Overview of 5G-NR-V2X System and Analysis Methodology of Communication Performance

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***Abstract*—This article describes the 5G-NR-V2X system and its communication performance methodology. We present a system that can develop and verify the performance of self-driving services and verify performance in a real road test environment using OBU and RSU for 5G-NR-V2X communication (level 4 or higher), ultra-high speed (150Mbps or more), ultra-low delay (3ms or less), and high reliability (99.99 percent) satisfaction of communication robustness under malicious conditions. The 5G-NR-V2X system and performance analysis method proposed in this paper are anticipated to aid in the development of V2X communication technologies that are ultrafast, ultralow-delay, and high-confidence. In addition, it is expected that the services validated by the suggested performance analysis technique will enhance technological competitiveness in the road, transportation, logistics, and commerce industries.**

Keywords*—*5G-NR-V2X, Autonomous Driving, Performance Verification, Next-generation Vehicle Communication

I. INTRODUCTION

Automobiles, as a significant mode of transportation in contemporary society, can provide people with comfort and convenience, but they can also create problems, such as driving safety. As a result of the evolution of the Internet of Things, vehicle-to-everything (V2X) has emerged with the goal of connecting vehicles, transportation infrastructure, pedestrians, and cloud platforms via on board unit (OBU), road side unit (RSU), and other devices to promote road safety [1]-[5]. V2X enables the sharing of information and provides driving solutions with a global perspective through the use of wireless communication and intelligent processing technologies. Intelligent decision-making and vehicle control can assist in reducing traffic congestion and enhancing driving efficiency and road safety. In response to V2X requirements and concerns for road safety, vehicles generate a vast quantity of data [6]. These data are essential and foundational for V2X communication and illuminating future autonomous vehicles, as they contain valuable driving details. Similarly, frequent and precise V2X messages can assure the safety of vehicles. However, when the erroneous message is broadcast, whether intentionally or unintentionally, it can cause confusion and even calamity for other drivers on the road. The study of data veracity in V2X communication is, therefore, of practical importance.

The present state of worldwide standards is as follows. In March of 2017, The 3rd Generation Partnership Project (3GPP) finalized the standardization for Long Term Evolution LTE vehicle communication (Rel.14), establishing the groundwork for the proliferation of vehicle communication by reducing latency with LTE technology and enabling direct communication between vehicles. In July, the 5G-NR-V2X (Rel.16) standard was announced; 5G-NR-V2X is a next-generation communication technology with ultra-low latency, large capacity, and high reliability [7]. New services necessary to realize the fourth industrial revolution are supported by 3GPP release-17, together with established 5G advanced standards. These standards account for any requirements that may arise as a result of commercialization [8], [9].

In recent years, the 5G Automotive Association (5GAA) has produced descriptions and specifications for numerous V2X use-cases and defined a number of novel and innovative use-cases in groups. Regarding standards, the radio layer is governed by 3GPP, which is presently developing Release 18 (completion is anticipated by the end of 2023 and will include new V2X enhancements). Regional standards development organizations (e.g. ETSI, SAE International, NTCAS, C-SAE, ARIB, etc.) are standardizing the upper layer as new advanced application cases, such as group start, require further research on profiles and protocols. Under ISO, standardization efforts for Automated Valet Parking (AVP) have begun in Europe and internationally. Through ongoing global standardization efforts and 3GPP 5G-V2X releases, technological enablers such as positioning, power consumption, and multi access edge computing have been improved to support linked assistance and cooperative driving services. Enhanced knowledge about the complexity of software and the required cooperation in the ecosystem have also had an influence on the updated version of the roadmap: network-based solutions are also an option for Vulnerable Road User (VRU) awareness, and deployment of certain safety and advanced autonomous driving use cases (e.g. group start, cooperative manoeuvres) will take longer [10], [11].

- Safety: Emergency braking, intersection management, collision warning, lane change, etc. for the safety of vehicles and drivers are equally applicable to autonomous vehicles and driver assistance systems.

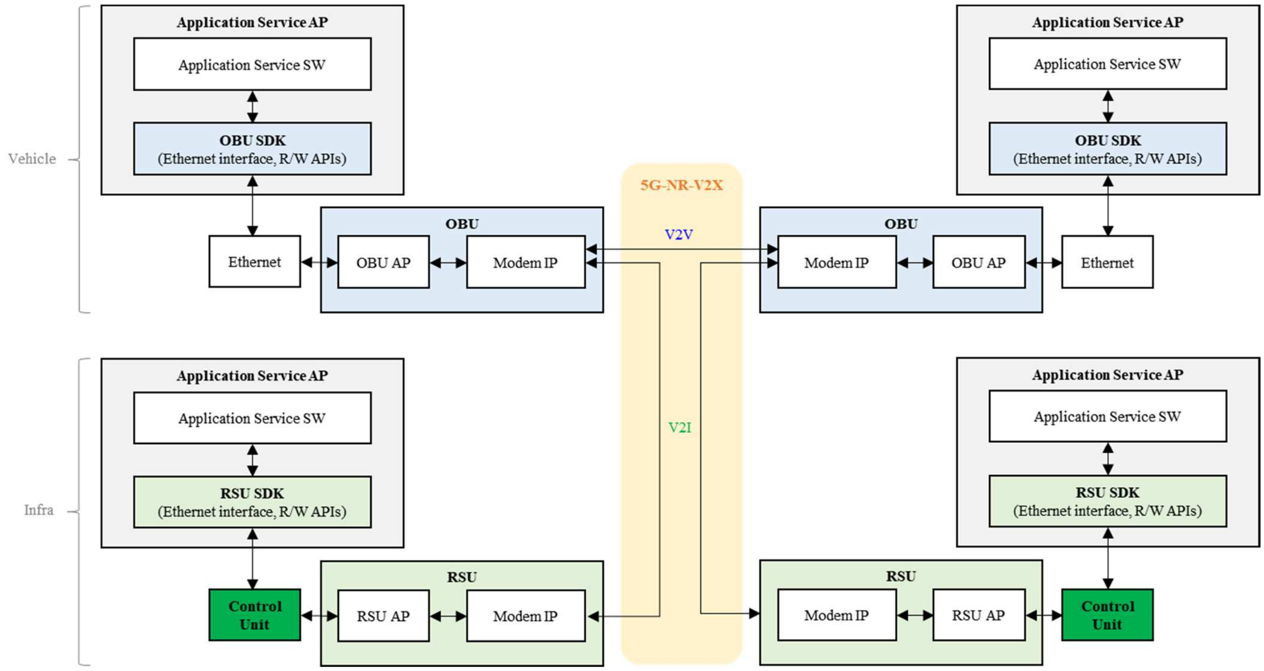

Fig. 1. A connected device structure of 5G-NR-V2X system (OBUs, RSUs, and control units)

- Autonomous Driving: The group's use cases pertaining to autonomous vehicle levels 4 and 5 provided information on when autonomous driving is permitted or not, control, remote driving, dynamic mapping, and cooperative interaction between vehicles is required to be efficient and secure.
- Platooning: Transportation companies and road operators/road traffic authorities have defined use-cases such as cluster driving management and cluster driving stability that make more efficient use of road infrastructure and offer environmental advantages such as emissions reduction.

This paper developed 5G-NR-V2X communication technology and presented a method for analyzing 5G-NR-V2X system and communication performance by developing sidelink IP, communication module, communication OBU, and RSU that adhere to 3GPP Release 16 specifications.

The remaining sections of this article are structured as follows. In Section II, we will first provide an overview of the current state of research and commercially available approaches for 5G-NR-V2X architecture. Then, in Section III, we will propose the message format of the solution connecting vehicles and infrastructure, provide some practical details, and discuss examples of data structures that would benefit from the resource sharing between these devices. In Section IV, we will present the methodology for analyzing the communication performance of 5G-NR-V2X. This article concludes with a discussion of the implementation difficulties associated with the proposed method.

II. A OVERVIEW OF 5G-NR-V2X SYSTEM

A. A Connected Device Structure of 5G-NR-V2X System

In this section, we will explore potential methods facilitating system procedure interactions and data exchange among V2X vehicle devices along with the infrastructure. Our goal is to establish seamless connectivity while maintaining the full functionality of the V2X stacks and SDKs offered by V2X device vendors, or adhering to the safety characteristics outlined by international standards. The components of basic V2X communication equipment are as follows.

- OBUs are car-mounted transceivers that collect data from the vehicle and transmit that data in real time to other linked vehicles or RSUs.
- RSUs are fixed communication nodes along a road that can exchange data with OBUs in passing vehicles and relay that data back to a centralized station.
- Control Units are the connection between the control center and the RSU. Due to the characteristics of RSU, it is highly probable that it is attached to the highest part of the telephone pole alongside the antenna. Thus, it is ground-control apparatus for RSU. The equipment could be present or absent based on the circumstances.
- Software Development Kits (SDK) are software that can connect V2X equipment and applications, as well as support equipment control, data transmission and reception, and a modem IP's communication status.
- Application Services are software for versatile situations such as platooning services, sensor sharing services, remote driving services, advanced driving services, and etc.

A connected device structure of 5G-NR-V2X System (OBUs, RSUs, and Control Units) is shown in Fig. 1.

B. A Framework of 5G-NR-V2X System

This section describes the reference framework that have been considered for the architecture of the 5G-NR-V2X communication technology. Fig. 2. illustrates the overview of the 5G-NR-V2X framework architecture. The proposed framework consists primarily of three systems. Each system has the following responsibilities: application system, OBU/RSU system, and 5G-NR-V2X modem IP system.

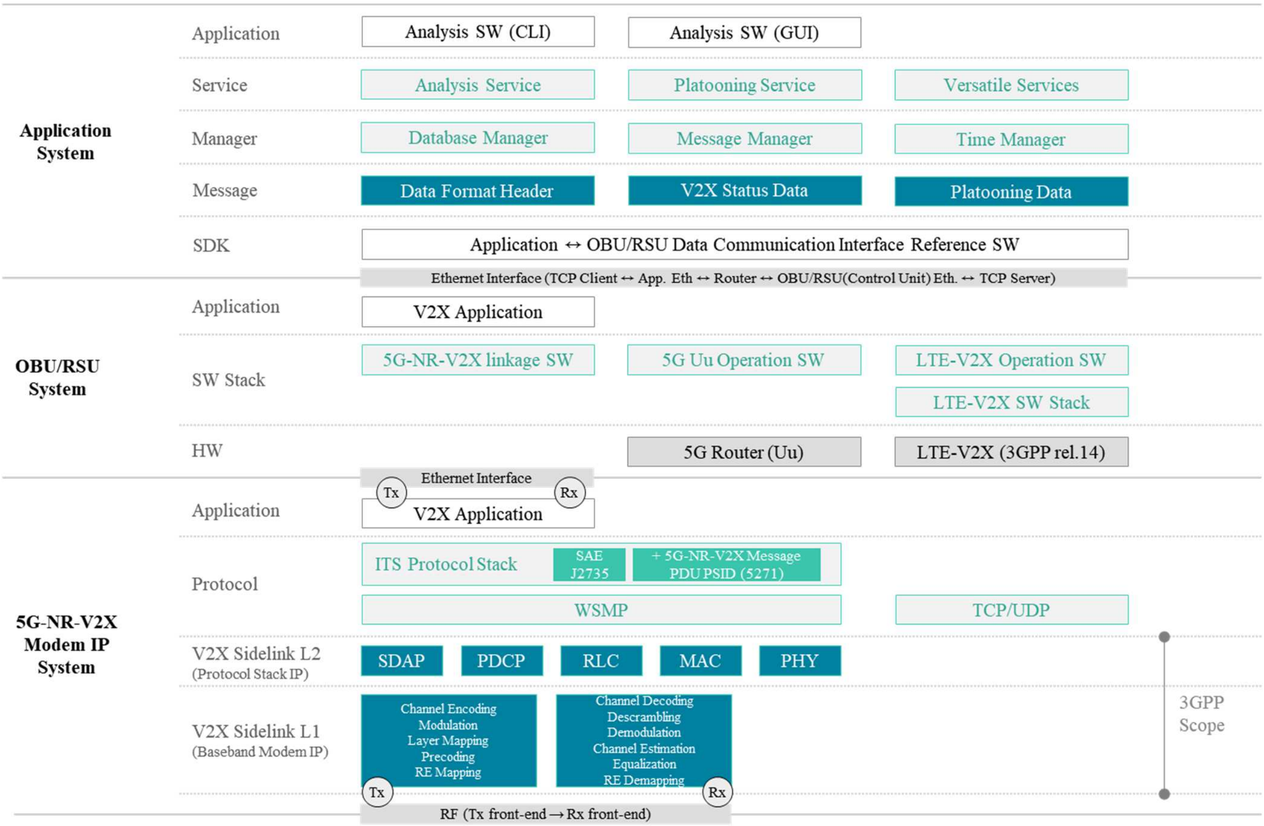

Fig. 2. The overview of the 5G-NR-V2X framework architecture.

The application system consists of a total of five layers. The application layer comprises a command line interface (CLI)-based service for real-time rudimentary unit-testing and debugging, and a graphical user interface (GUI)-based application service for real-time graphic result display. Due to the inherent characteristics of the embedded system, the CLI recommends implementing it using C/C++ in order to expedite future commercialization. Automobile manufacturers commonly employ QT, which is recommended by the user interface [12]. The service layer is the domain of scenarios. Numerous services may be added, such as the service layer depicted in Fig. 2., and platooning and analysis service are examples. For fulfilling the requirements of the application service, the message layer packetizes V2X message data. The SDK layer is described in the preceding section.

The OBU/RSU system includes an application layer, a software (SW) stack layer, and a hardware (HW) layer. The application layer controls the device's hardware and manages communication with the application service's application processor (AP). The SW stack layer is composed of 5G-NR-V2X linkage software and 5G Uu operation software. Additionally, LTE-V2X operation SW and LTE-V2X SW stack are supported for backward compatibility when supported by Modem IP or configured as a separate LTE Modem IP. The HW may be configured as a 5G Uu or LTE-V2X modem within the OBU/RSU device, or it may connect the device to the exterior. Figure 2 depicts a structure containing 5G Uu and LTE-V2X Modem on the inside and a 5G-NR-V2X modem IP system on the outside. Qualcomm, Autotalks, and Ettifos are currently developing the 5G-NR-V2X modem, and it was considered to connect modem IP with Ethernet to implement various modems in the order in which they were released prior to commercialization.

The 5G-NR-V2X modem IP (Intellectual Property) system consists of an application layer, a protocol layer, a V2X sidelink L2 layer, and a V2X sidelink L1 layer. The application layer controls the circuitry of the device and handles communication with OBU/RSU devices. The protocol layer will be discussed in depth in Section III on the message format for 5G-NR-V2X. The V2X sidelink L2 is an IP layer protocol stack composed of Service Data Adaptation Protocol (SDAP), Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC), Medium Access Control (MAC), and Physical (PHY) layer. The IP baseband modem is referred to by the L1 sidelink in V2X. The V2X sidelink L1 consists of Tx and Rx components. Channel encoding, modulation, layer mapping, precoding, and RE mapping are included in the Tx. Channel decoding, descrambling, demodulation, channel estimation, equalization, and RE demapping are included in the Rx. This paper does not provide a detailed definition of the term; instead, the reader is directed to the appropriate document [13].

III. A MESSAGE FORMAT OF 5G-NRV2X

This section describes reference message formats that have been considered for the evaluation of the 5G-NR-V2X communication technologies. These indicative message formats are mainly classified into two categories as adopted in the 5G-NR-V2X framework, namely safety applications and non-safety applications.

Message formats play a significant role in communicating among V2X devices. The European ITS-G5 standard as well

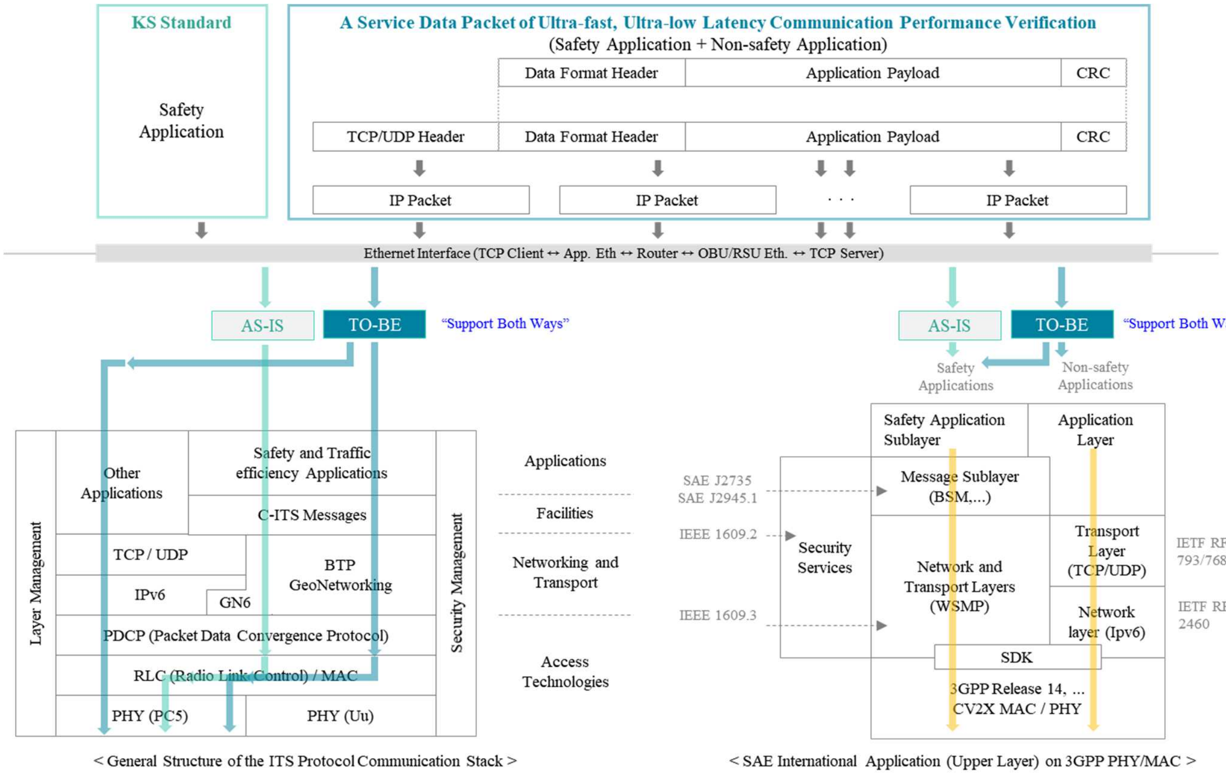

Fig. 3. A procedure of the verification of 5G-NR-V2X communication performance of connected vehicles employing message formats.

as its U.S. variant DSRC are well-established and mature technologies that have been researched and analyzed through simulations and mathematical evaluation, along with a number of test campaigns and pilot projects in Europe and around the globe. In contrast, cellular-V2X (C-V2X) PC5 is a newer technology that has not yet been thoroughly evaluated in realistic circumstances such as LTE-V2X, and 5G-NR-V2X.

The Fig. 3. illustrates the considering aforementioned realistic circumstances that a procedure for the verification of 5G-NR-V2X communication performance of connected vehicles employing message formats for both safety applications and non-safety applications. In order to have a benefit of various message formats, both KR standards and suggested message formats have been configured to transmit simultaneously in the same channels in the 5.9 GHz ITS band.

TABLE I. A SUGGESTED MESSAGE FORMAT OF 5G-NRV2X

Bit Offset	
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DB_V2X_DEVICE_TYPE_E eDeviceType	DB_V2X_TELECOMMUNCATION_TYPE_E eTeleCommType
ulDeviceId (32bits)	
ulTimeStamp (64bits)	
DB_V2X_SERVICE_ID_E eServiceId	DB_V2X_ACTION_TYPE_E eActionType
DB_V2X_REGION_ID_E eRegionId	DB_V2X_PAYLOAD_TYPE_E ePayloadType
DB_V2X_COMMUNCATION_ID_E eCommId	usDbVer (16bits)
usHwVer (16bits)	usSwVer (16bits)
ulPayloadLength (32bits)	
Reserved (32bits)	
Payload (Data)	
ulPacketCrc32	

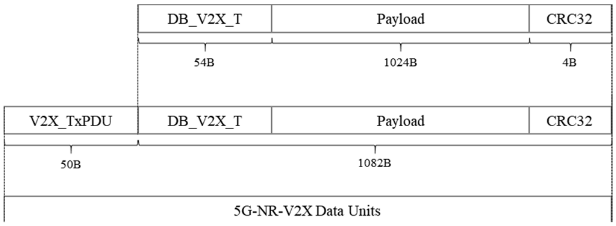

Fig. 4. A packetization of 5G-NR V2X message for safety applications

A. KR Standards for Safety Applications

The message format for safety applications has been Surface Vehicle Standard (SAE) international standardized for many years. SAE J2735 defines the V2X communications message set dictionary [14]. SAE J2945 describes on-board system requirements for V2V safety communications [15]. SAE J3224 explains V2X sensor-sharing for cooperative and automated driving [16]. For parts not specified by the SAE standard, the Korean standard further defines standardization to accommodate the Korean ITS environment. KS R 1600-1 specifies conceptual V2X scenarios [17]. KR R 1600-2 outlines fundamental safety messages for vehicles [18]. By 2024, the Korean government intends to have standardized traffic signals and map messages (KSR 1600-3), control messages (KSR 1600-4), driving environment messages (KSR 1600-5), pedestrian safety messages (KSR 1600-6) and collision risk messages (KSR 1600-7) for release in 2025. Since KR standardization has been achieved based on SAE, the existing ASN.1 is used, and concepts such as Basic Safety Message (BSM) and Probe Vehicle Data (PVD) are introduced as-is, allowing it to be used in the ITS industry without significant changes. However, the technology does

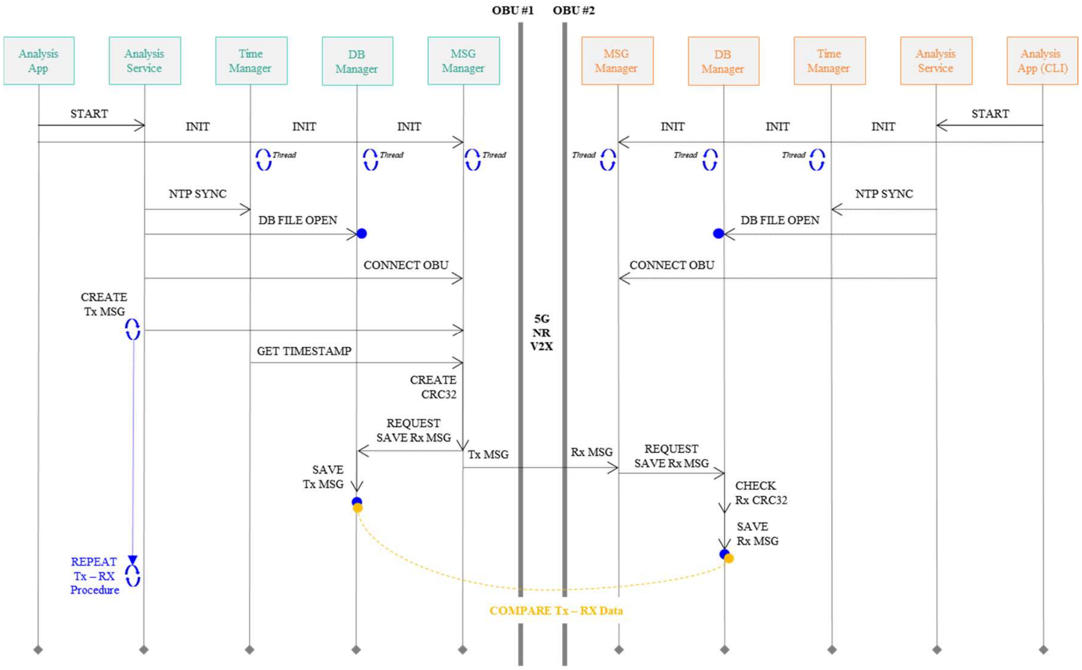

Fig. 5. A basic analysis procedure for Tx and Rx communication between V2X devices (OBUs).

have limitations from the user's perspective because it does not take into account the diversity that C-V2X can support.

B. *A Recommended Message Format of Ultra-fast, Ultra-low Communication Performance Verification for Both Safety Applications and Non-safety Applications*

In this section, a suggested message format of ultra-fast, ultra-low communication performance verification for both safety applications and non-safety applications has been described as depicted in Table I. Through the recommended format we could verify some specific scenarios such as platooning services, sensor sharing services, remote driving services, advanced driving services. Limited message formats of standards make development uncomfortable, but also pose a serious restriction to application users and Software Defined Vehicle (SDV). With the proposed message formats of 5G-NR-V2X, here is our guide to getting through one. The proposed method was devised by referencing the expanded Scalable service-Oriented MiddlewarE over IP (SOME/IP) characteristics that is a solution for automotive middleware that can be utilized for control communications. It was designed from the start to suit devices of various sizes and operating systems flawlessly. This includes compact devices such as cameras and AUTOSAR devices, as well as head units and telecommunications devices. It was also ensured that SOME/IP supports features of the Infotainment domain in addition to those of other domains in the vehicle, allowing SOME/IP to be used for MOST substitution situations as well as more traditional CAN circumstances [19]. Taking into account the in-vehicle characteristics of SOME/IP, we designed a message format by incorporating it into a V2X communication environment outside the vehicle. Refer to Table 1 for message format details. Refer to the KETI github source code headers for additional information [20].

It was determined that V2X_TXPDU and V2X_RXPDU could be additionally packetized at OBU AP using the existing SAE J2735 for safety applications and transmitted via the existing ITS stack as shown in Fig. 4. Except for V2X_TXPDU and V2X_RXPDU, it can be packetized and transmitted in the TCP/IP environment as DB_V2X_T, payload, and crc32. Consequently, the format can be applied to both safety and non-safety applications, and it is anticipated that the scalability will be very good because only payload configuration is required after defining DB_V2X_PAYLOAD_TYPE_E in the desired form in various application services.

IV. ANALYSIS METHODOLOGY OF COMMUNICATION PERFORMANCE OF 5G-NR-V2X

This section gives an overview of the analysis methodology that has been followed for the evaluation of the different V2X service scenarios on top of the 5G-NR-V2X testbed. In order to have a fair comparison of the results of V2X devices parameters are configured as following; frequency (5.965 GHz), bandwidth (20 MHz). Please contact the authors of the paper for more information, as some parameters are not permitted to be shared publicly. The suggested basic analysis procedure for Tx and Rx communication between V2X devices is depicted in Fig. 5. The analysis application launches a verification service and initializes all functions, including the time manager, database manager, and message manager. After initializing the system, it synchronizes time using Network Time Protocol (NTP) or a GNSS device, before opening a DB file and connecting the OBU AP. If the connection between the application AP and OBU AP is successful, 5G-NR-V2X communication could begin. In order to evaluate and confirm the reproducibility of the results, each test has also been repeated multiple times with identical parameters. The NTP is used by all RSUs and OBUs to synchronize their timing with the GNSS device as shown in Fig. 6. According to the specifications of the employed GNSS devices, they provide a time precision of 1 millisecond. However, we have observed that the accuracy may occasionally decrease by a few milliseconds. Nonetheless, as stated, this impact would be felt by both technologies, as they transmit simultaneously utilizing the same clocks, and each test has been conducted multiple times

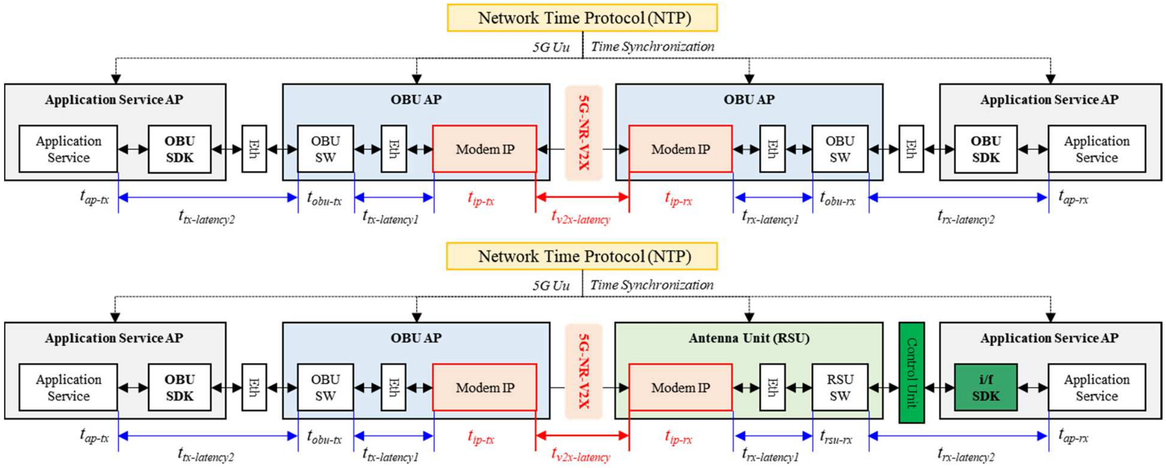

Fig. 6. Overview of time synchronization methodology of 5G-NR-V2X system.

and on various dates. Consequently, we believe that the impact of the variation in GNSS synchronization via NTP on the performance evaluation is negligible [21]. Both the OBUs and the RSUs record the transmitted and received messages locally. After a test concludes, the central logging server collects all the locally logged data from all the participating OBUs and RSUs. The information is then submitted to the central database. After the data have been inserted into the database, the post-processing tools can use it to analyze the 5G-NR-V2X communication performance.

V. CONCLUSION AND FUTURE WORK

Within the next few decades, it is anticipated that automobiles equipped with autonomous driving functionality will become the standard on our roadways. The communication performance technique for the 5G-NR-V2X system was outlined in this paper. We introduce a system that can use OBU and RSU for 5G-NR-V2X communication to create and validate the performance of autonomous driving services in a real-world road test environment. The validation of services through the proposed performance analysis method is thought to improve technological competitiveness in the transportation, logistics, and business sectors.

We hope to take things a step further in the near future by assessing the V2X technologies while they coexist in the same channel of the 5.9 GHz ITS band. Through this research, we can examine how several factors, including spectrum occupancy, packet-loss, latency, and so on, affect the performance of the various technologies. We may then analyze interference solutions in real-world circumstances, and we get insight into how technologies behave under mutual interference conditions.

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REFERENCES

[1] L. Zhao, et al., "A Social Computing Inspired Predictive Routing Scheme for Softwarized Vehicular Networks," in IEEE T-ITS, vol. 23, no. 7, pp. 9466-9477, Jul. 2022.

[2] S. Chen et al., “V2X services supported by LTE based systems and 5G,” IEEE Commun. Standards Mag., vol. 1, no. 2, pp. 70–76, Jan. 2017.

[3] S. Chen, J. Hu, Y. Shi, L. Zhao, and W. Li, “A vision of C-V2X: Technologies, field testing, and challenges with chinese development,” IEEE Internet Things J., vol. 7, no. 5, pp. 3872–3881, May. 2020.

[4] P. Liu, Y. Zhang, T. Fu, and J. Hu, “Intelligent mobile edge caching for popular contents in vehicular cloud toward 6G,” IEEE Trans. Veh. Technol., vol. 70, no. 6, pp. 5265–5274, Jun. 2021.

[5] A. F. Magnussen, N. Le, L. Hu, and W. E. Wong, “A survey of the inadequacies in traffic sign recognition systems for autonomous vehicles,” Int. J. Performability Eng., vol. 16, no. 10, 2020.

[6] C. Prehofer and S. Mehmood, “Big data architectures for vehicle data analysis,” in Proc. IEEE Int. Conf. Big Data, 2020.

[7] ETSI TS 122 186, “5G; Service requirements for enhanced V2X scenarios (3GPP TS 22.186 version 16.2.0 Release 16),” Nov. 2020.

[8] ETSI TS 122 186, “5G; Service requirements for enhanced V2X scenarios (3GPP TS 22.186 version 17.0.0 Release 17),” Apr. 2022.

[9] ETSI TS 122 261, “5G; Service requirements for the 5G system (3GPP TS 22.261 version 17.11.0 Release 17), Oct. 2022.

[10] 5GAA (5G Automotive Association), “A Visionary Roadmap for Advanced Driving Use Cases, Connectivity Technologies, and Radio Spectrum Needs, Nov. 2022.

[11] Qualcomm Research, “3GPP Rel. 17:To bring new system capabilities and expand 5G to new devices, applications, and deployment Completing the first phase of the 5G evolution,” Mar. 2022.

[12] The Qt Company, “https://www.qt.io/,” QT Software.

[13] Ali Zaidi, Fredrik Athley, Jonas Medbo, Ulf Gustavsson, Giuseppe Durisi, Xiaoming Chen, 5G Physical Layer, Academic Press, 2018.

[14] SAE (Surface Vehicle Standard) International, “J2735, (R) V2X Communications Message Set Dictionary,” Nov. 2022.

[15] SAE (Surface Vehicle Standard) International, “J2945, On-Board System Requirements for V2V Safety Communications,” Apr. 2020.

[16] SAE (Surface Vehicle Standard) International, “J3224, V2X Sensor-Sharing for Cooperative and Automated Driving,” Aug. 2022.

[17] Korean Agency for Technology and Stardards, “KS R 1600-1, V2X messages specification for cooperative automated driving systems - Part 1: Conceptual scenarios,” Korean Industrial Standards, Jun. 2023.

[18] Korean Agency for Technology and Stardards, “KS R 1600-2, V2X messages specification for cooperative automated driving systems - Part 2: Basic vehicle safety messages,” Korean Industrial Standards, Jun. 2023.

[19] AUTOSAR, “(R22-11) SOME/IP Protocol Specification,” Nov. 2022.

[20] V2X Data Format, “https://github.com/KETI-A/v2x_data_format/”.

[21] V. Maglogiannis, D. Naudts, S. Hadiwardoyo, D. van den Akker, J. Marquez-Barja and I. Moerman, "Experimental V2X Evaluation for C-V2X and ITS-G5 Technologies in a Real-Life Highway Environment," in IEEE Transactions on Network and Service Management, vol. 19, no. 2, pp. 1521-1538, Jun. 2022.