Indian Institute of Engineering Science and Technology, Shibpur

B.TECH. Project Thesis

Implementation of a Simulation Environment for Vehicle Platoons

Author:
Aadreesh Sahu
Anirban Mukhopadhyay
Rajeswar Banerjee
Koustav Sing

Thesis Committee:
Dr. Basabdatta Palit
Dr. Atri Mukherjee

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Abstract

B.TECH THESIS

Implementation of a Simulation Environment for Vehicle Platoons

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Aadreesh Sahu
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Next gen smart cities aim to develop autonomous vehicles without the interference of the drivers. Vehicle platooning plays an important role in making the system of vehicles and infrastructure to communicate amongst themselves satisfying the IEEE 801.11p protocol and using dedicated short range communication to communicate within a platoon. Vehicle platooning is a concept that aims to increase the current road capacity by making vehicles move along a platoon or in tight groups. The key in achieving this goal is the organization of vehicles in tightly controlled groups, also called platoons that operate close together.Vehicles in an autonomous platoon can exploit vehicle-to-vehicle (V2V) communications to collect information, such as velocity and acceleration, from surrounding vehicles so as to maintain the target velocity and inter-vehicular distance. First, stability analysis for the control system is performed and the maximum latency requirements are met. Which can prevent the instability of the platoon. Finally, delay analysis is conducted to determine the end-to-end delay, including queuing, processing, and transmission delay for the V-V communication link in the wireless network.

Acknowledgements

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Furthermore, we would like to deeply thank Dr. Atri mukherjee, for his valuable advice and guidance on technical difficulties, especially on Simulation Environment.

Last but not least we would like to express our deepest gratitude to our families and friends for the support during this thesis.

Aadreesh Sahu
Anirban Mukhopadhyay
Rajeswar Banerjee
Koustav Sing

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Dedicated to our families and friends. . .

Contents

1

Introduction

1.1 Motivation

The platooning concept can be defined as a collection of vehicles that travel together, actively coordinated in formation. Some expected advantages of platooning include increased fuel and traffic efficiency, safety and driver comfort. There are many variations of the details of the concept such as: the goals of platooning, how it is implemented, mix of vehicles, the requirements on infrastructure, what is automated (longitudinal and lateral control) and to what level.

We are targeting platooning because by using that technique an increased number of vehicles can be fit into a smaller space, thus optimising road capacity. Also, when heavy vehicles move in a platoon, the frontmost vehicle experiences normal air drag. The air drag for all the following vehicles are reduced significantly, leading to a more fuel efficient system. This also in turn reduces the emission of the pollutants of the entire group as a whole.

This thesis is concerned with an experimental platform for studying cooperative driving and techniques for embedded systems programming. Cooperative driving systems use vehicle-to-vehicle and vehicle-to-infrastructure communication for safe, smooth and efficient transportation.

1.2 Types of vehicle platooning

Adaptive Cruise Control (ACC)
Vehicles with ACC are equipped with a front radar. This radar can detect a preceding vehicle and is able to measure the distance and speed of this vehicle. This information enables ACC to react to speed changes and control the vehicle's time-gap to the preceding vehicle

Cooperative Adaptive Cruise Control (CACC)
Unfortunately, the front-radar of an ACC system is only able to detect vehicles in the line of sight. In practice, this means that a ACC system is not able to measure the distance and speed of vehicles driving a) in front of the immediate preceding vehicle, b) behind the vehicle, or c) driving in a different lane.

Automated Highway System (AHS)
A next step in vehicle platooning is a system in which vehicles are fully automated. Such a system, called AHS, has been under research by the Program for Advanced Technology for the Highway (PATH). AHS aims to produce a highway system where fully automated vehicles are guided to their destination and the flow of traffic is controlled and optimized for maximum efficiency and safety. However, AHS platoons are highly dependent on wireless communication to create automated and high cooperative vehicles.

1.3 Importance of Vehicle platooning

- **Increase of road capacity:** It is possible to make vehicles move in a close packed platoon which follows the front vehicle. Thus more vehicles can be accommodated within a given road capacity is the vehicles are at a constant distance apart.

- **Reduction of environmental impacts:** Wind tunnel tests and field experiments have revealed that closely operating vehicles in a platoon reduce the average air resistance and hence the fuel consumption, thus reducing the CO2 emissions.

- **Improved safety**: Majority of the traffic accidents are caused by human error. Vehicle platooning, which implements a variety of technologies can significantly minimise those errors, react quicker to dangerous situations, and detect such situations much earlier by extending the traffic view beyond the drivers line of sight by implementing wireless communication.

- **Improved driver comfort:** Depending on the degree of automation, various driver tasks may be delegated. This is particularly helpful for longer journeys. Additionally, comfort is further improved due to low congestion and faster movement on traffic flow by vehicle platooning.

Theoretical Background

In this Chapter, we describe in detail the theoretical background of vehicle platoon formation along with the tools used and the protocols governing them.

2.1 Tools used

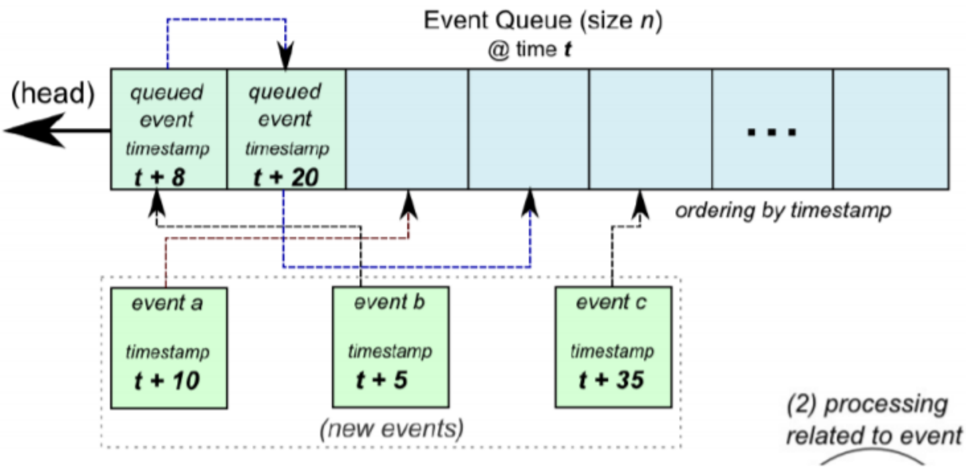
SUMO (Simulation of Urban Mobility)

Microscopic transport simulation where vehicles(cars,buses etc.) in the form of nodes run on a made roadway.

TraCI (Traffic Control Interface) allows access to a running road traffic simulation It allows to retrieve values of simulated objects and to manipulate their behavior on-line“ In our case Veins simulator connects to SUMO via TraCI!

OMNeT++

Objective Modular Network Testbed in C++ Discrete event simulator Provides generalized framework for network simulation Written in C++ Source code publicly available Simulation model for Internet, IPv6, Mobility, etc.



Veins Simulator

Open source framework for running vehicular network simulations.Based on two well-established simulators OMNeT++: network simulator SUMO: traffic simulator Allows online re-configuration and re-routing of vehicles in reaction to network packets .Relies on IEEE 802.11p and IEEE 16094 DSRC/WAVE network layers.

2.2 IEEE 802.11p Requirements

Communication link between the vehicles and the roadside infrastructure exist for only a short time interval . Vehicle at 100 kph to an RSU . Vehicle 100 kph running in opposite directions . No time for authentication and association procedures prior to exchanging data These sorts of functionality is moved to the upper layers. Changes in baseline 802.11p standards are required to Support longer ranges (up to 1 km). High speed of vehicles (up to 500 kph relative velocities) .Extreme multipath environment (many reflections with long delays) .The need for multiple overlapping ad-hoc networks to operate with high quality of service .The nature of automotive applications to be supported (reliable broadcast of safety messages).

2.3 IEEE 802.11p

Vehicular networking combines wireless communication, in-vehicle sensing module, and Global Positioning System (GPS) to enable a variety of applications in road safety, traffic efficiency, and infotainment domains. The current technologies are based on DSRC (dedicated short-range communications) global standard. In 1999, the FCC allocated 75 MHz of spectrum at 5.850 to 5.925 GHz frequency range. In the USA, the total bandwidth is divided in to seven 10-MHz bandwidth channels mainly of two types, i.e., control channel (CCH) and service channels (SCHs), while the remaining 5 MHz is dedicated as the guard band. The control channel (CCH) is dedicated for broadcasting short messages and communication management for the road safety applications, whereas the service channels (SSHs) is reserved for the traffic efficiency and infotainment applications. In order to widely spread these technologies, standardization at each layer of the networking protocol stacks has to be done. Therefore, a suite of protocols along with the architecture for the wireless environments with vehicles is developed called wireless access in vehicular environment or WAVE.

The WAVE protocol stack is composed of several components, most notably the IEEE 802.11p which is essentially an IEEE 802.11-based standard adapted for the vehicular networking environment. It consists of BSM(Base Safety Messages), WSM(Wave Short Message) and WSA(Wave Service Message) message packets for intervehicular communications. The noteworthy characteristic of the PHY layer is the reduction to 10 MHz bandwidth from IEEE 80.11a 20 MHz, which halves the data rate to 3 to 27 Mbps from 6 to 54 Mbps. The IEEE 802.11p MAC is 802.11e Enhanced Distributed Channel Access (EDCA) with quality of service (QoS) support. The PHY layer and the MAC layer together allow ad hoc communication among OBUs as well as between OBUs and the RSUs. The absence of infrastructure-assisted channel access mechanism and wireless communication among high-speed vehicles over the varying channel condition possesses significant challenges in terms of overall network performances.

Implementation

3.1 SUMO

Road Network Generation: SUMO road networks represent real-world networks as graphs, where nodes are intersections, and roads are represented by edges. Intersections consist of a position, a shape, and right-of-way rules, which may be overwritten by a traffic light. Edges are unidirectional connections between two nodes and contain a fixed number of lanes. A lane contains geometry, the information about vehicle classes allowed on it, and the maximum allowed speed. Therefore, changes in the number of lanes along a road are represented using multiple edges.

Vehicles and Routes: SUMO is a purely microscopic traffic simulation. Each vehicle is given explicitly, defined at least by a unique identifier, the departure time, and the vehicle's route through the network. By "route" we mean the complete list of connected edges between a vehicle's start and destination. If needed, each vehicle can be described in a finer detail using departure and arrival properties, such as the lane to use, the velocity, or the exact position on an edge. Each vehicle can get a type assigned, which describes the vehicle's physical properties and the variables of the used movement model. Each vehicle can also be assigned to one of the available pollutant or noise emission classes. Additional variables allow the definition of the vehicle's appearance within the simulation's graphical user interface.

The parameters used in the SUMO Krauβ model are:

a. Accel – acceleration ability [m/s^2],
b. Decel – deceleration ability [m/s^2],
c. sigma – driver imperfection (real value between 0 and 1),
d. tau – driver's reaction time *s+,
e. minGap – gap between preceding and following cars [m].

Scenario code:

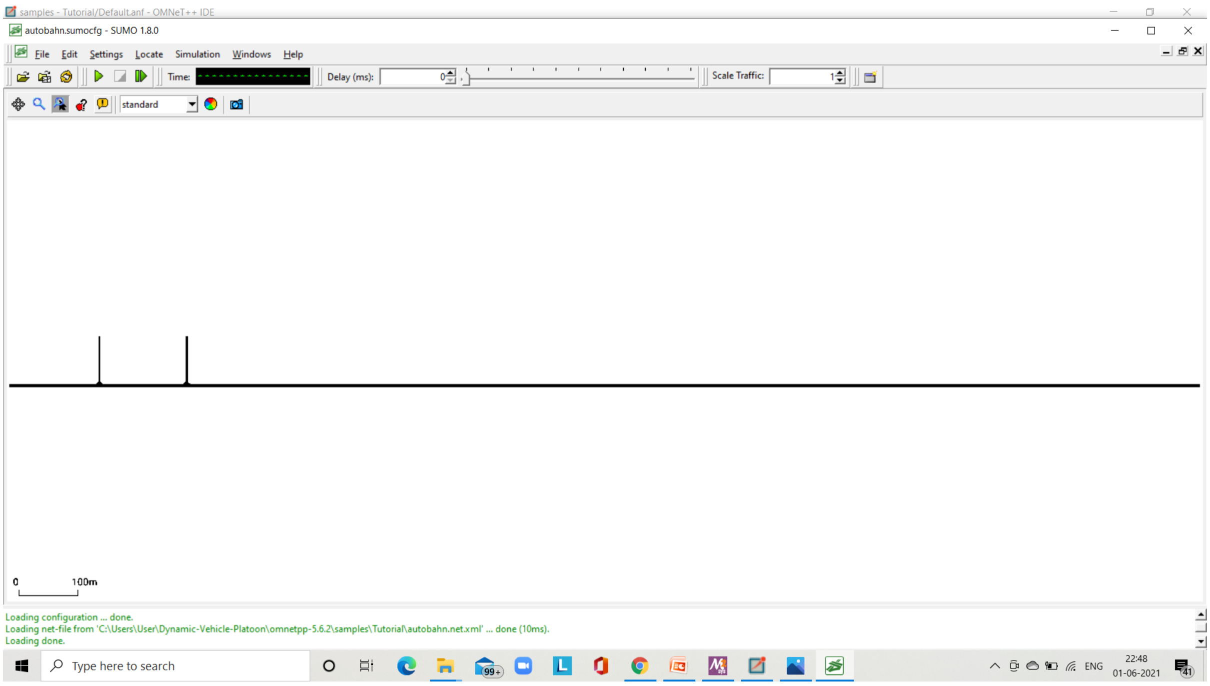
```
<routes>
    <vType id="normal_car" vClass="passenger" maxSpeed="40" speedFactor="0.9" speedDev="0.2" sigma="0.5" />
    <vType id="coach" vClass="coach"  maxSpeed="30" speedFactor="1." speedDev="0.1" />

    <flow id="normal" type="normal_car" begin="0" end="0" number="2" from="entry" to="exit" />



 </routes>
```

Two types of roads simulated.



3.2 OMNET++

OMNeT++ (Objective Modular Network Tested in C++), is an extensible and modular component-based C++ simulation library and framework that is running on different operating systems such as 13 Linux, Mac OS X, other Unix-like systems and Windows. Primarily, OMNET++ is developed for building network simulators. The simulator can be used for traffic modelling of telecommunication networks, protocol modelling, queuing networks modelling, multiprocessors and other distributed hardware systems modelling, hardware architectures validating, evaluating performance aspects of complex software systems and modelling any other systems where the discrete event approaches are suitable.

An OMNeT++ model is combined by simple modules by using the NED language while the simple modules themselves are programmed in C++. The simulation system provides two components: simulation kernel containing the code that manages the simulation and the simulation class library; user interfaces. Graphical, animating user interfaces are highly useful for demonstration, while command-line user interfaces are best for batch execution. Thus, the way of how OMNeT++ is used is as follows. First, the NED files are compiled into C++ source code, using the NEDC compiler which is part of OMNeT++. Then all C++ sources are compiled and linked with the simulation kernel and a user interface to form a simulation executable.

Flow of execution:

1)new WaveApplFile

2)new WaveApplFile (ned)

3)make Wave Service Announcements

Types of WAVE messages available in Veins :

- Wave service message (WSM) - Data messages being exchanged: Requires WSA before sending.
- Wave service announcement (WSA) - WSA include information about one or more DSRC services that are offered in an area. A service can be any information exchange, e.g., tolling traffic alert, navigation, restaurant information, entertainment, etc. Most services are provided by the RSU, but vehicles can also send WSA. Only sent in CCH interval.
- Basic safety messages (BSM) - Conveys critical vehicle state information in support of V2V safety applications It is not considered a service, and therefore, BSM doesn‘t require a WSA. If every vehicle starts broadcasting BSM, soon there will be a lot of collisions (active research field: how to adjust the sending rate)

4) Sending Velocity Information

We update the member variables curPosition and curSpeed defined in class BaseApplLayer using the traCI interface (mobility)

- We make a WAVE packet, in this case a BSM, populate the packet, and schedule to send it later

- It is likely that we would require this information periodically

5)Periodic Transmission of WAVE Messages
6) Changing the Speed of the Lead Vehicle

7) Read the distance to the preceding vehicle only and try to adjust the acceleration of the current vehicle.

$$a = p \cdot (d - ddesired)$$

8)Letting all nodes to broadcast

9)Identifying the Sender

As, we can't assume the sender is the lead vehicle, upon receiving BSM identification of the sender is required before taking action . Reading the sender ID from BSM and check whether it's from the preceding vehicle.

10)Adjust the Vehicle Velocity

11)Setting Acceleration Values

12) setting up TracI server.

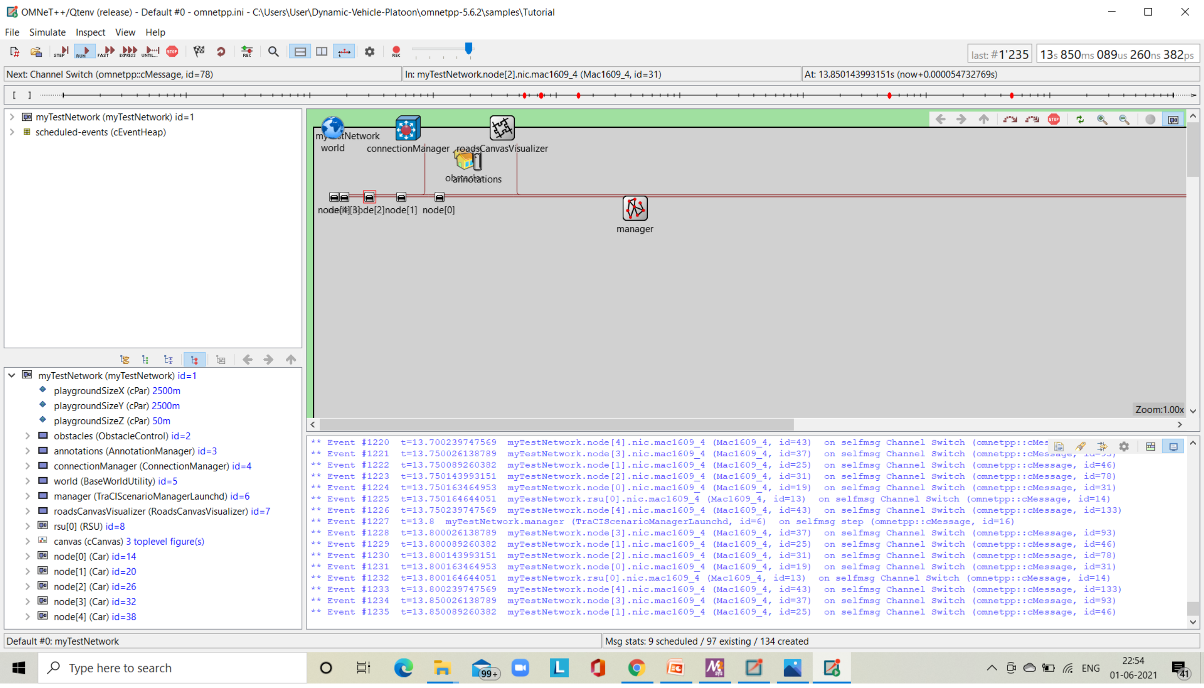
3.3 VEINS

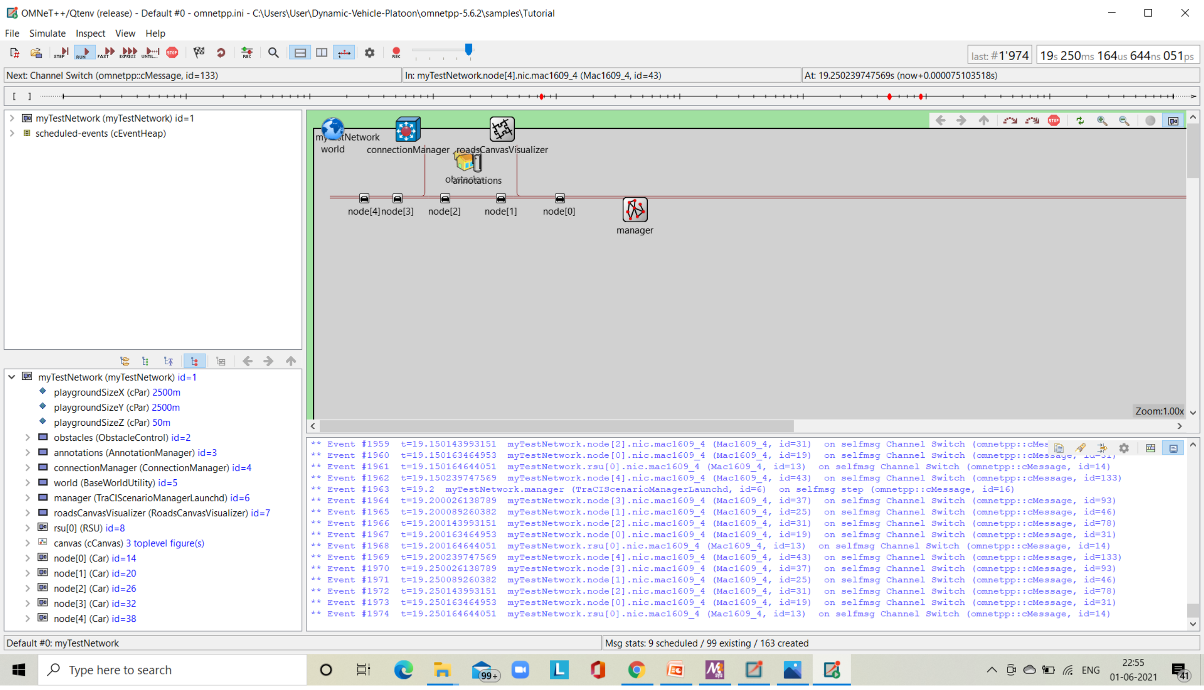
Veins is an additional supportive application which enables complex urban simulation in sumo with the help of Omnet++.
The complete 802.11p protocol can be enabled by integrating veins. We have created a simulation specific application **VehicleControlApp** from

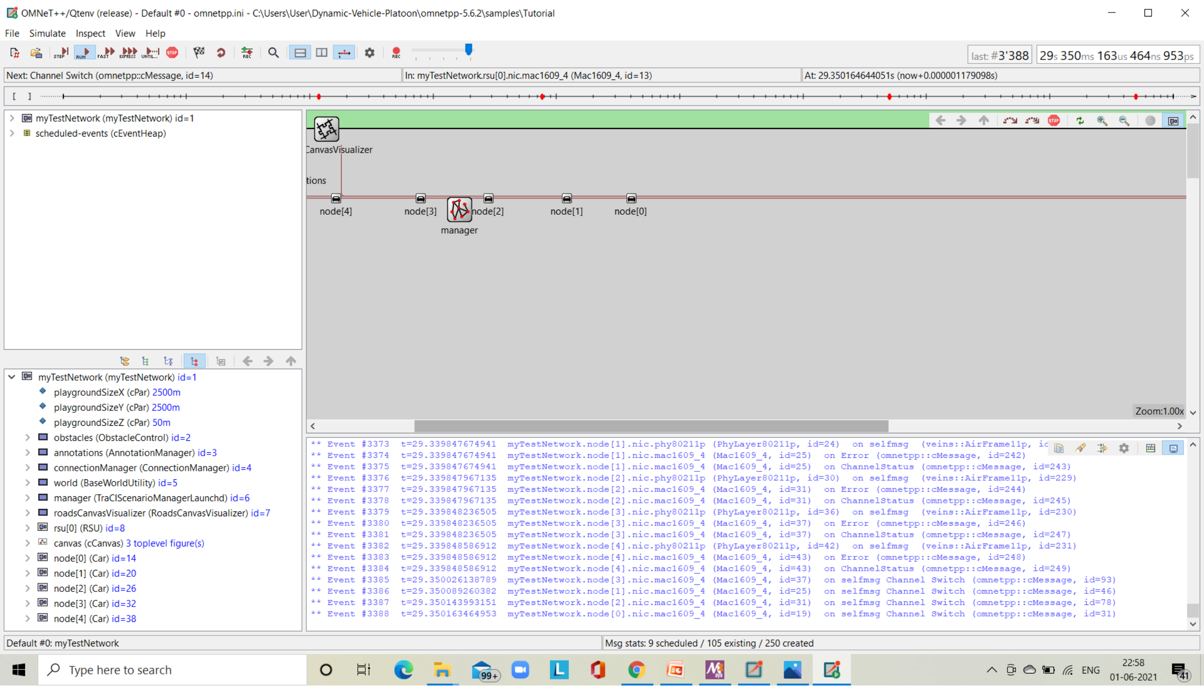
MyVeinsApp file to create the simulation environment. Bsm, wsm and wsa packets exchanges are also taken care of. The time interval and structure of communicating nodes are configurable within the initialisation files. Flexible utilisation MAC and PHY layers actually enables almost error free simulations maintaining very low BER.

Results

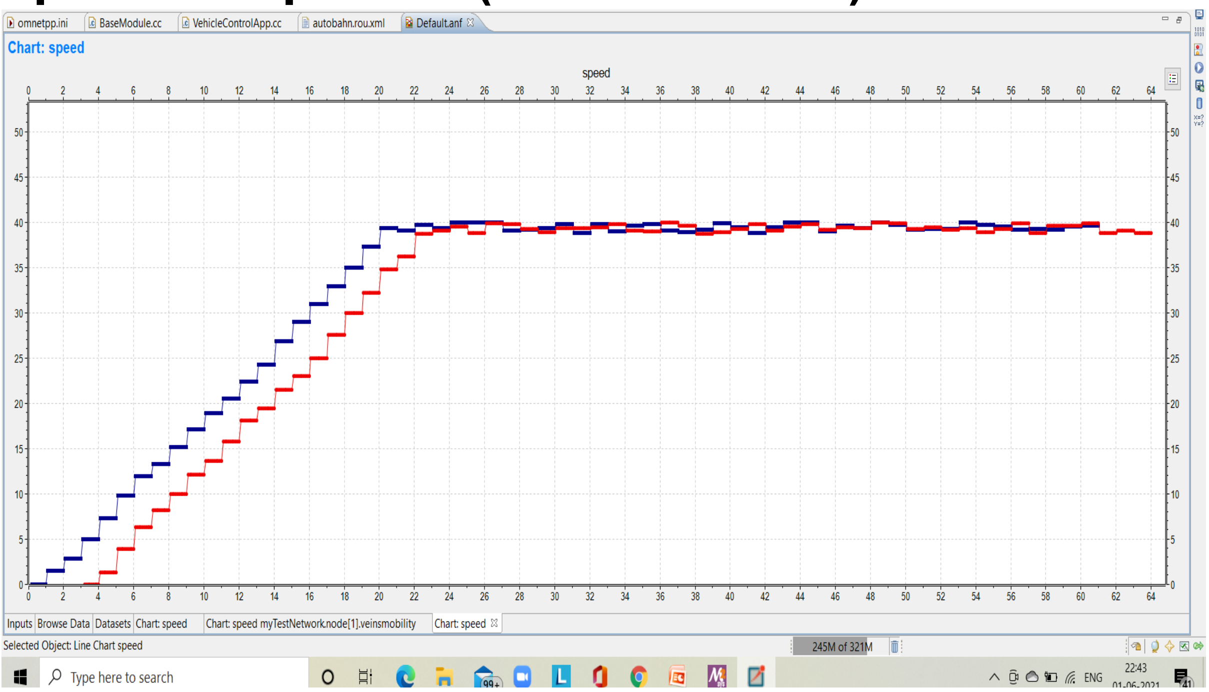
Simulation scenario



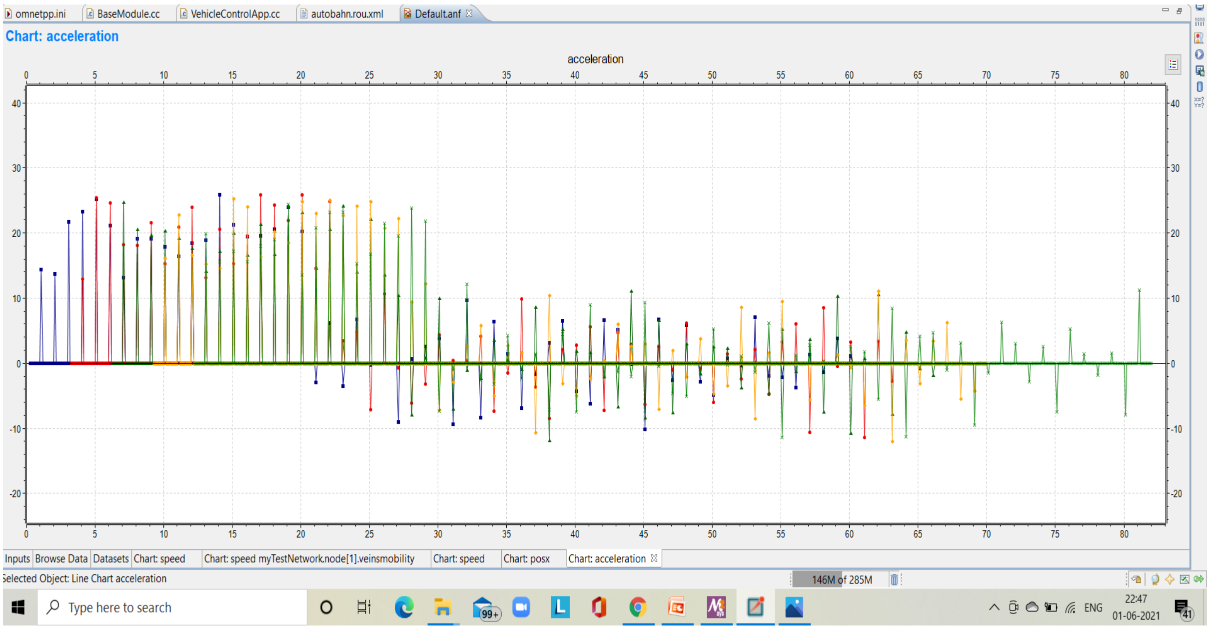




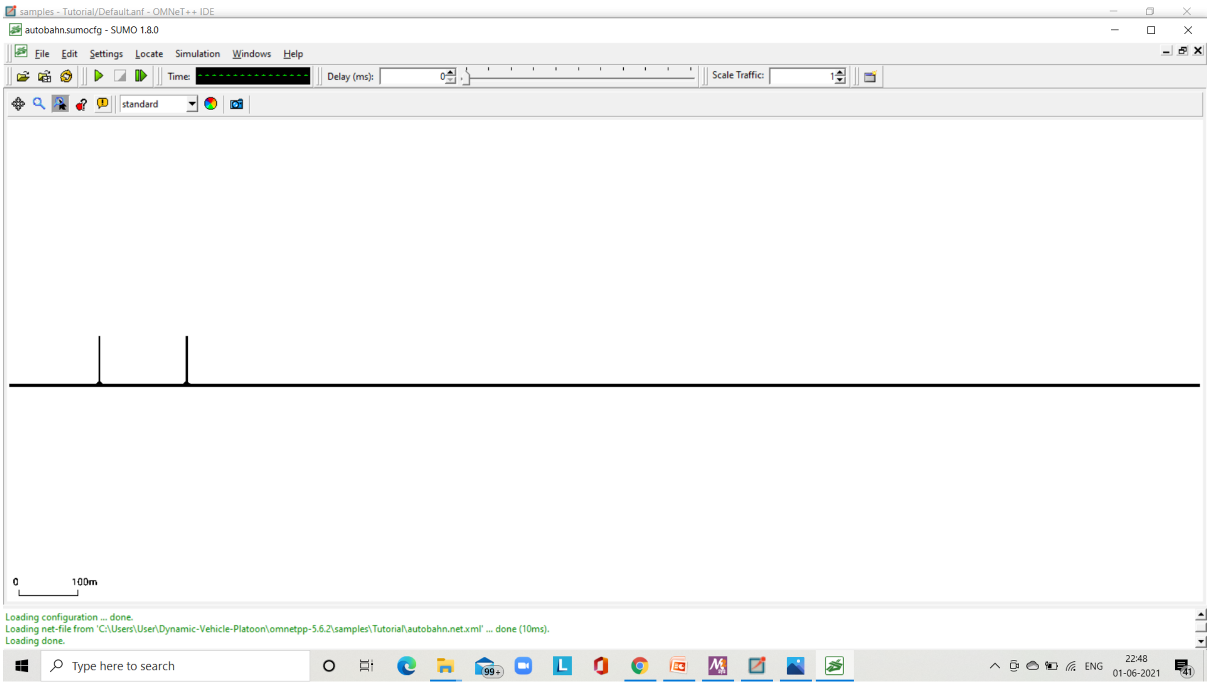
Speed comparison(For 2 vehicles)



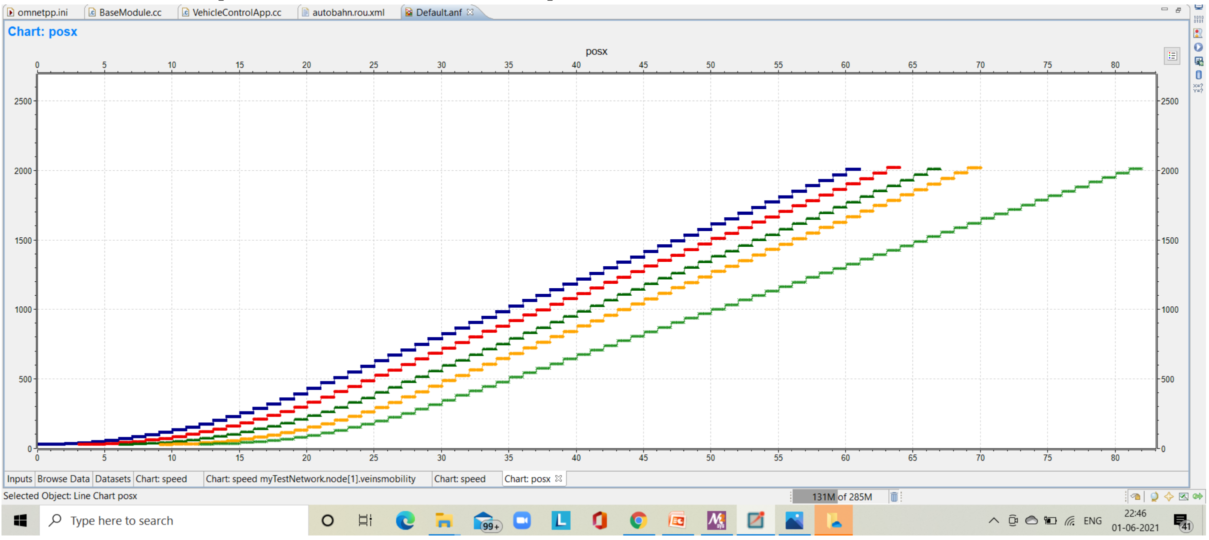
Acceleration of all vehicles



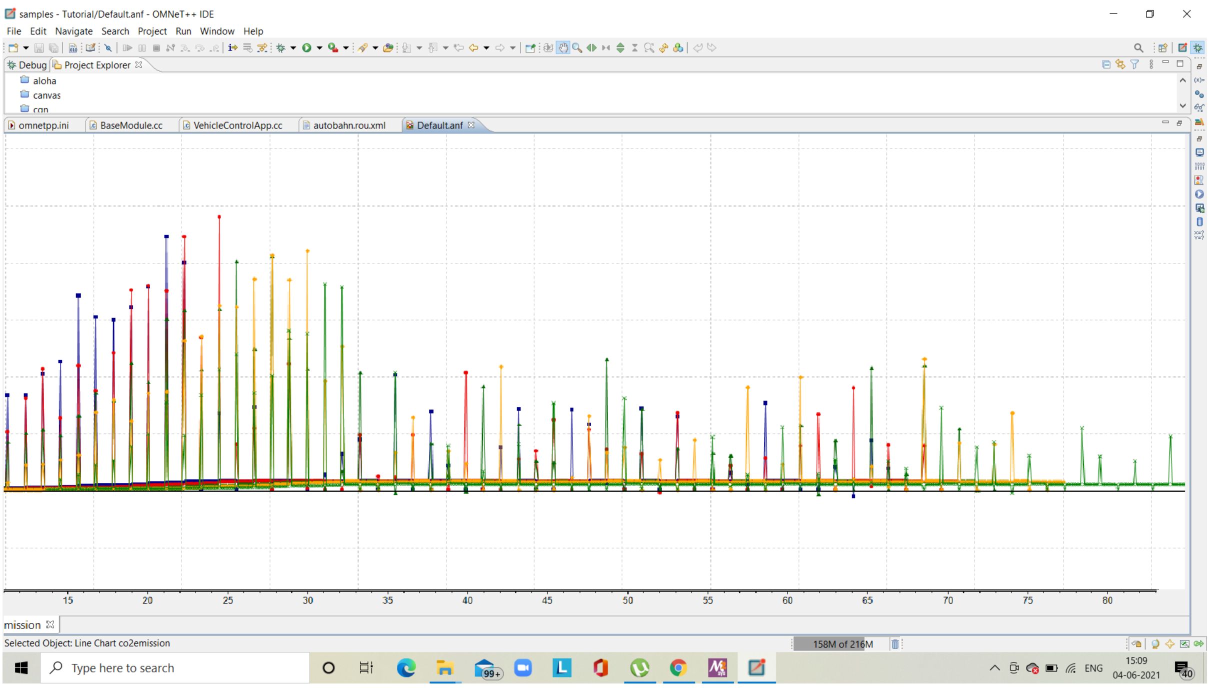
Track in Sumo



Position(x-coordinate) of all vehicles



CO2 emission



Conclusions and Future Works

This chapter will sum up and evaluate this Thesis' work. Furthermore opportu-nities for future work will be rising and how this Thesis's Robustness Vehicle platoon formation using omnet++ ,veins and sumo.

5.1 Conclusions

All four vehicles move at a constant speed maintaining a particular gap between them.

- The last vehicle moves out of the platoon as the delay from the first vehicle to the last exceeds the time limit. IEEE802.11p gives an end to end latency of 1ms, the duration of transmission between 1st and 5th becomes greater than 1ms, hence the 5th vehicle moves out of the platoon.

- Cars move in a form of groups so that communication takes place at a regular interval. This is done by bsm message. Every car that's preceding another sends a message to car right behind him. CACC type of platooning where every car preceding one provides information about the speed,velocity and distance inside a message frame. The sender adjusts itself according to the message passed by the vehicle just behind it. All vehicles try to keep the same minimum distance between them.

- The cars also communicate with the RSU's and this is a function of distance,due to fading. RSU is a road side unit with which the car exchanges messages. This is a vehicle to infrastructure communication. This is necessary for a vehicle within a cellular network to remain in that particular lan.

- Parameters taken under consideration:- position,acceleration,speed,co2 emission,mingap. The relative positions and velocity can be send easily through BaseWaveApp layer. The front vehicle adjusts itself by receiving the message. These parameters can be configured.

5.2 URLLC

The upcoming fifth generation (5G) wireless communication system is expected to support a broad range of newly emerging applications on top of the regular cellular mobile broadband services. One of the key usage scenarios in the scope of 5G is ultra-reliable and low-latency communications (URLLC).

Ultra reliable and low latency communications (URLLC) is a new service category in 5G to accommodate emerging services and applications having stringent latency and reliability requirements.(5G) wireless communication system is expected to support a broad range of newly emerging applications on top of the regular cellular mobile broadband services.posing unprecedented challenges in terms of capacity, latency, reliability, and scalability further more risk arises 1) a growing network size and increasing interactions between nodes; 2) a high level of uncertainty due to random changes in the topology; and 3) a heterogeneity across applications, networks and devices.Moreover, the typical block error rate (BER) of 4G systems is 10−2 which can be achieved by channel coding (e.g., Turbo code) and retransmission mechanisms (e.g., via HARQ). By contrast, the performance requirements of URLLC are more stringent with a target BER of [10^{-9} - 10^{-5}]. The end-end latency constraint is 1ms.

Risk: risk is naturally encountered when dealing with decision making under uncertainty, when channels are time-varying and in the presence of network dynamics. Here, decentralized or semi-centralized algorithms providing performance guarantees and robustness are at stake, and notably game theory and reinforcement learning.

Tail: The notion of tail behavior in wireless systems is inherently related to the tail of random traffic demand, tail of latency distribution, intra/inter-cell interference, and users that are at the cell edge, power-limited or in deep fade.

Scale: this is motivated by the sheer amount of devices, antennas, sensors and other nodes which pose serious challenges in terms of resource allocation and network design.

5.3 Future Works

Optimal Platoon Formation using multivariate polynomial regression After the values of the various parameters are obtained from the simulations it is required to select the
variables which are more likely to influence the platoon length. For that the obtained data needs to be fed into a feature extraction algorithm. Doing so will greatly reduce the number of variables to be worked with. And also increase the performance of the machine learning model to be used later. The algorithm which is used to determine the length of the platoon depending on the extracted features is the Multivariate Polynomial Regression model. This model is used because it is one of the simplest mathematical models suitable for the problem at hand. Also due to its simple nature it can also be faster to train than other

models.The data set obtained after the feature extraction process are split in a 70% training set and 30% test set. Though splitting of data is not a necessity of the Multivariate Polynomial Regression, a test set is kept aside to obtain a realistic evaluation of the learned model and the remaining data set is used to evaluate the effectiveness of the predicted outcome. The model thus obtained is static in nature i.e. the model will not go through further training while operating in real vehicles. Keeping the model static also ensures that the model present in all vehicles is similar throughout and that the vehicles behave similarly. The model thus obtained will determine the length of the vehicle platoon which may change when the values of the features change in real time. The operator or driver of these vehicles will have the option to turn on or turn off this model on the highway if desired.

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