VANET-Based Traffic Light Management for an Emergency Vehicle

Adel Izadi(✉), Ashkan Gholamhosseinian, and Jochen Seitz

Technische Universität Ilmenau, Communication Networks Group, Ilmenau, Germany
{adel.izadi,ashkan.gholamhosseinian,jochen.seitz}@tu-ilmenau.de

Abstract. Wireless communications have affected our lifestyle in the last decades. It is helpful to improve quality of life for communities. Communications among vehicles usually take place in vehicular ad-hoc networks (VANETs). Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications are aspects of communications in the transportation which are growing rapidly. They can play a pivotal role in the transportation field. Management of traffic lights (TLs) is crucial to control traffic flow especially at an intersection. The goal of this paper is to manage the TLs at an intersection when an emergency vehicle (EV) is approaching. First, we simulate an intersection which includes TLs via simulation of urban mobility (SUMO). Later, we simulate VANETs communication to manage the TLs at the intersection when the EV is coming with the help of objective modular network testbed in C++ (OMNeT++) and vehicles in network simulation (Veins). Finally, the impact of V2I communication on delivery efficiency of the emergency service is investigated. Simulation results show an improvement in delivery efficiency of the emergency service.

Keywords: VANETs · SUMO · OMNeT++ · Veins · IEEE 802.11p · vehicle-to-infrastructure communications (v2i) · emergency vehicle (ev) · traffic lights (tls) · vehicle-to-vehicle communications (v2v)

1 Introduction

Increasing number of vehicles has caused more traffic jams especially at crossroads during the recent years. Traffic jams at the intersection may cause many problems and increase response time specifically for EVs such as ambulance, rescue truck, etc. To control the intersection, the advent of TLs has really helped to increase the traffic performance. Management of the traffic flow at an intersection can increase delivery efficiency of the emergency services. It has been demonstrated that human errors have a pivotal role in road accidents by 75% [1,2]. It is obvious that an EV should arrive at the location immediately.

Testing new technologies in a real world is expensive and not safe. Besides, it is difficult to repeat the experiment and control the conditions in the real world for repetition, so simulation would have some benefits in this regard. Typical

E. Sabir et al. (Eds.): UNet 2022, LNCS 13853, pp. 129–137, 2023.
https://doi.org/10.1007/978-3-031-29419-8_10

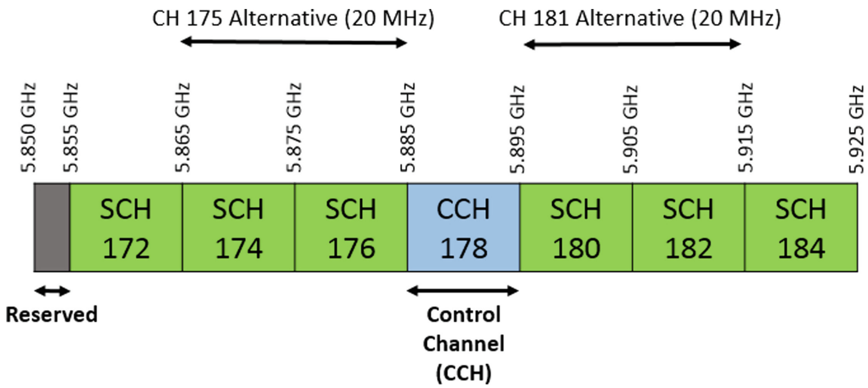

Fig. 1. DSRC channel spectrum in the U.S.

application of VANETs-based communications are EV warning or accident alert [2,3]. VANETs-based communications have been regulated in the IEEE-802.11p standard [1].

Dedicated short range communication (DSRC) was developed to add wireless access in vehicular environment and support vehicle-to-everything (V2X) communications. DSRC works using a 75 MHz spectrum in 5.9 GHz frequency band in the United States while in Europe and Japan it performs on a 30 MHz spectrum in the 5.8 GHz band. It can prepare services to both V2V and V2I up to 1 km and supports data rate of up to 27 Mbps [4,5]. The spectrum of DSRC is divided into seven 10 MHz channels with a 5 MHz guard band at the low part. Pairs of 10 MHz channels can also be combined to a 20 MHz channel. The United States federal communication commission (FCC) has nominated each channel as either service channel (SCH) or as control channel (CCH). The CCH notion labels one channel (channel number 178) in the U.S. as a "rendezvous" channel. The U.S. FCC has nominated channel 172 specially for V2V safety communications and accident avoidance, mitigation, safety of life and property applications [6]. DSRC band plan is illustrated in Fig. 1. DSRC stack depicts standards for layers: physical (PHY), data link (including MAC layer), network/transport and application layers. At the PHY and MAC layers, DSRC exploits IEEE 802.11p. In the middle, a suite of standards defined by 1609 working group are applied. At the top, the SAE J2735 defines a set of message formats that support a diversity of vehicle-based applications. The most prominent of all is the basic safety message (BSM) which transfers vehicle state information. BSM messages contain position, sender speed and channel number (CCH 178) [6].

One of the goals of this research is to decrease the response time which is one of the crucial issues for an EV especially in large cities with heavy traffic jams. The EV must travel through the intersection without any problem and delay. One of the solutions involves the construction of new infrastructure. This solution is very costly and requires huge investments. However, new technologies such as V2I and VANETs are cost-effective solutions to control traffic flow and manage TLs at the intersections [7,8].

The remainder of the paper is organized as follows. Section 2 is about the current state of the art. Section 3 deals with the frameworks that have been used for the simulation and our implementation. Results are evaluated in Sect. 4, where the impact of TLs on travel time of an EV by VANETs is assessed. Finally, a conclusion and future work are provided in the last section.

2 State of the Art

Jayaraj et al. [9] proposed an automatic green light during traffic flow for an EV in a specific route using SUMO and NS-2. It showed a traffic scenario where there was signalling transmission between the EV and other vehicles or TLs. When the TL received the message from the EV, it needed to alter from red to green. The green signal was maintained for that lane or road till that particular vehicle passed. The idea served to improve the network efficiency where there was minimum loss of data packets and minimum end-to-end delay. Authors in [10] discussed about the system design of an EV warning system called SafeSmart using V2I communications. A primary model of the system was tested and simulated including EVs and TLs. System performance was examined to compare the travel times for EVs in normal traffic with the time when the system is in use. System results provided EVs with a faster and safer path from one point to another, mostly in traffic jam scenarios where other drivers might not have enough space to clear the path for the EV.

Furthermore, Padmapriya et al. [11] adopted an EV transit approach (EVTA) associated with the road side unit (RSU) and traffic management center (TMC) for transport of EVs. Accurate location of the EVs were offered by both GPS and Kalman Algorithm (KA) to the EVTA. The proposed approach aimed to minimize the travel time of the EVs to reach the hospital with the concerted effort of the RSU and TMC. Simulation results confirmed that geographical parameters prepared by GPS are continuous. However, mentioned parameters provided by KA are 5% more authentic than GPS method. In a research project by Noori et al. [2], conducted for Cologne city in Germany, 20 EVs were involved in the simulation. In the experiments, authors aimed to analyze the response time and delay of the waiting vehicles at red light when TL status changed to green for an EV 50 m, 300 m and 5 km away from the crossroad. In case of 50 m, response time showed the highest value, but the waiting time for the other vehicles remained minimum in the junction. However, 5 km distance from the intersection experienced the lowest response time and the highest waiting time for other vehicles.

Moreover, Obrusnik et al. [12] utilized a new method for EV preemption at a signalized intersection. Simulation was conducted for a part of Brno City in Czech Republic. V2I communications were used to estimate the number of vehicles in the queue and a mathematical model was used to clear the queue of vehicles. There existed three simulations in different modes as follows. First, EV had no preference on the TLs. Second, EV was broadcasting preemption request after crossing a specific distance from the intersection. Third, EV was propagating its location and the TL controller decides about starting time of the preference based on actual traffic situation. Varga et al. [13] devised a feasible architecture for V2X communication centric TL controller. Their solution employed regulated C-ITS messaging techniques and helped vehicles to base their junction crossing measures on actual information coming from the infrastructure. A controller was also involved to make its decision on applicable information coming from vehicles. To implement the introduced V2X communication-centric controller system, five elements were designed, i.e. a Java-based STLM module, Commsignia RSU, Raspberry PI 2, NETIO equipment and TLs.

3 Simulation

We have benefited from SUMO as an open source traffic simulator [14], OMNeT++ and Veins [15] to simulate VANET-based TLs management. SUMO simulates traffic flow, vehicles and TLs while OMNeT++ handles wireless communications between nodes such as EV and the RSU. Veins bidirectionally connects SUMO and OMNet++ via a TCP socket. Traffic simulation starts in SUMO and OMNeT++ acts as a network simulator. Then, OMNeT++ considers all vehicles as nodes and simulates the scenario. When a change happens in OMNeT++, Veins is able to apply that in SUMO accordingly [16,17]. For instance, when EV sends its message to the RSU and asks for changing the state of the TL, transferring this request to SUMO to change the state of the TL is carried out by Veins. A disadvantage of Veins is that it only recognizes vehicles in OMNeT++. Therefore, TL also is considered as a node.

Forty conventional vehicles are inserted in a four-leg intersection and start traveling on four 400 m road length as depicted in Fig. 2. There are no communications between vehicles and the RSU. On the other hand, a connected EV is inserted on the perpendicular road and travels downward broadcasting a BSM once per second to the RSU. When it arrives at 300 m distance from the intersection and the BSM is received by the RSU, then TLs change their state to green for the EV and red for the other road. Ten seconds after EV has crossed the intersection, status of the TLs return to the previous status. Basically, state of the TLs change every 15 s from red to green and vice versa, also there is three seconds yellow state in between. Signal propagation conditions inherit from free space model. Main parameters of the simulation are shown in the Table 1. Algorithms 1 and 2 feature the behavior of EV and the RSU in sending and receiving the BSM respectively.

Algorithm 1. EV in sending state

1: **Input:** State of the vehicle
2: **Output:** BSM
3: Broadcast BSM every 1 s

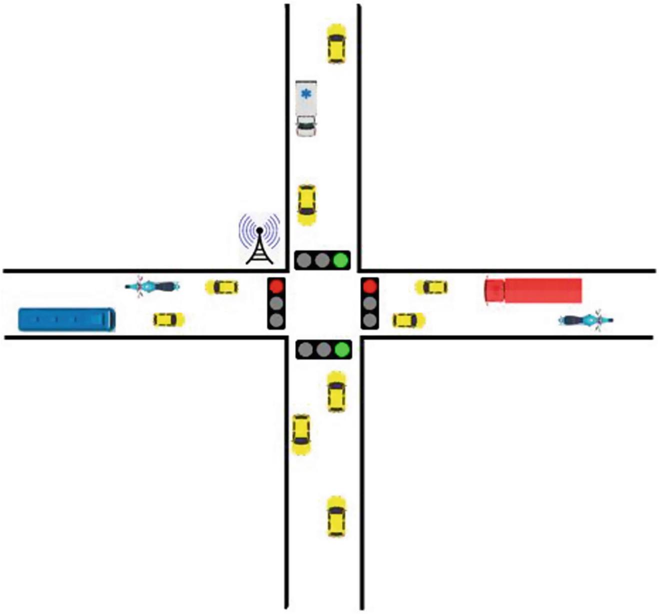

Fig. 2. Intersection layout

Table 1. Simulation parameters

Parameters	Values
Tx Power	20 mW
Bit Rate	6 Mbps
RSU Beacon Interval	1 s
Channel Number	178
Road Length	4 × 400 m
TLs green phase duration	15 s
Vehicle speed	70 km/h

4 Evaluation of Results

4.1 BSM Message

BSM is one of the message types for V2X communications that we have used in this simulation. It is transmitted over DSRC and it is suitable for low latency and localized broadcast which is required in V2X safety applications. Connected V2X safety applications are generated around SAE J2735 BSM [18]. Number of sent and received BSM messages are derived from OMNeT++. Totally, 21 BSM messages were disseminated by EV and 20 BSM messages were received

Algorithm 2. RSU in receiving state

```
Input: BSM
Output: TL state change
Retrieve mobility information from the BSM
if Distance to intersection == 300 then
    Change TLs state to green for EV
    Change TLs state to red for other vehicles
    if EV crossing time == 10 s then
        Change TLs state to green for other vehicles
    end if
end if
```

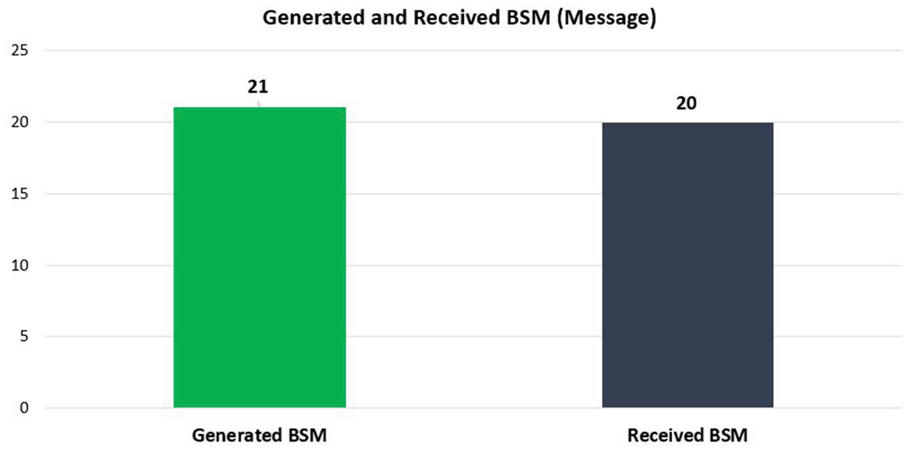

Fig. 3. Number of sent and received BSM messages

by the RSU. Success ratio of packet delivery exhibited 95.2%. Number of sent and received BSM messages are shown in Fig. 3.

4.2 Travel Time

Travel time of EV is a crucial factor in saving human lives. Figure 4 shows the comparison of average travel time for EV and some vehicles traveling ahead of the EV in traditional and connected intersections. Average travel time of EV and cars demonstrated 34 and 35 s in a traditional intersection respectively. However, their travel time improved to 21 and 22 s in the intersection where EV was connected to the TLs. Figure 4 manifested lower EV travel time at a connected intersection compared to the traditional one. This implies that in the connected intersection, EV could constantly pass through the intersection while in the other scenario EV along with other leading vehicles had to stop behind the TLs for some time. Furthermore, connected intersection hugely enhanced the average travel time of the vehicles ahead of the EV. This occurred due to the EV

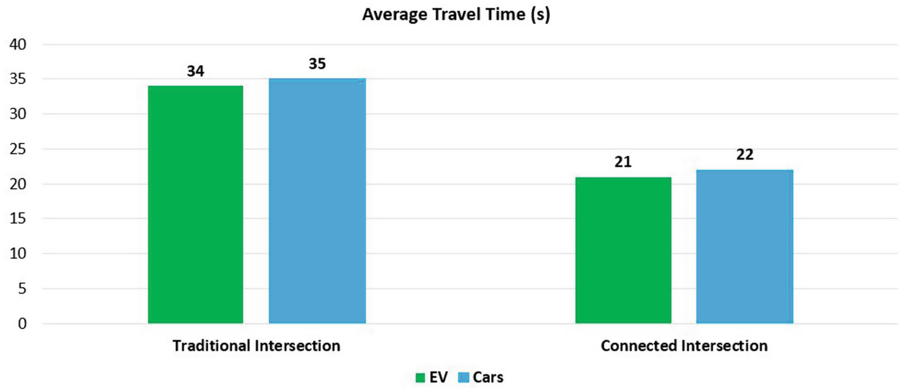

Fig. 4. Travel time of the vehicles (s)

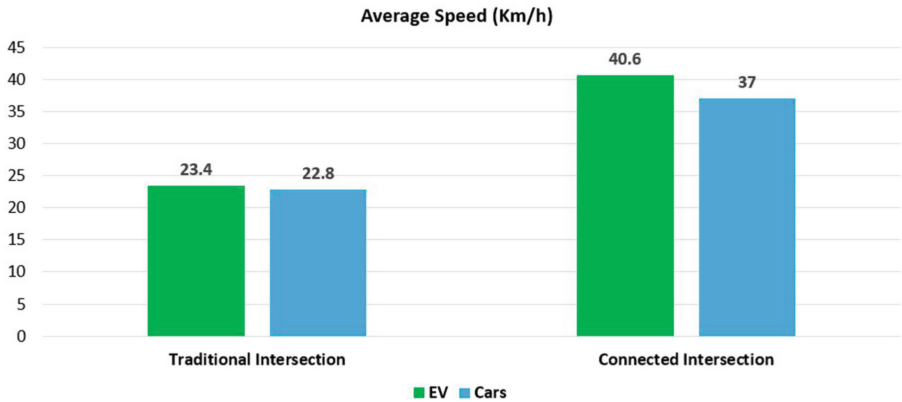

Fig. 5. Speed comparison of vehicles (km/h)

that altered the TLs state to green in advance such that they could continuously travel through the intersection together with the EV.

4.3 Vehicles Speed

Speed comparison of the EV and some other vehicles are in traditional and connected intersections are illustrated in Fig. 5. As mentioned before, EV and leading vehicles cross the intersection continuously in a connected intersection that results in higher average speed. On the other hand, in a traditional intersection, EV is blocked by some cars which greatly decreases its average speed. Besides, vehicles traveling in front of the EV also experienced lower average speed as they stopped at the intersection entrance due to the red TLs.

5 Conclusions

In this paper, we compared travel time and speed of a EV between a traditional intersection and a connected one. Our goal was to control TLs when an EV is approaching to reduce response time for the EV. We used SUMO for the traffic simulation and OMNeT++ for the network simulation. Also, we benefited from Veins to be able to connect two mobility and wireless network simulators together. Communication was based on DSRC helping EVs to communicate with the RSU. EV broadcast BSM messages to the RSU which is located near the intersection. Later, it signals the TL to change its state to green for the road that the EV is coming. Based on the simulation, after changing the state of the TL, EV can cross the intersection continuously. Therefore, EV could travel through the intersection without facing any problem. Simulation showed a decreased response time and an improved delivery efficiency of the EV as well as the leading vehicles. Future work includes a simulation of a train and controlling a TL at the junction.

References

1. Gholamhosseinian, A., Seitz, J.: A comprehensive survey on cooperative intersection management for heterogeneous connected vehicles. IEEE Access **10**, 7937–7972 (2022)
2. Noori, H.: Modeling the impact of VANET-enabled traffic lights control on the response time of emergency vehicles in realistic large-scale urban area. In: 2013 IEEE International Conference on Communications Workshops (ICC), pp. 526–531 (2013)
3. Hager, M., Seitz, J., Waas, T.: Literature survey on recent progress in inter-vehicle communication simulations. J. Transp. Technol. **5**(3), 159–168 (2015)
4. Anwer, M.S., Guy, C.: A survey of VANET technologies. J. Emerg. Trends Comput. Inf. Sci. **5**(9), 661–671 (2014)
5. Arena, F., Pau, G., Severino, A.: A review on IEEE 802.11p for intelligent transportation systems. J. Sens. Actuat. Netw. **9**(2) (2020)
6. Kenney, J.B.: Dedicated short-range communications (DSRC) standards in the united states. Proc. IEEE **99**(7), 1162–1182 (2011)
7. Noori, H.: Realistic urban traffic simulation as vehicular ad-hoc network (VANET) via veins framework. In: 2012 12th Conference of Open Innovations Association (FRUCT), pp. 1–7 (2012)
8. Noori, H., Valkama, M.: Impact of VANET-based V2X communication using IEEE 802.11p on reducing vehicles traveling time in realistic large scale urban area. In: 2013 International Conference on Connected Vehicles and Expo (ICCVE), pp. 654–661 (2013)
9. Jayaraj. V., Hemanth. C.: Emergency vehicle signalling using VANETS. In: 2015 IEEE 17th International Conference on High Performance Computing and Communications, IEEE 7th International Symposium on Cyberspace Safety and Security, and 2015 IEEE 12th International Conference on Embedded Software and Systems (2015)
10. da Costa, L., et al.: Poster: safesmart-a VANET system for efficient communication for emergency vehicles. In: IFIP Networking Conference (Networking) (2020)

11. Padmapriya, V., Ashok, A.K., Sujatha, D.N., Venugopal, K.R,: Road side unit assisted emergency vehicle transit approach for urban roads using VANET. In: IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT) (2019)
12. Obrusník, V., Herman, I., Hurák, Z.: Queue discharge-based emergency vehicle traffic signal preemption. IFAC-PapersOnLine **53**(2), 14 997–15 002 (2020)
13. Varga, N., Bokor, I., Takács, A., Kovács, J., Virág, L.: An architecture proposal for V2X communication-centric traffic light controller systems. In: 2017 15th International Conference on ITS Telecommunications (ITST), pp. 1–7 (2017)
14. SUMO. [Online]. https://www.eclipse.org/sumo/
15. Veins. [Online]. https://veins.car2x.org/
16. OMNeT++ Network Simulation Framework. [Online]. http://www.omnetpp.org/
17. Izadi, A., Gholamhosseinian, A., Seitz, J.: Modeling and evaluation of the impact of motorcycles mobility on vehicular traffic. J. Transp. Technol. **11**(3), 426–435 (2021)
18. Cronin, B.:Vehicle based data and availability. United States Department of Transportation ITS Program Advisory Committee, 2012. [Online]. https://documents.pub/document/vehicle-based-data-and-availability-intelligent-based-data-and-availability-brian.html