Enhancing Intersection Traffic Management Through V2V Communication

Redes e Sistemas Autónomos

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2023/2024

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Introduction

1.1 Overview

With the advancement of communication systems in cars, modern vehicles are now equipped to improve traffic flow, particularly at intersections. These systems enable vehicles to communicate not only with each other but also with roadside units, facilitating a more organized and efficient traffic management process. This inter-vehicle and vehicle-to-infrastructure communication significantly reduces the need for stops, minimizes congestion, and enhances overall safety on the roads.

The development and implementation of such vehicular communication technologies represent a major step forward in smart traffic management. By sharing critical information about their speed, location, and direction, vehicles can make real-time decisions to optimize traffic flow. This report delves into the mechanisms of these communication systems, the algorithms used to process and act on the shared data, and the resulting benefits for urban traffic management. Through this exploration, it aims to highlight the potential of advanced vehicular communication to transform our streets into smarter, safer, and more efficient transportation networks.

1.2 Motivation

The rapid advancement of vehicular communication technology offers unprecedented opportunities to enhance urban traffic management. Traditional traffic control systems often struggle with congestion, inefficiency, and delays, particularly at intersections. By leveraging Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication, we can create smarter and more responsive traffic systems.

This project aims to explore how integrating OBUs in cars and RSUs at intersections can streamline traffic flow, reduce stops, and minimize congestion. The motivation behind this research is to improve safety, reduce travel time, and enhance the overall efficiency of urban transportation networks. By demonstrating the potential of these technologies, this project seeks to contribute to the development of smarter cities and pave the way for future advancements in intelligent transportation systems.

1.3 Objectives

The primary objectives of this project are centered around enhancing traffic management through advanced vehicular communication technologies.

First, we aim to implement Vehicle-to-Vehicle (V2V) communication by installing On-Board Units (OBUs) in automobiles. These OBUs will use Cooperative Awareness Messages (CAMs) to relay critical information about the vehicle, such as its location and speed, to other OBUs and Roadside Units (RSUs). This real-time data sharing is essential for creating an interconnected traffic network.

Second, the project focuses on developing an algorithm that uses CAM messages from nearby OBUs to make decisions about street priority. This algorithm will determine which vehicles on a street should stop, slow down, or continue moving based on proximity and other relevant factors. The goal is to optimize traffic flow and minimize congestion at intersections.

Finally, the project aims to facilitate the exchange of information between OBUs and RSUs using CAMs and Signal Phase and Timing (SPaT) messages. While CAMs will provide essential data about cars and stations, SPaT messages will relay the status of traffic lights of the streets associated to the RSU. This communication will help vehicles make informed decisions on whether to stop, slow down, or proceed, enhancing overall traffic efficiency and safety.

Architecture

2.1 Project Architecture

The architecture of the system is designed to facilitate seamless communication and data exchange between vehicles and roadside units. It includes N cars equipped with On-Board Units (OBUs) and M stations with Roadside Units (RSUs), all interconnected through a Docker virtual network. This network utilizes IEEE 802.11p (WAVE) L2 Broadcast for reliable wireless communication.

A shared resource area is implemented to allow car and station threads to exchange information efficiently. This shared space ensures that all relevant data is accessible to both OBUs and RSUs, facilitating coordinated decision-making.

To provide a clear understanding of system interactions, a visualizer is included in the architecture. This visualizer displays the real-time interactions between cars and stations, illustrating how the system dynamically manages traffic flow and enhances intersection efficiency.

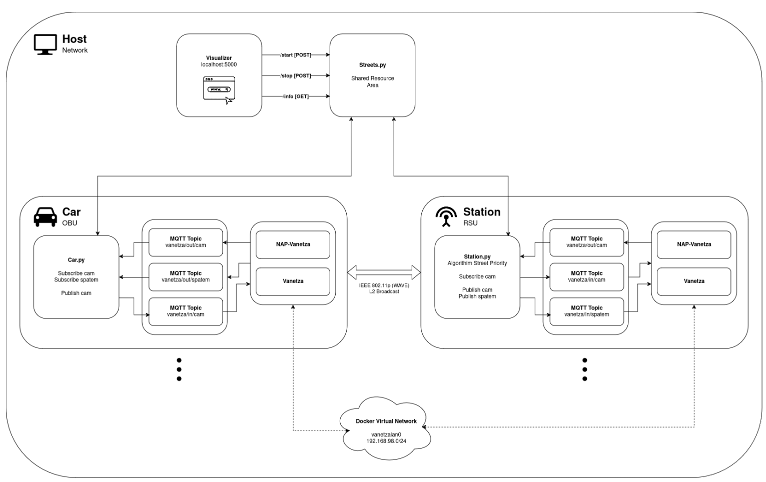

Figure 2.1: Architecture of Project

2.2 Technological View

The system comprises N cars equipped with Onboard Units (OBUs) and M stations fitted with Roadside Units (RSUs), all interconnected through a Docker virtual network. In the demo setup, there are 5 OBUs and 4 RSUs. A shared resource area facilitates the exchange of information between car and station threads. Additionally, a visualizer displays the interactions between cars and stations, providing a clear view of the system's functionality.

The simulation starts with the host initializing the environment, establishing a virtual shared street area. Threads for cars and stations are then created. The streets monitor the presence of cars within the station's range, controlling communication between their OBUs and RSUs.

Vehicles and stations communicate using CAM messages to report and gather data about their current conditions. When two cars approach an intersection at approximately the same distance, the RSU determines the preferred approach. It then modifies the traffic signals (semaphore) for the intersection's streets and broadcasts a SPaT message. Upon receiving the SPaT message, cars will either slow down, stop, or continue driving based on the semaphore assigned to their street.

To run this project, a Docker setup is essential to create and manage the virtual network. OBU and RSU hardware are required to simulate vehicle and roadside unit communication. A thread management system is needed to handle the creation and operation of car and station threads. Additionally, a visualizer tool is used to display interactions and traffic flow visually. The implementation of CAM and SPaT message protocols is crucial for data exchange and traffic management, ensuring efficient traffic flow at intersections. This system reduces stops, minimizes congestion, and enhances safety through advanced vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication.

Implementation

3.1 Configurations

To run the project, a comprehensive configuration process is necessary to set up various components and ensure smooth simulation of vehicular communication at intersections.

The project configuration utilizes Docker to deploy RSUs (Roadside Units) and OBUs (Onboard Units) for a VANET (Vehicular Ad-hoc Network) simulation. RSUs (rsu1 to rsu4) and OBUs (obu1 to obu5) are configured with unique identifiers, MAC addresses, and environmental variables like station type and communication interfaces. They communicate over the VANETZA protocol within a Docker virtual network (vanetzalan0).

The simulation begins with the host initializing the environment. This involves shutting down any existing Docker Compose setup and starting a new one. A brief pause ensures the network initializes properly. The setup includes creating a virtual street area, defining a graph that represents the street layout, and loading coordinates for each street segment from predefined files.

A shared region for the streets is established, defining the edges and intersections. Intersections are mapped to their corresponding street segments, enabling accurate simulation of traffic flow and vehicle interactions at these critical points.

Threads for OBUs and RSUs are created and started, running concurrently to simulate real-time interactions between vehicles and stations. These threads enable the continuous exchange of information and execution of traffic management algorithms.

3.2 Dashboard Webapp

The visualizer is a crucial component of the simulation system, designed as a web application to offer a dynamic and interactive display of vehicular communication and traffic management processes. This tool provides a real-time view of car locations and movements, highlighting their interactions with roadside units (RSUs) and displaying several key attributes.

The visualizer tracks each car (OBU) in real-time, showing its current location on a map. As cars move, their positions are continuously updated, giving users a clear visualization of traffic flow. Additionally, the visualizer displays which RSU each car is connected to at any given moment, revealing the range and influence of each RSU within the network.

Each car's detailed information is presented, including its current speed, exact coordinates, and the status of its virtual semaphore. The virtual semaphore indicates whether the car should stop, slow down, or continue, based on the traffic signals for the street it is on.

For the RSUs, the visualizer shows their exact locations on the map and lists the cars currently connected to them. This information highlights the active communication links within the system. Furthermore, the visualizer displays the status of the traffic signals managed by each RSU, indicating which streets are signaled as red, yellow, or green.

The user interface of the visualizer is designed to be intuitive and user-friendly, facilitating easy navigation and clear visualization. Users can interact with the map by zooming in and out to view different levels of detail and clicking on cars or RSUs to access specific information.

The central feature of the visualizer is the map view, which displays the street layout, car positions, and RSU locations. Information panels provide detailed data about selected cars or RSUs, and color-coded signals visually indicate the status of the virtual semaphores (red, yellow, green).

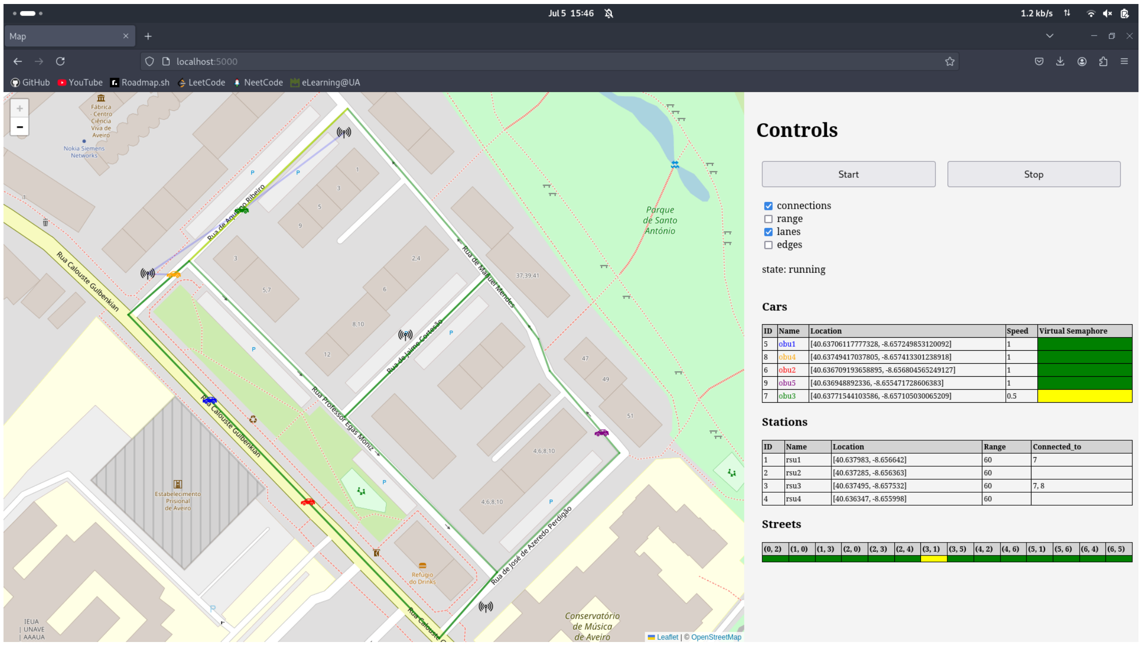

Figure 3.1: Dashboard

3.3 Simulation Flow

The simulation process begins with the host initializing the environment. A shared street area is established, and threads for cars (OBUs) and stations (RSUs) are created. The system monitors the range of each station to determine which cars are within range and accordingly blocks or allows their communication with the RSUs.

Once the environment is set up, the connection range between OBUs and RSUs is simulated. The streets continuously check the station's range for cars, deciding whether to block or unblock their communication based on their positions.

Each car and station announces itself through CAM (Cooperative Awareness Messages) messages. These messages contain vital information such as location and speed, enabling other entities to interact appropriately. This continuous exchange of CAM messages ensures real-time updates on the conditions of all participating vehicles and stations.

The system gathers data from the received CAM messages, including the cars' locations and speeds. Based on this information, an algorithm prioritizes vehicles that are closest to an intersection while instructing those farther away to slow down or stop. The algorithm effectively determines which street and which cars should have the right of way at an intersection.

To manage traffic flow, the corresponding semaphore (traffic light) adjusts to yellow or red, signaling that vehicles on that street need to halt or slow down. Cars use SPaT (Signal Phase and Timing) messages, disseminated by RSUs, to receive information on the condition of each street. These messages help cars determine if they are in a zone where they need to slow down.

As the simulation runs, vehicles and stations continuously communicate using CAM messages to report and gather data about their current conditions. When two cars approach an intersection at approximately the same distance, the RSU determines which car should have priority. The RSU then modifies the semaphore for the intersection's streets and broadcasts a SPaT message to inform the cars of the updated traffic signals. Upon receiving the SPaT message, a car will either slow down, halt, or continue driving based on the semaphore assigned to its street.

This real-time traffic management process ensures an efficient and dynamic flow of vehicles, reducing stops, minimizing congestion, and enhancing overall safety at intersections. The simulation provides a comprehensive demonstration of how vehicular communication systems can optimize traffic management through advanced V2V (Vehicle-to-Vehicle) and V2I (Vehicle-to-Infrastructure) communication.

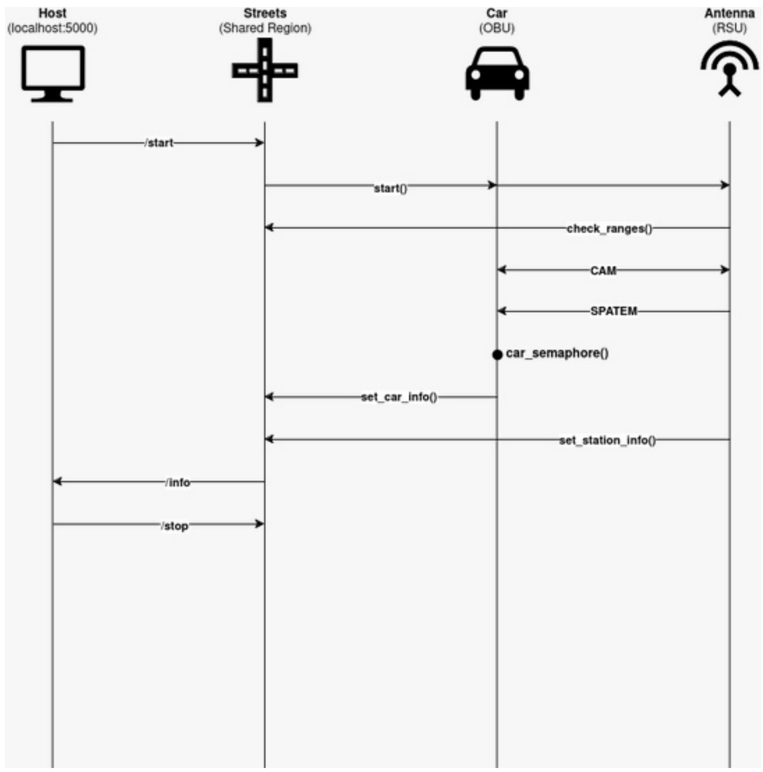

Figure 3.2: Dashboard

Demonstration

During the demonstration, Cooperative Awareness Messages (CAMs) will facilitate communication between the Roadside Units (RSUs) and Onboard Units (OBUs) in the cars. RSUs will utilize CAM messages to recognize their connection with OBUs on the streets.

As vehicles approach intersections, RSUs will employ decision-making algorithms to determine the optimal approach. Once decided, the RSUs will broadcast Signal Phase and Timing (SPaT) messages to communicate their traffic management decisions.

The visualizer will depict the operational range of streets, displaying connections between OBUs and RSUs. It will also use color coding to indicate the semaphore status of each street, ensuring a clear representation of traffic signals—whether they are red, yellow, or green.

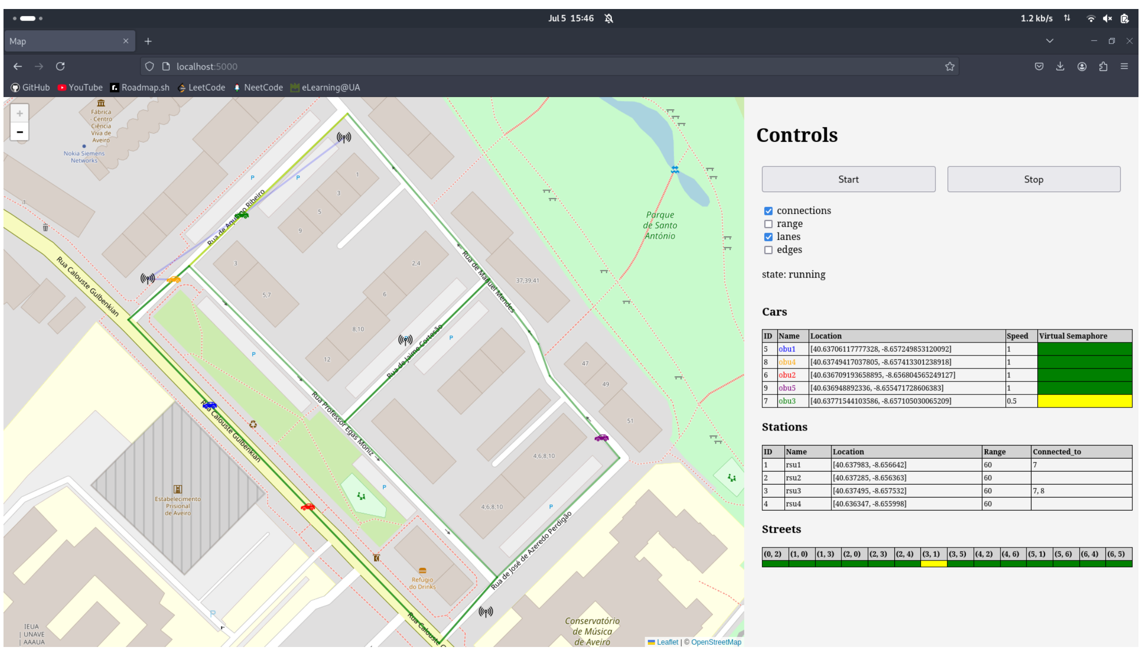

Figure 4.1: Dashboard

Conclusion

In conclusion, this project has demonstrated the efficacy and potential of vehicular communication systems in enhancing urban traffic management. Through the exchange of Cooperative Awareness Messages (CAMs) between Roadside Units (RSUs) and Onboard Units (OBUs), the system efficiently coordinated vehicle movements and optimized intersection operations.

The simulation showcased how RSUs can intelligently prioritize vehicle approaches at intersections using Signal Phase and Timing (SPaT) messages. By dynamically adjusting traffic signals based on real-time data from OBUs, the system effectively minimized congestion and improved overall traffic flow.

The visualizer provided a clear representation of the system's capabilities, illustrating street connections, vehicle positions, and semaphore statuses. This visual feedback underscored the importance of real-time monitoring and decision-making in managing urban traffic dynamics.

Overall, this project contributes valuable insights into the potential of vehicular communication technologies to create smarter, more efficient cities. By leveraging data-driven decision-making and seamless vehicle-to-infrastructure communication, these systems hold promise for addressing modern urban mobility challenges effectively.

Future Work

In future work, the project will expand by increasing the mapped area and demonstration zone to provide a broader view of traffic management capabilities. The emulation environment will transition to Raspberry Pi devices, including one equipped with a GPS module to simulate vehicle movement realistically.

An Onboard Unit (OBU) container will be integrated using the BATMAN interface for inter-Raspberry Pi connectivity, ensuring seamless communication within the network. Additionally, a dashboard will display the virtual semaphore status of the vehicle, enhancing monitoring capabilities and user interaction.

Resources

Link to code repository with the demo: https://github.com/TiagoMostardinha/rsa-melhoria