V2X Traffic-Load Generator System for Enabling Efficient Vehicle Communication Load-Balancing

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***Abstract*— The research related to Connected Vehicle and Connected Autonomous Vehicle utilizing V2X technology is growing worldwide. The advancement of V2X technology enables safe vehicle operations on the road. However, as the number of vehicles equipped with V2X communication devices increases, issues related to communication performance and environment can arise. An increase in the number of vehicles on the road is associated with a decrease in communication latency and throughput. Therefore, this paper introduces the V2X Traffic-Load Generator system and proposes a system that can be prepared for deteriorating communication conditions. The proposed system consists of a part that generates real-time communication loads and a part that collects and analyzes data, with consideration for future expansion with actual equipment.**

Keywords—V2X communication, Connected Vehicle (CV), Connected and Autonomous Vehicle (CAV), Load-balancing

I. INTRODUCTION

The research on connected vehicle (CV) technologies for safety and smooth traffic flow on roads, and on connected and autonomous vehicle (CAV) technologies that integrate vehicle communication and autonomous driving [1, 2] is steadily increasing globally. The Vehicle-to-Everything (V2X) communication that underpins CV and CAV enables services such as Cooperative-Intelligent Transport System (C-ITS) to send and receive SAE J2735 messages (BSM, PVD, SPaT, MAP, RSA, etc.) to drive safely on the road [3, 4]. V2X communication started with WAVE, and recently, the final stage of LTE-V2X was validated in Korea, and 5G-NR-V2X-based research is also being conducted actively [5, 6]. 3GPP has announced 5G-NR-V2X (Rel.16, 17), which is characterized by ultra-low latency, high capacity and reliability, and 5GAA has defined various use case studies related to safety, autonomous driving, and platooning [7, 8]. As such, V2X communication technology for safety and autonomous driving on the road is advancing, and various issues are expected to arise as more vehicles equipped with V2X communication devices appear on the road in the future. As the number and density of vehicles equipped with V2X communication devices on the road increase, the performance of vehicle communication can deteriorate due to communication environment issues such as interference and traffic. According to [9], it can be seen that as the number of vehicles on the road increases, the communication latency increases and the throughput declines. In [10], similar results showed that the packet reception ratio increased from 96.4% when the number of UEs was 96 to 80.36% when the number of UEs increased to 1,920. Therefore, this paper introduces the V2X Traffic-Load Generator System as a solution to overcome these issues. It generates an environment where vehicles equipped with V2X communication devices occupy more than 80% of the actual roadway, allowing for preparation in situations where the communication environment deteriorates.

This paper is organized as follows: overview of V2X Traffic-Load Generator system, detailed overview, examples, discussions & conclusions.

II. OVERVIEW OF V2X TRAFFIC-LOAD GENERATOR SYSTEM

The proposed V2X Traffic-Load Generator system generates V2X communication load on virtual vehicles and infrastructure based on data obtained when multiple vehicles equipped with V2X devices drive on roads with infrastructure, and manages and analyzes real time and cumulative data to show results. The system is composed of Real Time Traffic Data Generating part, which generates real

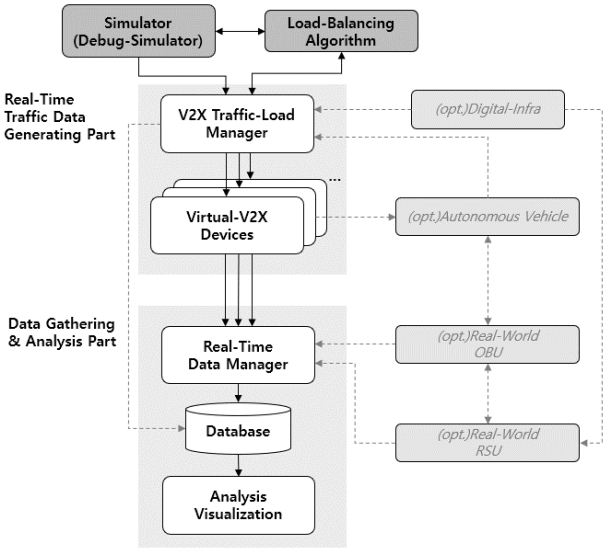

Fig. 1. V2X Traffic-Load Generator system configuration.

time communication load, and Data Gathering & Analysis part, which collects and analyzes the generated load data (Fig. 1). The blurred dotted lines in the figure and the blocks designated as (opt.) are intended for future expansion of the interface with real devices, which will enable the collection and analysis of communication traffic information from real devices as well as virtual communication traffic.

A. Real Time Traffic Data Generating Part

The Real Time Traffic Data Generating part consists of V2X Traffic-Load Manager (TL Manager) and Virtual-V2X Devices (VVD), and their respective roles are as follows. TL Manager is responsible for creating load generation commands based on the location information of virtual (or real) communication devices received from external devices such as simulators, taking into account the V2X communication radius of each device. Each VVD is characterized by as an independent process, and it processes the load generation command received from TL Manager to generate the actual communication load and receives and processes communication data such as service messages from other VVDs.

B. Data Gathering and Analysis Part

The Data Gathering & Analysis part consists of Real Time Data Manager (RTD Manager) and Analysis Visualization (AV), and their respective roles are as follows.

RTD Manager receives real time load data from VVD, stores them in database (DB), and manages the data. AV monitors, analyzes, processes, and visualizes real time or accumulated data from the DB and presents them to users.

III. Detailed System Overview

This section describes the connections between each subsystem, their main functions, and the information they send and receive.

A. V2X Traffic-Load Manager (TL Manager)

The main function of TL Manager is to communicate with VVD, DB, and authorized external devices such as simulators. TL Manager is the TCP-Server and the other subsystems operate as TCP-Clients. Open-source-based DB servers are configured separately, and TL Manager works as a client here (Fig. 2, Table.1).

The information that TL Manager receives from the simulator, Load Balancer, and DB is as follows. From the simulator, TL Manager receives regarding the location (latitude/longitude/altitude) and state (speed, braking, acceleration/deceleration, etc.) of each VVD, which behaves as an independent object. From the Load Balancer, it receives information related to Load Commands. Lastly, from the DB, it receives management information about virtual devices such as type, attributes, and communication methods.

TL Manager transmits the following information to devices including dst-device list, and message type list, etc. to VVD and Load Commands such as traffic status information to Load Balancer. In addition, it transmits Load Commands logs (traffic status analysis) to the DB.

B. Virtual-V2X-Devices (VVD)

Although VVDs are virtual devices, they run as independent processes to behave like real equipment, and it is aimed to run 30 to 400 devices simultaneously and link them together. Main functions of VVDs are TCP/IP communication with TL Manager and RTD Manager, and individual UDP communication between VVDs. TL Manager and RTD Manager operate as TCP-Servers, while VVD operates as a TCP-Client (Fig. 3, Table.1).

The information VVD receives is as follows. Each individual VVD receives and processes Load Commands such as dst-device list, outgoing message type list, etc. from TL Manager. The information that individual VVDs receive/transmit to each other over UDP is the service messages (BSM, SPaT, MAP, RSA, etc.) within the virtual communication radius.

The information that the VVD transmits to RTD Manager includes load occurrence information such as the time, size, number, and type of messages.

C. Real Time-Data Manager (RTD Manager)

The main function of RTD Manager is to communicate with VVD based on TCP/IP to manage multiple and simultaneous connections, monitor connection status, and send data to the DB server (Fig. 4, Table.1).

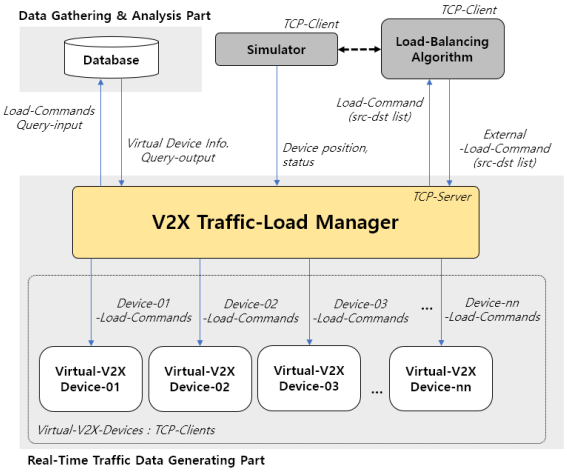

Fig. 2. Overview of system linkage of V2X Traffic-Load Manager.

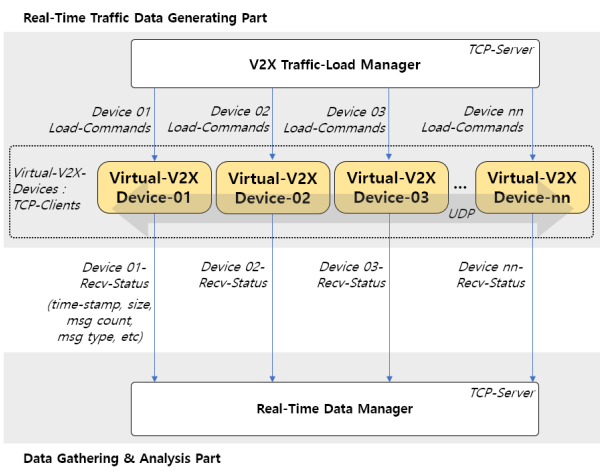

Fig. 3. Overview of system linkage of Virtual-V2X Devices.

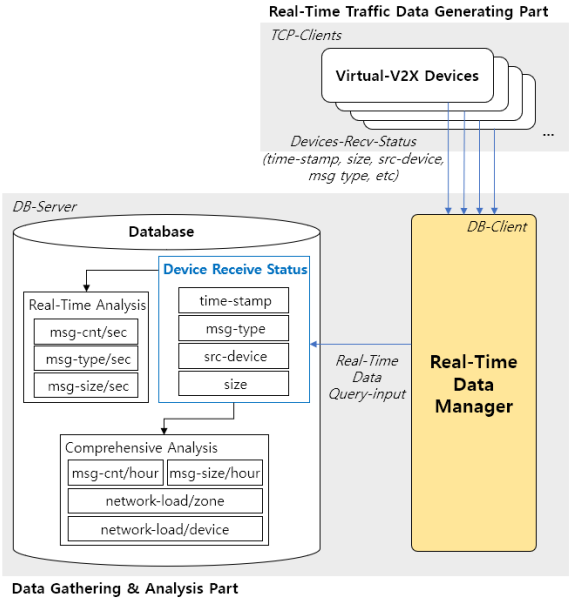

Fig. 4. Overview of system linkage in Real Time Data Manager.

RTD Manager receives and processes real time information from each independent VVD, including the time, size, number, and type of messages. Then, it sends real time information received from the VVD to the DB server and loads them (Query-input). Based on the loaded information, DB server performs real time analysis (number/type/size of messages per second processed in real time) and comprehensive analysis (number/size of messages processed in one hour, network load analysis by area, network load analysis by device, etc.).

D. Analysis Visualization

The main function of AV is to connect to the DB server as a client and display real time/detailed analyzed contents loaded into the DB (Fig. 5, Table.1).

Real time data analysis and visualization is as follows:

- Extract and analyze data from real time received status information tables in real time
- Manage real time analysis data and load analysis data
- Display chart and graphs in real time, such as number of messages/type/size received per second
- Display Real time devices location based on HD map
- Display communication load by real time area(V2V/ V2I/I2V, etc.) based on HD map

A detailed analysis and visualization of the cumulative data is as follows:

- Extract data from real time analysis data table and analyze cumulative data
- Manage cumulative data tables and load detailed analysis data
- Display detailed analysis charts and graphs, including 1-hour cumulative message count/size analysis and device-specific communication load analysis

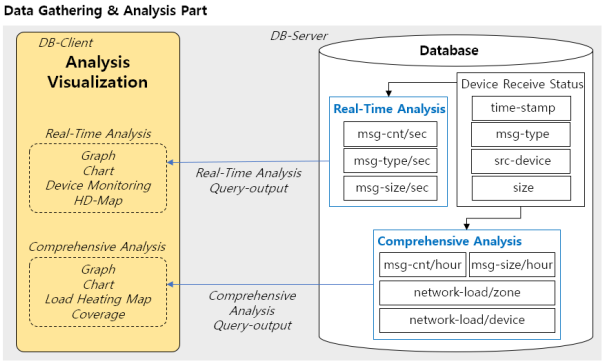

Fig. 5. Overview of system linkage in Analysis Visualization.

TABLE I. MAIN FUNTIONS & RECEIVING AND TRANSMITTING INFORMATION OF EACH SUBSYSTEM

Traffic-Load Manager (TL Manager)		
Main Function	- TCP/IP communication with authorized external devices, VVDs, and DBs	
Receiving Information	External equipment (Simulator)	- Location of the VVD (latitude/longitude/altitude) - State (speed, braking, acceleration, deceleration, etc.)
	Load Balancer	- Load Commands
	DB	- Types, properties, communication methods, etc.
Transmitting Information	VVD	- dst-device list - Send message types list
	Load Balancer	- Load Commands
	DB	- Load Commands Log
Virtual-V2X Devices (VVD)		
Main Function	- TCP/IP communication with TL Manager and RTD Manager	
Receiving Information	TL Manager	- dst-device list - Outgoing message types list
	VVD	- Service messages (BSM, SPaT, MAP, RSA, etc.)
Transmitting Information	RTD Manager	- Message occurrence time, size, count type, etc.
	VVD	- Service messages (BSM, SPaT, MAP, RSA, etc.)
Real Time Data Manager (RTD Manager)		
Main Function	- TCP/IP Communication with VVD - Sending data to the DB server	
Receiving Information	VVD	- Message occurrence time, size, count type, etc.
Transmitting Information	DB server	- Real time information received from the VVD
Analysis Visualization (AV)		
Main Function	- Connect to DB server as a client and visualize and display real time/detailed analyzed contents loaded in DB	

- Display detailed analysis of communication load by area based on HD map
- Display detailed analysis of movement history and location-based network load for specific V2X devices based on HD map

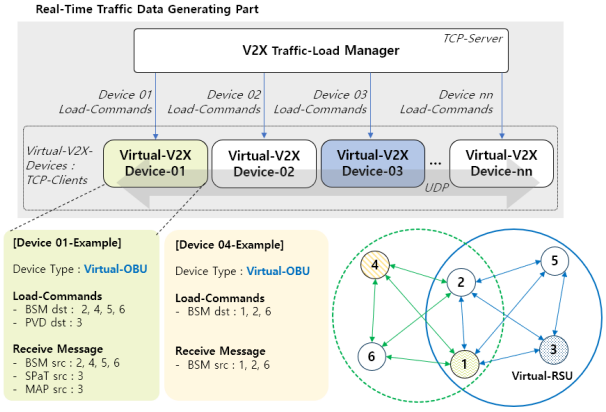

Fig. 6. Example of traffic generation information of Load Commands and Virtual-V2X Device.

IV. Example of Virtual-V2X-Devices Operation

This section provides an example of how the VVDs in the proposed system will communicate in concert. Each VVD has a communication radius, which is indicated by the solid blue and dashed green lines in the example illustration. There are three VO s (1, 2, and 5) and one VR (3) within the communication radius of the solid blue line, and four VOs (1, 2, 4, and 6) within the communication radius of the dashed green line. VO 1 is in both the solid blue and dotted green communication radius, so it can communicate V2V (BSM) with VOs 2, 4, 5, and 6, and V2I (PVD) and I2V (SPaT, MAP) with VR 3. As VO 4 exists in the dotted green communication radius, communication between V2V (BSM) communication with VOs 1, 2, and 6 is possible (Fig. 6).

V. Discussions and Conclusions

The system proposed in this study generates traffic data in consideration of the communication radius of VVDs operating as independent objects, and displays real time data and cumulative data analysis results to users. In the future, work on the proposed system will be continued to extend the interface with real-world equipment to collect and analyze not only virtual communication traffic, but also communication traffic information from real-world equipment.

Currently, work is underway to visualize and present the below to users (Fig. 7). It is planned that the image will display the device type, V2X communication radius, transmitted message, velocity, and direction of each VVD in real time, and the list will display the VVD's ID, connection status, and tracking status. The total count of messages, V2V/ V2I/I2V count, and message size (Total, V2V, V2I, I2V) will be displayed as a chart in real time. In addition to real time data, cumulative data will be displayed following analysis. It is planned that when the Device ID is selected from the VVD list, the area traveled by the selected device will be presented with a heat map that can show the amount of data received by the V2X device.

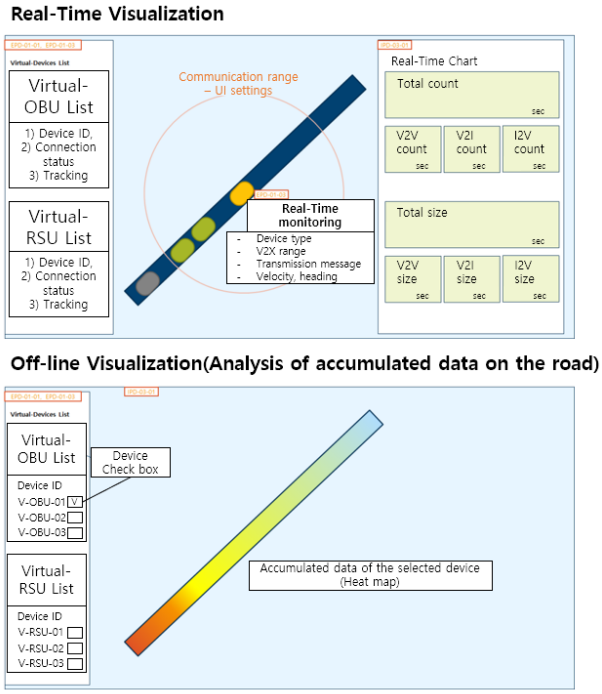

Fig. 7. Example of Visualization.

Utilizing this system will allow users to test many situations and will help users identify situations where communication overload can occur in real-world situations and organize a strategy to distribute the load. As shown in the example part, the proposed system can be used to determine the communication performance by generating a load considering the communication radius of each VVD based on the virtual (or real) communication equipment location. This system enables real-time and cumulative data analysis of VVD loads in diverse environments, providing insights that can be leveraged for load balancing strategies. Through this, it is expected to solve problems related to communication performance depending on the density of vehicles on the road and problems that can occur due to communication overload. Additionally, it is expected to prepare for situations where the communication performance does not meet the requirements of the use cases related to cooperative autonomous driving of 3GPP and 5GAA due to the decline in communication performance.

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