V2I and V2V service demonstration of millimeter wave communication in urban road environment

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***Abstract*—The demonstration result of a millimeter wave based communication system was introduced. The test system was set up in a complex urban road to demonstrate the service in vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) connection. Passengers in a vehicle can measure data rate using a commercial Apps and experience high-end data service by wearing augmented reality (AR) glasses. V2I had a maximum data rate of over 700 Mbps and V2V had a maximum data rate of over 800 Mbps. Passengers can experience stable AR service. However, the quality of service (QoS) was suddenly degraded due to the condition of wireless link. So, networks with more beam management capability should be considered in urban roads to avoid degradation of QoS.**

Keywords— millimeter wave, 5G new radio, vehicle-to-vehicle communication, mobile backhaul, V2I

I. Introduction

V2X communications contains vehicle-to-vehicle (V2V), vehicle-to-network (V2N) or vehicle-to-infrastructure (V2I), vehicle-to-road side unit (V2I), and vehicle-to-pedestrian (V2P) [1]. The services of V2X are necessary to increase vehicle safety, utilize traffic information, provide people with variable data rates, and ultimately make practical autonomous driving. Specifically, the V2V communications are useful for urgent safety related messages and also regarded as an efficient communication means for platooning [2]. Further, the V2V communication can be used as a coverage extension scheme. For an example, in the 5th Generation (5G) New Radio (NR) standardization, user equipment (UE)-to-UE relay and UE-to-Network relay have been studied for coverage expansion [3].

LTE V2X was the first cellular V2X (C-V2X) presented by 3GPP Release 14 and was further enhanced in Release 15 (Rel. 15) [4]. 3GPP decided to develop a new V2X standard based on 5G-NR standard. To provide high-throughput, low-latency, and high-reliability services associated with V2V, 5G NR Release 16 specified new sidelink features including feedback channels, grant-free access, synchronization, QoS management, and more [5]. Some advanced features such as beamforming, scheduling UEs, power saving, and advanced MIMO in the sidelink were covered in Release 17. Sidelink improvements are in progress, including UE-to-UE relay and UE-to-network relay, in release 18.

5G-NR standard specifices two frequency ranges as FR1 and FR2. FR2 corresponds to millimeter waves from 24 GHz to 52 GHz. Because millimeter waves has high propagation loss and less refraction/reflection ratio, it has smaller communication coverage than that of low frequeny band. So, there have been many researchs and experiments to verify the feasibility of millimter wave based mobile communication.

A project for 5G-NR based mobile backhaul has been conducted. Mobile backhaul refers to connection between vehicles and external networks such as Internet. In the first step of the research, V2I communication technology was developed based on the specification of the 5G NR release 15 [6]. The developed V2I test system adopted a 22 GHz RF transceiver and baseband modem. In addition to physical layer development, higher layer protocol stacks had been developed to provide services such as video streaming, online gaming, and real-time webcams. The V2I system was used to provide these services to the vehicle's passengers in a highway test road environment. In another approach, we started research for V2V communication system based on the sidelink concept of the 5G NR release 16. The V2V technology was implemented in the same hardware platform with V2I. In [3], physical layer measurements and demonstration results of V2V communication were shown.

In this paper, the V2I/V2V service demonstration results in a complex urban road environment are summarized. Additionaly, physical layer measurements such as signal-to-noise ratios and data rates recorded in the demonstration are shown.

II. System overview

The overall architecutre of our communication system for mobile backhaul is depicted in the Fig. 1. Outside the bus, there are two types of wireless links, the one is the link between BS and TE, and the other is link between two TEs. The BS-TE link and TE-TE link are realized by V2I and V2V communication respectively.

The network side of the system is composed of a 5G core network and base stations (BSs). The 5G core network handles a wide variety of essential functions in the mobile network, such as connectivity and mobility management,

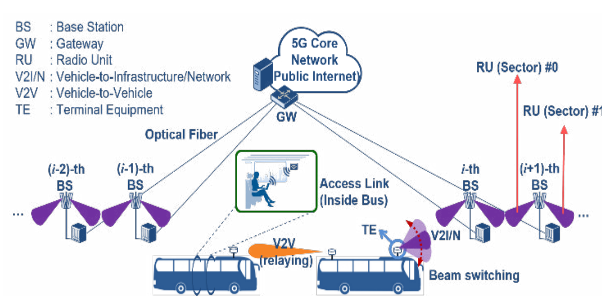

Fig. 1. system architecture

authentication and authorization, subscriber data management and policy management, among others [10]. The BS can be implemented in a manner of function splits such as a central unit (CU) and a distributed unit (DU). The BS is installed alongside the road and manages its own cell area. The terminal equipment (TE) is loaded on the vehicle. It communicates with the BS and has a wired connection to a Wi-Fi AP. The Wi-Fi AP is used for passenger's network access. Therefore, the proposed system is considered to provide wireless backhaul.

The proposed system utilizes the direct link between vehicles. Because the system uses milllimeter wave frequency (22.5 GHz), line-of-sight (LoS) environment is needed to preserve stable link quality. In urban roads, there are many obstacles that might prohibit the LoS channel. In these situations, V2V communication can be used instead of V2I to access the network. V2V specification defines control channel and data channel to manage device-to-device (D2D) communication. In relaying mode based on V2V, a TE connected to a serving cell can operate as a relay node, and a TE connected to the relay node can act as a remote node. The relay node TE can relay the remote node TE via the sidelink interface.

III. Implementation and Test

The interface between BS and TE is known as Uu interface. Through Uu interface, BS and TE commucates in uplink and downlink according to transmission direction. The interface between BSs is PC5 interface. Sidelink in 5G-NR speceification has to be implemented for PC5 interface. Both wireless interfaces are implemented based on the 5G NR Rel. 16.

Two types of layer 1 (L1) prototypes have been deveolped : radio unit (RU) and TE. The physical layer of base station including baseband processing are implemented in a radio unit (RU). RU and TE prototypes have common baseband platform and different architecture of RF module. The RU has one transmitter-receiver (TR) unit but the TE has three TR units having their own beam direction to broaden the beam range [9]. The TE has a TR selection unit to select the best beam. The baseband platform has three FPGAs on the board, one master FPGA and two slave FPGAs. The master FPGA dealts with external interface with higher layer and RF module. Each slave FPGA does baseband processing for three component carriers (CCs), so total six CCs are available. According to the content of the FPGA, the slave FPGA operates as Uu link or sidelink.

Table 1. Parameters of L1 prototype

Parameter	Value
TX power (FACS)	17dBm
Antenna gain	19 dBi
System bandwidth	600 MHz (22GHz)
subcarrier spacing	60 kHz
number of antenna	2T2R
slot duration	250 us
Duplex	TDD
Downlink/uplink ratio	7 : 1
Beamwidth	18 degree (HPBW)

The L1 prototype uses the 22 GHz frequency specified as flexible access common spectrum (FACS) in Rep. of Korea. Total frequency band includes six bands of 100 MHz bandwidth. Some key features of the prototype system are described in the table1.

In addition to the L1 prototypes, other higher layer protocols for base staions and TEs have been developed. Higher layer operating servers are connected to L1 prototpyes via optical lines.

Testbed was set up in a highway test road to observe communication performance and to verify the network operation. The highway test route was about 3 km long with five RUs. In the field trial, the maximum data rate of Uu interface reached 2.7 Gbps when using all six CC [9]. It was observed that the data transmission rate varied greatly depending on the structural conditions around the moving vehicle. In the next step, the handover between cells were tested and efficient handover techniq was found. About a year later, V2V compatible algorithms and FPGA codes were developed. In the V2V test, the SNR and data rate were measured up to 1.1 km along the road in a LoS environment. The measured SNR varied between 29 dB and 10 dB, and the data throughput fluctuated between between 1,400 Mbps and 220 Mbps [10]. In the test, three CCs were assigned for sidelink. For more practical verification of our system, more complex environment test was needed.

IV. Demonstration

A. Environment

A V2I/V2V service demonstration was conducted in a complex urban road to verify the feasibility of our mobile backhaul system. The area near Gimpo international airport is suitable for our experiment because it has a variety of transportation infrastructure and many vehicles are in operation. The whole test route is 2.7 km long and have 4-lane, 2-lane road and 1-lane down ramp. For the purpose of tests and demos, two RUs were deployed along the road, and then the RUs were connected to digital(central) units inside a control room located at the management building via optical lines [3]. The distance between the start point and the first RU was 306 m and the distance between two RUs was 277 m. TEs was loaded in the roof of two mini-buses.

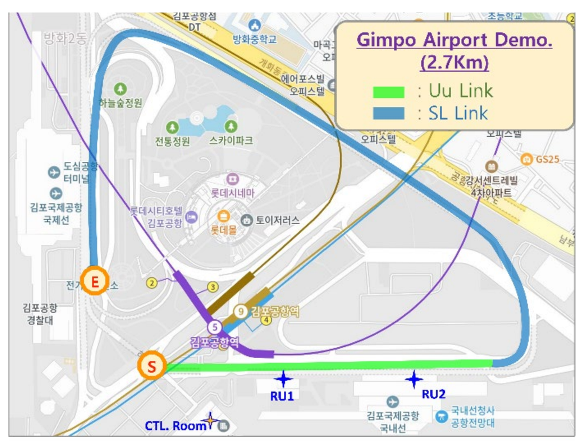

Fig. 2. map of test route

In the test route, V2I communication conducted from the start point to the RU2 using Uu link, and V2V communication based on sidelink operated in the rest of the path. In the Uu link test, the mini-bus initially accessed the

RU1 cell and then moved to the RU2 cell, so there was a handover operation between the two cells. After passing RU2, the mini-bus conneted to another mini-bus to start communication in sidelink. Then two mini-buses ran 10-20m apart to the end point.

B. Measuremet

During the service demonstration, the transmission performance can be measured in physical layer domain by sampling the baseband board outputs. Fig. 3 and Fig. 4 show examples of signal-to-noise ratio and data rate respectively. Because the distance in silelink is shorter than Uu link, the signal quality is better at some extent. The data rate in Fig. 4 shows the peak data rate of Uu link was around 700 Mbps and the peak data rate of sidelink was above 800 Mbps.

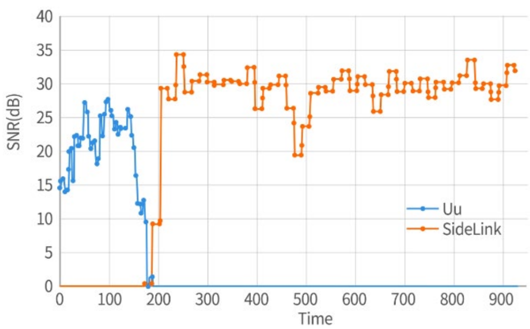

Fig. 3. measured SNR

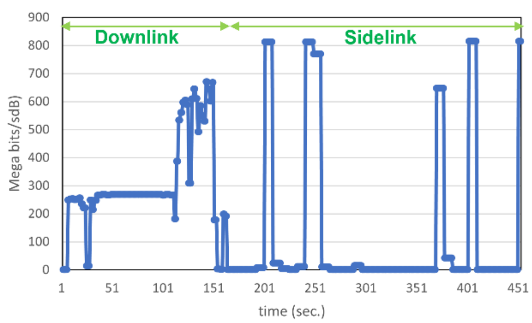

Fig. 4. mesured Data rate

C. Service test

In the aspect of measuring the service quality, the bus Wi-Fi service was tested. Passengers inside the vehicle checked video streaming with smartphones by browsing contents in the application server. They also measured Wi-Fi speeds by using an App named Benchbee. As shown in the Fig. 5(a), the maximum speed was over 700 Mbps, which was similar to the physical layer measurement. However, there was loss or degradation of service quality due to the loss of LoS condition.

It is not easy for users to directly experience high-speed wireless service. Augmented reality (AR) glasses were used to cope with that problem. In the demonstration, AR glasses were successfully operating by communicating stably with the AR server in the control room. The quality of AR video was grade of 4K and streamed through AR glasses seamlessly.

(a) (b)

Fig. 5. Application services : (a) Wi-Fi speed measurement (b) AR glass

V. Conclusion

V2X communication is considered the most important factor in autonomous driving. Among various V2X modes, this paper showed results of testing V2I and V2V communication in an urban road environment. Our test system is proposed to provide wireless connectivity to vehicles using millimeter waves. Despite the high data rate, the millimeter wave based communication system has signal weakness due to the characteristics of the frequency band. By setting up a test environment on a busy city road, we were able to evaluate the feasibility of a millmeter wave based mobile communication system. Because the test system implements the full protocol stack, it can measure physical layer performance and deliver a service-level experience to passengers. V2I had a maximum data rate of over 700 Mbps and V2V had a maximum data rate of over 800 Mbps. In the service demonstration, passengers could use an App to measure internet speed and experience AR glasses. Sidelink in V2V communication have been observed to be sufficient to provide AR services. Based on our test results, it can be expected that V2V and V2I connectivity will be possible on urban roads, but loss or degradation of service quality happen to occur due to the loss of LoS condition. Therefore, when using mmWave, networks with higher beam management capabilities should be considered in an urban road environment.

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