PROJECT REPORT
WS 2025/26

Technische Hochschule Deggendorf

Faculty of Applied Computer Science

Master of Automotive Software Engineering

Lecture: Wireless and Car2X-Communication

Project 2: Smartphone-Based RSU – Car2X Demo

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Abstract

The development of Cooperative Intelligent Transport Systems (C-ITS) is one of the most important aspects of improving safety on our roads and increasing the efficiency of our street traffic. As the network of C-ITS continues to grow rapidly at a much faster rate than other areas of transport, the use of Vehicle to Everything (Car2X) communication will be crucial for ensuring that we continue to see improvements in both safety and efficiency within our transport system.

Traditionally, C-ITS partners have first built Road Side Units (RSUs) which typically consist of an array of Road Side Units (RSUs) using RSUs and using On Board Units (OBUs) in vehicles. In most cases RSUs and OBUs are extremely expensive to build and implement into universities and companies in research and experimental environments. This project outlines the design, construction, and implementation of an inexpensive Smartphone-Based RSU - Car2X Demonstration System based on the basic principles of standard Android smartphones.

The proposed demonstration system simulates vehicle to roadway infrastructure (V2I) communications through two separate Android applications, a Vehicle Application representing a Vehicle on Board Unit, and a Roadside Application representing an RSU Roadside Unit. The vehicle application periodically broadcasts Cooperative Awareness Messages (CAMs), which provide real-time data on the position of the vehicle, the speed of the vehicle and the identity of the vehicle using UDP over a local WiFi. The RSU application receives this data, processes it, displays vehicle activity using an OpenStreetMap interface, and calculates the risk of a vehicle collision, based on a combination of distance-based and speed-based standards. If the vehicle ever exceeds a predefined set of safety parameters a warning of the possible collision is generated and sent back to the Vehicle Application providing a timely warning. Filtration methods were used to control GPS signal disruptions including: GPS accuracy-based rejection; GPS implied speed validation; GPS exponential averaging of prior location data to establish the average distance from the asset or user to the point of travel.

Testing was done in the real world through field experiments outdoors, where participants travelled on foot and bicycle to evaluate how accurately they were able to detect vehicles; how quickly the vehicle was able to communicate with the vehicle, and how reliable the warning was that initiated from the vehicle using smartphone-based assistance. Under field conditions, the test results indicate that the vehicle can be detected by both the vehicle and the smartphone user in low latency time frames and therefore, the smartphone-based demonstration of Car2X is feasible.

This project provides a viable model of a low cost Car2X (car to car) system that could serve as a prototype for educational institutions and developers who are at the earliest stages of developing the technology, as well as provide guidance on future product development direction through more sophisticated trajectory prediction techniques and integration into a dedicated V2X vehicle/vehicle communication systems.

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1. Introduction

An important area of research and development in airline operations has been improving safety records and the ability of aircraft to navigate through crowded skies with maximum efficiency, and to support intelligent transportation systems (ITS), particularly with respect to Cooperative Intelligent Transportation Systems (C-ITS). C-ITS are being developed to create a communication network between vehicles and other infrastructure (V2X), along with technologies for sending information between vehicles and other infrastructure (V2I) more effectively and efficiently. Car2X communications is one type of C-ITS technology, allowing vehicles to share information between themselves and other infrastructure such as traffic signals, road signs, etc. In real-world implementations, Car2X systems are typically implemented using dedicated On-Board Units (OBUs) within the vehicle and dedicated Roadside Units (RSUs) at the roadside, using either ITS-G5 or Cellular V2X (C-V2X) technologies. Accessibility and cost of these systems typically limit their application and use to educational or research institutions.

This research examined the potential for using consumer-grade, commercially available Android smartphones for emulating Car2X communication. By leveraging the GPS receiver, wireless connectivity and processing capabilities of the smartphone, use as a RSU and vehicle system allowed for the simulation of V2I communication scenarios.

Detecting vehicles as they approach and determining collision risk using distance and speed are two major foci of this project. The next step is the development of a real-time warning system for drivers of incoming threats or hazards during everyday driving. The Connected Vehicles/C-ITS module serves an educational purpose demonstrating to the user how to collect and interpret information related to approaching vehicle dangers. In addition, the Connected Vehicles/C-ITS module demonstrates important practical challenges facing the development and implementation of these types of systems, including GPS accuracy, communication latency, and safety logic design.

2. Project Objectives

This project's primary purpose is to create, develop and test a low-cost smartphone-based Car2X Communication and demonstrate the basic principle of V2I Vehicle-to-Infrastructure Communication as part of Cooperative Intelligent Transport Systems (C-ITS). Additionally, the goal of this project is to combine the theoretical background of Connected Vehicle Technologies with the practical implementation of software using commercially available consumer-quality hardware.

The specific objectives of the project are as follows:

- The objective of this project is to create a smartphone-based Roadside Unit (RSU) to receive and process vehicle messages in real-time.
- The second objective of this project will involve creating a Vehicle Application (On-Board Unit – OBU) that transmits Cooperative Awareness Messages (CAM) on a periodic basis with vehicle position, speed, and identification information.
- The third objective of this project will include creating low-latency UDP-based communication over a local wireless network which is capable of mimicking direct Car2X communication.
- The fourth objective of this project consists of applying filtering and smoothing methods to GPS data in order to reduce the effect of sensor noise, as well as to improve the stability of the location of the vehicles being monitored.
- The fifth objective of this project will verify that the distance between the vehicle and the RSU is calculated accurately, as well as assess the occurrence of any potential instances of collision risk based on pre-defined safety limits.
- The sixth objective of this project involves generating and transmitting Decentralized Environmental Notification Messages (DENM) from the RSU to the vehicle when detecting hazardous conditions.
- The seventh objective of this project is to create visual representations of the vehicles' movements and their safety zones/trajectories using a map-like interface to increase situational awareness.

- The eighth objective of this project will provide for a structured format for storing both communication events and safety events for offline analysis, as well as performance assessment.
- Finally, the ninth objective of this project is to validate the functionality of the proposed systems through real-world field tests under different vehicle movement/speed scenarios.
- We will give you an education and demonstration on how to utilize the techniques associated with Car to exchange (i.e., vehicle-to-infrastructure) communications without needing expensive specialized hardware devices.

3. System Overview

This project implements a smartphone-based Car2X (Vehicle-to-Infrastructure) demonstration system designed to emulate key functionalities of Cooperative Intelligent Transport Systems (C-ITS). The system is fully software-defined and operates using standard Android smartphones connected through a local wireless network. It focuses on real-time data exchange, safety evaluation, visualization, and warning generation.

The overall system follows a distributed architecture, where the vehicle and the roadside infrastructure operate as independent entities that communicate directly with each other. This architecture closely resembles real-world Car2X deployments while remaining simple and cost-effective for academic experimentation.

3.1.System Components

The system consists of two main functional components implemented as separate Android applications:

1) Vehicle Application (On-Board Unit – OBU)

The Vehicle Application presents a vehicle on the go in the Car2X ecosystem. It gathers live, actual-time information about the car's operations and then sends the information to the RSU.

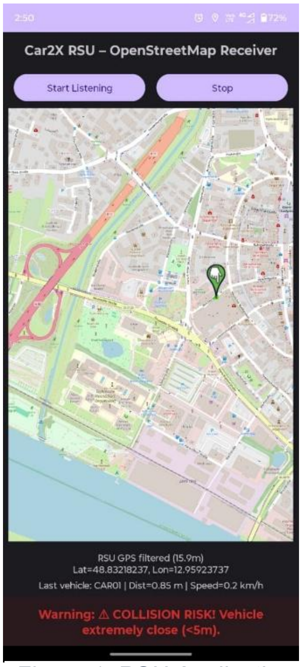


Figure 1: RSU Application visualizing vehicle position and safety zones

Key functionalities:

- Acquisition of GPS-based position (latitude, longitude)
- Calculation of vehicle speed
- Filtering of inaccurate GPS readings
- Periodic transmission of Cooperative Awareness Messages (CAM)
- Reception of Decentralized Environmental Notification Messages (DENM)
- Display of safety warnings to the user

Using a fixed period of time to distribute a CAM message, it allows an RSU to see if a complete picture of the vehicle has been captured so they have an idea of where the vehicle is heading and what dangers are present (e.g. hazardous road conditions).

2) RSU Application (Roadside Unit)

The RSU Application functions as the intelligent infrastructure component within the system. It is usually located in a permanent location where it continually observes vehicles coming near.

Key functionalities:

- Reception of CAM messages via UDP
- Stabilization of RSU GPS position using filtering techniques
- Real-time distance calculation between vehicle and RSU
- Risk assessment based on distance and speed thresholds
- Generation and transmission of DENM warnings
- Visualization of vehicle position, geofencing zones, and trajectories
- Logging of communication and safety events

Through its user interface, the RSU provides visual representations (maps) of the approaching vehicle as well as dynamic safety notifications transmitted to the vehicle.

3.2.Network Setup

A local WiFi network is used to allow communication between the Vehicle Application and the RSU Application, with both applications being connected to the same local WiFi network. This configuration allows for direct communication between devices, without the requirement for supporting infrastructure.

Characteristics of the Network:

- Protocol: Protocol used is UDP (User Datagram Protocol)
- Type of Network: Local WiFi network (under different categories of hotspot / ad hoc / shared router)
- No internet or cellular network dependency
- Capability to provide low latency and enable real-time safety alert communication

This configuration mimics the type of communication typically used in Car2X, such as ITS-G5 or C-V2X PC5, where local messages are exchanged between two devices without using backend servers.

Flow of Messages

- Vehicle Application broadcasts CAM message at regular intervals
- The RSU Application listens and receives these messages
- RSU determines if any of the safety requirements have been satisfied
- DENM warnings are sent back to the vehicle when a risk is detected

4. Communication Architecture

The communications architecture allows for the exchange of data from the Vehicle Application and the RSU Application in real time. This is necessary for the Car2X system since it involves low-latency data broadcasting and rapid warning dissemination.

4.1. Protocol Selection

The system employs UDP (User Datagram Protocol) for the purpose of communication because of its low overhead and low delay. This is most probably because UDP provides a fast connectionless data transfer, which makes it particularly appropriate for sending periodical beacon packets and time-critical safety notifications. This is notably similar to actual Car2X systems like ITS-G5 and C-V2X (PC5), for which reliability is obtained through frequent rebroadcasting of packets.

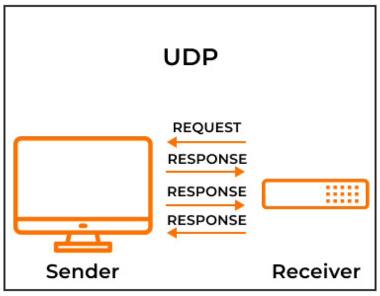


Figure 2: UDP-based communication model used for low-latency Car2X messaging

4.2. Message Types

4.2.1. Cooperative Awareness Message (CAM)

The CAM message is broadcast by the Vehicle Application at regular intervals, signalling its presence and status to the surrounding environment.

- Sender: Vehicle Application (OBU)
- Frequency: 2 Hz (every 500 ms)
- Information includes: Car identity, location, speed, IP address
- Purpose: Constant awareness with regard to the movement of the vehicle for the RSU

4.2.2. Decentralized Environmental Notification Message (DENM)

The DENM message is prepared from the RSU based on the type of dangerous situation identified either through distance or speed thresholds.

- Sender: RSU Application
- Trigger: Collision or safety risk detection
- Content: Event type, severity, cause
- Purpose: Warning the vehicle about hazardous conditions

5. Vehicle Application Design

The Vehicle Application acts as an On-Board Unit (OBU) and is responsible for collecting vehicle data, broadcasting status messages, and receiving safety warnings from the RSU.

5.1. Data Management and GPS Filtering

In order to provide accurate data regarding position and speed, GPS data undergoes a filtering process to eliminate any inaccuracies.

- GPS updates with low accuracy are not considered
- Unrealistic speed increases are excluded
- They allow transmission based solely on stable location information

This eliminates false alarms due to GPS jitter.

5.2. Beacon Broadcasting Logic

The Vehicle Application sends out its Cooperative Awareness Messages (CAM) periodically using UDP.

- Transmission rate: every 500 ms (2 Hz)
- Message content: vehicle ID, position, speed, IP address
- Allows constant vehicle awareness at the RSU

5.3. Vehicle User Interface

The user interface is designed for simplicity and clarity.

- Displays transmission status and GPS availability
- Shows received DENM warnings in a clear format
- Provides immediate feedback to the user during critical events

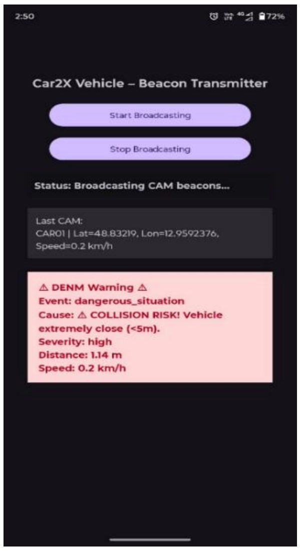


Figure 3:Vehicle Application (OBU) displaying transmission status and warning alerts

6. RSU Application Design

The RSU Application acts as the intelligent infrastructure component responsible for receiving vehicle data, evaluating safety conditions, and issuing warnings.

6.1. Map Visualization

It uses a map interface to display vehicle and infrastructure information.

- Showing RSU and vehicle locations in real-time
- OpenStreetMap Integration for Location Visualization
- Increases situational awareness

6.2. RSU Location Stabilization

To reduce GPS drift, the RSU applies location smoothing.

- Uses filtering techniques to stabilize the position
- Prevents marker movement if RSU is stationary
- Encourages accurate distance estimation

6.3. Geofencing Zones

RSU is encircled by the safety zones for determining the risk levels.

- Warning zone: 7 meters
- Critical zone: 5 meters
- Zones visually indicate risk severity

6.4. Trajectory Visualization

The movement of the vehicle is displayed to indicate the direction of approach.

- Establishes a distinction between vehicle and RSU
- Enables understanding of vehicle movement patterns and potential collision risks

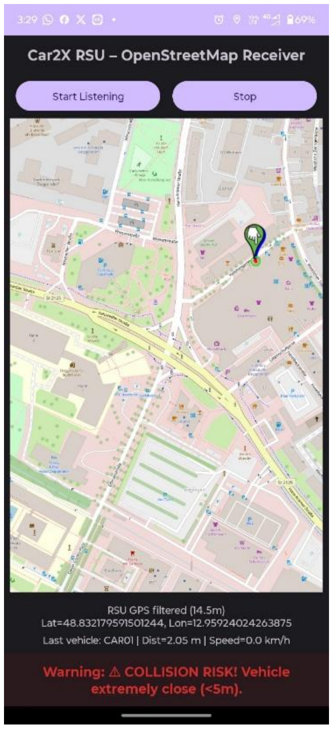


Figure 4: RSU Application Running Mode

7. Safety Logic and Algorithms

The safety logic is implemented in the RSU Application to evaluate collision risk and generate warnings based on vehicle distance and speed.

7.1. Distance Calculation

The distance between the vehicle and the RSU is calculated using GPS coordinates.

Formula (Haversine / Android Location API concept):

$$d = R \times \arccos(\sin\phi 1 \sin\phi 2 + \cos\phi 1 \cos\phi 2 \cos(\lambda 2 - \lambda 1))$$

Meaning of Each Term

- d– Distance between two locations (in meters)

- R– Radius of the Earth (≈ 6,371,000 meters)
- ϕ_1, ϕ_2– Latitudes of point 1 and point 2 (in radians)
- λ_1, λ_2– Longitudes of point 1 and point 2 (in radians)
- arccos – Inverse cosine function

7.2. Risk Evaluation Logic

Collision risk is determined using distance and speed thresholds.

Condition	Criteria	Risk Level
A	d<5m and $v > 30\ km/h$	Critical Risk
B	d<5m	Collision Risk
C	d<7m	Approaching

7.3. Warning Generation (DENM)

If a hazardous condition is detected, the RSU sends a DENM warning.

Trigger Logic:

$$\text{If } (d < d_{critical}) \rightarrow \text{Send DENM}$$

- DENM contains event type and severity
- Warning is sent via UDP to the vehicle
- Ensures real-time driver alerting

8. Field Testing and Evaluation

Field tests have been implemented for the purpose of confirming the operation, accuracy, and reliability of the Car2X system designed for the smartphone.

8.1. Test Setup and Methodology

- Tests conducted in an open outdoor setting with clear GPS satellite visibility
- One smartphone set up as RSU (stationary)
- One smart phone used as Vehicle Application (moving)
- Communications via local WiFi with UDP
- Vehicle approached the RSU at different speeds

8.2. Test Scenarios and Results

The system operated correctly in terms of successfully recognizing vehicles that were approaching the system and providing a warning with a low latency response.

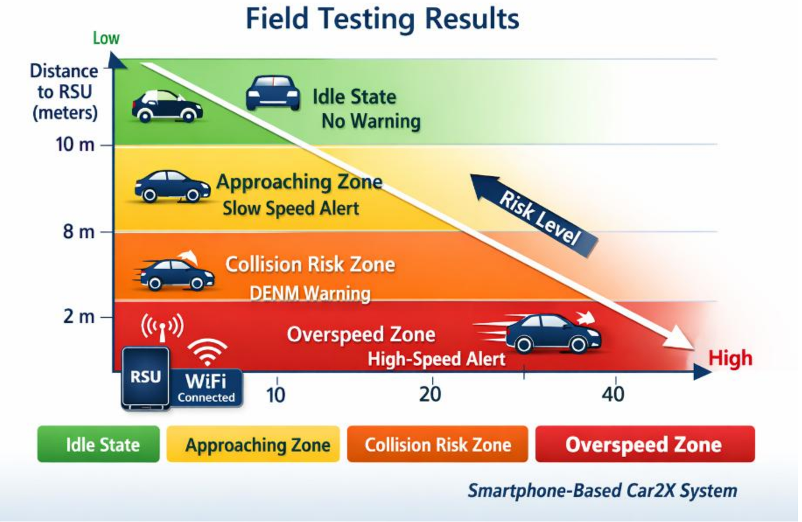


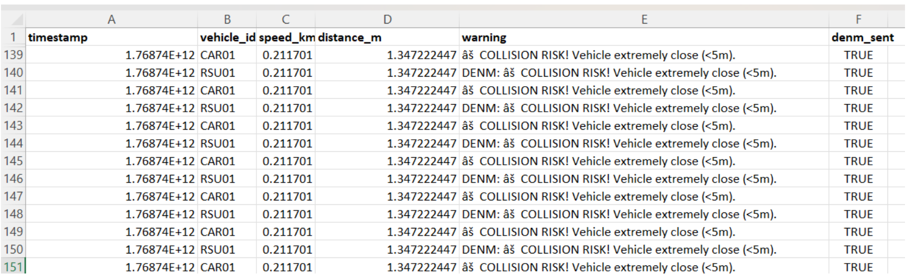
Figure 5: Field Testing Results

9. Data Logging and Performance Analysis

In RSU Application, a data logging system is developed to register and record all communication and safety-related events happening with/in the system. This system is used to assess system behavior, detection accuracy, and communication performance.

Data Logging

- All the received CAM messages are recorded in the RSU
- Tags are saved as CSV to support easy evaluation
- Recorded parameters include:
  - Timestamp
  - Vehicle ID



	A	B	C	D	E	F
1	timestamp	vehicle_id	speed_km	distance_m	warning	denm_sent
139	1.76874E+12	CAR01	0.211701	1.347222447	âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
140	1.76874E+12	RSU01	0.211701	1.347222447	DENM: âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
141	1.76874E+12	CAR01	0.211701	1.347222447	âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
142	1.76874E+12	RSU01	0.211701	1.347222447	DENM: âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
143	1.76874E+12	CAR01	0.211701	1.347222447	âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
144	1.76874E+12	RSU01	0.211701	1.347222447	DENM: âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
145	1.76874E+12	CAR01	0.211701	1.347222447	âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
146	1.76874E+12	RSU01	0.211701	1.347222447	DENM: âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
147	1.76874E+12	CAR01	0.211701	1.347222447	âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
148	1.76874E+12	RSU01	0.211701	1.347222447	DENM: âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
149	1.76874E+12	CAR01	0.211701	1.347222447	âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
150	1.76874E+12	RSU01	0.211701	1.347222447	DENM: âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE
151	1.76874E+12	CAR01	0.211701	1.347222447	âš COLLISION RISK! Vehicle extremely close (<5m).	TRUE

- Vehicle speed
- Distance to RSU
- Warning status (DENM sent or not)

Figure 6: Data Log CSV. Format File Data

Performance Analysis

- Logged data is analysed to ensure the correct identification of risks
- System response time is noted to be low latency, ideal for real-time safety applications
- DENM messages are created based on the violation of safety thresholds to prevent false notifications

Outcome

Logging data verifies that the system performs well in recognizing dangerous conditions and warning users accordingly, proving that the applied Car2X safety logic is functional and efficient.

10. Deliverable Achieved

All the needed deliverables in the project have been satisfied as stated in the project specification.

- A fully functional mobile phone-based Car2X demo application, made up of a Vehicle Application and an RSU Application
- Effective implementation of Vehicle to Infrastructure Communication using UDP
- Field testing and evaluation of real-world vehicle detection and warning messages
- Map display showing vehicle locations, geofenced areas, and paths
- Logging of communication and safety-related data for performance measurement
- Recorded demo video of the system's working
- A detailed tech report that outlines system design, implementation, and outcomes

11. Conclusion and Future Improvements

Conclusion

This project was able to conclusively prove the effectiveness of using smartphone-based Car2X communication for Vehicle-to-Infrastructure applications. This system had the ability to detect approaching vehicles, estimate collision risks, and provide warnings based on factors of vehicle speed and distance. This project was able to achieve:

- Effective UDP Communication
- Correct GPS data filtering
- Real-time collision risk detection and warning alerts
- Map visualization for situation awareness
- Comprehensive data logging for performance analysis

The system turned out to be an effective and inexpensive teaching tool for comprehending and designing Car2X technology.

Future Improvements

- Though the system fulfilled all project requirements, there exist a number of development fields in the future:
- Improvement of the communication layer: Upgrade from WiFi to either Bluetooth Low Energy (BLE) or C-V2X to support power efficiency.
- Trajectory prediction: Develop and integrate Kalman Filters for vehicle trajectory prediction in order to improve vehicle collision avoidance systems operating in dynamic road conditions.
- Scalability: Enhance the system to incorporate connected vehicles and actual infrastructure to facilitate extensive V2X simulation.
- Real-world RSU integration: Integration of the system with real RSUs will help in analyzing its functionality in a real-world environment of connected vehicles

12. GitHub Repository Link

Here is Link:

https://mygit.th-deg.de/smartphone_based_rsu-car2x_demo_ase/smartphone-based-rsu-car2x-demo/

This repository includes the following components:

- **RSU Application Code:** Contains the code for the RSU application, which interacts with the vehicle and receives real-time data.
- **Vehicle Application Code:** Includes the code for the vehicle's app that sends location and movement data to the RSU.
- **Demo Application Video:** A video demonstrating how the RSU and vehicle applications work together, showcasing the entire interaction between the systems.
- **Real Detection Test Cases:** A set of test cases designed to evaluate the functionality of the real detection system in the RSU application, ensuring accurate data capture and processing.

13. References

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