Integrative Development and Evaluation of V2X Communication Architectures to Support Autonomous Driving Systems in 5G Campus Networks

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***Abstract*—This paper provides an overview of our upcoming research project, which focuses on the development and application of a dynamic driving task with autonomous vehicles based on Cellular Vehicle-to-Everything (C-V2X) functionalities as well as the evaluation of values added with the application through 5G communication within a campus network. Particular interest lies on low-latency and high-throughput 5G communication and Vehicle-to-Everything (V2X) Day-2-Use-Cases as well as the analysis and implementation of corresponding requirements. This paper outlines the pursued concept and lists planned scenarios.**

***Keywords* — V2X, C-V2X, 5G, autonomous driving.**

I. Introduction

Highly automated driving will have a significant impact on future mobility. The interaction of already available Advanced Driving Assistance System (ADAS) allows much shorter reaction times in unpredictable traffic situations than humans are capable of. Current available ADASs essentially rely on sensor data from an ego vehicle. Some Original Equipment Manufaturers (OEMs) have started to roll out Day-1 V2X use cases that allow the first possibilities of perceiving external sensor data. The sensor data recorded by sensors of other road users and the corresponding sensor fusion offers great potential for autonomous driving functions and for increasing traffic safety in general.

V2X in the 5G network offers considerable potential, especially for so-called *Day-2-Use-Cases*, which represent more advanced vehicle communication scenarios. These use cases go beyond basic functions such as emergency brake warnings and use the extended capabilities of 5G to enable more complex and safety-critical applications [1].

Network slicing allows the 5G network to create specific virtual networks for different use cases so that safety-critical applications such as teleoperation or emergency communication are prioritized and executed with maximum reliability [2].

Vehicles can perform complex maneuvers such as automated overtaking on multi-lane roads in close coordination with other road users. In emergencies or difficult situations, control of a vehicle could be handed over to a remote control center operating via a stable 5G connection.

The rest of the paper is structured as follows. In Section II, we give a short overview of our planned concept. Section III presents several scenarios to be examined within the project. Finally, we conclude the work in Section IV.

II. Concept

An important part of the project is equipping a reference track on the Wolfenbuettel campus of the Ostfalia University of Applied Sciences with infrastructure components for vehicle-to-infrastructure communication (V2I) with so-called Road Side Units (RSUs). These RSUs are used to provide data and traffic information on the one hand and to provide information for other road users (e.g., information about detected pedestrians, cyclists and public transport users) via established WiFi standards on the other. The RSUs will also collect data from connected infrastructure sensors (e.g., cameras, laser scanners, radar or Light Detection and Ranging (LiDAR) sensors). If required, this data can be transmitted to a traffic management center. Autonomous vehicles rely on a combination of four primary sensor types: cameras, ultrasonic sensors, radar, and LiDAR. However, each of these sensors has its own limitations. Camera-based sensors are not able to detect objects in foggy areas, in the rain or at night. Radar uses radio waves to detect vehicles/objects and is accurate in all visibility conditions, but cannot distinguish the type of objects without a human driver due to its longer wavelength. A classic 4G connection is sufficient for use cases of extended route guidance using V2X [3], [4]. For future cooperative use cases of autonomous driving, however, an architecture is required that bundles both local and remote information and can process and send it in real time. 5G New Radio (5G NR) improves the latency, reliability and throughput of mobile networks and offers new opportunities to support advanced V2X applications for connected and autonomous driving [5], [6]. Furthermore, 5G NR also improves the accuracy of positioning by real-time kinematics of the satellite navigation system in the centimeter range. These opportunities also arise from the introduction of Mobile Edge Computing (MEC) in 5G. The high communication effort and the enormous amount of data within the development period speak in favor of setting up a dedicated Radio Access Network (RAN) - a campus network based on 5G [7]. This dedicated network enables latencies in the order of 5 ms, which offers a remarkable increase in performance for researching future traffic scenarios, V2X applications and autonomous driving functions.

The objective is to establish an autonomous shuttle service that operates using conventional sensor technology, supple-

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mented by V2X communication and a 3rd Generation Partnership Project (3GPP) Release 16 campus network, which will be deployed near the Ostfalia University campus in Wolfenbuettel, Germany. The autonomous shuttle service drives around a circular route on our campus, characterized by several intercections with poor visibility. An RSU shall be positioned at a 3-way-intersection, equipped with a radar sensor to detect objects in the intersection area to share information using Collective Percepion Message (CPM) messages via C-V2X. This autonomous shuttle service and the campus network will serve as a research platform for the following research questions: 1. To what extent do network slicing and a 5G Standalone Network (5G SA) improve the quality of communication between the vehicle and a teleoperator compared to existing technologies? 2. How helpful are V2X Day-2-UseCases especially in complex intersection scenarios? 3. What is the impact of 5G SA and Ultra Reliable Low Latency Communication (URLLC) to the process of teleoperation and how realistic are low latencies of 1 ms specified by 5G-SA and URLLC in a real environment? 4. How can the application of MEC support participants in the decision making and increase traffic safety by handling computaionally intense operations.

III. Scenario

Consider a scenario in which an autonomous vehicle is operating in an urban environment, embedded in a 5G data network that enables it to communicate in real time via C-V2X (Cellular Vehicle-to-Everything). The vehicle approaches a complex intersection where visibility is severely limited by urban development and sharp angles, requiring increased communication requirements between vehicles and the surrounding infrastructure.

In this scenario, the autonomous vehicle continuously receives high-resolution sensor data from 5G-enabled infrastructure elements strategically positioned at the intersection. These sensors provide detailed information about the flow of traffic, the position and speed of other road users, as well as the movements of pedestrians and the current status of traffic light signals. This information is transmitted to the vehicle via the 5G-SA network with minimal latency, enabling precise and dynamic decision-making.

In parallel, the vehicle sends its own telemetric data, including its position, speed and planned route, to the surrounding traffic infrastructure as well as to other C-V2X-enabled vehicles. This creates a cooperative traffic control system based on a continuous, bidirectional flow of information to ensure adaptive and safe navigation. In this specific situation, the vehicle uses the received data to detect the presence of an oncoming vehicle approaching the intersection from a hidden position and adjusts its driving strategy accordingly to minimize a potential collision risk.

In addition, the autonomous vehicle is confronted with an unforeseen challenge: A sudden obstacle blocks the lane and the applicable traffic rules, such as a solid line, prevent safe overtaking. The autonomous system analyzes the situation in real time and uses 5G communication to request assistance from a remote traffic control center or to evaluate and implement alternative route and driving strategies. These decision-making processes are carried out within milliseconds, without disrupting the flow of traffic or compromising the safety of other road users.

IV. Conclusion

With the introduction of 5G, V2X communication will not only be improved, but fundamentally transformed. The promisingly low latency times enable vehicles to react to environmental information in near real time, which is particularly crucial for safety-critical applications such as collision avoidance. The higher data rates of 5G allow the exchange of large amounts of information between vehicles and the infrastructure, which leads to a more precise perception of the traffic situation. Vehicles can access not only their own sensors, but also information from other vehicles, traffic lights or cameras, which significantly increases safety and efficiency in road traffic.

In addition, the higher connection capacity of 5G enables thousands of vehicles and sensors to communicate simultaneously in urban areas. This creates the basis for a fully networked traffic system in which all road users interact in real time. The reliability of 5G is particularly important for applications that cannot tolerate delays or data loss. Network slicing, a key technology of 5G, ensures that such applications can be operated with the necessary stability.

Overall, 5G lays the technological foundation for more advanced forms of autonomous driving and the integration of vehicles into the smart city infrastructure, which can lead to more efficient traffic and lower emissions. In the long term, this will lead to safer, more efficient and smarter transportation systems and fundamentally change our mobility.

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