EVENT SIMULATION OF INTELLIGENT TRAFFIC LIGHTS INTEGRATING V2V AND V2I FEATURES TO IMPROVE TRAFFIC FLOW

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ABSTRACT: *Traffic regulations on the roads mostly aim to ensure the safety of road users. Vehicles may come across many traffic lights (TL) on their way, and some of them will reach TLs in the green phase when others are in yellow/red phases. Reaching a traffic light on the yellow or the red phase means a loss of inertia or kinetic energy that could also be interpreted as a loss of fuel because after the light turns green, the vehicle will resume its normal speed using extra fuel (compared to moving without stopping at traffic light). The economic reasoning may seem negligible to some, but in case of heavy cars or trucks, stopping can be very expensive, especially when fully loaded. Another effect of such movement interruptions is safety leakages. In some cases, drivers could simply be late after a slow down. Moreover, the slowing down that is required to stop the vehicle at traffic lights forces the driver to undergo unhealthy deceleration. One of the simple solutions of the given problem is to change the route from a disallowed to an allowed one at traffic lights; in contrast to moving directly on the route that will require the driver to stop and wait for a red light, a heavy truck can turn right or left in order to take a slightly longer route if possible, thereby increasing its travel distance but saving inertia. This study proposed an alternative solution to the described problem as an intelligent speed control that mostly relies on knowing the traffic light's state and aims to control the vehicle's speed in such a way that it always tries to reach the traffic light in its green phase.*

KEYWORDS: cloudlet, green traffic light, internet of things, vehicular communication,

1 INTRODUCTION

Traffic regulations on the roads mostly aim to ensure the safety of road users. In addition to the list of specific rules (i.e., traffic laws) for both drivers and pedestrians, passive road elements, like road marking, road signs, speed bumps, and road delimiters, active traffic regulators are also used. The most common "active traffic regulator" is a traffic light, which usually is used on those road segments where several routes (crossroads, crosswalks, railroad crossing, etc.) cross. To avoid vehicle-to-vehicle (V2V) or vehicle-to-pedestrian (V2P) intersections, such road segments need to be controlled. In the simplest case, a traffic light is a system that shows whether the movement is allowed simultaneously for different routes (i.e., from one specific controlled traffic lane to another controlled lane) by three different colors, namely, green, yellow and red.

During the last 10 years, computing systems have proliferated due to the need for enabling the setting up and deployment of vehicular communications in a variety of traffic environments. One of the recent achievements in vehicular communications is the development of a 75 MHz spectrum with a speed of 5.9 GHz for enabling short-range communications in both (V2V) networks and vehicle-to-infrastructures (V2I). as well as in roadside units (RSU). Such communications provide the possibility of fast and accurate sharing of critical information, such as accidents, emissions, and traffic, that would not be feasible without this rapidly advancing technology. Vehicular communications provide new ways of improving and optimizing intelligent transport systems in highly advanced cities such as Paris, London, Rome, and New York. The technology is also applicable in commercial activities for both safety and non-safety implementations.

Safety implementations consist of but are not limited to accident avoidance and cooperative driving [1], while non-safety implementations could consist of the sharing of traffic information [2], internet access, toll services [3], and cooperative entertainment.

Vehicular communication is composed of nodes-vehicles with various internet of things devices, such as GPS, wireless communication devices, optional sensors, and digital maps for disclosing vehicle information pertinent to computations and decision-making in traffic situations. V2V communications require creative cloudlet routing algorithms to enable data propagation to centralized cloud servers. With the advancement of smartphones, it has become important for mobile devices to serve with excellent performance in processing tasks when compared to the performance of static clients accessing the servers. The initial challenges of cloud computing in mobile phones in the last decade have been confined to memory, weight, heat dissipation, and battery life. In overcoming these challenges in mobile devices, solutions have been developed to solve issues such as long-latency and costly roaming charges for cellular networks. Cloudlets have emerged as the best solution for these challenges in accessing distant cloud data using mobile phones, thereby enabling faster data transfer, including high processing speed and low usage of mobile resources.

Although information technologies are well developed, there is a substantial challenge that impedes the rapid advancement of secured vehicular networks. As has always been established to be the case, vehicles are extremely constrained by computing resources, such as storage, computation, and communication bandwidth. Due to the need of low-cost and small-size hardware systems, single node-vehicle has restricted storage and computation resources with the ultimate outcome of limited capacity for high data processing speed. There are many emerging applications, which are complex in nature, for example, in-vehicle entertainment, vehicular socialization, and location-based services.

2 LITERATURE REVIEW

Cloudlets are defined as a micro cloud positioned at the middle layer of mobile phone in the cloud hierarchy, i.e., a mobile-cloudlet-cloud architecture. Cloudlets are designed to extend cloud-based services to mobile users. There are few research studies that have reported the possibility of integrating cloud-based services into vehicular communications. Magar defined a cloudlet as a “data center in a box” that is often installed in military vehicles in strategic environments [4]. The researcher argued that mobile phones equipped in military vehicles help combat soldiers to store and off-load processing. Satyanarayanan *et al.* defined a cloudlet as a trusted resource-rich computer or cluster of computers that is associated with the internet and is accessible by nearby mobile phones [5]. The researcher also defined a roadside cloudlet as a small-scale RSU that provides services to bypassing vehicles. In this respect, a vehicle selects an RSU cloudlet nearby and personalizes a transient cloud for utilization. The term “transient cloud” is used to refer to the fact that the cloud is available to serve a connected vehicle temporarily. Upon leaving an RSU cloudlet, the cloud is subsequently deleted, and the vehicle is now prepared to be connected to the next RSU cloudlet for resource allocation.

The researcher also argued that vehicular ad hoc networks (VANETs) can be utilized in interconnecting cloudlets and, in such a case, multiplying the storage capacity and computational power available to combat soldiers. Olariu, Eltoweissy, and Younis introduced the idea of autonomous vehicular clouds (AVC) to exploit the nonutilized resources in VANETs [6]. In this regard, [7] proposed a platform as a service model for supporting cloud-based services for mobile vehicles.

The vehicular cloud (VC) has recently been described in recent literature as a local cloud that is formed exclusively for vehicles through V2V networks. A VC can either be formed as dynamic or stationary [8]. As the latter, the VC functions as a conventional cloud, occurring mostly in static environments such as garages or parking lots. These static environments can function as spontaneous data centers where engaged vehicles share their resources within the onboard unit. Dynamically formed VC are found in vehicles, which are in constant movement, entering and exiting the local VC. In static environments, one vehicle is established as a cloud leader or broker to negotiate between vehicles or nodes forming the cloud. In this regard, a VC is a self-maintaining cloud-based setup where the cloud leader assigns tasks within the cloud. The authors in [9] presented a case study involving a VC scenario in which they provided a clear explanation of the steps taken in the vehicular cloud in discovering, forming, maintaining, and releasing the cloud, as well as indicating the functions of the cloud leader. However, rather than utilizing a vehicle as a broker of cloud leaders in a dynamic environment, it is essential to use a cloud controller for creating, maintaining, and deleting a VC [10]. With face-to-face resource management, the dynamic design is equivalent to a traditional cloud deployment strategy where a controller is active in scheduling cloud resources.

3 IMPLEMENTATION

3.1 Proposed Work

In this study, a secured communication model is proposed to enable vehicles to communicate with their surrounding objects to reach the TLs in the green phase. The main idea of the proposed solution is that in most cases, traffic lights have cycling programs, and their phases are change one-by-one through the time shifts determined for a period. Therefore, the traffic light’s state could be predicted by knowing the traffic light’s program and its initial state (knowing its state at some fixed time), as shown in Figure 1.

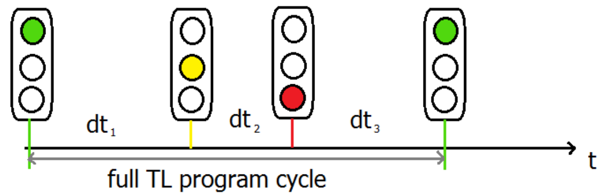

Figure 1: Shows the simplest example of the traffic light program; in real situations, the program could be much more complex. This example is close to the situation of a traffic light controlling pedestrian crosswalk.

Knowing the parameters specified in figure 1 is not enough to make a prognosis of a TL state in an arbitrary time. The parameters should be supplemented by the time when the TL is one of its states. For example, the time in the past when the TL was in green phase could be described by two times, namely, some fixed time in the past (t_0) or an offset ($_{offset}$) time from the green phase (i.e., time gone from the previous "green phase"/"previous program cycle begins"), as shown in figure 2.

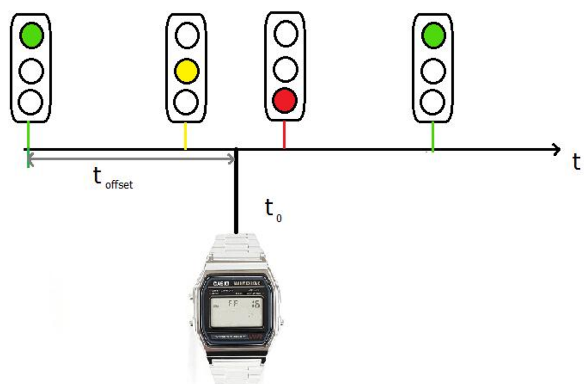

Figure 2: TL program and state definition

In the given TL program and state definition, the state of the specific TL at an arbitrary time t could be easily predicted as follows:

$$\begin{cases} t_{OFFSET} = \left(t - t_0 + t_{offset}\right) \% \sum_i dt_i \\ \quad GREEN \quad if \quad 0 \leq t_{OFFSET} < dt_1 \\ YELLOW \quad if \;\; dt_1 \leq t_{OFFSET} < dt_2 \\ \quad RED \quad if \;\; dt_2 \leq t_{OFFSET} \end{cases},$$

where % denotes the remainder of the division.

3.2 Traffic control

Suppose that vehicles know the $\{t_0, t_{o-ffset}, dt_1, dt_2, dt_3\}$ parameters of the TL and the distance L to this traffic light. Then what the speed a vehicle should maintain to the TL in order to arrive in its green phase?! To answer this question, we will assume a simple linear motion:

- Assume that car is moving with constant speed u from its current position in the direction of TL;
- The distance between the TL and vehicle is L;
- TL parameters $\{t_0, t_{o-ffset}, dt_1, dt_2, dt_3\}$
- Desired arriving OFFSET: $0.1 * dt_1 \leq t_{OFFSET} \leq 0.9 * dt_1$ is taken with a small margin (to make the optimization more stable).
- The vehicle should arrive at the specified desired offset but with smallest possible trip time $T = \frac{L}{u}$
- Vehicle speed should not exceed the speed limit v_{max}

We can formulate the optimization problem as follows:

$$\begin{cases} T(u) = \frac{L}{u}, \quad t_{OFFSET}(u) = \left(T(u) + t - t_0 + t_{offset}\right) \% \sum_i dt_i \\ GOAL: \quad \boldsymbol{T(u) = min} \\ CONDITIONS: \ \boldsymbol{0.1 * dt_1 \leq t_{OFFSET}(u) \leq 0.9 * dt_1}, \ \ \boldsymbol{0 \leq u \leq v_{max}} \end{cases}$$

The above is a minimization problem with constraints that may be solved in different ways; for example, the simplex method of gradient descent by forming the error function of the goal function is as follows:

$$GOAL(u) = T(u) + a_1 * (\boldsymbol{0.1 * dt_1 \leq t_{OFFSET}(u) \leq 0.9 * dt_1}) + a_2 * (\boldsymbol{0 \leq u \leq v_{max}}),$$

where a_1, a_2 are certainly big numbers that will, in a classical way, incorporate the constraints inside the goal (error) function.

Finally, to provide for the optimization of vehicle movement, i.e., to find the optimal speed, the TL parameters should be known. Parameters can be recovered through different scenarios. In this work, we investigated communication with traffic lights (V2I communication) and communication with other vehicles (V2V communication) scenarios.

3.3 Communication

For optimizing traffic flow, it could be useful to construct an intelligent road where the road and its controlling objects, such as traffic lights, will be equipped with sensors aggregating different information about each vehicle or passenger participating in the road's activity. All gathered information in such a system may be used to control each road participant individually by giving appropriate recommendations or instructions as to how to move. Such a system is much more complex than is investigated in this work, but it is similar and could be assumed as a further improvement. Nevertheless, both an intelligent road and the individual speed optimization technique exanimated here require vehicle-to-vehicle or vehicle-to-infrastructure communication.

V2I communication can be implemented in various ways, namely, by internet or by a direct local connection via short-range (Bluetooth) or mid-range (Wi-Fi) technologies that all can be combined in a mesh-net. The internet could easily bound all infrastructures with vehicles and at first, sight, seems to be the best candidate, but some road regions could have a bad GSM internet connection (i.e., 2G/3G/4G, etc.). That poor connection would create big lags and pauses, so we assume that it would be better to implement the vehicle-to-infrastructure communication through the local mid- or short-range radio and to bind all local radio points in a mesh-net that will implement infrastructure-to-infrastructure communication if needed. In this work, we assumed traffic lights are equipped with mid-range radio that works as follows:

- At each moment of time, each TL emits a message in the radio with its program (with all required for speed optimization data);
- There is a nonzero probability that messages sent by the TL will be registered by vehicle;
- The probability p of receiving the message from TL by vehicle depends on the distance D between the TL and the vehicle by the law given below and presented in figure 3.
- The vehicle obtains and processes the message during a negligibly small time (in our model – immediately).

We assumed the following probability function for obtaining the message by TL:

$$p(D) = e^{-\left(\frac{D}{300}\right)^2}$$

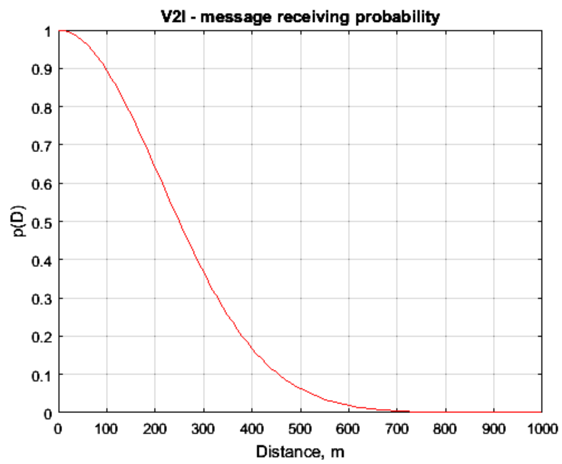

Figure 3: V2I communication, message-receiving probability

In the V2V scenario, we assumed an immediate communication between two vehicles. The first vehicle waits for a message with information about the TL from the second vehicle. The second vehicle sends information about the TL that is located in the "line of sight" (within a 30 m range). Communication, in this case, maybe assumed to be a fast internet connection. The second vehicle is also driving on the road and meeting the same TL that will be passed by the first vehicle, but in another order and with different timings, thereby supplying the first vehicle with actual information. In contrast to V2I communication, where the information about each TL is likely to be obtained before passing the corresponding TL, in V2V, the first vehicle may obtain the information about some TL too late (i.e., after passing the TL when this information becomes useless).

4 SIMULATION SETTINGS

To provide the described investigation, the Simulation of Urban MObility (SUMO) package and TraCI4 MATLAB libraries were used as the core for simulation. Different calculations and interfaces have been implemented by MATLAB scripts.

The simulation scene consists of the Z-road segment, with a total length of 2200 m. The road includes three traffic lights controlling three pedestrian crosswalks, as shown in figure 4.

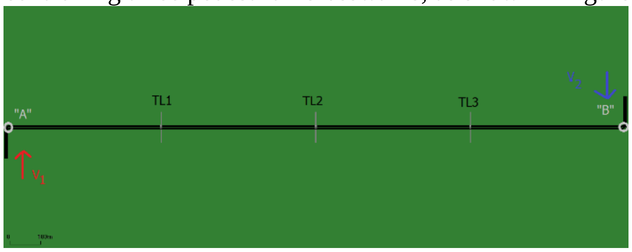

Figure 4: Simulation scene

The main vehicle (V_1) moves in the right direction, and the helping vehicle (V_2) moves in the left direction. The V_1 vehicle starts moving 35 seconds after V_2, which provides an opportunity for V_2 to supply V_1 with information about the TL (mainly TL_3 and TL_2). Both vehicles, V_1 and V_2, begin their trips from the opposite ends of the road. The simulation finishes when V_1 reaches the end of the road. In addition to the two cars (V_1 and V_2), there are two traffic flows that are moving in both directions (left and right).

Three scenarios were implemented in the simulation. The first scenario was without communication between vehicles (and therefore without speed optimization); the second scenario used V2I communication, while the third scenario used V2V communications. At the end of the simulation, the program provided statistics of obtained durations of the trip and the evolution of the V_1 coordinates, speed, and acceleration that clearly show whether the car has been stopped at traffic lights and how each scenario influences the speed and acceleration profile of the car.

5 RESULTS

A few snapshots of the simulation are shown in figures 5, 6 and 7.

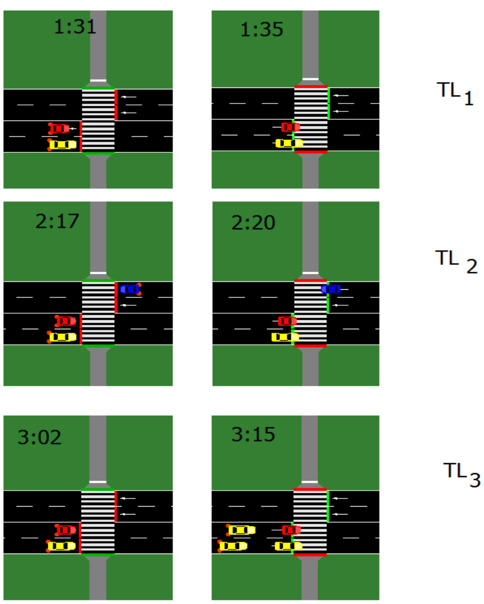

Figure 5: No communication simulation

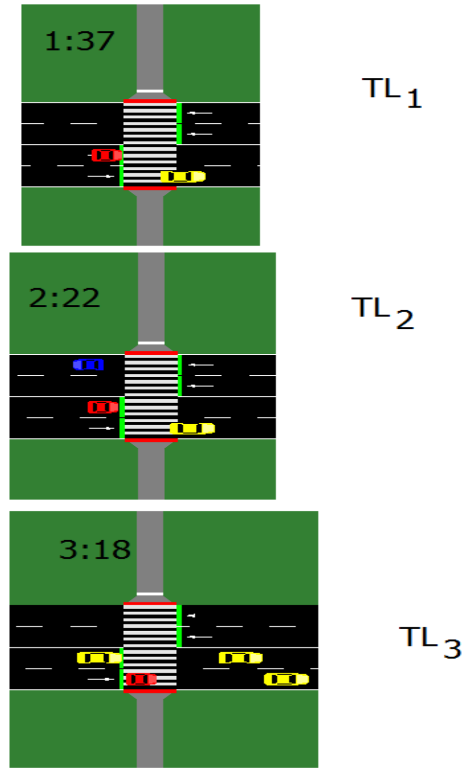

Figure 6: V2I simulation

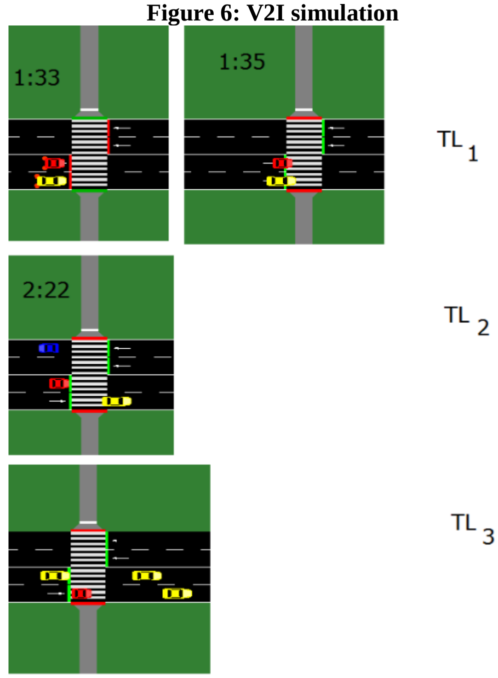

Figure 7: V2V simulation

The results of the simulation with different communication techniques are shown in figures 8, 9, and 10 through the evolution of vehicle coordinates, speed, and acceleration. figures 11 and 12 show statistics about the messages received by each car.

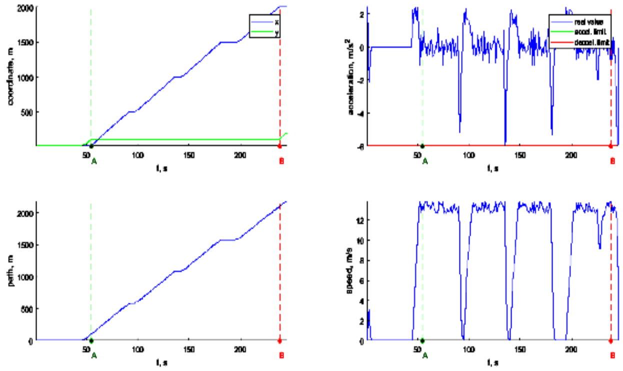

Figure 8: V_1 Vehicle motion, no communication

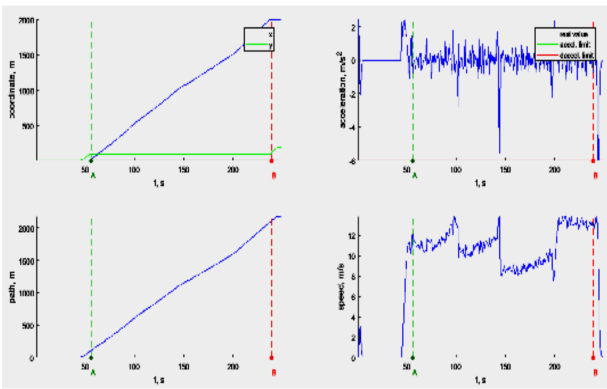

Figure 9: V_1 Vehicle motion, V2I communication

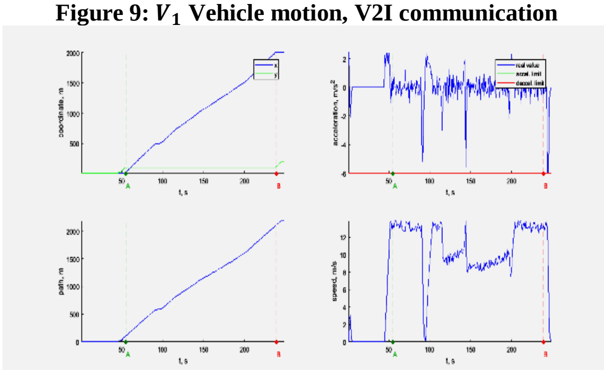

Figure 10: V_1 vehicle motion, V2V communication

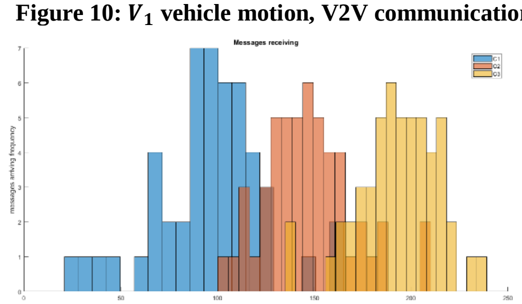

Figure 11: V2I communication, statistics of received messages

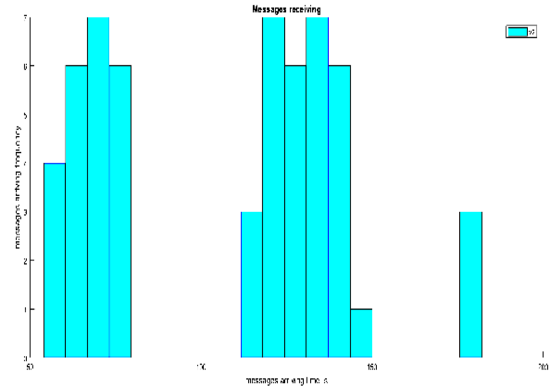

Figure 12: V2V communication, statistics of received messages.

From the figures presented above, it can be seen that in the case of no communication, when the vehicle was driven at the maximum speed with no corrections, it was forced to stop at each traffic light, thereby losing its inertia (and potentially wasting fuel).

In the case of V2I commination, as is evident from Figure 11, V_1 has received messages about each traffic light before arriving at the appropriate traffic light. These messages helped the vehicle successfully optimize its speed to reach the traffic light in its green phase, which is clearly seen from Figure 9 (i.e., the speed has not fallen below 7 m/s on all paths between points of interest "A" and "B").

In the case of V2V communication, the second vehicle has managed to send the messages about traffic lights #3 and #2 in time, but as was expected, it sent the information about traffic light #1 too late because its route was opposite to that of V_1, and they usually meet at traffic light #2. Therefore, it is physically impossible for V_2 to get to traffic light #1 earlier than V_1, which is clearly seen from Figure 10, where the speed has fallen to zero only at traffic light #1.

All motion data are also illustrated on the snapshots shown above. The snapshots precisely show the most characteristic moments of the simulation (i.e., arriving at traffic lights).

6 CONCLUSION AND FUTURE WORK

The SUMO package is a light and useful utility for traffic simulation, which, in combination with TraCI4 MATLAB, provides an opportunity to simulate the actual problems of modern roads. Both packages are still in development, and some advanced functionality may require additional coding as it did in this work, where the communication and speed optimization has been implemented by MATLAB scripts. Nevertheless, combining the efficiency of the SUMO, TraCi4 MATLAB packages and the mathematical and graphical flexibility of MATLAB may provide a great experiment.

Simulation of V2V and V2I communication scenarios in the context of traffic control problems has shown that both approaches may improve efficiency and potentially save fuel (i.e., by maintaining inertia and thus saving the vehicles from slowing down or stopping at traffic lights). Comparing V2V and V2I, it is obvious that the configuration proposed in this work forced V2I to be the winner because, in the V2V scheme, the information about one of the three traffic lights could not be received in time. Nevertheless, it was shown that V2V is also a workable solution. If this solution could be extended to multiple vehicles, providing vehicles with mesh-net results could be much better.

In future research, a secured billing model will be proposed for the developed cloudlet routing for vehicular communication. Future research can be extended through further simulation to enable a comparison of various prevailing vehicular cloud architectures.

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