabled Webster's, and an optimized fixed-time signal control, in terms of its ability to decrease the average delay per vehicle.

TABLE II
Simulation Parameters

Parameter	Value
Simulator	NS-2
Transmission range (m)	250
Simulation time (s)	2000
Simulation area (m^2)	1000 X 1000
Number of Traffic Lights	1
Number of Vehicles	200 - 1000
α	1.5
Simulation map	4-leg Traffic Intersection

In our experiments, we first compare the delay per vehicles, caused by the traffic light queuing delay. We then compare the total delay required for all detected vehicles inside the ready area at any certain time to cross the road intersection. Finally, we evaluate the throughput of each compared mechanism, by counting the number of vehicles that cross the intersection per second. Table II illustrates the main parameters used in our experiments.

Figure 3 illustrates the comparative performance of ITLC and the OAF [13]. We have executed each experiment for thirty different scenarios. The confidence interval for each experiment is 95%. Figure 3(a) illustrates the average delay per vehicle, where ITLC decreases the average delay for each traveling

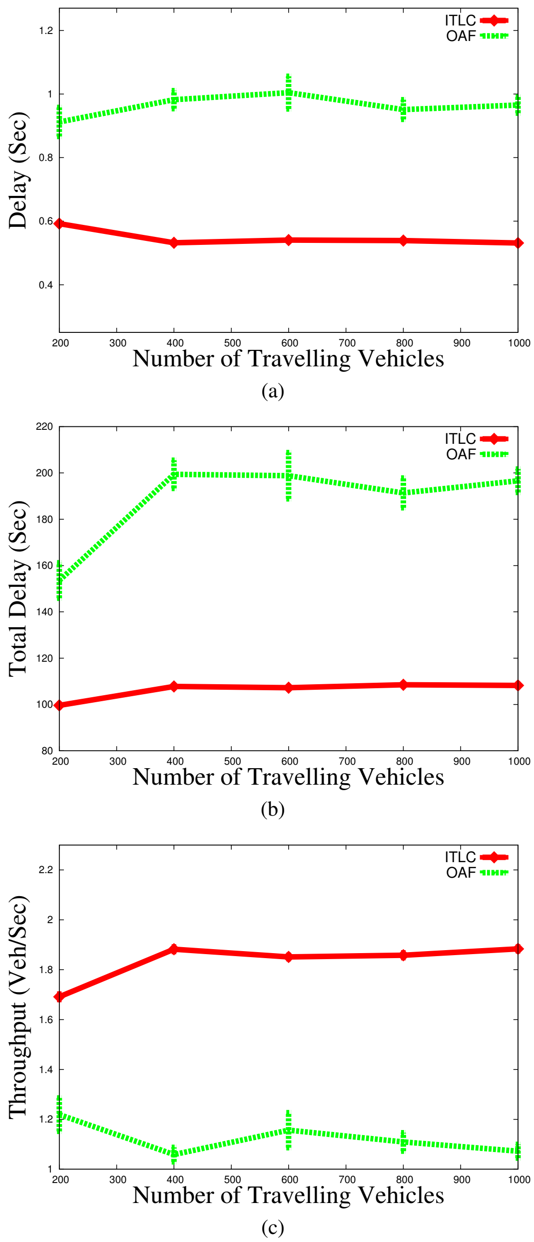

Fig. 3. The performance evaluation of ITLC compared to OAF [13]: (a) The delay per vehicle on the traffic light, (b) The average total delay of all detected vehicles inside the ready area to pass the traffic light, and (c) The throughput of the traffic light (i.e., number of vehicles pass the traffic light per second)

vehicle by 30% compared to OAF [13]. On average each vehicle waits 30% less time at the road intersection when ITLCS is used instead of OAF.

We have measured the total delay that is required by all detected vehicles, at a certain point of time to cross an intersection. The total delay in ITLC, is 25% less than the required delay in OAF; this is illustrated in Figure 3(b). In general, as inferred from Figure 3(a) and Figure 3(b), ITLC decreases the queuing delay of traveling vehicles by 25% on average compared to OAF for all traffic density scenarios.

On the other hand, Figure 3(c) illustrates the throughput of a traffic intersection that utilizes ITLC and OAF to schedule the traffic light signal phases. As we can see from Figure 3(c), the number of vehicles that pass the road intersection per second, using ITLC algorithm, is 30% greater than the number of vehicles that pass the road intersection per second, using OAF algorithm. This is due to the principle of the maximum density first schedule of ITLC, which assigns the longest green phase to the largest detected density and less number of vehicles wait on the traffic flows with the lowest traffic density. Moreover adjusting the green time of each phase based on the estimated location of the furthest vehicle on each traffic flow, decrease the waiting delay time of the next competing flows. This also increases throughput of the road intersection, because no time is wasting after the last detected vehicle pass the intersection.

VI. Conclusion

In this paper, we have introduced an intelligent traffic light scheduling algorithm (ITLC). This algorithm utilizes the vehicular ad hoc technology to gather the real-time traffic characteristics of each surrounding traffic flow. The largest density first schedule is implemented to set the phases of each traffic light cycle. The ready area is defined around the signalized road intersection to determine the maximum allowable time for each phase. The maximum allowable time should not exceed the maximum green time. The actual time set for each phase depends on the location of the farthest vehicle in each process of the traffic flow. From the experimental results, we infer that ITLC algorithm achieves a better performance compared to previously introduced algorithms in this field. In terms of the average delay taken for each vehicle to cross a signalized road intersection, ITLC decreases the delay by 25%. At the same time, ITLC increases the throughput of each road intersection by 30%.

Acknowledgment

This work is partially supported by NSERC DIVA Strategic Network, Canada Research Chairs Program, and MRI/OIT Research funds.

References

[1] ”Network Simulator nss-2,” *http://www.isi.edu/nsnam/ns/*
[2] M. Bani Younes and A. Boukerche, *Efficient traffic congestion detection protocol for next generation VANETs,* Communications (ICC), 2013 IEEE International Conference on , vol., no., Pages 3764-3768, 9-13 June 2013.
[3] F. Webster, *Traffic Signal Settings*, Road Research Laboratory Technical Report, HMSO, London.
[4] M. Behrisch, L. Bieker, J. Erdmann and D. Krajzewicz, *SUMO Simulation of Urban MObility: An Overview*, SIMUL 2011, The Third International Conference on Advances in System Simulation, 2011, Pages 63-68, Barcelona, Spain, October.
[5] D. Krajzewicz, J. Erdmann, M. Behrisch, and L. Bieker, *Recent Development and Applications of SUMO Simulation of Urban MObility*. International Journal On Advances in Systems and Measurements, 5 (3and4):128-138, December 2012
[6] Dunn Engineering Asociates In association with Siemens Intelligent Transportation Systems, *TRAFFIC CONTROL SYSTEMS HANDBOOK*. Federal Highway Administration Office of Transportation Management Room 3404 HOTM 400 Seventh Street Washington, D.C. 20590, October 2005
[7] F. Al-Nasser and M. Mahmoud, *Wireless Sensors Network Application: A Decentralized Approach for Traffic Control and Management, Wireless Sensor Networks - Technology and Applications,* Dr. Mohammad Matin (Ed.), ISBN: 978-953-51-0676-0, InTech, DOI: 10.5772/48212. Available from: http://www.intechopen.com/books/wireless-sensor-networks-technology-and-applications/wireless-sensors-network-application-a-decentralized-approach-for-traffic-control-and-management

[8] J. Bonneson, S. Sunkari, and M. Pratt, *Traffic Signal Operations Handbook.* Report $No.FHWA/TX-09/0-5629-P1$. Texas Transportation Institute, College Station, Texas, March 2009.

[9] J. Bonneson, M. Pratt, and K. Zimmerman, *Development of Traffic Signal Operations Handbook*. $No.FHWA/TX-09/0-5629-1$. Texas Transportation Institute, Texas A and M University System, 2009.

[10] D. Krajzewicz, E. Brockfeld, J. Mikat, J. Ringel, C, Rssel, W. Tuchscheerer, P. Wagner, R. Wsler, *Simulation of modern Traffic Lights Control Systems using the open source Traffic Simulation SUMO*. In: Proceedings of the 3rd Industrial Simulation Conference 2005, Pages 299-302. EUROSIS-ETI. 3rd Industrial Simulation Conference 2005, 2005-06-09 - 2005-06-11, Berlin (Germany).

[11] C.T. Barba, M.A. Mateos, P.R. Soto, A.M. Mezher, M.A. Igartua, *Smart city for VANETs using warning messages, traffic statistics and intelligent traffic lights*. Intelligent Vehicles Symposium (IV), 2012 IEEE , vol., no., Pages 902,907, 3-7 June 2012

[12] D. Greenwood, B. Burdiliak, I. Trencansky, H. Armbruster, and C. Dannegger, *GreenWave Distributed Traffic Intersection Control,* Greenwood greenwavedistributed,

[13] K. Pandit, D. Ghosal, H.M. Zhang, C. Chen-Nee, *Adaptive Traffic Signal Control With Vehicular Ad hoc Networks,* Vehicular Technology, IEEE Transactions on , vol.62, no.4, Pages 1459-1471, May 2013

[14] N. Maslekar, M. Boussedjra, J. Mouzna, H. Labiod, *VANET Based Adaptive Traffic Signal Control,* Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd , vol., no., Pages 1-5, 15-18 May 2011

[15] V. Gradinescu, C. Gorgorin, R. Diaconescu, V. Cristea, L. Iftode, *Adaptive Traffic Lights Using Car-to-Car Communication,* Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th , vol., no., Pages 21-25, 22-25 April 2007

[16] P. Mirchandani, L. Head, *A real-time traffic signal control system: architecture, algorithms, and analysis,* Transportation Research Part C: Emerging Technologies, Volume 9, Issue 6, December 2001, Pages 415-432,

[17] T. Bellemans, B. De Schutter, and B. De Moor, *Model predictive control for ramp metering of motorway traffic: A case study,* Control Engineering Practice, vol. 14, no. 7, Pages 757-767, July 2006.

[18] C. Priemer, B. Friedrich, *A decentralized adaptive traffic signal control using V2I communication data,* Intelligent Transportation Systems, 2009. ITSC '09. 12th International IEEE Conference on , vol., no., Pages 1-6, 4-7 Oct. 2009

[19] L.D. Baskar, B. De Schutter, J. Hellendoorn, Z. Papp, *Traffic control and intelligent vehicle highway systems: a survey,* Intelligent Transport Systems, IET , vol.5, no.1, Pages 38-52, March 2011