Field Trial of Millimeter-Wave-based MHN System for Vehicular Communications

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***Abstract*—In this paper, we presented a preliminary field trial conducted at Yulgok street in Gangneung city, Korea, which is a typical urban environment, and showed the feasibility of millimeter-wave (mmWave)-based Mobile Hotspot Network (MHN) system for vehicular communications. The paper also provided a brief overview of the MHN system mainly focusing on the design of physical layer, radio frequency (RF) and antenna. Using the first version of MHN prototype, we tested the performance of the system at three different paths of Yulgok street, and the test results revealed that the downlink data rate of 1Gbps was achievable at most of testing paths except for some spots where slight performance degradations were observed mainly due to the beam misalignment and blockage of line-of-sight (LoS) signal. Through the field trial, we can also draw several conclusions giving us valuable insights into developing future versions of MHN system for vehicular communications.**

***Index Terms*—mobile hotspot network (MHN), vehicular communications, field trial.**

I. Introduction

In recent years, vehicular communications, or vehicle-to-everything (V2X) communications that incorporate various types of communication such as vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P) and vehicle-to-infrastructure/network (V2I/N), have attracted more and more attention from both industry and academia owing to their potential to provide various applications such as road safety improvement, traffic efficiency optimization, automated driving, ubiquitous Internet access on vehicles and so on [1]-[5]. To support these kinds of applications, high-speed and low-latency wireless communication links are required. In the case of automated driving application, since the resolution of current two-dimensional (2D) maps and accuracy of position information are not sufficient, high resolution and real-time maps, also called dynamic High Definition (HD) maps, which are required to maneuver the vehicles safely, become considerably indispensable [5].

Some of the most relevant international standardization bodies like the 3rd Generation Partnership Project (3GPP) and Institute of Electrical and Electronics Engineers (IEEE) 802 have developed their own standards for vehicular communications, which are Long Term Evolution (LTE)-based V2X standard and IEEE 802.11p, respectively. In the 3GPP, standardization activities for LTE-based V2X phase 2 is currently underway mainly focusing on enhancements to V2V [6]-[8] and it is expected to be completed by the second quarter of 2018. IEEE 802.11p is an approved amendment to the IEEE 802.11 standard to add Wireless Access in Vehicular Environments (WAVE), a vehicular communication system [9]. It defines enhancements to 802.11 required to support Intelligent Transportation Systems (ITS) applications, and supports both V2V and V2I/N communications in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz). It is also the base of a European standard for vehicular communications known as European Telecommunications Standards Institute (ETSI) ITS-G5.

However, as identified in [1], the existing technologies including the aforementioned IEEE 802.11p/ITS-G5 and LTE-based V2X are unable to meet the requirements of data rate and delay for the future V2X services. Therefore, as a promising solution to overcoming the data rate and latency limitations of existing technologies, communication systems operating in the millimeter-wave (mmWave) where its vast amount of spectrum remains underutilized, have been proposed for fifth generation (5G) communication systems supporting typical cellular communications, vehicular communications and high-speed train (HST) communications. The 3GPP is also preparing for a new study item for the V2X phase 3 focusing on 5G New Radio (NR)-based V2X standardization [10]-[13] where mmWave is being considered as one of the operating frequencies. Meanwhile, in February 2017, Electronics and Telecommunications Research Institute (ETRI) conducted a field trial with a mmWave-based Mobile Hotspot Network (MHN) system prototype along 2.4 km long subway track through three stations of Seoul subway line 8 [17]. During the field trial, it was shown that the downlink data rate of mobile wireless backhaul (MWB) link close to 1.25 Gbps was attainable most of the time, which enables the system to provide onboard passengers with broadband mobile hotspot services. This was the world first mmWave-based prototype system successfully demonstrated in the running subway train.

Since the MHN system was initially designed not only for HST communications, but also for typical vehicular communications, the main objective of this paper is to validate the feasibility of the system for vehicular communications in typical urban environments by carrying out a field trial with the MHN prototype system and comparing with the results observed in the previous field trial at Seoul subway line 8.

The rest of this paper is organized as follows. In section

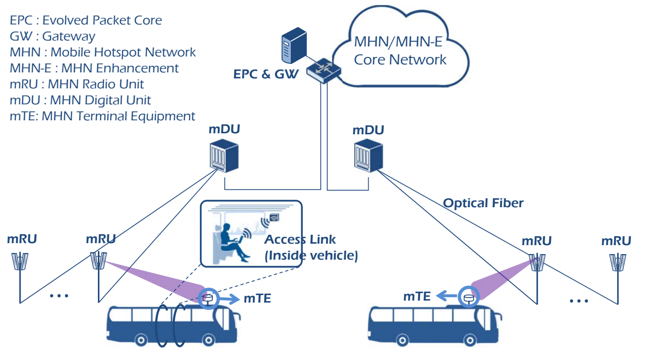

Fig. 1. The basic system architecture of MHN system for vehicular communications

II, we provide a brief overview of the mmWave-based MHN system including its basic architecture, and system design. Next, field trial of the MHN system are presented in section III. Finally, we make conclusions of the paper with brief discussions of future work in section IV.

II. System Description

In this section, a brief overview of mmWave-based MHN system for vehicular communications is presented.

A. Basic System Architecture

Similar to the network architecture of MHN system for HST communications [15]-[17], the MHN system for vehicular communications, as illustrated in Fig.1, is also based on the two-hop architecture, where an MHN terminal equipment (mTE), also known as an MHN vehicular equipment (mVE), is responsible for transmitting/receiving MWB signals to/from an MHN radio unit (mRU) deployed along roadside. One or two mTEs may set up inside or on top of the vehicle, and the number of mTEs depends on the size of the vehicle. Users inside the vehicle can be served by onboard access link (e.g. wireless fidelity (WiFi) or femto-cell) connected to the mTE, and the onboard access link is beyond the scope of this paper since the radio propagation characteristics inside a vehicle are basically similar to the indoor environment. This two-hop system architecture is not only particularly advantageous for overcoming high penetration loss caused by train carriage made of metal alloys, but also capable of avoiding huge signalling overhead caused by group handover [14].

In the network, multiple MHN digital units (mDUs), each of which is interconnected with a single mRU via radio-over-fiber (RoF) link (or optical fiber), can be co-located in a control center to form an efficient cloud radio access network (C-RAN). The mDUs connected through a gateway (GW) to the public Internet, are responsible for physical layer processing and higher layer functionalities such as inter-mRU mobility management. An mRU consists of radio frequency (RF) transceivers and beamforming (BF) antennas for mmWave-based transmission and reception.

B. System Design

Table I summarizes the numerology of MHN system for vehicular communications, which is identical to that of MHN system for HST communications [17]. In fact, the numerology of MHN system was initially designed to support not only HST communications, but also typical vehicular communications considering the maximum root mean square (RMS) delay spread of mmWave reported by several studies and the maximum Doppler frequency shift occurred by high-mobility of up to 500km/h. One may claim that the subcarrier spacing designed for HST communications is unnecessarily large for vehicular communications due to relatively small mobility of normal vehicles (e.g., cars and buses). However, the wireless channel characteristics in vehicular communications might be much more severe than the channel of HST communications, which will be seen in the next section. In HST communications, channel of most scenarios has a large Doppler frequency shift with dominant power, which can be simply compensated at the receiver by automatic frequency control (AFC) algorithm and its RMS Doppler spread causing inter-carrier interference (ICI) is very small. On the other hand, in vehicular communications, since there are a lot of scatterers causing multi-path signals received from different directions, RMS Doppler spread might be much larger than that of the HST case, which results in rapid fluctuations of the channel in time domain and is impossible to be corrected by the AFC. For these reasons, although the velocity in this case is much lower as compared with that of HST scenario, there is a strong need to maintain large subcarrier spacing of 180kHz.

The MHN system supports orthogonal frequency division multiple access (OFDMA) as the multiple access scheme, and time-division duplex (TDD) for uplink-downlink duplexing. The details of frame structures of MHN and MHN enhancement (MHN-E) systems can be referred to [15] and [16], respectively, and both systems have same reference signal structure described in [15]. Table II shows design requirements of the first version of MHN prototype system, where the aggregation of up to four component carriers (CCs) is defined to make use of 500 MHz of transmission bandwidth while the MHN-E system [16], which is currently being developed for aiming at demonstration during the 2018 PyeongChang Winter Olympics, will support the transmission bandwidth of up to 1GHz by aggregation of eight CCs.

III. Field Trial

This section mainly describes a preliminary field test conducted along Yulgok street in Gangneung city, Korea, which has been recently decided as a place for a showcase of the MHN technology during the 2018 PyeongChang Winter Olympic. The main objective of the test is to investigate the propagation characteristics and performance of the first version of MHN prototype at Yulgok street, which is expected to give valuable insights into developing the next version of the MHN prototype system to be demonstrated during the 2018

TABLE I
NUMEROLOGY OF MHN SYSTEM FOR VEHICULAR COMMUNICATIONS

Parameters	Values
Carrier frequency (GHz)	25.5
Subcarrier spacing (kHz)	180
Sampling rate (MHz)	184.32
System bandwidth of each CC (MHz)	125
Fast Fourier Transform (FFT) size	1024
Number of resource blocks (RBs) in frequency domain	50
Number of subcarriers per RB	12
Cyclic prefix (CP) duration (μs)	0.69
OFDM symbol duration w/o CP (μs)	5.56
Transmission time interval (TTI) duration	0.25
Number of OFDM symbols per TTI	40

TABLE II
REQUIREMENTS FOR MHN PROTOTYPE DEVELOPMENT

Requirements	Values
Carrier frequency (GHz)	24 $\sim$ 26.5
Number of supported CCs	4
System bandwidth of each CC (MHz)	125
Duplex mode	TDD
Target downlink data rate (Mbps)	1250
Target uplink data rate (Mbps)	180
RF TX/RX paths	1TX/2RX
EIRP (dBm)	36
Maximum TX antenna gain (dBi)	19
Maximum RX antenna gain (dBi)	22
TX power (dBm)	17
Connection between mDU and mRU	RoF
Target coverage (curved path)	>300m
Target coverage (straight path)	>500m

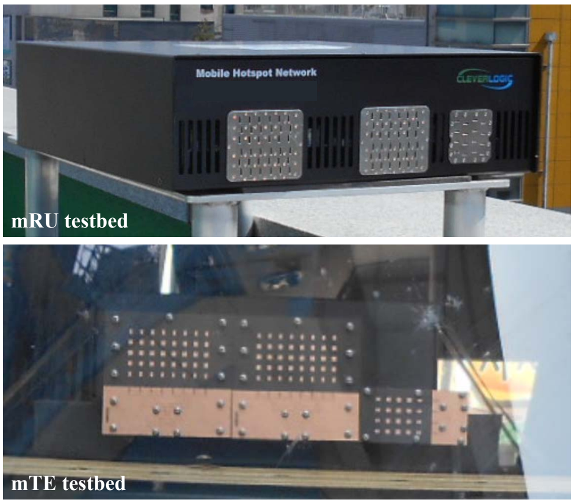

Fig. 2. Prototype of MHN System

PyeongChang Winter Olympic and another future version of MHN system for vehicular communications.

A. Prototype of MHN System

This subsection briefly provides an overview of the MHN prototype system used for filed trial at Yulgok street in Gangneung. Fig. 2 shows the prototypes of MHN system. Both mRU and mTE testbeds were implemented on Xilinx Field Programmable Gate Arrays (FPGAs), and the mRU testbed shown in Fig. 2 was actually used for mTE testbed in the previous field trials. In the RF design, four CCs, which are contiguously allocated, are employed for carrier aggregation (CA). Since the configuration of the RF transmit (TX) and receive (RX) paths for both mTE and mRU testbeds are 1TX/2RX, both testbeds are equipped with one TX antenna and two RX antennas as shown in Fig. 2. For the antenna design, slotted waveguide array antennas with 4x4 and 6x6 radiating elements are employed for TX and RX antennas of the mRU testbeds, respectively, and patch antennas with 4x5 and 5x8 elements are employed for TX and RX antennas of the mTE testbed, respectively. In addition, since it is mandatory to comply with Effective Isotropic Radiated Power (EIRP) requirement regulated by Korean government, where the maximum EIRP allowed in the spectrum band for the field test is 36dBm, the TX antenna gains of both mTE and mRU testbeds designed to be 19 dBi and the maximum TX power is 17 dBm. On the other hand, since there is no specific restriction on the RX antenna gain, we set much higher gain of 22dBi to achieve the coverage requirements.

Due to the antenna configuration of both testbeds, only single antenna transmission is employed at the transmitters of both downlink and uplink, and maximal ratio combining (MRC) technique is used at the receiver side. For the future field trial to be demonstrated during the 2018 PyeongChang Winter Olympics, since two TX antennas at mRU will be available, both spatial frequency block code (SFBC) and open-loop spatial multiplexing (OLSM) techniques will be supported for performance improvement.

B. Test Environments

Fig. 3 shows the map of the testbed deployment for the preliminary field trial at Yulgok street in Gangneung city. Two mRU testbeds, mRU 1 and mRU 2 are installed on the rooftops of the two buildings located near Imdang four-way intersection and Okcheon five-way intersection, respectively, and a vehicle carrying a testbed of mTE inside drove along the three different paths of the street, which are path 1, path 2 and path 3 as shown in Fig. 3. The length of path 1, path 2 and path 3 are 570m, 410m and 400m respectively, and the average velocity of the vehicle was around 60km/h. The first test was carried out as the vehicle moved from point A to point C, and in this case, the antennas direction of mRU 2 was set to point B. When mTE was located at path 1 and path 2, it communicated with mRU 1 and mRU 2 respectively, and since the main objective of the test was to investigate the propagation characteristics and the feasibility of the MHN system for vehicular communications in urban scenario, we didn't apply

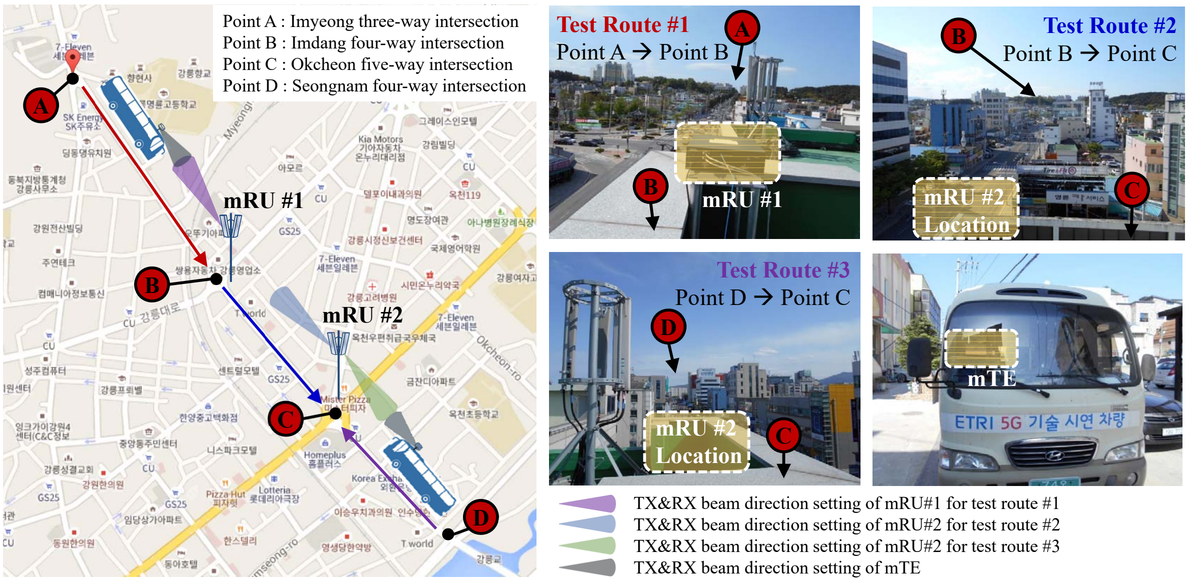

Fig. 3. Test Environments

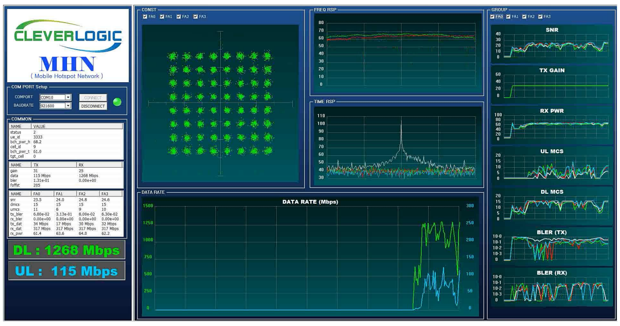

Fig. 4. Performance Monitoring Display

any handover algorithm for simplicity. Instead, when the mTE lost the connection with the serving mRU, it will simply search for the serving mRU and make connection again. The second test was conducted at path 3 starting from point D to point C, and in this case, we had the antenna direction of mRU 2 changed so that the TX beam of the antenna was well aligned with the RX beams of the mTE. The entire test including the test 1 and test 2 was done twice. During the test, various performance metrics (uplink/downlink data rate, block error rate (BLER), signal-to-noise ratio (SNR), etc.) were monitored in real time using a performance monitoring display connected to the mTE testbed as shown in Fig. 4. The display also showed the instantaneous time/frequency response of channel and constellation of received signals.

C. Test Results

Fig. 5 - Fig. 7 show the captured performance monitoring displays of path 1, path 2, path 3, respectively, where green line and blue line represent data rates of downlink and uplink, respectively. The mTE measured the channel qualities based on the received reference signal, and reported them to the net-

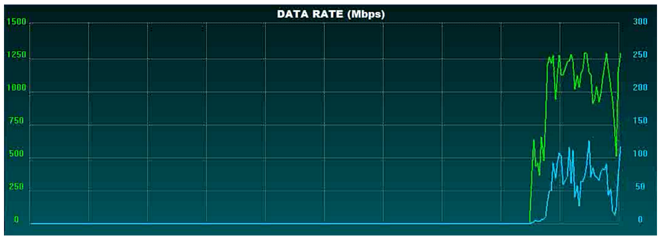

Fig. 5. Test Results at path 1

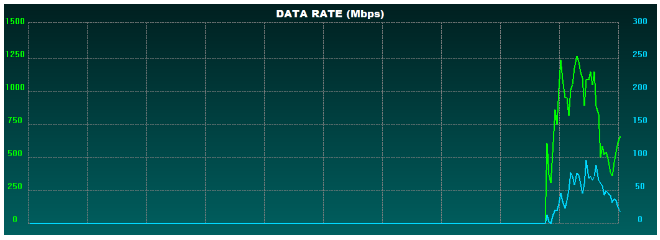

Fig. 6. Test Results at path 2

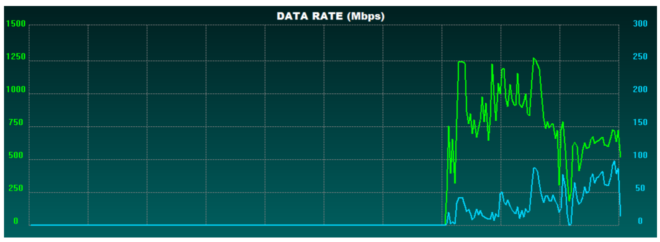

Fig. 7. Test Results at path 3

work (i.e. mDU) through an uplink so that the scheduler could instantaneously change the modulation and coding schemes (MCSs) for link adaptation. Therefore, as we can see in the three figures, both downlink and uplink data rates fluctuated wildly, which is totally different from what we observed in the field trial at Seoul subway line 8, where around 1.25 Gbps downlink data rate was attainable most of the time except for four handover points [17] where the mTE passed by each mRU. Note that the reason why uplink data rate is much lower than the downlink data rate is the TDD configuration, where the ratio of downlink to uplink is equal to 7.

More specifically, during the test at path 1 and path 2, the downlink data rates ranging from 800Mbps and 1.25Gbps were observed most of the time and in some regions, downlink data rate dropped even below 500 Mbps due to the misalignment between TX beam and RX beam caused by a slanted direction of the vehicle. In the case of the test at path 3, significant performance degradation was observed in some regions where the performance was lower than 350 Mbps, which is mainly due to blockage of line-of-sight (LoS) signal by obstacles like trees and road signs. This also means that if a larger vehicle drives between an mTE and its serving mRU, the vehicle may act as communication blockages significantly degrading the performance. From the test, we can see that the performance is highly vulnerable to the misalignment between TX and RX beams and the LoS blockage, and the propagation environment in the urban environment is much more severe than that of tunnel environment of Seoul subway line 8 [17], where the surrounding environment is almost fixed, and the tunnel ifself has a waveguide effect providing better channel characteristics as well as link budget. Moreover, since only fixed RF beamforming (BF) was supported at the tranceivers of both mRU and mTE, which is one of the bottlenecks of the current version of prototype system, the performance degradations caused by the aforementioned beam misalignment and signal blockage are inevitable. Alternatively, the next version prototype system to be used for the field trial at Yulgok street during the 2018 PyeongChang Winter Olympics is being designed to configure 2TX/2RX for RF path in mDU testbed enabling OLSM and SFBC for performance improvement while not a fundamental solution to the aforementioned problems. In addition, the next version of prototype system is currently being developed based on the MHN-E specification [16], and it will allow the aggregation of a maximum of eight CCs to attain a total transmission bandwidth of up to 1GHz in order to achieve the maximum downlink data rate of up to 2.5Gbps.

IV. Conclusion

In this paper, we presented a preliminary field trial conducted at Yulgok street in Gangneung city, Korea, which is a typical urban environment, and showed the feasibility of mmWave-based MHN system for vehicular communications. Using the first version of MHN prototype, we tested the performance of the system at three different paths of Yulgok street, and the results revealed that the downlink data rate of 1Gbps was achievable at most of testing paths except for some spots where slight performance degradations were observed mainly due to the beam misalignment and blockage of line-of-sight (LoS) signal. However, considering that only transmission mode of 1x2 MRC is supported in the testbeds, further performance enhancement is expected in the future field trial during the 2018 PyeongChang Winter Olympics by using a new prototype system of MHN-E that we are currently developing. For a future work, we are considering to apply an adaptive BF technique at least at RX antennas of a future MHN system in order to overcome the performance degradations caused by the beam misalignment, limitations of the fixed RF BF applied at the tranceivers of both mRU and mTE.

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References

[1] A. Tassi, M. Egan, R. J. Piechocki and A. Nix, "Modeling and design of millimeter-wave networks for highway vehicular communication," *IEEE Trans. Veh. Technol.*, vol. 66, no. 12, pp. 10676-10691, Dec. 2017.

[2] H. Seo, K. D. Lee, S. Yasukawa, Y. Peng and P. Sartori, "LTE evolution for vehicle-to-everything services," *IEEE Commun. Mag.*, vol. 54, no. 6, pp. 22-28, Jun. 2016.

[3] T. G. McGiffen, S. Beiker and A. Paulraj, "Motivating network deployment: vehicular communications," *IEEE Veh. Technol. Mag.*, vol. 12, no. 3, pp. 22-33, Sep. 2017.

[4] L. Liang, H. Peng, G. Y. Li and X. Shen, "Vehicular communications: a physical layer perspective," *IEEE Trans. Veh. Technol.*, vol. 66, no. 12, pp. 10647-10659, Dec. 2017.

[5] Kei Sakaguchi et al., "Where, when, and how mmWave is used in 5G and beyond," *IEICE Trans. Electron.*, vol. E100C, no. 10, pp. 790-808, Oct. 2017.

[6] *Study on LTE-based V2X Services (Release 14)*, 3GPP TR 36.885, V14.0.0, Jun. 2016.

[7] *Study on LTE support for V2X Services*, 3GPP TR 22.885, V14.0.0.

[8] *Revision of WI: V2X phase 2 based on LTE*, RP-171069, Huawei, HiSilicon.

[9] A. Bazzi, B. M. Masini, A. Zanella and I. Thibault, "On the performance of IEEE 802.11p and LTE-V2V for the cooperative awareness of connected vehicles," *IEEE Trans. Veh. Technol.*, vol. 66, no. 11, pp. 10419-10432, Nov. 2017.

[10] *Study on enhancement of 3GPP support for 5G V2X services*, 3GPP TR 22.886.

[11] *Study on scenarios and requirements for next generation access technologies*, 3GPP TR 38.913.

[12] *Study on new radio access technology physical layer aspects*, 3GPP TR 38.802.

[13] *New SI proposal: study on evaluation methodology of new V2X use cases for LTE and NR*, RP-1708373, LG Electronics.

[14] J. Kim and I. G. Kim, "Distributed antenna system-based millimeter-wave mobile broadband communication system for high speed trains," in *2013 International Conference on ICT Convergence (ICTC)*, Jeju, 2013, pp. 218-222.

[15] S. W. Choi, H. Chung, J. Kim, J. Ahn, and I. Kim, "Mobile hotspot network system for high-speed railway communications using millimeter waves," *ETRI J.*, vol. 38, no. 6, pp. 1052-1063, Dec. 2016.

[16] J. Kim, H. S. Chung, S. W. Choi, I. G. Kim and Y. Han, "Mobile hotspot network enhancement system for high-speed railway communication," in *2017 11th European Conference on Antennas and Propagation (EuCAP)*, Paris, 2017, pp. 2885-2889.

[17] H. Chung et al., "From architecture to field trial: a millimeter wave based MHN system for HST communications toward 5G," in *2017 European Conference on Networks and Communications (EuCNC)*, Oulu, 2017, pp. 1-5.