Leveraging edge computing and orchestration platform for enhanced pedestrian safety application : the DEDICAT-6G approach

Leveraging Edge Computing and Orchestration Platform for Enhanced Pedestrian Safety Application: The DEDICAT-6G Approach

§*Salah Eddine Merzougui, †*Xhulio Limani, †*Andreas Gavrielides,
†*Phillipe Reiter, §‡Claudio E. Palazzi, †*Johann Marquez-Barja
†{Xhulio.Limani, Andreas.Gavrielides, Phil.Reiter, Johann.Marquez-Barja}@uantwerpen.be
§{merzougu,cpalazzi}@math.unipd.it
*University of Antwerp - imec, IDLab - Faculty of Applied Engineering, Belgium
‡University of Padua - Department of Mathematics, Italy

***Abstract*—The DEDICAT-6G project is set to contribute to the improvement of future wireless networks by stressing dynamic resourcing, connection, flexibility, and trustworthiness, particularly for new human-centric services with different computing needs. In this context, we have developed a Vulnerable Road User (VRU) safety solution, which is imperative to improve due to the pressing need for enhanced pedestrian safety in an increasingly urbanized and digitally connected world. In this work, we address this critical concern by harnessing edge computing, communication protocols, and efficient resource management to reduce the risk of accidents at intersections where visibility challenges pose significant safety threats to both VRUs and vehicle drivers. Our architecture includes Road-Side Units (RSUs), On-Board Units (OBUs), and Vulnerable Road Users (VRUs). For real-time metric analysis, we combine an Edge Computing component hosting a Collision Detection Edge Application to analyze data sent between nodes and a Monitoring System to monitor different resources utilization such as CPU load and network traffic (see Figures 1 and 2). We conducted an experiment where we considered the scenario of a vehicle coming at a high speed to an intersection where a pedestrian is about to cross the road where none of them has a clear sight of the other. The experiment, which was carried out in simulated situations with limited sight at intersections, shows encouraging early findings. Our future work include real-world deployment, sophisticated algorithm integration, resource optimization, and environmental effect assessment, all of which contribute to the evolution of adaptive and secure communication systems as envisaged by DEDICAT-6G.**

***Index Terms*—Edge Computing, Collision Detection, Pedestrian Safety, Vulnerable road user (VRU), Network Orchestration, Containerization.**

I. Introduction

In the context of developing human-centric services with varied processing demands, future 6G wireless networks must offer more dynamic resourcing and connection to increase flexibility, performance, and trustworthiness [1]. DEDICAT-6G project [2] aims to create a smart connectivity platform using artificial intelligence and blockchain techniques, allowing 6G networks to combine current communication infrastructure with innovative edge intelligence distribution (data, processing, and storage), allowing flexibility and energy-efficient real-time experience realization [3], [4].

The goal of DEDICAT-6G is to advance beyond 5G by addressing approaches for obtaining and sustaining effective dynamic connection and intelligent computation placement in the mobile network. The project proposes and develops mechanisms for dynamic coverage extension by using innovative terminals and mobile client nodes, such as smart connected automobiles, robotics, and drones [5]. Furthermore, DEDICAT-6G tackles security, privacy, and trust assurance, particularly for mobile edge services and facilitators of innovative human-digital system interaction. The main goals are to accomplish (i) efficient resource utilization, (ii) lower latency, (iii) reduced reaction time, (iv) lower energy consumption, (v) lower overhead, (vi) reduced capital expenses, and (vii) robust security, (viii) improved privacy preservation, and (ix) Trustworthiness [3].

DEDICAT-6G tackles four use cases for proof of concept: smart warehousing, enhanced experiences such as: multimedia applications and enhanced navigation options, public safety, and a smart highway. These use cases are able to pilot the developed solutions thanks to simulations and demonstrations conducted in laboratory environments and larger field evaluations that exploit various assets and testing facilities [2]. The efforts of the project are to achieve improvements in intelligent network load balancing and resource distribution, increased connection, improved security, privacy, trust, and human-machine interactions.

Within the context of public safety and smart highways, our experiment revolves around a use case designed to enhance pedestrian safety at intersections where visibility between pedestrians and vehicle drivers was obstructed by obstacles. We designed a Safety Mobile Application (SMA) to prioritizes pedestrian safety at busy intersections, and it capitalizes on advanced technologies to bridge the gap between pedestrians and vehicles. It leverages real-time location tracking, smart communication technologies, and collision prediction algorithms to provide pedestrians and vehicle drivers with immediate, potentially life-saving alerts. With a user-friendly interface that dynamically changes color to convey the safety status based on the situation (see Figures 3 and 4), the

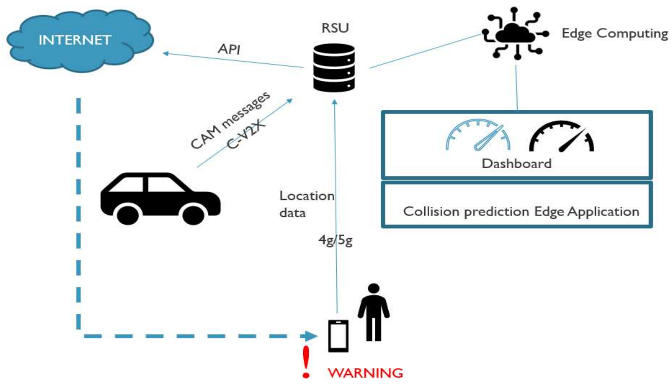

Fig. 1. Network architecture.

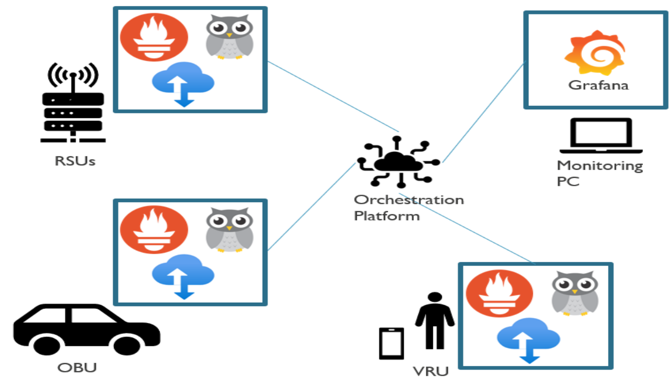

Fig. 2. Monitoring infrastructure.

application will be an indispensable tool for both pedestrians and vehicle drivers safety preservation.

The rest of this paper is organized as follows: In Section II, we dive into the methodology of our study, presenting the architectural components and details of our experiment. Section III presents the results we expect to obtain from our experiments, and outlines the anticipated impacts. Finally, we draw conclusions from our ongoing work and define our future research directions in Section IV.

II. Methodology

A. Architecture

The architecture model of our solution consists of three nodes: RSU, OBU, and VRU represented by the SMA that connects to the RSU. It also comprises of two main components are vital to the architecture: the Edge Computing component, encompassing the Collision Detection Application, and a comprehensive monitoring system that ensures real-time tracking and visualization of critical metrics (see Figure 1).

1) VRU Safety Mobile Application (SMB): The SMB facilitates real-time location tracking for users. This application operates in both driver and pedestrian modes, leveraging the C-V2X [6] and ITS-G5 [7] communication protocols for seamless communication with the road infrastructure.

The Collision Prediction Edge Application is at the heart of the system. Positioned at the edge of the network, this application analyzes CAM messages from vehicles and GPS location data from pedestrians for potential collision risks. This application is able to identify that, by using location, speed, and other parameters, and when it determines a potential risk of collision, it promptly notifies users through a combination of pop-up notifications, sounds, vibrations, and voice assistant prompts sent through the mobile application.

2) Monitoring Infrastructure: To effectively manage the network, containers are deployed across all nodes, including RSUs and OBUs(see Figure 2). Each of these containers runs Prometheus servers [8] with two agents: Node Exporter and cAdvisor. Additionally, a centralized Grafana Dashboard [9], connected to the Prometheus servers, offers real-time insights into the performance and health of RSUs, OBUs, and SMA (see Figure 5). The dashboard actively displays metrics collected and stored by Prometheus, such as CPU usage, disk space, memory utilization, and data traffic, aligning with the project's vision of efficient resource management and scalability through containerization.

B. Experiment

To assess the real-world applicability and effectiveness of the pedestrian safety system, we are designing a system to simulate a scenario in which a car is driving along a road, generating CAM messages and sending them to the RSU. At the same time, a pedestrian equipped with a mobile phone running the SMA intends to traverse the road. Both the vehicle's driver and the pedestrian are concealed from each other's view due to an obstacle positioned between them. Initial results recorded from the experiment such as CPU load and Network traffic show the effectiveness of the architecture.

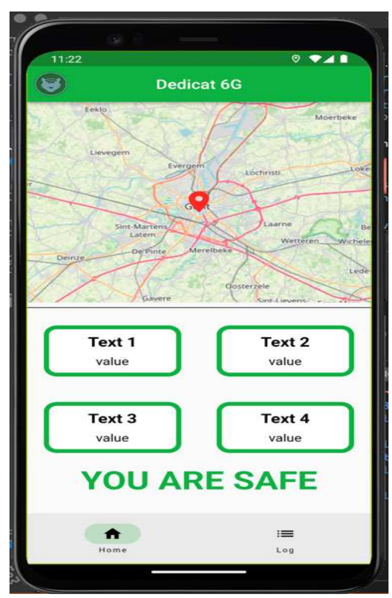

Fig. 3. Mobile application interface safe display.

The key elements of this experimental system include:

Fig. 4. Mobile application interface warning display.

- Vehicle-Car Communication: The vehicle generates CAM messages that simulate real-world communication between vehicles on the road. These messages are transmitted to the RSU over the designated C-V2X network.
- Pedestrian Safety Application: The pedestrian carries a smartphone equipped with the VRU SMA, which continuously tracks their GPS location even when running in the background. The application establishes communication with the RSU through ITS-G5, receiving notifications about nearby dangers.
- Collision Prediction Edge Application: At the RSU, the collision prediction edge application comes into play. It analyzes the incoming CAM messages from the vehicle and the GPS location data from the pedestrian, simulating a scenario where neither party can visually detect the other due to the view-obstructing obstacle.
- Alert Generation and User Feedback: In the event of a potentially dangerous situation, such as the car approaching a concealed pedestrian, the collision prediction edge application promptly generates alerts. These alerts are relayed back to the pedestrian's mobile application, where they will be displayed as pop-up notifications. The application's color changes to indicate the severity of the situation (see Figures 3, 4), thereby providing immediate and intuitive user feedback.
- Monitoring system: As the experiment unfolds, we closely monitor the network using the Grafana dashboard linked to Prometheus servers, Node Exporter, and cAdvisor deployed on the network nodes. These monitoring tools provide real-time insights regarding the performance metrics on the network nodes, such as CPU usage, disk space, memory utilization, and data traffic (see Figure 5).

Through this experimental setup, we aim to validate the effectiveness of the pedestrian safety system in scenarios where visibility between road users is obstructed, thereby highlighting the role of edge computing and containerized monitoring in ensuring safety at intersections within the DEDICAT-6G framework.

III. Results

In our system, where the monitoring system is integrated into the hardware, we anticipate several expected results and impacts.

A. Expected Results

- State (On/Off): We expect to observe the real-time state transitions of the RSU, edge, and mobile applications. This metric is useful for detecting and troubleshooting when one of the components fails and stops working.
- CPU Usage: Monitoring CPU usage will provide insights into the computational load imposed by the edge application and other system processes. We anticipate fluctuations in CPU usage as the edge application processes incoming CAM messages and GPS location data.
- Memory and Disk Usage: We foresee that memory and disk usage metrics will provide valuable information about how efficiently the system manages data storage and processing. This includes retaining historical data for analysis and potential optimizations in memory utilization.
- Data Traffic (Sent/Received): Monitoring data traffic metrics will shed light on the efficiency of data transmission between the RSU, edge application, and pedestrian safety application. We expect to see peaks in data traffic when CAM messages and GPS location data are exchanged between vehicles and the RSU.

B. Expected Impact

- Operational Efficiency: We want to uncover possibilities for improving resource consumption within the edge computing environment by constantly monitoring CPU, memory, and disk usage. This statistic can help us in efficiently reducing overhead and energy use.
- Enhanced Network Performance: Monitoring data traffic both transmitted and received helps us evaluate network performance during RSU-to-mobile application connections. These two metrics will aid us understand throughput which is the reflects the amount of data exchanged and latency which shows delays in the network, leading to a better management.
- Responsiveness and dependability: Real-time status monitoring will assist in maintaining system dependability by recognizing and responding to component faults or issues as soon as they occur. Maintaining a continuous and real-time surveillance of the pedestrian safety system requires tracking the system components condition.
- Resource Allocation for Edge Computing: Memory and disk use measurements will help guide decisions about resource allocation for edge computing applications. This will lead to a more balanced and efficient resource

Fig. 5. Grafana dashboard monitoring the resources utilization of an RSU.

allocation, ensuring that crucial operations are allocated the computational power they require.

In summary, the mobile application, serving both drivers and pedestrians, will be a key focus of our assessment, providing real-time tracking and alerting functionalities to enhance road safety. This holistic approach, combining edge computing and mobile app capabilities, underscores our commitment to comprehensive pedestrian safety solutions. Furthermore, during the trial, the integrated monitoring system (Prometheus, Node Exporter, cAdvisor, and the Grafana dashboard) will be our primary instrument for measuring the performance and effectiveness of the pedestrian safety system. The above-mentioned projected outcomes and consequences will help us fine-tune the system for maximum safety and efficiency in instances where vision between road users is impeded.

IV. Conclusions & Future Work

In conclusion, our system showcases the significant potential of edge computing and monitoring systems to improve pedestrian safety, particularly in challenging scenarios with limited visibility between pedestrians and vehicles. Our comprehensive architecture model, integrating edge computing and advanced communication protocols like C-V2X and ITS-5G, represents a significant step towards achieving the overarching goals of the DEDICAT 6G project. This project strives to develop dynamic, adaptable, and reliable communication systems that cater to the evolving demands of human-centric services. The successful integration of edge computing, real-time communication, and monitoring systems in our experiment highlights the path toward safer and more efficient urban mobility solutions in the context of DEDICAT 6G.

Future work will include transitioning the experiment to real-world traffic conditions for practical validation and refinement of the collision prediction algorithm in order to enhance accuracy. Additionaly, optimizing resource allocation for efficient edge computing, strengthening privacy and security measures, extending the system's scope to encompass various modes of transportation for comprehensive road safety, and evaluating the system's environmental impact while exploring sustainable practices is necessary in order to optimize the experiment to align with the broader goals of DEDICAT-6G.

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