2024 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT) | 979-8-3503-6808-6/24/$31.00 ©2024 IEEE | DOI: 10.1109/COMNETSAT63286.2024.10862830

Integration of C-V2X with an Obstacle Detection System for ADAS Applications

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***Abstract*— Cellular Vehicle-to-Everything (C-V2X) technology is essential for enhancing road safety by connecting vehicles, roadside infrastructure, and networks. It improves safety by transmitting vital warnings and traffic updates that vehicle sensors might miss. This paper presents a novel C-V2X-based object detection system designed for intersections, leveraging cutting-edge 5G sidelink technology and advanced Deep Neural Networks (DNNs) deployed on edge computing units. The system utilizes Basic Safety Messages (BSMs), which convey timestamps and location data of detected objects, sent from a Roadside Unit (RSU) to On-Board Units (OBUs) via 5G sidelink. The proposed system was tested using an outdoor testbed at the GMMRC testing track at Kettering University. The system continuously monitors the intersection, with the RSU broadcasting detection results to nearby vehicles equipped with OBUs. Utilizing the depth perception capabilities of the stereo camera, the system accurately determines the distance of objects from the camera. Performance evaluations conducted through real-time experiments on the test track demonstrated the system's efficiency, achieving an average latency of just 1 millisecond in V2X communication across various scenarios. The 5G-enabled communication offers minimal latency, high data rates, and reliable connections, making it exceptionally well-suited for C-V2X applications. These results highlight the considerable potential of this technology for advancing vehicular communication and safety across diverse applications.**

Keywords—*5G sidelink, ADAS, C-V2X, connected vehicles, DNN, DSRC, object detection, OBU, RSU*

I. INTRODUCTION

The 5G era has initiated a significant transformation in wireless communication, characterized by elevated data rates, minimal latency, and enhanced connectivity. A notable advancement is 5G sidelink technology, which enhances Vehicle-to-Everything (V2X) connectivity and has the potential to reduce traffic congestion, car accidents, and environmental impact. Two key radio access standards for vehicular communication are Dedicated Short-Range Communication (DSRC) and Cellular Vehicle-to-Everything (C-V2X) [1]. While DSRC, based on IEEE 802.11p, has been the dominant technology, it faces significant limitations, including poor scalability and quality of service [2-3]. In contrast, C-V2X, introduced by the 3GPP in Release 14 and upgraded in Release 17, includes Vehicle-to-Pedestrian (V2P) and Vehicle-to-Network (V2N) links, offering broader coverage and better reliability [4]. C-V2X supports both safety and non-safety applications, leveraging sidelink technology for direct device-to-device communication, thereby improving the efficiency and reliability of data transmission. Fig. 1 shows a system of sidelink communication, showcasing how Roadside Units (RSUs) interact with multiple On-Board Units (OBUs).

To successfully implement an environmental perception system utilizing deep Convolutional Neural Networks (CNNs) in Autonomous Driving (AD) and Advanced Driver Assistance Systems (ADAS), it is essential to recognize objects and ascertain their positions in real-time. Since the advent of CNNs [5], extensive applications in computer vision have been developed. CNNs are remarkably effective at detecting objects because they can learn hierarchical picture properties on their own. This article identifies autos and pedestrians using YOLOv5 [6] in conjunction with a stereo camera sensor. Additionally, depth information is used to compute the distance between the identified objects and the camera sensor. Then, utilizing 5G sidelink technology, Basic Safety Messages (BSMs) are sent from an RSU to OBUs, including timestamps and the locations of identified objects (see Fig. 1).

This paper is organized as follows: Chapter 2 reviews the literature on V2X communication and DNN-based object detection for ADAS. Chapter 3 presents the proposed methodology for developing a C-V2X enabled object detection system, integrating C-V2X communication and DNN-based object detection technologies. Chapter 4 discusses the experimental results obtained on the testing track. Finally, Chapter 5 summarizes the findings and insights from the study.

II. LITERATURE REVIEW

Due to the performance of V2X communication varying greatly depending on the situation and surroundings, McCarthy et al. [7] emphasized the need for further research to assess how well next-generation V2X communication systems perform. Bae et al. [8] evaluated the effectiveness of DSRC-based V2X communication technology in a variety of real-world situations, taking into account variables including transmission power, antenna, and geographic location. Packet delivery ratio, throughput, packet error rate, packet reception rate, inter-packet interval, and received channel power indicator were among the performance indicators they examined in a variety of scenarios. In [8], the authors claimed that packet receiving rate performance was improved regardless of the RSU's location, whether inside or outside the tunnel, which is another point of emphasis in the study.

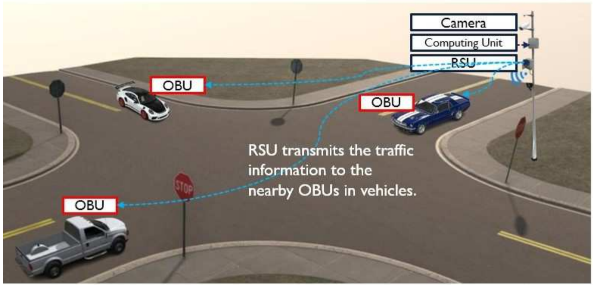

Fig. 1. Sidelink relaying communication modes

Islam et al. [9] claims that latency is a major problem with LTE-V2X-enabled AD and is impacted by a number of variables, including network coverage, antenna height, and ambient conditions. In large European cities, the average delay was 50 milliseconds (ms), although in certain situations, it may increase to 150–350 ms. For use cases that are sensitive to latency, including vehicle-to-vehicle (V2V) applications, the 3GPP has limited the latency and reliability standards for LTE-V2X to 20 ms. With an antenna height of 3.8 meters, their tests showed latency levels of less than 30 ms. However, when the antenna height was low (1.4 meters), strong scattering from trees, unfavorable weather circumstances like rain, and intersection topology increased delay and packet loss rate. The study also points out that compared to cellular-based V2X communication, sidelink communication in LTE-V2X has a substantially shorter end-to-end latency.

According to Huang and Lai [10] and Pham et al. [11], AD vehicles often use Vehicle-to-Infrastructure (V2I) communications to transfer sensor data processing to a dedicated server, either at the edge using 5G Multi-access Edge Computing (MEC) devices [11] or within a robust cloud infrastructure [12]. V2I communications operate through an upload/download path [13], with the autonomous vehicle assigning computation tasks to the edge or cloud server, which performs the necessary computations and sends the results back to the vehicle. In this setup, the local device handles essential preprocessing functions such as compression or encoding [14]. Furthermore, as discussed by Tsao [15], there is additional transmission latency when sending data to the cloud via V2I. However, V2I transmission latency can be reduced using MEC, which provides lower transmission delays than cloud-based solutions. Nonetheless, the limited resources of edge devices may restrict the range of applications.

In their study, Xu et al. [16] explored advancements in traffic management and lane detection using 5G-V2X technology and deep learning techniques. Addressing challenges related to generalization and accuracy in dynamic environments, they introduced a novel approach for lane marker detection. The authors developed a method that uses CNNs, 5G-V2X connectivity, and traditional algorithms to identify road areas, detect lane markers, and fit lane lines using straight-line and curve-fitting models. This method improved detection speed, precision, and optimal parameter equations.

CNNs are predominantly utilized for object detection in environmental perception tasks. These networks involve stages such as feature extraction from input images, object localization, and classification. Noteworthy models in this domain include Faster R-CNN [17], Single Shot multi box Detector (SSD) [18], and the highly acclaimed YOLO series [19]. YOLO partitions input frames into grid cells and predicts bounding boxes for objects within each cell. It is trained end-to-end with a loss function that considers bounding box accuracy, object presence probabilities, and class assignments, achieving outstanding performance in both accuracy and inference speed.

In this paper, the authors present procedures for implementing a C-V2X-based connected object detection system that leverages the remarkable efficiency of 5G sidelink technology and integrates a state-of-the-art stereo camera-based object detection and distance measurement system on an edge computing platform. The proposed system effectively broadcasts traffic information from any cross section to nearby OBUs in real-time. To date, there has been very little research on C-V2X sidelink-based object detection, as most studies have focused on DSRC technology.

III. METHODOLOGY

The RSUs and the OBUs are the two primary parts of the C-V2X ecosystem. With high-performance antennae and communication interfaces to create reliable links for V2X communication, RSUs act as communication hubs placed strategically along roads and intersections. Because they allow RSUs and OBUs to exchange data in real time, these linkages are essential for C-V2X applications. The connected object detection system increases field of view, especially in non-line-of-sight locations, which improves safety in AD and ADAS applications. This clever cooperative system combines a DNN-based object detection system with C-V2X communication technology. The general design of the connected object detection system installed at junction regions is shown in Fig. 2.

A. Hardware Setup

The hardware setup for C-V2X consists of two main parts: infrastructure setup and in-vehicle setup. The infrastructure setup includes three essential devices, illustrated in Fig. 3: a stereo camera, an RSU, and one edge computing unit. The in-vehicle setup contains one OBU with GPS receiver and one in-vehicle computing unit for each testing vehicle.

The following detailed description highlights the capabilities and specifications of each component within the infrastructure setup, emphasizing their roles in supporting advanced AI-driven applications in transportation and traffic management systems. A key component of the infrastructure configuration, the stereo camera offers a broad field of vision that improves depth accuracy and permits the production of high-resolution images and videos. In particular, the Zed 2 camera, created by Stereolabs, is the selected stereo camera [20]. The Zed 2 camera has an inbuilt USB 3.0/2.0 interface with a maximum field of view of 110° (horizontal) x 70° (vertical) x 120° (diagonal). Its depth range spans from 0.3 meters to 20 meters, making it suitable for detailed environmental perception tasks.

The RSU is a crucial component in the infrastructure setup, contributing to improved road safety and traffic management through cooperative collision avoidance and dynamic traffic management capabilities. In this setup, the Cohda Mk6C RSU [21] is employed, operating within the 5.9 GHz ITS spectrum with a 20 MHz bandwidth. It is powered by the Qualcomm 9150 chipset, which is specifically made for direct connection without the need for conventional cellular networks, and it makes use of the UMV-9150LGA DR solution (L1 Band). The Mk6C RSU has a Class 3 peak transmission power of 21.5 dBm and a C-V2X receiver sensitivity of -93.4 dBm. By supporting GPS, GLONASS, Galileo, and BeiDou systems and being compatible with Qualcomm Dead Reckoning (QDR), GNSS integration improves positional capabilities. Additionally, it complies with SXF1800 FIPS 140-2 level 3 security criteria [22] and is built to resist temperatures ranging from -40°C to +85°C.

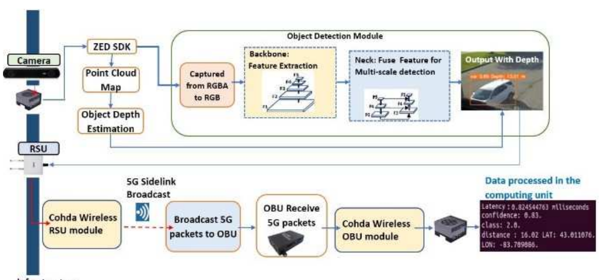

Fig. 2. An overview of the suggested C-V2X connected object detecting system's architecture.

(a) (b)

Fig. 3. Establishment of infrastructure. a) one ZED 2 stereo camera, one computing unit, and one RSU; b) deployed infrastructure image.

The NVIDIA Jetson Orin device [23] is used for computational activities in this setup. A highly adaptable and energy-efficient central processor unit created especially for robotics and artificial intelligence applications is the Jetson Orin. The Jetson Orin platform powers the object detection module in this configuration, allowing for real-time intersection monitoring and rapid decision-making based on real-time data analysis.

As presented in Fig. 4, the OBU is smoothly incorporated into cars for the in-vehicle setup, creating reliable communication connections with RSUs and nearby cars. A range of C-V2X applications, including adaptive cruise control and intersection collision alerts, are made possible by the OBU's sophisticated communication systems and antennas, which are built to efficiently collect and transmit data. In particular, the Cohda MK6C EVK [24] is selected as the OBU due to its wide range of connectivity possibilities and small size (193 x 160 x 51 mm). It is designed to take advantage of C-V2X technology and uses a 20 MHz bandwidth in the 5.9 GHz Intelligent Transportation Systems spectrum. Strong communication capabilities are made possible by the module's use of the UMV-9150LGA DR solution (L1 Band) and Qualcomm 9150 chipset.

Fig. 4. In the C-V2X vehicle setup.

The Cohda MK6C EVK boasts a C-V2X receiver sensitivity of -93.4 dBm and a maximum transmit power classified as Class 3, reaching 21.5 dBm [24]. Inside the vehicle, the computing unit responsible for processing data received from the OBU and determining obstacle locations is the NVIDIA Jetson Orin [23]. This powerful computing platform is integral to the vehicular communication system, collaborating closely with OBUs to facilitate V2X communication and perform onboard processing tasks effectively.

B. Object Detection with a Stereo Camera

By offering vital distance metrics required for sophisticated collision avoidance techniques and accurate trajectory planning, stereo-camera vision greatly improves object detection and tracking. The two synchronized cameras in this advanced system are placed at a precise distance from one another, which is comparable to the interpupillary distance in human eyes. With this configuration, the system can see its environment in three dimensions, similar to how human eyesight perceives depth. Triangulation, a technique that determines object distances by comparing the differences between images taken by the synchronized cameras, is the foundation of stereo vision. Through built-in redundancy, this method not only improves accuracy but also guarantees system durability, enabling continuing operation even in the event that one camera experiences technical difficulties or partial obstruction.

The research uses C-V2X technology to detect road obstacles with high precision. The YOLOv5 model [6], specifically tailored for stereo cameras, processes camera feeds to determine object distances and provide bounding box coordinates and object class information. This combines depth information from stereo vision with object detection results, enabling a comprehensive environmental understanding and real-time collision avoidance in V2X systems. This system transmits safety messages to OBUs in vehicles.

To assess the accuracy of the stereo-camera system, a static testing setup was conducted to validate the distance information from the stereo camera. The testing vehicles were positioned within a 20-meter radius of the camera setup. Objects were methodically located at measured intervals, and corresponding distance measurements from the stereo camera were meticulously collected and analyzed. The findings indicate that the camera delivers accurate distance information for objects located within 5 meters; however, accuracy decreases for objects positioned farther away. To address this, the following formula (1) is utilized to correct observed distance errors in the detected object distances.

$$D = d + d \times integer(d/4) * 0.1 \quad (1)$$

, where D is the corrected distance and d is the distance calculated by the camera. The results of the object distance experiment are displayed in Fig. 5, where the true distance, the distance as determined by the stereo camera, and the corrected distance using the equation are represented by blue, black, and red plots, respectively.

Fig. 6 shows the results of object detection with the corrected distance information. The object detection system can identify several different types of objects, including cars and pedestrians. In this paper, the authors focused on vehicle detection for a collision avoidance system. Future research could extend the testing scenarios to include pedestrian crossings using the proposed system. By providing precise object detection capabilities and reliable distance measurements, stereo vision technology proves indispensable for advancing critical automotive applications, ensuring safer roads and optimized traffic management.

C. Connected object Detection using C-V2X

The NVIDIA Jetson Orin platform is used to implement the object detection method, a powerful AI computing device designed for high-performance tasks. This platform is connected via an Ethernet interface to the Cohda Wireless RSU, ensuring stable and high-speed data transmission. The detection results, including detailed distance information, are transmitted to the RSU using the User Datagram Protocol (UDP), which is known for its low-latency communication. Fig. 7 illustrates the communication framework of the Cohda Wireless RSU module.

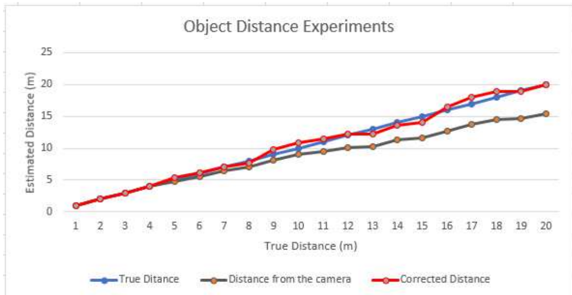

Fig. 5. The experiments on the object distance correction.

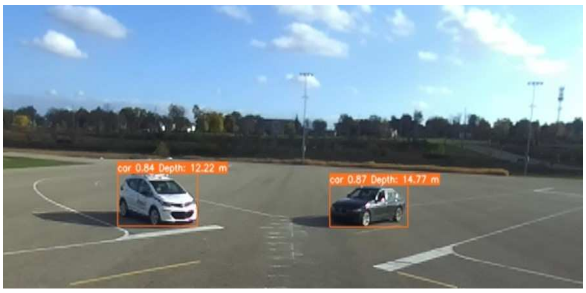

Fig. 6. The results of object detection with the corrected distance information.

In the 5.9 GHz ITS frequency, RSU uses a dual-radio configuration known as Radio-1 and Radio-2 that uses the 802.11p protocol. Strong and dependable communication in dynamic conditions is ensured by this specification, which is especially designed for automotive applications. In order to transmit Wireless Access in Vehicular Environments (WAVE) short messages—which are crucial for V2I and V2V communication—the Cohda Wireless RSU uses this complex configuration.

Fig. 8 illustrates the communication framework of the Cohda Wireless OBU module. Upon receiving the WAVE short messages, the OBU decodes these messages and transmits the data to the in-vehicle computing unit, specifically the NVIDIA Jetson Orin platform, across an Ethernet connection utilizing the UDP protocol. The Jetson Orin on the OBU side processes GPS data of observed objects, computes communication latency, and presents the results to the vehicle's system. This entire process is crucial for ensuring timely and accurate information for the vehicle's autonomous or driver-assistance systems.

IV. Experimental Results

The C-V2X devices, including the RSU and OBU elements, work together to facilitate real-time and effective data transmission, which is critical for the system's performance in fast-moving vehicular environments. The use of advanced networking protocols ensures minimal latency and high reliability, both of which are essential for the safety and effectiveness of AD and ADAS technologies.

The C-V2X system was tested in real-world conditions at the Kettering University GM Mobility Research Center (GMMRC), as illustrated in Fig. 9. The ZED-2 camera was mounted at a height of 2.74 meters for an excellent viewing angle. The RSU and Nvidia Orin computing device were affixed to the same pole, as illustrated in Fig. 3b. An OBU and an auxiliary computer device were installed in each vehicle (see Fig. 4), with the antenna and GPS receiver affixed to improve signal reception. In the dynamic testing scenario, three testing vehicles equipped with OBUs move in different directions within the intersection area at speeds of 20 mph at GMMRC. The monitors in each testing vehicle display the received signals from the RSU, as shown in Fig. 10.

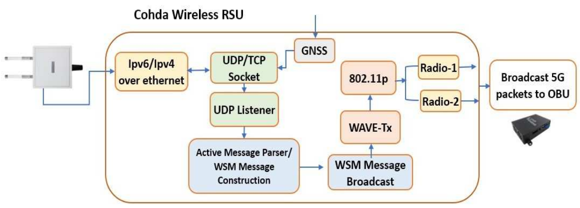

Fig. 7. The communication framework of the Cohda Wireless MK6 RSU.

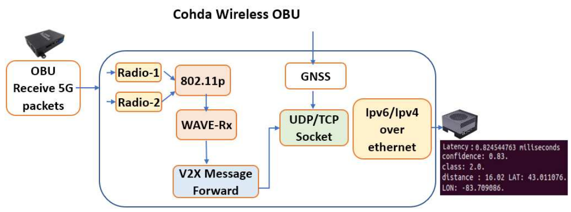

Fig. 8. The communication frmaework of the Cohda Wireless MK6 OBU.

Fig. 9. Image of the testing track for C-V2X experiments at the GMMRC.

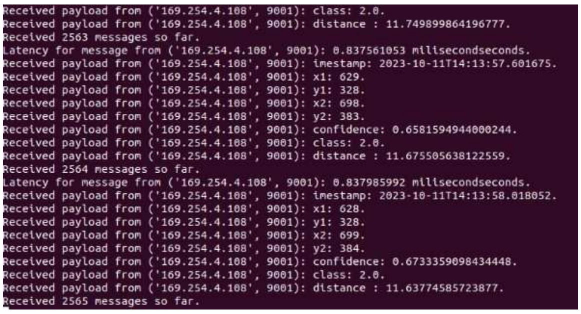

Fig. 10. Received signals from the RSU on OBUs in the test vehicles.

The RSU transmitted object class information, distance, and timestamps to the OBUs, as illustrated in Fig. 10, resulting in data traversing distance and time with an average latency of 1 ms, demonstrating the effectiveness of the communication system within the design. Latency in C-V2X sidelink communication measures the time required to transmit data from the RSU in the infrastructure to the OBU in the testing vehicles. The emphasis is on transmission efficiency rather than the processing time of object detection or other computational tasks involved. The three in-vehicle OBUs precisely exhibited the received data, so confirming the reliability of this configuration. The testing findings illustrate the V2X application's capacity for real-time object recognition and uninterrupted data transmission. The system effectively integrated the camera and DNN module with the RSU and OBUs.

V. Conclusions

An important step toward realizing the full revolutionary potential of 5G technology in the automobile sector has been taken with the implementation of an advanced vehicular communication system on an embedded platform. This advanced system achieves real-time object detection by utilizing the accuracy of stereo camera sensors in conjunction with the computer vision capabilities of CNNs. The system can precisely identify a variety of barriers, such as vehicles and pedestrians, by integrating a cutting-edge DNN model, guaranteeing a strong and dependable environmental perception system. Since it offers essential information for autonomous navigation and collision avoidance, the system's capacity to estimate the distance to detected objects is essential for improving vehicle safety.

The smooth coordination between RSUs and OBUs, made possible by the exceptional efficiency of 5G sidelink technology, is essential to the system's successful deployment. The system's core is this state-of-the-art technology, which offers the vital infrastructure required for safe, dependable, and fast communication. It makes it possible to exchange BSMs—which include crucial details about the locations of items that have been detected—with unmatched speed and effectiveness. Vehicle safety and communication systems are greatly improved by this quick data interchange, which is necessary for situational awareness and real-time decision-making.

The recognition of connected objects utilizing C-V2X technology signifies a significant progression in automobile safety and communication systems. C-V2X technology enables vehicles to communicate essential information, like speed, location, and intents, with adjacent vehicles and infrastructure components. The swift dissemination of traffic information greatly enhances the awareness range for networked vehicles, enabling them to react more efficiently to changing driving conditions. The implementation of this technology illustrates its significant potential for many applications in vehicle communication and safety. Although the present outcomes are encouraging, further efforts are necessary. Continuous improvements to this technology will result in more sophisticated and effective solutions within the C-V2X application domain. Future advancements may concentrate on augmenting the precision and velocity of object recognition, bolstering the dependability of data transfer, and broadening the system's capacity to manage more intricate driving situations.

ACKNOWLEDGMENT

This research work was supported in part by US National Science Foundation (NSF) Grants 2128346. We thank the GMMRC at Kettering University for allowing us to conduct the testing at the GMMRC testing track.

REFERENCES

[1] K. Ansari, "Joint use of DSRC and C-V2X for V2X communications in the 5.9 GHz its band," IET Intelligent Transport Systems, vol. 15, no. 2, pp. 213–224, 2020, doi: 10.1049/itr2.12015.

[2] ETSI TS 136 214 V16.1.0 (2020-07), "Technical Specification," https://www.etsi.org/deliver/etsi_ts/136200_136299/136214/16.01.00_60/ts_136214v160100p.pdf, Oct. 2023.

[3] M. Amadeo, C. Campolo, and A. Molinaro, "Enhancing IEEE 802.11p/WAVE to provide infotainment applications in VANETs," Ad Hoc Networks, vol. 10, no. 2, pp. 253–269, 2012, doi: 10.1016/j.adhoc.2010.09.013.

[4] 3GPP, "Study on NR sidelink relay," Technical Report (TR) 38.836, 3rd Generation Partnership Project (3GPP), Version 17.0.0, Mar. 2021.https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3725

[5] Y. LeCun, Y. Bengio, and G. Hinton, "Deep learning," Nature, vol. 521, no. 7553, pp. 436–444, 2015, doi: 10.1038/nature14539.

[6] Ultralytics, "Comprehensive guide to Ultralytics YOLOv5," https://docs.ultralytics.com/yolov5/, Oct. 2023.

[7] B. McCarthy, A. Burbano-Abril, V. R. Licea, and A. O'Driscoll, "OpenCV2X: Modelling of the V2X cellular sidelink and performance evaluation for aperiodic traffic," arXiv, 2021. [Online]. Available: https://arxiv.org/abs/2101.00000

[8] J. Bae, M. Park, E. Yang, and D. Seo, "Implementation and performance evaluation for DSRC-based vehicular communication system," Practical Innovations, Open Solutions, vol. 9, pp. 6878–6887, 2021, doi: 10.1109/access.2020.3044358.

[9] A. Islam, A. Debnath, M. Ghose, and S. Chakraborty, "A survey on task offloading in multi-access edge computing," Journal of Systems Architecture, vol. 118, no. 102225, 2021, doi: 10.1016/j.sysarc.2021.102225.

[10] C. Huang and C. Lai, "The mobile edge computing (MEC)-based vehicle to infrastructure (V2I) data offloading from cellular network to VANET using the delay-constrained computing scheme," in 2020 International Computer Symposium (ICS), 2020.

[11] Q. Pham, F. Fang, V. Ha, M. Piran, et al., "A survey of multi-access edge computing in 5G and beyond: Fundamentals, technology integration, and state-of-the-art," IEEE Access, vol. 8, pp. 116974–117017, 2020,

[12] M. Khan, E. Baccour, Z. Chkirbene, and A. Erbad, et al., "A Survey on Mobile Edge Computing for Video Streaming: Opportunities and Challenges," IEEE Access, vol. 10, pp. 120514–120550, 2022, doi: 10.1109/access.2022.3220694.

[13] G. Nardini, G. Stea, A. Virdis, and D. Sabella, "Simu5G: A System-level Simulator for 5G Networks," in Proceedings of the 10th International Conference on Simulation and Modeling Methodologies, Technologies and Applications, SCITEPRESS - Science and Technology Publications, 2020.

[14] Y. Siriwardhana, P. Porambage, M. Liyanage, and M. Ylianttila, "A survey on mobile augmented reality with 5G mobile edge computing: Architectures, applications, and technical aspects," IEEE Communications Surveys & Tutorials, vol. 23, no. 2, pp. 1160–1192, 2021, doi: 10.1109/comst.2021.3061981.

[15] S. Tsao, "Enhanced GTP: an efficient packet tunneling protocol for General Packet Radio Service," in ICC 2001. IEEE International Conference on Communications. Conference Record (Cat. No.01CH37240), 2002.

[16] C. Xu, H. Wu, Y. Zhang, S. Dai, et al., "A real-time complex road AI perception based on 5G-V2X for smart city security," Wireless Communications and Mobile Computing, vol. 2022, pp. 1–11, 2022.

[17] S. Ren, K. He, R. Girshick, and J. Sun, "Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks," 2015, doi: 10.1109/TPAMI.2016.2577031.

[18] W. Liu, D. Anguelov, D. Erhan, C. Szegedy, S. Reed, C.-Y. Fu, and A. C. Berg, "SSD: Single Shot MultiBox Detector," 2015, doi: 10.1007/978-3-319-46448-0_2.

[19] J. Redmon, S. Divvala, R. Girshick, and A. Farhadi, “You Only Look Once: Unified, Real-Time Object Detection,” 2015, doi: 10.1109/CVPR.2016.91.

[20] Zed 2 stereo camera, https://www.stereolabs.com/zed-2/, Oct. 2023.

[21] Cohda MK6C RSU,
https://www.cohdawireless.com/wp-content/uploads/2022/10/CW_Product-Brief-sheet-MK6C-EVK-RSU-v2.pdf, Oct. 2023.

[22] SXF1800: Cryptographic Module Non-Proprietary Security Policy,
https://csrc.nist.gov/CSRC/media/projects/cryptographic-module-validation-program/documents/security-policies/140sp3691.pdf

[23] Nvidia Jetson Orin, https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/jetson-orin/, Oct. 2023.

[24] MK6C-EVK,
https://www.cohdawireless.com/solutions/hardware/mk6c-evk/ , Oct 2023.