Co-operative Intelligent transport systems using LTE based V2X in Support of Vehicle Priority System

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A Thesis Submitted to the Academic Faculty in Partial Fulfillment of the Requirements for the Degree of

BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

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Gazipur, Bangladesh

March 2021

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Date: 10/03/2021

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List of Acronyms

V2X	Vehicle-To-Everything
V2I	Vehicle-To-Infrastructure
V2P	Vehicle-To-Pedestrians
V2V	Vehicle-To-Vehicle
VIP	Very Important Person
D2D	Device-To-Device
DSRC	Dedicated Short-Range Communication
ITS	Intelligent Transport Systems
SUMO	Simulation of Urban Mobility
LTE	Long Term Evolution
RSU	Road Side Unit
EMS	Emergency Medical Services
OBU	On Board Unit
CPE	Customer Premises Equipment

Acknowledgements

We would like to express our gratitude to our supervisor, Mohammad T Kawser, who guided us throughout this project. We would also like to thank our course instructors and other faculty members who supported us and offered deep insight into the study. We wish to acknowledge the help provided by the technical and support staff in the Electrical and Electronic Engineering department of Islamic University of Technology.

Abstract

In this thesis we propose a smart traffic control system that can take into account the needs of special vehicles such as police cars, ambulances and fire trucks responding to an emergency, freight, etc. The system needs to take into account the time and energy saved by giving priority to certain vehicles. This will be done through LTE based V2X with the help of a central control station and RSUs (Road Side Unit). A simulation of the proposed idea was done using Eclipse SUMO (Simulation of Urban Mobility). A rough estimate of energy saved due to the proposed change was also added.

Chapter 1

Introduction

The new traffic control system is in need of replacement. It fails to meet the demands of today's fast-paced world, and it fails to give priority to those who need it most urgently. Prioritizing public transportation, rescue and emergency services, special VIP vehicles, and heavy goods vehicles is a common requirement around the world. A traffic controller at a road intersection cannot have information beforehand about the classification of vehicles entering the intersection, making it impossible for it to make the necessary pre-adjustments to ensure that prioritized vehicles flow smoothly.

Since everybody is treated equally, vehicles that would benefit greatly from priority-based traffic control, such as police cars, fire trucks, and ambulances, as well as freight, do not receive the assistance they need.

1.1 Basic Functionalities

A vehicle will notify the center of its destination before beginning its journey using V2X-based signal prioritization and a centralised traffic control system, and the system will establish routes for it based on the type of vehicle, and ensure that traffic lights are monitored to give these vehicles the support they need if they need it. V2X can enable roadside infrastructure to automatically recognize the unique properties of a vehicle and take optimal action.

1.2 Different Aspects

Our proposed system has 2 main aspects: a) Route optimization,

b) Relative priority system.

The central system will create optimized routes for emergency vehicles, and it will instruct other vehicles to move out of the way of emergency vehicles. And also, locally the emergency vehicle will instruct other vehicles to move out of the way. This idea is expanded in chapter 4.

1.3 V2X

As the number of autonomous, connected cars and 5G connectivity is constantly rising the future of mobility has opened new dimensions in the way vehicles, pedestrians and road side infrastructures can communicate with each other. This type of communication, which is essentially wireless between vehicles and its surroundings for instance vehicles, pedestrians, RSUs and smart homes, is termed as Vehicle to everything (V2X).

There are multiple components of V2X, like vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and vehicle-to-network (V2N) communications. In this multifaceted ecosystem, cars communicate to other cars; traffic lights or parking spaces; pedestrians with smart devices, and to data centres, by using cellular networks. Different sets of requirements are needed depending upon the use and the communications system must handle efficiently and cost-effectively.

The original V2X standard is based on a Wi-Fi offshoot. V2X communication via IEEE 802.11p[2] goes beyond line-of-sight-limited sensors such as cameras and radars and covers V2X use cases such as collision warnings, speed limit alerts, and electronic parking[1]. It also includes short range (under 1km), low latency (~2ms) and high reliability. So, 802.11p extends a vehicle's ability to 'see' the environment around it.

1.4 Cellular V2X

C-V2X[3] could be a new alternative to the existing IEEE 802.11p standard. 5G Automotive Association and Qualcomm are its main supporters. The key advantage of C-V2X is its 2 operational modes which cover most possible events. The first is low-latency C-V2X Direct Communications over the PC5 interface on the 5.9 GHz band designed for active safety messages like road hazard warnings and other V2X situations. This mode is comparable to what is offered by the incumbent IEEE 802.11p technology. The other mode is communications over the Uu interface on the regular licensed-band cellular network, and can handle V2N use cases like infotainment and safety messages concerning longer-range road hazards or traffic conditions. Because it doesn't use cellular connectivity, IEEE 802.11p can only be comparable to this mode by making ad hoc connections to roadside base stations.

The current C-V2X Rel-14 specification that is an element of the worldwide 3GPP Rel-14 standard and LTE Advanced Pro, had been finalised a few years ago. Compared to IEEE 802.11p, C-V2X is several years behind in terms of deployment in the V2X market.

IEEE 802.11p has the advantage of earlier development and deployment. However, C-V2X provides arguably better performance, the ability to employ both direct and network-assisted communication[4].

Other relevant findings of the V2X (Vehicle-to-Everything) are:

- DSRC proponents are pushing ahead with their plans to roll out IEEE 802.11p in North America, Europe and Japan. But pre-commercial C-V2X deployments have gained considerable momentum, led by cellular industry giants such as Qualcomm and Huawei with support from automakers including Ford, BMW and Volkswagen's luxury brand Audi.
- V2X communications technology can become a standard safety feature on an increasing number of vehicles, through its unique non line-of-sight sensing capability. Moreover the commercialization of next-generation V2X standards, specifically 5G-V2X and IEEE 802.11bd will make this technology even better.
- The 5.9 GHz band is the preferred spectrum for V2X communications technology. But there are a few exceptions where other frequencies are used for safety-related applications based on V2V and V2I communications.

Chapter 2

Literature Review

2.1 Radio Resource Allocation Algorithm

For a better transportation system, real-time, easily reliable, and actionable information flows are required to allow for safety, mobility, and environmental applications. Wireless network engineers are increasingly using device-to-device (D2D) communication to improve network efficiency. It enables Vehicle-to-everything (V2X) applications, which are strongly reliable and meet low latency requirements as it is able to improve traffic efficiency, safety and comfort.

Ahlem Masmoudi, Souhir Feki, Kais Mnif and Faouzi Zarai[5] researched on the topics of radio resource management (RRM) in the field of D2D-based V2X communications, including vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V). To successfully optimize the sum rate of V2I users without compromising the reliability of V2V users, they proposed an algorithm called Efficient Resources Allocation for V2X Communications (ERAVC).

2.2 Demonstration of an Emergency Vehicle Priority System

With funding from Japan's Ministry of Internal Affairs and Communications, and in partnership with Panasonic Corporation's Connected Solutions Company, and with approval from the Ahmedabad Municipal Corporation in India, ZERO-SUM, LTD. conducted an experiment in December 2019 demonstrating an emergency vehicle priority system (Green Corridor System) which utilises a UHF band based international standard V2X communication technology originated in Japan[6].

This experiment showcased the benefits that an emergency vehicle priority system has because it allows an emergency vehicle, such as an ambulance, and traffic signals to communicate with each other over the UHF band using the aforementioned Japanese V2X communication technology. On a public road, this was the world's first demonstration of its kind.

After the demonstration, it was discovered that by monitoring the traffic signals in the emergency vehicle's approaching direction, the vehicle went through the intersection smoothly and cut its travel time to its destination in half. Furthermore, it was discovered that when emergency vehicle approaching information is shown on traffic information boards, most vehicles shift to the side to allow the emergency vehicle priority passage, allowing the emergency vehicle to operate smoother and minimize travel time even further.

2.3 DSRC versus 4G-LTE for Connected Vehicle Applications

The United States Department of Transportation (US DOT) started[7] planning in 2011 in order to implement vehicle-to-vehicle (V2V) communication between light-duty vehicles in the United States. At UMTRI, a new study was conducted to see if V2V communication might be able to be implemented in a large-scale, real-world setting. Three scenarios that include Connected Vehicle application were set and they were Collision Avoidance, Traffic Text Message Broadcast, and Multimedia File Download, respectively.

With the built hardware and software platform, the communication performance of DSRC and LTE was investigated and analyzed. It was concluded that the combination of DSRC and LTE could be a good solution for Connected Vehicles as compared to the conventional computer simulation approach for vehicle network efficiency. It not only enables

safe driving but also can supply high-quality telematics service to the drivers.

2.4 DSRC V2V performance in truck platooning

Via real-world experiments, Song Gaoa, Alvin Lima, and David Bevlyb investigate DSRC Vehicle-to-Vehicle (V2V) success in truck platooning scenarios[8]. In their report, commercial DSRC equipment and semi-trailer trucks were used. On each side of the truck, a DSRC antenna was mounted. To investigate DSRC behaviors under different situations, one set of dynamic tests and a few sets of static tests were performed.

Steep roads can affect delivery ratio and antennas mounted on opposite sides of a truck can suffer from low delivery ratio on curved roads, according to the test results. Furthermore, even when the trucks are on straight paths, antennas will suffer from low distribution ratios. This is caused due to reflections from the surrounding terrain. But, the delivery ratio can be greatly improved by using the two side antennas alternately.

Chapter 3

Materials and methods

3.1 The Required Technology

Vehicle-to-everything (V2X), which includes vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure communications, improves road safety, traffic efficiency. 3GPP Release 12 and Release 13 adds proximity services (ProSe) where devices can directly communicate with each other over PC5 interface (Sidelink) without passing via network infrastructure[9].

There are two resource allocation modes: the underlay mode and the overlay mode. In the underlay mode, the cellular and vehicular users (V-UEs) can share the same resources, so they can achieve better spectrum efficiency. However, a strong interference could be generated among these users. On the other hand, overlay mode has dedicated resources that are allowed for V-UEs. The advantage of this mode is that the eNodeB (eNB) does not need to handle interference among the cellular and V-UEs.

Orthogonal Frequency Division Multiple Access(OFDMA) can support multiple access for both V2X and cellular communications. The total uplink bandwidth is divided into F RBs for each scheduling unit[7] (each RB). Therefore, it is supported by high capacity V2I communication where V2I-UEs are considered as cellular users. Whereas, safety critical information, implies broadcast safety related messages among vehicles.

Hence, it is supported by the D2D links, which impose strict latency and reliability requirements.

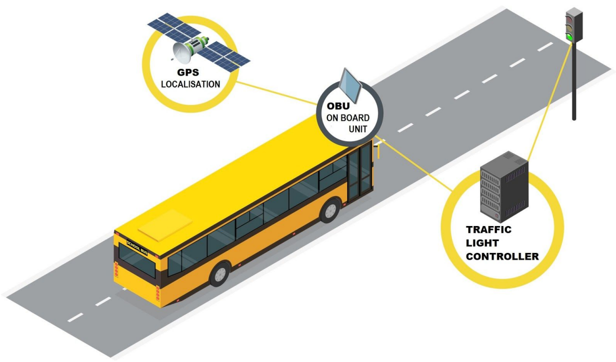

Figure 1 : Major Components required to be deployed

3.2 Overall structure

The infrastructure needed to realise the proposal are smart roadsides, connected and automated vehicles, heterogeneous network, and transportation applications servers.

Short-range wireless system with DSRC roadside units (RSUs) and 4G-LTE cellular communication system comprise a specialized vehicular communication platform; An OBU that connects LTE network, and realizes LTE protocol stack and TCP/IP protocol stack by using wireless or wired mode to transmit data to the destination through 4G network. The eNode-B is responsible for the wireless bearer, downlink dynamic wireless resources, data packet scheduling, and mobility management. Both DSRC and LTE systems are isolated from the public telecom network.

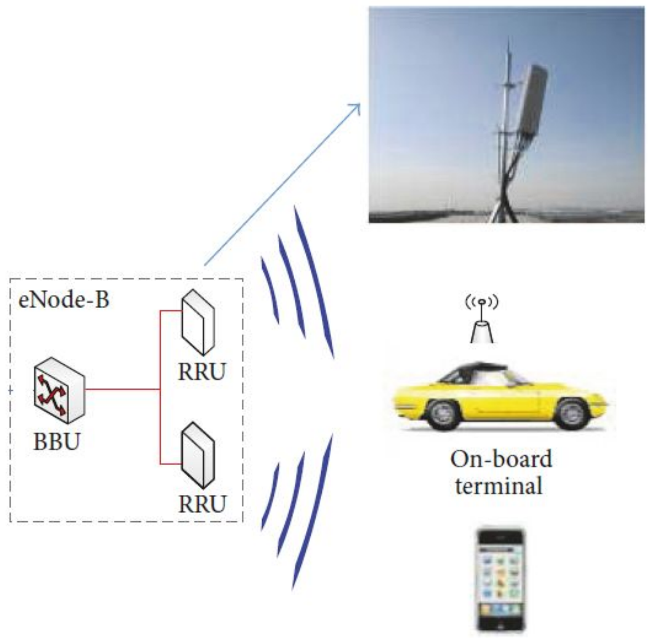

Figure 2 : The LTE network

3.3 Setup of the On-Board Devices

A computer needs to be fixed on the vehicles. A GPS receiver has to be connected to the computer. A LTE CPE for example can be linked to the computer via Ethernet interfaces. Three kinds of antennas are mounted on the roof of the vehicles and they are connected to LTE terminal, DSRC terminal, and GPS module respectively. Each vehicle can talk with the other via 2 kinds of network within the coverage area. The DSRC RSU and LTE eNode-B can also send text messages or digital files to the vehicle.

Chapter 4

Proposed System

The research delves into decision making based on both local and central data, priority of vehicles, energy and time saving and simulation of a simple scenario of an emergency vehicle passing through an intersection. The software calculated the time saved, and then we manually calculated the energy saved based on some assumptions.

The two main aspects of are : a) Route optimization
b) Relative priority system

We expect that these aspects will be conducive to fully autonomous vehicles of the future.

The route optimization that we suggest is dynamic in nature. Which means that a vehicle will receive continuous updates about its route. The current optimum route may not be usable a few moments later as traffic conditions change rapidly. So, to resolve this issue the vehicle will receive updated routes from the eNodeB and the RSUs.

The relative priority system provides higher priority to the vehicles that deserve it like ambulances, fire trucks, law enforcement vehicles etc . This higher priority status will be updated regularly. Therefore, an ambulance carrying a patient will receive a higher priority than an empty ambulance and the higher priority status will be rescinded after the ambulance is not on active duty. Higher priority vehicles will hardly have to stop at the intersections because the eNodeB and the RSUs will ask the nearby vehicles and the traffic lights to let the higher priority vehicles pass. So, the lower priority vehicles will have to wait for the higher priority vehicle to move forward ensuring that help is given to those who need it the most.

In both of these aspects, a vehicle receives data from the eNodeB through V2N and the RSUs, nearby vehicles, pedestrians through V2I, V2V and V2P respectively. We refer to the eNodeB as the central data provider and the RSUs, nearby vehicles, pedestrians are referred as local data providers. The local data providers can only information about a small region around the vehicle because they use short range communication. On the other hand, the eNodeB can provide information about a large region like a city or town. So, the eNodeB provides data pertaining intersections, road conditions that are far away from the vehicle. As a result a vehicle may receive conflicting suggestions and data from the local and central data provider. The vehicle will make a decision by combining the two types of data through the use of suitable algorithms and policies.

Especially cities located near international borders and ports of entry, must efficiently move freight through their roadways. As a result, properly implemented signal prioritization will ensure that large freight vehicles move as quickly as possible and without halting too much, resulting in significant fuel savings and a reduction in the environmental impact of large vehicles.

A bigger challenge exists in the advanced and prohibitively expensive emergency systems that integrate routing information with priority rather than preemption, allowing the EMS route to be cleared in advance of the vehicle. When they approach at high speeds, EMS drivers are often unaware whether there are pedestrians in a crosswalk. There are currently no mature systems that allow connected vehicles to see non-connected objects in a crosswalk, such as pedestrians. Once again, V2X-based signal prioritization appears to be the best option for developing an effective model to address these issues.

Finally, for V2X to run safely, it requires a security framework that verifies the validity of any message sent. Each message's source must be trusted, and the content of the message must be protected from outside intrusion or alteration. The ability for various V2X devices to communicate with each other securely is ensured by interoperability of message content and security credentials.

In the current scenario, emergency vehicles are not given priority in the roads. They are treated the same as any other vehicle. However in the optimised scenario emergency vehicles which are on active duty are given priority by the traffic system itself. The emergency vehicles will broadcast the status packages to the RSU and other OBUs of vehicles in close proximity, via LTE network. The package size includes vehicle ID, package ID, package type, package time tag, GPS data, and vehicle kinematic parameters.

The RSU can convey the message to nearby intersections so that the traffic signal shows green at the intersection for the emergency vehicle. In case of scenarios where multiple emergency vehicles reach an intersection, the traffic controller chooses priority in terms of the level of emergency.(i.e an ambulance gets priority above a cargo truck). The other OBUs will let the drivers know that there is a priority vehicle, so they will try to clear up one lane to let it pass quickly. This will save crucial time for emergency vehicles, for example: ambulances carrying patients; police vehicles rushing to the crime scene; fire brigade rushing to affected areas.

Chapter 5

Results

5.1 Calculating Fuel Saved

An average Class 4 truck has a GVWR (Gross Vehicle Weight Rating) of 6,000 kg. Assuming it is moving at a speed of 35 kilometers per hour (9.7 meters per second), it has a kinetic energy of 282,270 joules. When it stops, this energy is dissipated as heat in the brakes. When it resumes again, this energy is expended again as it accelerates back to speed(neglecting rolling resistance and energy efficiency). More energy is wasted while the truck is idling at the stop. Therefore, the similar priority system for freight will allow heavy trucks to pass through intersections without having to stop.

In order to understand the cost benefits, assuming the vehicle runs on diesel, we can calculate in terms of USD ;
Diesel weighs about 3.175 kg per gallon, and a gallon of Diesel costs 2.654 USD. The calorific value of diesel fuel is roughly 45.5 MJ/kg (megajoules per kilogram). So, there is roughly 144,462 kJ in a gallon of diesel. Every time when stopping and starting, 564,540 Joules (282,270*2) are wasted. Taking the average efficiency of a diesel engine as 40%, 0.009769 gallons are wasted. That amounts to 0.025928 USD per vehicle.

In cities near ports or simply areas where there are high amounts of shipment happening, this becomes very significant. For example , there are a total of 125,621 truck crossings into Manhattan per day, so at every intersection , if these trucks did not have to stop at the intersection , an estimated total of USD 3257 would be saved in every intersection every day.

However, if there are many vehicles approaching the intersection, it might be more economical if the heavier is stopped instead. This dilemma might be solved by truck platooning. The central authority will have information about all the vehicles, their energy cost and efficiency. It can decide which vehicles to stop and which vehicles to let through, for maximum fuel and time efficiency.

5 .2 Simulation

The Software Eclipse SUMO (Simulation of Urban Mobility) was used to simulate the current scenario of intersections and the optimised scenario that has been proposed. The flow option is used to generate the vehicles in sumo. The number of emergency vehicles is less than the common vehicles. It shows how emergency vehicles can freely cross an intersection without having to stop.

Current scenario

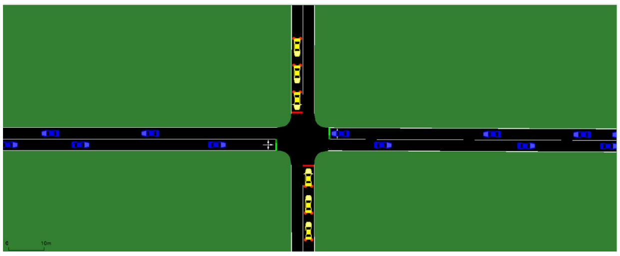

Figure 3 : Emergency vehicles(yellow) are waiting

The emergency vehicles are treated like any regular vehicle and have to stop in the intersection because of the red signal. This as mentioned before is inefficient in terms of both time and energy.

Proposed scenario

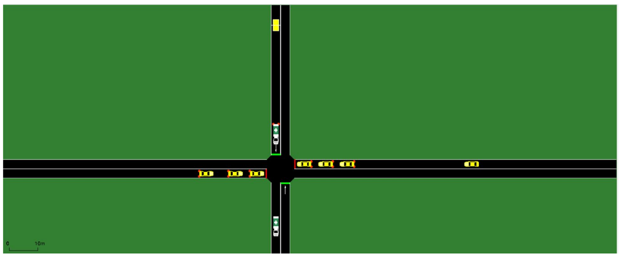

Figure 4 : Emergency vehicles(in white) are given priority whenever they are detected.

The detection of the emergency vehicles is performed by the induction loop detector (the small rectangular yellow box in the route going from north to south). After detecting, the traffic lights of the routes connecting the east and west sides are turned yellow and then red until all the emergency vehicles have crossed the intersection. This enables the emergency vehicles to reach their destination without stopping.

Comparison between the two scenarios

vehicle:flow_2.0 Parameter

Name	Value	Dynamic
lane [id]	gneE9_0	✓
position [m]	48.97	▣
lateral offset [m]	0.00	▣
speed [m/s]	0.00	▣
lateral speed [m/s]	0.00	▣
acceleration [m/s^2]	0.00	▣
angle [degree]	180.14	▣
slope [degree]	0.00	▣
speed factor	1.01	✗
time gap on lane [s]	-1.00	▣
waiting time [s]	28.00	▣
waiting time (accumulated, 100.00s) [s]	28.00	▣
time loss [s]	32.87	▣
impatience	0.09	▣
last lane change [s]	0.00	▣
desired depart [s]	0.00	✗
depart delay [s]	0.00	✗
odometer [m]	43.87	▣

Table 1: Parameters of the first emergency vehicle in the current scenario.

vehicle:down_61.3 Parameter

Name	Value	Dynamic
lane [id]	4i_0	✓
position [m]	491.41	▣
lateral offset [m]	0.00	▣
speed [m/s]	14.26	▣
lateral speed [m/s]	0.00	▣
acceleration [m/s^2]	-2.69	▣
angle [degree]	180.00	▣
slope [degree]	0.00	▣
speed factor	0.94	✗
time gap on lane [s]	-1.00	▣
waiting time [s]	0.00	▣
waiting time (accumulated, 100.00s) [s]	0.00	▣
time loss [s]	15.77	▣
impatience	0.00	▣
last lane change [s]	0.00	▣
desired depart [s]	318.00	✗
depart delay [s]	18.00	✗
odometer [m]	494.41	▣

Table 2: Parameters of the emergency vehicle that is about to pass the intersection in the optimised scenario.

5.3 Calculating Time Saved

The waiting time dropped from 28 seconds to 0 seconds

For every trip there is a hypothetical duration tMIN that could be achieved if the vehicle was driving with its maximum allowed speed (including speedFactor) and there were no other vehicles nor traffic rules.

timeLoss = tripDuration - tMIN

Time loss dropped from 32 seconds to 15 seconds

Chapter 6

Conclusion

As seen in the background work section, an experiment was conducted to show how cars can successfully communicate with other cars and RSUs. Then, Zero Sum tried to simulate an emergency vehicle priority system in Ahmedabad using Japanese UHF band frequency.

In this thesis we showed how the widely implemented LTE technology in most countries around the world, can be taken advantage of and made to enable a vehicle priority system in intersections. The advantages that different sorts of vehicles can gain from this new system were analysed and seen to produce a faster response to

- Medical emergencies
- Fire accidents
- Criminal activity

And a significant cost benefit for cargo shipment in port cities.

Due to limitation of resources, this could not be simulated in practice, therefore there is ample opportunity to extend on the proposal and implement a physical experiment using LTE technology, before this idea is successfully commercialised

There are plenty of opportunities for future research in this field. Simulations which show message sending and receiving from RSUs and its effect on traffic, practical simulations, creation of new protocols.

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