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Towards a Smart Intersection using Traffic Load Balancing Algorithm

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Abstract—Over the past few years vehicle usage has increased exponentially worldwide, but the capacities of transportation systems are still limited, and have not improved in a tantamount way to expeditiously cope with the number of vehicles traveling on them. As a result, road jamming and traffic correlated pollution has increased, and became complicated and chaotic, leading to an adverse effect socially and financially worldwide. Fortunately, Intelligent Transportation Systems are promising technologies that have been introduced to assist in reducing the side effects of these problems. The intelligence of these systems mainly depends on the accuracy and timely reliable application of real time traffic information. In this paper, we propose a novel mechanism based on queuing theory aiming at enhancing the load balancing and reducing waiting times on busy road intersections. The simulation results were obtained using the OpNet simulator and have shown that the proposed mechanism can effectively reduce average waiting time and queue lengths up to 44% and thus provide an efficient solution for the load balancing problem.

Keywords—Intelligent Transportation Systems (ITS); VANET; M/M/1 Queueing Model; Traffic Congestion; Traffic Load Balancing; Smart Traffic Light

I. INTRODUCTION

Legacy transportation systems are considered to be among the most important systems that need to be addressed in a proper manner. This is due to the fact that traffic jamming and environmental pollution has increased with the associated adverse social and financial effects on different markets worldwide. Based on a report published in 2014 by Victoria Transport Policy Institute's Urban Mobility (UMR) [1], it is estimated that a huge amount of time and money are wasted. For example, they reported a time delay of 5.5 billion hours and fuel loss of 2.9 billion gallons in urban areas of the United States only due to traffic jamming in the time period between 2000 and 2010. Congestion is considered as one of the common problems cited in the literature [2,3], especially during peak times of the day because of the weakness of the absorptive capacity of the roads network and the inefficiency of the transportation system to meet the required demands of the increasing traffic size. As an example, the signal timing model of the conventional urban system uses a fixed-time slots algorithm to control traffic lights across an intersection that may have different vehicles' arrival rates on each of its roadsides. Therefore, the design of a smart/reactive signal

timing model for an intersection is important to increase the efficiency and utilization of such systems.

Intelligent Transportation Systems (ITSs) have been introduced by the research community and industrial sectors to assist in solving some of the problems raised by legacy systems. The main idea behind these systems is to apply efficient methods onto the existing infrastructure with the aim of increasing the road capacity, human safety, reduce traffic pollution, and minimize waiting times in dense and congested urban areas. In order to achieve these goals, these intelligent systems use several real data collection mechanisms and smart algorithms. One of the most dominant and cost effective approaches for real-time data collection are different IEEE networking standards, including Wireless Sensor Networks (WSNs), Zig Bee, Bluetooth, General Packet Radio Service (GPRS), Global System for Mobile communication (GSM), Wi-Fi and Wi-MAX [4]. These new technologies can be used to obtain road traffic information such as traffic volume, vehicles intended destinations/routes, and type of vehicle, among other things. Also, they can control traffic signals, cycles, and timing for improving traffic flows, enhancing vehicle energy efficiency by reducing the engine operating time and increasing safety.

The main contribution of this paper is to develop a smart and lightweight control mechanism to load balance the traffic coming into an intersection using an adaptive signal timing model according to real-time traffic flows. The proposed algorithm automatically decides the signal cycle to avoid the congestion problem; *i.e.*, it increases the green light period in some lanes and decreases it based on the incoming traffic load on the lane. The structure of the paper is as follows. First, in section II, we review relevant previous works. In section III, we explain the proposed system architecture and simulation setup. In section IV, we present simulation results and analysis. In section V, we present validation comparison with a relevant work, and finally in section VI we give the conclusion remarks.

II. RELATED WORK

A thoroughly review of the literature of ITSs and the deployed mechanisms shows several research proposals on urban traffic management focusing on different traffic parameters. These research proposals came from both academic institutions and industrial sectors. In this section we review the most relevant ones.

Recently, Akyildiz I. F. *et al.* [5] made a comprehensive taxonomy of different traffic management schemes used for avoiding congestion. They also emphasized that despite the large number of research activities and the excellent progress that has been made in traffic management systems in recent years, significant challenges associated with congestion control, average waiting time reduction, prioritizing emergency vehicles and many design requirements of intelligent traffic system are still missing and need more effective solutions. Wang *et al.* [6] proposed a model vehicle queuing system on intersections based on Monte Carlo's method to generate random numbers, combined with the MATLAB language to realize the intersection vehicles queuing system simulation. According to the authors' claim, the results have shown that there is an improvement to the existing access program of the intersection that can effectively relieve the vehicles queuing problem and promote the social service intensity of ITS. Li *et al.* [7] designed an algorithm based on the temporal-spatial queuing model to describe the fast travel-time variations using both the speed and headway time series that are collected using upstream and downstream detectors. The numerical studies have shown that the proposed algorithm yields good results in utilizing the dynamic traffic flow information that is embedded in the speed/headway time series in some special cases. G. Comert [8] proposed an analytical model for real-time estimation of queue lengths at signalized intersections using Poisson arrivals with known arrival rates. The author calculated the cycle-to-cycle queue lengths using primary parameters such as arrival rate, probe vehicle proportions, and signal phase durations. For probe information types, they formulated different probability distributions and moment generating functions. Several numerical examples are presented to analyze the relationship between the percentage of probe vehicles and the accuracy of the estimates with good results.

L. Dong and W. Chan [9] developed a real-time traffic signal timing model to appropriately decide the signal cycle and efficient green time on an intersection. They firstly analyzed the current traffic flow using a matrix. Next, they proposed a Webster split optimal model to minimize the vehicle average delay and the number of stops at an intersection. Al-Holou *et al.* [10] made a study about the impact of increasing the number of vehicles on the environment, jamming and traffic safety. They proposed a multi-dimensional model with an adaptive sign control application directed to attain two main goals: improving traffic flow and diminishing traffic density; and refining traffic safety at intersections. They argued that the proposed adaptive traffic light controlling approach, which uses Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications will enhance the traffic management area. Tubaishat *et al.* [11] proposed an adaptive traffic light control mechanism using a WSN for real-time data collection. The architecture consisted of three layers: a WSN for data collection; a local traffic flow model policy; and the last layer consisted of the communications between the traffic light control agents at intersections. The same idea was adopted by Chen *et al.* [12]; they proposed a three-layered wireless sensor based intelligent transportation system employing a star-based topology for the intercommunication between various nodes. Vehicle units are

used to transmit their traffic parameters to the Road Side Units (RSUs), and every RSU communicated directly with intersection units that collect data from all RSUs after a pre-defined interval of time; and since all the communication is done on a single frequency channel, to avoid sending data to all the road units, the vehicle nodes only send data to the road units on their right. The drawback of this mechanism is high communication overhead due to the communication on the same channel. Ahmad *et al.* [13] proposed a reliable and robust channel switching technique that reduces the response time, energy consumption and connectivity delay, while increasing the reliability of packet delivery. They used the IEEE 802.15.4 protocol for implementing the system architecture. However, in this architecture, there is no direct interaction between different RSUs; the communication is normally done between RSUs and On Board Units (OBUs) that are installed on vehicles. The proposed architecture in this paper will add another communication channel between different RSUs using IEEE 802.11p with the aim of helping in reducing energy consumption as well as every OBU will not have to scan for different channels. Nafi N. S. and Khan J. Y. [14] proposed a V2I Intelligent Road Traffic Signaling System (IRTSS) using IEEE 802.11p. The architecture consists of a single base station located at the intersection, which takes information from the OBU vehicles and sends the packets over the wired Ethernet to the signal control system. They discussed the advantages of using VANET based infrastructure for IRTSS. These advantages are low infrastructure cost and systems are scalable and wide range applicable. The simulation is performed in the OPNET for testing the performance of the system. Srivastava J. R. and Sudarshan T.S.B [15] suggested a WSN based adaptive intelligent traffic light control algorithm, they call it Maximum Intersection Utilization and Empty lane with Green Light. It uses variable sign boards for traffic control to prove the average waiting time reduction at a junction in order to make traffic regulation more adaptive. They tested the feasibility of this proposed algorithm using a Java based simulated platform called Green Light District Simulator, and argued that the proposed algorithm optimized the traffic flows by utilizing the free roads. Also, Seungbae L. [16] proposed an 802.11n (V2V) communication infrastructure based on a previous proposed system that used several technologies: IEEE 802.11p, V2V, and V2I. The author argued that due to unavailability of the radio for 802.11p, 802.11n based testing was performed. The results are collected in terms of delay, jitter and throughput for multi-hop communication between V2V, and showed that there is an enhancement.

In addition to the aforementioned works, Angius *et al.* [17] proposed an urban traffic optimization approach based on a heuristic paradigm. In this work, the authors partitioned the whole urban map into different topologies, and each one is studied separately in order to understand how it reacts to different traffic patterns and intensities. The output of the first step is leveraged to allow the computation of minimal delay route between the different topologies. They applied this approach on a realistic urban scenario, and according to their claims the results have shown significant improvements. In the same direction, Zhao *et al.* [18] proposed a two-level hierarchical framework to model traffic networks. At the first

level, the network is portioned into different parts (subnetworks), and in each part several traffic parameters are regulated based on the concept of Macroscopic Fundamental Diagram (MFD). At the second aggregated level, the timing information of all intersections are determined by using a flow coordination MPC controller, with the aim of distributing the number of vehicles homogeneously across all intersections. The simulation results have shown that the proposed method is efficient in terms of increasing the weighted average traffic flow.

To summarize, the research idea presented in this paper is a mixture of techniques and technologies used in references [14] and [15]. However, in these works, the authors did not employ queuing theory models to account for real traffic generation (such as the Poisson probability density function). End-to-end delays and queue sizes plus other parameters are well observed during the simulation, and by applying the architecture proposed in this paper, we eliminate the situation of missing vehicles and the communication between vehicles and RSUs will be more reliable.

III. THE PROPOSED SYSTEM ARCHITECTURE

The corner-stones of our proposed model are twofold:

- 1) Proposing a smart load-balancing scheme to give the right of access at the intersection for the roadside which has the longest queue and/or the most average waiting time.
- 2) Applying the M/M/1 queueing model to achieve the closest approximation to the real world road traffic.

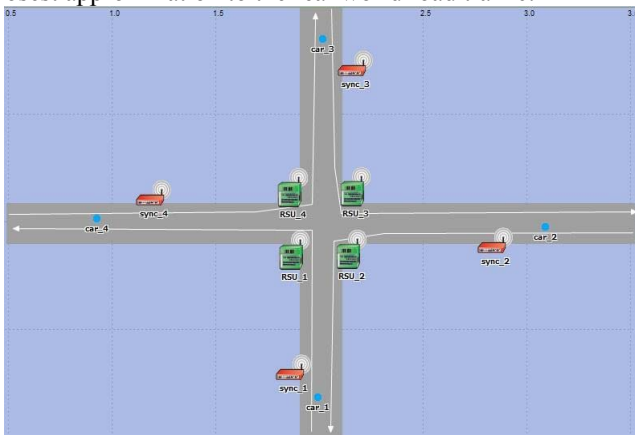


Fig. 1. Intersection layout

Before presenting our simulation mode, we would like to address the theory and some technical aspects. As mentioned above, we used the M/M/1 queueing model, which basically represents a queue with exponential inter-arrival times with

mean $1/\lambda$, and exponential service times with mean $1/\mu$ and a single server. The arrival rate into the system is $\lambda < \mu$. It is also assumed that the queue can be of infinite length (although in our simulation we will limit the queue size to the number of vehicles that can fit in 500 meters). The average number of customers (i.e. vehicles) in the system is calculated by:

$$L_s = \frac{\lambda}{\mu - \lambda} = \frac{\rho}{1 - \rho}$$

Where $\rho = \lambda / \mu < 1$, represents the fraction of time the server is working or otherwise the queue length becomes infinite, and the average time a vehicle spends in the system is:

$$W_s = \frac{1}{\mu - \lambda}$$

Our simulated system will represent an intersection with an area of 4x4 Km; it has a distance of 2km on each side. The SYNC modules will be placed at a distance of 500 meter away from the intersection (as a standard). This distance should be enough for the vehicle to establish the communication with SYNC module and thus achieve success communication with upcoming RSU module. Figure 1 depicts the experiment layout. It is important to mention that we will consider a single intersection at this stage; in future work, we will consider the effect of applying our algorithm on several consecutive and logically connected intersections. Here we can see the four sides at the intersection where each side has its own SYNC and RSU modules. The wireless receiver at each RSU keeps track of the location of the vehicle that is closest to the intersection for each roadside. The low-level design with specific values and protocols will be presented in the experiment shortly.

It is worth mentioning that we have a single controller (the main control module in Figure 2) that will collect information from the four RSU modules and run the load-balancing algorithm and thus control the traffic-lights. Each one of the four RSU modules should send a packet to the main module periodically (i.e. once every 10 seconds) to update its variables like the *Average Waiting Time* and the *Queue Size*. This will incur some communication overhead which can be ignored for two reasons: (1) these packets can be sent when the RSU is idle or during traffic-light transitions (on the yellow light), and (2) the packets are very small and they are sent directly to the main module over a very short distance (30 meters maximum) – no routing is needed. But in a future research, when the system is more complex, and if we consider a large urban area (i.e. multiple intersections), we will take the communication overhead into consideration.

```

On Road  $j$ ,
Vehicle  $V_x$  arrives;
 $V_x$  Performs Sync with Sync module  $j$ ;
Insert  $V_x$  in  $Q_j$  (Update  $QL_j$ );
Start the "Waiting Time" counter/timer (initially zero) of  $V_x$ ;
//Wait for the green light on road  $j$  to turn on;
While (GreenLight  $_j$  == on)
{
    Remove  $V$  from  $Q_j$ ; // update  $QL_j$ 
    Calculate new  $AWT_j$  for  $Q_j$ ;
}

Main Control module
Repeat Forever (or for time of session)
{
    AvgAWT = average ( $AWT_1, AWT_2, AWT_3, AWT_4$ );
    AvgQL = average ( $QL_1, QL_2, QL_3, QL_4$ );
     $i$  = Queue id with max ( $AWT_1, AWT_2, AWT_3, AWT_4$ );
     $k$  = Queue id with max ( $QL_1, QL_2, QL_3, QL_4$ );
    while ( $QL_i > AvgQL$ ) && ( $AWT_k > AvgAWT$ )
        GreenLight  $_i$  = on;

    GreenLight  $_i$  = off;
}
    
```

Fig. 2. Admission control and load balancing algorithm

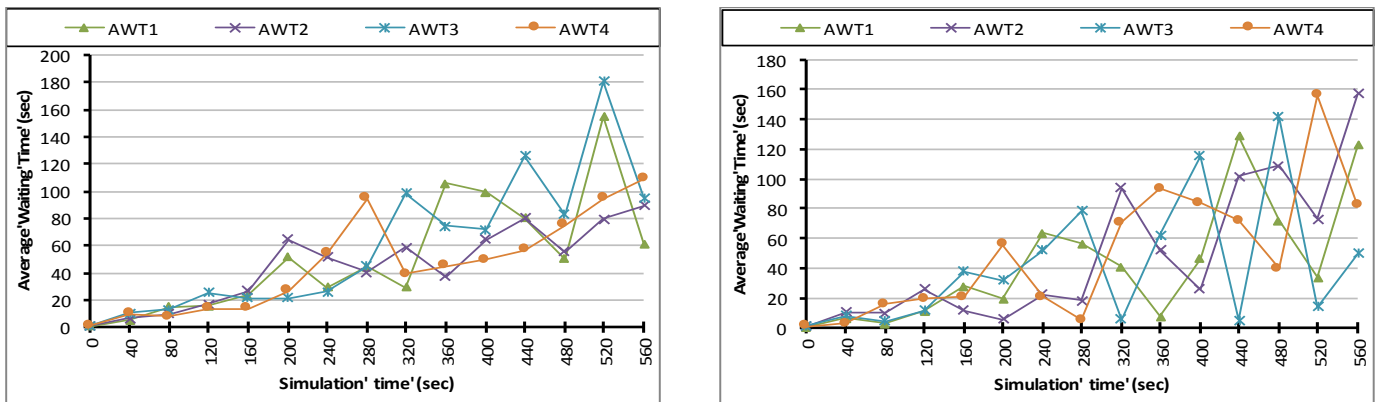


Fig. 3. Average waiting time analysis

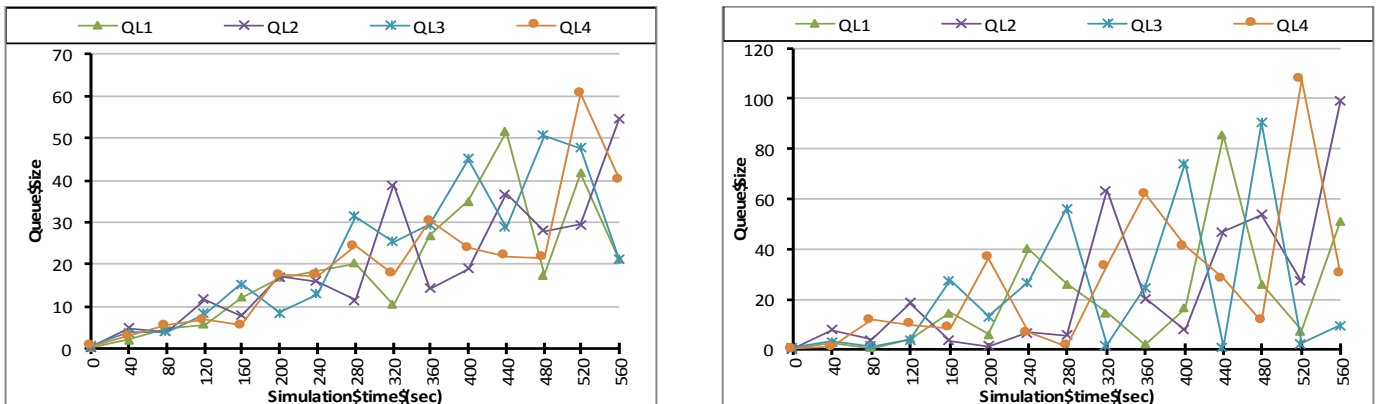


Fig. 4. Queue size analysis

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Frequency channel of RSU1	5870 MHz
Frequency channel of RSU2	5910 MHz
Frequency channel of RSU3	5900 MHz
Frequency channel of RSU4	5880 MHz
Frequency channel of SYN1	5861 MHz
Frequency channel of SYN2	5901 MHz
Frequency channel of SYN3	5891 MHz
Frequency channel of SYN4	5871 MHz
Road-ID	10,11,12,13
BSS-ID	1
Wireless MAC Address	1,2,3,4
Normal velocity of vehicle	30-40 km/h
Velocity at intersection	4-5 km/h
Channel bandwidth	10 MHz
Packet length	28 bits
Transmission range	650m
SYN broadcast interval	Outcome mean 0.3s with
RSU broadcast interval	Outcome mean 1s with
CAR generation interval (sec)	1: very high 2: high 3: moderate 4: low 5: very low
Simulation duration	10 minutes
Seed	128

Table 1 shows the relevant simulation parameters. Here we have used different frequencies for each roadside (also for the SYNC and RSU) to minimize interference and thus eliminate packet loss. This will provide high reliability of the system. Also, it is worth mentioning that we will generate traffic (i.e. admission rate) into the four queues at the four road sides using a Poisson function with five levels as shown in the (*Car Generation Interval*) parameter in the table.

The admission control and load balancing algorithm at the intersection is shown in Figure 2. The logic behind this algorithm is very simple and light-weight; it basically keeps track of the average queue length and average waiting time within each queue, and then the right of the road at the intersection is given to the roadside which has the highest values. This is done in a round-robin fashion on the four roadsides. The admission control assumptions are as follows:

- Vehicles will be inserted into the queue based on M/M/1 generator after they perform the hand-shake with the SYNC module.
- The Queue Stats (Queue Length, Average Waiting Time) on each roadside will be maintained by the respective RSU module.
- The distribution algorithm will control who gets a green light on the four queues (and thus gets served) based on a smart load-balancing technique. The algorithm will perform an optimization solution so as to maintain minimum average queue-length and minimum average waiting time for the vehicles in the queues.
- QL_i = Queue length of queue i;
- AWT_i = Average Waiting Time approximation of all vehicles in Queue i.

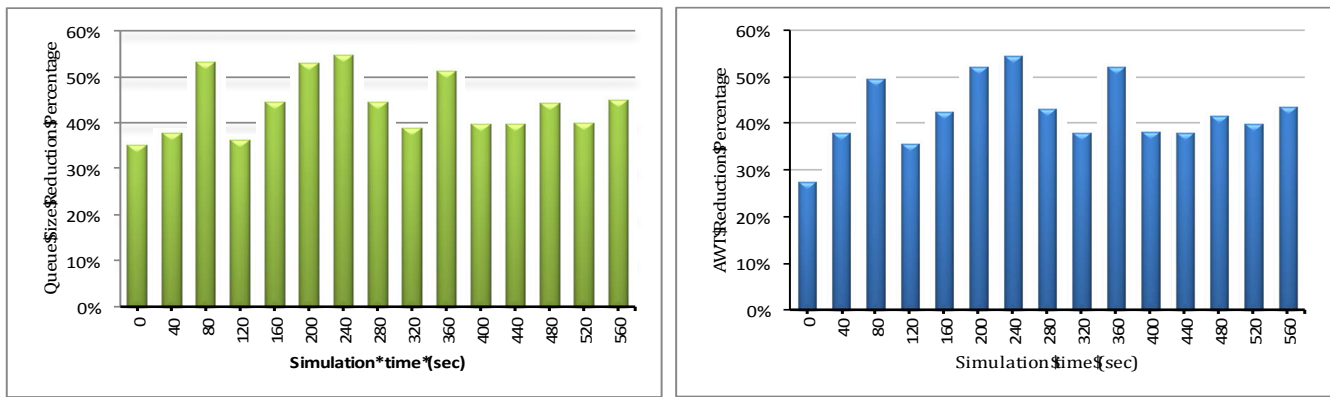


Fig. 5. Queue size reduction

IV. SIMULATION SCENARIOS AND RESULTS

We ran our simulator using two scenarios: the *Mute* (non-load-balancing) and the *Intelligent* (with load-balancing). With the *Mute* case, we did not make an intervention; we made the service rate (green light on the intersection) as a uniform (equal) turns with each roadside queue getting 0.25 of the time regardless of the queue size or the waiting time within each queue. While on the *Intelligent* case we applied the load-balancing algorithm depicted above. We ran each scenario of the simulator with the same parameters shown in Table 1, but we varied the traffic generation function into each queue (i.e. the cars that will enter the queue on each roadside) between 1 and 5: with 1 being intense (average 1 car per second), and 5 being slow (average 1 car every 10 seconds), these variations were random on the four roadsides according to the Poisson distribution.

Figure 3 shows the plot of the Average Waiting Time (AWT) on the four roadsides (i.e. the four RSUs) over the 10-minutes run of the experiment. Part (A) of the figure shows the *Intelligent* case, and part (B) shows the *Mute* case. By comparing these two plots, we can clearly observe that the *Intelligent* case is much smoother with waiting times concentrated between 50 and 100 seconds, while on the *Mute* case, the plot is noisy, jumpy and uncertain, with waiting times scattered all over the spectrum from zero to 160 seconds with a linear shape increase over time. In the same way, in Figure 4 we present the plot of the Average Queue Size on the four roadsides: (A) for the *Intelligent* case and (B) for the *Mute* case. Also here we see a significant improvement in minimizing the Queue Size; in plot (A) – the *Intelligent* case – we see the bulk of dots between 10 and 50 seconds, while in plot (B) – the *Mute* case – we see the dots scattered in a linear behavior from 0 to 100 seconds.

In Figure 5, we summarize these findings according to the maximum numbers on each case. Part (A) of the figure presents the percentage of reduction in the Average Queue Size (AQS), the columns represent the difference between the maximum AQS in both runs (*Mute* vs. *Intelligent*) on the four roadsides at a 40-seconds time intervals (from time 0 to time 600). The average height of these bars computes to an overall reduction for the whole 10-minutes to 43%. Part (B) of the figure presents the percentage of reduction in the same way

for the Average Waiting Time (AWT); also here we took the difference between the maximum AWT on the four roadsides and plotted them every 40-seconds. The overall reduction here is 44% in AQS.

V. COMPARATIVE ANALYSIS

In this section, we chose the research by Nafi and Khan [15] – the VANET approach, which is close to our approach in terms of methodology, networking infrastructure and intersection assumptions, and made a small validation comparison based on the Average Waiting Time analysis. We took the first 12 cycles (intervals) and calculated the percentage in the AWT reduction as follows:

$$P_i = \frac{F_i - A_i}{F_i} \times 100\%$$

Where P_i is the percentage of improvement for interval i , A_i is the Adaptive (smart case) reading of the AWT, F_i is the Fixed (mute case) reading of the AWT. We give the comparative summary in Table 2. As can be seen, we have achieved a total average reduction of 41.58% while the VANET based method had achieved 33.41% average reduction. We can consider this improvement of about 8% as an initial indicator of the validity and correctness of our method due to its simplicity and its light-weight design. But as we mentioned earlier, we will make a more depth comparisons and analysis in the future work.

TABLE II. AWT COMPARATIVE SUMMARY

Interval	VANET (Nafi & Khan's)	Smart-Intersection (Our approach)
1	37%	35%
2	28%	43%
3	20%	52%
4	35%	55%
5	49%	43%
6	39%	37%
7	29%	52%
8	32%	28%
9	38%	28%
10	39%	42%
11	28%	39%
12	27%	45%
Average	33.41%	41.58%

VI. CONCLUSION AND FUTURE WORK

In this research, we have designed and implemented a simulation for a novel optimization scheme to reduce congestion on busy roads' intersection. The simulation was designed to achieve a close approximation of the real world traffic which represents bursty traffic incoming into the four roadsides of the intersection according to the M/M/1 queueing model. We have designed a smart load-balancing algorithm to achieve a fair distribution of the right-of-way at the intersection to the longest queues and/or to the queue with the maximum average waiting time (whichever is higher) in a dynamic behavior. We have compared our Intelligent scheme with the regular (mute) traffic-light that gives a uniform intervals of green-light (25%) of the time to each roadside. In the analysis, we have achieved a significant reduction of both parameters (AWT and AQS) up to 44%, and the validation comparison with the VANET based method [15] gave about 8% improvement. We intend to continue investigating this technique by applying it on multiple consecutive intersections and with other scenarios like an intersection with a main/busy road and a smaller/sparse road and with other realistic parameters like the time-of-day and varying intervals.

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