Recent Activities of 5G Experimental Trials on Massive MIMO Technologies and 5G System Trials toward New Services Creation

Yukihiko OKUMURA†, Satoshi SUYAMA†, Jun MASHINO†, Senior Members, and Kazushi MURAOKA†, Member

SUMMARY In order to cope with recent growth of mobile data traffic and emerging various services, world-wide system trials for the fifth-generation (5G) mobile communication system that dramatically extends capability of the fourth-generation mobile communication system are being performed to launch its commercial service in 2020. In addition, research and development of new radio access technologies for 5G evolution and beyond 5G systems are beginning to be made all over the world. This paper introduces our recent activities on 5G transmission experiments that aim to validate Massive MIMO technologies using higher frequency bands such as SHF/EHF bands, that is, 5G experimental trials. Recent results of 5G system trials to create new services and applications in 5G era in cooperation with partners in vertical industries are also introduced.

key words: Fifth generation mobile communication system, radio access technology, higher frequency band, experimental trial, system trial

1. Introduction

The fifth-generation (5G) mobile communication system is expected to fulfill the demand for super high-bit-rate communication that future mobile communication devices and various applications will require [1]. To achieve larger system capacity and higher bit-rate communication than the current fourth-generation (4G) mobile communication systems while maintaining coverage provided by 5G, the 5G systems will introduce higher frequency bands into small/semi-macro cells that are overlaid on macro cells using existing frequency bands [1]. In addition, massive multiple-input multiple-output (Massive MIMO) that uses very large number of antenna elements attracts much attentions as one of the most promising radio access technologies for 5G. This is because Massive MIMO can effectively compensate for the larger path-loss in the higher frequency bands by beam-forming (BF) gain and can provide the larger number of spatially multiplexed streams than the conventional MIMO does [2]-[5].

Candidate frequency bands for 5G commercial services are categorized into low SHF (3-6 GHz) bands, high SHF (6-30 GHz) bands, and EHF bands. A BF algorithm suitable for each frequency band should be designed [6], [7]. For example, in the low SHF bands, Massive MIMO can employ a fully digital architecture using a digital BF algorithm. This is because the signal bandwidth of 100-200 MHz is narrower than that of several hundred MHz in the high SHF bands or 1-2 GHz in the EHF bands and the number of antenna elements such as almost 100 antenna elements is smaller than several hundred antenna elements in the high SHF and EHF bands [8]-[26]. On the other hand, in the high SHF and EHF bands, analog BF algorithms or hybrid BF algorithms, which are combined analog BF with digital precoding, have been studied due to implementation issues [27]-[42].

In this paper, as NTT DOCOMO’s activities for 5G realization, recent activities of 5G transmission experiments, that is, 5G experimental trials with world-leading vendors are introduced to verify the potential of the Massive MIMO technologies in the high frequency bands. Note that some 5G experimental trials target research and development of new radio access technologies for 5G evolution and beyond 5G systems.

Moreover, 5G provides not only the large system capacity and the super high-bit-rate communication but also new capabilities and features such as massive connectivity, low latency, and high reliability. Early realization of 5G is desired as an information and communication technology (ICT) infrastructure in the Internet of Things (IoT) era, which is essential for economic growth. To ensure that Japan leads the world in social implementation of 5G while strengthening collaboration with the United States, Europe, and other Asian countries, the Ministry of Internal Affairs and Communications (MIC), Japan initiated three research and development (R&D) projects in fiscal year 2015 to achieve a 5G system, and NTT DOCOMO has been entrusted with two projects related to the 5G R&D projects. Additionally, MIC began comprehensive demonstration trials of 5G (5G Field Trials) in fiscal year 2017 [43]. The 5G Field Trials are being carried out in various application areas [44]-[46], and are technically investigated by six study groups. The trials have started in Tokyo and other metropolitan areas as well as in rural areas. They aim to lead the world in
social implementation of 5G in Japan by establishing an open environment in which companies and universities around the world can participate and by contributing to international standardization activities.

This paper describes some results of the 5G Filed Trials as recent activities of 5G system trials [43]-[49]. 5G Filed Trials in study group I (GI) are conducted by NTT DOCOMO in densely populated urban environments to examine 5G technical specifications for a data rate exceeding 10 Gbps. On the other hand, NTT Communications (NTT Com) in collaboration with NTT DOCOMO promotes 5G Filed Trials in study group II (GII) to examine 5G technical specifications for a data rate of 2 Gbps in high-mobility environments over 90 km/h.

The rest of this paper is organized as follows. Section 2 describes our recent activities on the 5G experimental trials that aim to validate the Massive MIMO technologies using the higher frequency bands such as the SHF/EHF bands. In Sect. 3, recent results of GI and GII in MIC’s 5G Field Trial in cooperation with the vertical partners in a variety of application areas are shown. Finally, we conclude this paper in Sect. 4.

2. 5G Experimental Trials on Massive MIMO

2.1 Overview of Recent 5G Experimental Trials

NTT DOCOMO has built relationships to collaborate on the 5G experimental trials with the major world-wide vendors. This paper introduces an overview of the 5G experimental trials and their results in collaboration with the major world-wide vendors, focusing on verifying the Massive MIMO technologies in the higher frequency bands [6], [7]. Figure 1 summarizes NTT DOCOMO’s 5G experimental trials on the Massive MIMO technologies. It is important to design an appropriate BF scheme for each frequency band. Figure 1 also shows specifications of Massive MIMO for realizing 10 Gbps data rates, and digital BF, hybrid BF, and analog BF schemes are suitable for low SHF, high SHF, and EHF bands, respectively.

![Fig. 1 NTT DOCOMO’s 5G experimental trials on Massive MIMO.](image)

In the low SHF bands, the Massive MIMO technology employing the fully digital BF is being investigated in collaboration with NEC [8]-[13], Huawei [14]-[21], and Nokia [22], [23]. Intersite coordination algorithm exploiting beam search information in the digital BF algorithm has been proposed [10] and performances of the proposed algorithm have been evaluated by computer simulations using channel data measured in outdoor propagation experiments [11]. Ultra-high-throughput Massive MIMO field trial with peak spectrum efficiency of 79.82 bps/Hz has been conducted [17], [18].

In addition to localized Massive MIMO (above-mentioned typical Massive MIMO), distributed Massive MIMO technology is being studied by the low-SHF-band experimental trial in collaboration with Fujitsu [24]-[26]. Performance comparison between the localized Massive MIMO and the distributed Massive MIMO were made [25], [26], and the distributed Massive MIMO can achieve higher area spectral efficiency than the distributed Massive MIMO.

The Massive MIMO technologies in the high SHF bands is being studied in collaboration with Ericsson [27]-[34], Samsung Electronics [35]-[37], and Mitsubishi Electric [38]-[40]. The collaboration with Ericsson has evaluated 15 GHz-band experimental equipment supporting analog BF generated by 64 antenna elements, and then 28 GHz-band experimental equipment are being evaluated. The collaboration with Samsung Electronics has verified 28 GHz-band beam tracking capability to a velocity of 150 km/h in Fuji Speedway [36]. In addition, we have verified the potential of the proposed hybrid BF algorithm by computer simulations exploiting 28 GHz-band propagation experimental results in the collaboration with Mitsubishi Electric. A user selection algorithm with rank adaptation for multi-user Massive MIMO with the hybrid BF has been also proposed and evaluated [39].

Moreover, in the EHF band, NTT DOCOMO has verified the potential of millimeter-wave analog BF technology using a lens antenna in 39 GHz-band with Huawei [41] and 70 GHz band with Nokia [42], respectively.

2.2 28 GHz-Band Massive MIMO Experimental Trial with Ultra High-Mobility

5G Experimental trials using 28 GHz-band at which almost 1 GHz bandwidth will be available have been performed all over the world. To realize large coverage at such a high frequency band, BF by Massive MIMO is necessary to compensate large path loss. Furthermore, the beam tracking which adaptively changes beam direction according to user location is an important function to support user mobility. Authors already conducted high-mobility trials at the velocity of 150 km/h using 28 GHz-band 5G prototypes implementing the beam tracking. In order to support ultra-high mobility on a bullet train, in April 2018, we conducted outdoor trials using
the specially customized vehicle with the velocity of up to 300 km/h [37]. This paper reveals the latest downlink performance results of the trial.

Figures 2 and 3 show appearances of the base station (BS) and the mobile station (MS) of the 5G prototypes operating at 28 GHz band, respectively. Table 1 shows the specifications of the 5G prototypes. Two subarrays are separately arranged at upper side and at lower side of one antenna unit. Each subarray is composed of 48 elements (8 horizontal × 6 vertical) to perform beamforming. The beam candidate has 14 directions in the horizontal plane between -36 ° and +36 °, and 2 directions in the vertical plane, 0 ° or -10 °. Thus there are 28 beam candidates in total. Two subarrays in one antenna unit correspond to polarized waves of +45 ° / -45 °, and support two streams of spatial multiplexing. On the other hand, cyclic delay diversity is applied to the upper subarrays of the two antenna units and to the lower sub arrays. MS has 32 elements (8 horizontal × 4 vertical) corresponding to polarization of +45 ° / -45 ° to perform beamforming. Beam tracking is realized by adaptively selecting combination of BS-side beam candidate and MS-side beam candidate, which maximizes received power. Rank adaptation is applied to change the number of spatial multiplexed streams between 1 and 2. Two streams are spatially multiplexed by two subarrays with different polarization in one antenna unit, while one stream is transmitted by two subarrays to exploit polarization diversity gain in case of single-stream transmission. Adaptive modulation and coding is also applied. When 64QAM, coding rate of 5/6, and 2-stream spatial multiplexing are selected, the maximum throughput of downlink transmission reaches 3.3 Gbps.

The experimental trial was carried out at the oval track course in Shirosato Test Center of the Japan Automobile Research Institute (JARI) in Ibaraki Prefecture, Japan. Figure 4 shows the straight course where a BS was deployed. Setting the corner end position before the straight as the origin (0 m) of axis for position, the position of the BS was 400 m. From the driving lane of the experimental vehicle, the BS was set 15 m inside of the course. MS was installed in the passenger seat section of the vehicle traveling on the course. The vehicle ran on the straight from 0 m side and passed the BS. The BS antenna height is 2.5 m, whereas the MS antenna height is 1.0 m. Since we conducted an experiment in the straight course, propagation environment between BS and experimental vehicle was Line-of-Sight (LOS).

Figure 5 shows downlink throughput of three cases: (1) running at a speed of 90 km/h (accelerating from stationary state at the position of 60 m), (2) running at a speed of 260 km/h after going around the oval course, and (3) running at a speed of 300 km/h. Here, BS is installed at the 400 m position of the horizontal axis. First, it is found that the throughput of the case of 90 km/h rapidly increases as the MS approaches the BS and
reaches 3 Gbps, then sharply decreases after moving to the back side of the BS antenna. Throughput of the cases of ultra-high speed mobility, 260 km/h and 300 km/h, are comparable to that of 90 km/h in the range of 0 to 200 m. The maximum throughput of 260 km/h and that of 300 km/h were 2 Gbps around 220 m and 1.1 Gbps around 80 m, respectively. On the other hand, throughput degradation compared to the case of 90 km/h was observed when MS was close to the BS. Detailed discussion of this reason is a future work through analysis of variation of measured beam directions, SNR, MCS (Modulation and Coding Schemes), rank, and Doppler shift.

2.3 28 GHz-Band Maritime Massive MIMO Experimental Trial

5G has attracted much attention to provide various kinds of services and applications for 2020 and later. To verify the feasibility of high presence public viewing service, the world’s first maritime 5G experiment is conducted in Windsurfing World Cup 2018 [34]. In the experiment, 5G is used for 4K video transmission from a ship to public viewing area at land. This paper briefly reports that downlink and uplink maritime transmission performance of 5G employing 28 GHz-band Massive MIMO and the success of the public viewing trial.

A MS is set on a deck of a ship which is 300-1000 m away from a BS, according to the race course of windsurfing as shown in Fig. 6. Four movies recorded in video cameras installed on the ship and drones are aggregated into a 4K video footage, and then it is compressed by H.265/HEVC (High Efficiency Video Coding) encoder. The compressed video, whose required bitrate is 80 Mbps including forward error correction (FEC) bits added in the application layer, is transmitted to the BS located at a seaside hotel via 5G uplink; see Fig. 7. MMT (MPEG Media Transport) is utilized for synchronized transmission with other video streams and to apply the FEC. In public viewing area, race movies are displayed in real-time by switching several kinds of video footages including both movies transmitted from the ship and ones recorded from land.

Table 2 shows major specifications of 5G radio equipment. Both BS and MS have antenna panels of vertical and horizontal polarization for beamforming. Both BS and MS have ability of beam tracking for mobile communication by selecting one beam direction from dozens of beam candidates. The designed maximum bitrate is 2.0 Gbps at the highest modulation and coding scheme (MCS). The antenna height of BS is 20.4 m and mechanical tilt is set as 0 degree. The antenna height of MS is approximately 3 m.

<table>
<thead>
<tr>
<th>Table 2 Major specifications.</th>
<th>BS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center frequency</td>
<td>27.7 GHz</td>
<td></td>
</tr>
<tr>
<td>Bandwidth</td>
<td>365 MHz</td>
<td></td>
</tr>
<tr>
<td>Number of component carriers</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Radio Access/Duplex</td>
<td>OFDMA/TDD</td>
<td></td>
</tr>
<tr>
<td>(DL : UL = 2 : 8 ; 48 : 2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-carrier spacing</td>
<td>75 kHz</td>
<td></td>
</tr>
<tr>
<td>Radio frame duration</td>
<td>10 ms (with 50 sub-frames)</td>
<td></td>
</tr>
<tr>
<td>Number of antenna elements</td>
<td>64</td>
<td>16</td>
</tr>
<tr>
<td>Number of beam candidates</td>
<td>48</td>
<td>40</td>
</tr>
<tr>
<td>MIMO multiplexing</td>
<td>2 layers</td>
<td></td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16QAM, 64QAM</td>
<td></td>
</tr>
</tbody>
</table>

First, downlink transmission experiment is conducted to evaluate basic transmission performance and to optimize adaptive modulation and coding (AMC) setting. Figure 8 shows the result of cumulative distribution function (CDF) for downlink throughput when d, the distance between BS and MS, is 400 m. Note that the throughput is measured for every 100 ms in duration of
40 s. TDD ratio is set as downlink (DL) : uplink (UL) = 48 : 2. Since AMC scheme selects the best MCS to achieve target block error rate (BLER), higher order modulation schemes are selected much more frequently when higher target BLER is set. As a result, the maximum throughput of 1257 Mbps is achieved when target BLER is 10 % in this experiment. On the other hand, higher throughput is achieved in region where CDF is lower than 28 % because smaller target BLER can suppress throughput fluctuation. While there is a trade-off between the maximum throughput and robustness, we decided to set target BLER as 1 % for the following uplink 4K video transmission experiment that requires stable communication link.

3. Recent Activities of 5G System Trials

3.1 Overview of 5G Field Trials in Dense Urban Environments

The 5G Field Trials being conducted by the MIC in various application fields are proceeding with a 3-year plan starting in FY2017, keeping in mind the implementation of 5G in society, building an open environment in which enterprises and universities from around the world can participate, and working toward a world-leading introduction of 5G in Japan. As part of this, NTT DOCOMO has conducted studies to understand radio propagation characteristics and evaluate 5G performance for ultra-high bit-rate transmission using the 3.6-4.2 GHz, 4.4-4.9 GHz and 27.0-29.5 GHz bands. These were done in densely-populated urban environments with user terminals travelling at speeds up to 30 km/h, so that 5G can be introduced using these frequency bands. We observed throughputs of up to 10.2 Gbps with two users, both connected in an outdoor environment at Tokyo Skytree Town, and this confirmed that ultra-high bit-rate and high-capacity communication can be achieved in the field. Besides the experimental trial, the study group GI evaluated radio propagation characteristics, performed simulations of transmission characteristics, and conducted trials to check the feasibility of various 5G services in the areas of entertainment, smart city, and medicine, in collaboration with partner enterprises. These case studies are introduced below.

3.1.1 5G Field Trials in Entertainment Area

In December 2017, we conducted a trial of a VR entertainment system which captured video using a 4K high-definition (HD) 360° live camera at Tokyo Skytree Town, and the video which was then transmitted using 5G to a head-mounted display with 220° wide-viewing angle as shown in Fig. 10 (a). Stable delivery was achieved using a variable-rate video encoder implemented on the distribution server, compressing the video according to the transmission quality for each user, from one minute to the next. During the same period, 28 GHz-band 5G connection was made from inside the observation deck of Tokyo Skytree (340 m above the ground) to the roof of Asakusa train station (340 m above the ground) for a trial of a new communication style using mixed reality (MR) technology. For the trial, video of people inside the Asakusa station building as shown in Fig. 10 (b) was transmitted at speeds up to 4.5 Gbps, even at the transmission distance of 1.2 km, successfully reproducing the people from the remote location on a 3D holographic video display.

In March 2018, we built indoor and outdoor trial environments in Tokyo Skytree Town and Tokyo Soramachi, and verified the feasibility of 5G services in a densely populated commercial facility as shown in Fig. 11. In
one trial, 8K multi-channel video was transmitted using 5G, confirming the ability to stably receive the 8K video transmission after forward error correction on both the radio access (physical) layer and the video (application) layer. In a digital signage trial using ultra-low-power reflective displays, four tiled reflective displays were installed outdoors, and 4K video content simulating advertising was sequentially transmitted to them from a base station and displayed. This trial confirmed that the content could be reproduced in outdoor light without loss of image quality, and with good contrast, and color reproduction. In a trial of video transmission in an indoor environment modeled after a commercial facility, 5G ultra-high-density distributed antennas were deployed, transmitting 4K HD video to a mobile terminal, with several pedestrians walking around the terminal. This trial confirmed that stable transmission of video was possible, even when entering tenants having complex premises.

3.1.2 5G Field Trials in Smart City Area

We conducted a trial of a new security model for urban spaces needed in smart cities, toward realization of advanced security services. The advanced security services can handle crimes such as terrorism, random attacks, child predation, etc. that current preventative measures cannot prevent. The trial used HD video, AI, and 5G to capture predictors of crime so they can be prevented before they occur.

In November 2017 at the National Museum of Emerging Science and Innovation (“Miraikan”), we conducted a trial of a new security system for inside facilities, using high definition surveillance camera video and face-recognition access gates as shown in Fig. 12 (a). The information needed to implement security for specified areas is recognized in images obtained using the surveillance cameras in real time, using image recognition technology involving face comparison and AI. We confirmed the ability to increase the frequency of face checks by a factor of six with 5G, compared with using 4G.

In March 2018, we conducted a trial of wide-area monitoring using a 4K high-definition camera mounted on the observation deck of Tokyo Skytree and an AI processing server. We analyzed the video from the wide-area camera to recognize vehicles driving on highways, areas of congestion potentially caused by traffic accidents, fires and other phenomena as shown in Fig. 12 (b). The results showed that the ability to distinguish distant objects was clearly superior when using the relatively higher-resolution video transmittable using 5G, compared with 4G.
3.1.3 5G Field Trials in Medical Area

We conducted a trial of an advanced remote medical examination service, providing improved medical examinations in rural and mountainous areas, comparable to those available in urban general hospitals in Fig. 13. We connected the Wakayama Medical University Community Medical Support Center (Wakayama City) and the Japan National Health Insurance Kawakami Clinic (Hidakagawa Town, Wakayama Prefecture) by network including 5G. We then introduced capabilities to transmit video from a 4K high-definition close-up camera used for diagnosis of conditions of the skin, dental/oral, and other external injury, and from other equipment used for internal examinations, such as ultrasonic imaging (echograms), and also a 4K high-definition video conferencing system for medical interviews and consultations between doctors.

In February 2018, we conducted a trial following the medical treatment of patients for five cases (three dermatology, one plastic surgery, and one cardiology case). Impressions from the doctors and patients participating in this trial are described below.

(1) **Doctor impressions:**
- Using the 4K camera capabilities and ability to examine closely, I was able to see the external trauma well and perform the examination, which was not possible using earlier video conferencing systems. Wonderful! (Dermatologist).
- The 4K video was clear and of quality in no way inferior to the images when using the echogram directly. I look forward to using it to improve medical treatment in regional communities (Cardiologist).
- The feeling that specialists can be present immediately is reassuring. This should be very effective in improving care at clinics, and especially as an educational tool for young doctors. (Clinic doctor).

(2) **Patient impressions:**
- With the doctor from the Medical University on the large screen, I was able to receive the medical examination exactly as if I was there as an outpatient.
- This time, I used this remote medical examination to get a second opinion. I had the examination through a screen that gave a strong sense of presence, and received excellent findings and new treatment methods as I would expect from a specialist at the general hospital. It was a real eye opener!
cation in the 28 GHz band, the study group GII measured radio propagation characteristics, performed simulations of transmission characteristics, and conducted trials to check the feasibility of various 5G services in the area of entertainment for passengers when traveling on high-mobility trains and motor vehicles in collaboration with partner enterprises. In the Field Trials on Tobu Railway Nikko Line, we demonstrated that very high throughputs in excess of 2 Gbps were feasible at speeds of 90 km/h. This ability will open the way to new 5G entertainment services so as to provide live video clips of the 2020 Tokyo Olympics and Paralympic Games to passengers while travelling on Japan’s high-speed trains.

3.2.1 5G Field Trials in High-Mobility Environment over 90 km/h

The train trials were done in collaboration with Tobu Railway on February 19-23, 2018. For the purpose of these trials, 5G transmission zones were deployed near Ienaka Station and Niregi Station along the Tobu Nikko Line, and 5G wireless content was transmitted to the 634 series Skytree Train as shown in Fig. 14.

The equipment was set up so we could assess handover performance of 5G transmissions: the base stations were under the control of the core network near Ienaka Station, with base station base band unit 1 deployed at the north end of the platform and base station base band unit 2 set up in a vacant lot south of the station. Two antenna units were connected to each base station base band unit to provide transmission diversity. The antenna was attached to the mobile station in such a way that it was visible through the front windshield of the train crew cabin. Specifications of the transmitting equipment were as follows: center frequency of 27.875 GHz, bandwidth of 700 MHz, and number of antenna elements (base station: 96, mobile station: 64). Based on the trials, we were able to verify a maximum throughput of 2.08 Gbps when the train was moving at a speed of 90 km/h. We also confirmed that the handover occurred seamlessly without issue.

The two antenna units subordinate to the base station base band unit installed near Niregi Station were deployed in a distributed configuration. Specifications of the transmitting equipment were as follows: center frequency of 27.900 GHz, bandwidth of 730.5 MHz, and number of antenna elements (base station: 128 × 2 unit, mobile station: 8). To make sure the mobile station was within direct line-of-sight of the base station transmission point inside the train car, the antenna was mounted on the front windshield in front of the driver’s seat shielded by a sheet of clear acrylic. Here again we verified a maximum throughput of 2.90 Gbps when the train was traveling at 90 km/h.

Riding long distances on public transportation can take considerable time, and this of course increases the demand for ever faster travel speeds. Providing passengers with entertainment in the form of high-definition video services while traveling is also exceedingly important, for it helps passengers pass the time while in transit. These considerations led us to carry out these trials to test and evaluate 5G high-definition video services for passengers riding on trains and trolleys operated by passenger automobile transport businesses at speeds in excess of 90 km/h.

We might assume that the most basic 5G services sought by train and car service passengers will be Internet connectivity services. But the goal of these trials was to assess and visualize services that exploit 5G capabilities, so we focused on high definition video services for passengers traveling at high speed on various modes of public transportation. Compared to legacy transmission services, delivering high-definition video to passengers in trains and vehicles offers significant advantages, most notably the very high capacity of 5G transmission. We can anticipate that this larger capacity will provide sharper higher definition video, a greater range of channels, and instantaneous live feeds and other information delivery services.
There are two types of video distribution services—linear distribution (program organization) services and on-demand distribution services—but for these trials we deployed very few base stations and the communication time was exceedingly limited. So for our purposes, we adopted a hybrid compromise type distribution service so we could assess both the instantaneous nature of the linear distribution service, and the convenience of the on-demand distribution service.

We installed a video distribution server (master server) on the base station side and a cache server between passenger user terminals inside the train, then split the network into two sub-networks: an inter-server network between the master server and the cache server, and an end-user network between the cache server and the user terminals. With this architecture, even if the cache server cannot exploit 5G communication to add and update content added or updated on the master server by the carrier, content on the cache server can be appropriately updated later using 5G communications to deliver almost instantaneous services very similar to live streaming to users.

Using this system, we conducted trials on February 19-23, 2018 by downloading multiple 4K/8K video files within the 5G transmission zone near Ienaka Station on the Tobu Railway in Fig. 15. During the 21 seconds it took for the train to pass through the 5G transmission zone, a total of 1.2 GB of 4K/8K video data was transmitted over the systems which were shown on a 40-inch 4K display and on a 17-inch 8K display set up in the train for the experiment. By providing very high-speed Gbps-class communications in high-speed mobile environments, this will make it possible to deliver breaking news and other high-definition video clips in a timely manner to passengers riding on high-speed trains.

4. Conclusion

This paper introduced our recent activities of 5G experimental trials on Massive MIMO technologies in higher frequency band such as SHF/EHF band. In addition, to create new services and applications in 5G era in cooperation with partners in vertical industries, recent results of 5G system trials, especially focusing on 5G Field Trials in dense urban environments and high-mobility environments were also introduced.

Acknowledgments

This paper includes a part of results of "The research and development project for realization of the fifth-generation mobile communications system" commissioned by the Ministry of Internal Affairs and Communications (MIC), Japan. In addition, this paper includes a part of results of the trial conducted by NTT DOCOMO under a project commissioned by Japan’s MIC to research and examine the technological requirements for the fifth generation mobile communication systems that can realize a data communication speed of 2 Gbps in high-mobility environments.

References


Yukihiko Okumura received his M.S. degree in electrical engineering from the Tokyo University of Science, Tokyo, Japan, in 1991, and his Ph.D. degree in engineering from the Tohoku University, Miyagi, Japan, in 2006. Since 1992, he has been engaged in the research, standardization and development of wideband/broadband mobile radio communication technologies, terminals and systems, at NTT DOCOMO, INC., Kanagawa, Japan, and is currently engaged in the research of 5G radio access technologies and is promoting field trials of 5G system. He is a Leader of 5G Trial Promotion Group, the Fifth Generation Mobile Communications Promotion (5GMF). He is a senior member of The Institute of Electrical and Electronics Engineers, Incorporated (IEEE).

Satoshi Suyama received the B.S. degree in electrical and electronic engineering, the M.S. degree in information processing, and the Dr. Eng. degree in communications and integrated systems, all from Tokyo Institute of Technology, Tokyo, Japan, in 1999, 2001, and 2010, respectively. From 2001 to 2013, he was an Assistant Professor in the Department of Communications and Integrated Systems at the Tokyo Institute of Technology. He has been engaged in research on OFDM mobile communication systems and applications of the adaptive signal processing, including turbo equalization, interference cancellation, and channel estimation. Since April 2013, he has joined NTT DOCOMO, INC. and is involved in research and development of fifth generation mobile communications system. Dr. Suyama is a member of IEICE and IEEE. He received the Young Researchers' Award from IEICE in 2005, the Best Paper Prize from the European Wireless Technology Conference (EuWIT) in 2009, Best Paper Award from International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) in 2016, and the Paper Award from IEICE in 2012.

Jun Mashino received the B.E. degree in electrical and electronic engineering and M.E. degree in communications and computer engineering from Kyoto University, Japan in 2003 and 2005, respectively. He joined NTT Access Network Service Systems Laboratories, NTT Corporation in 2005. He has been engaged in the research and development of intelligent interference compensation technologies, and signal processing for future wireless communication systems. Since 2016, he has been working as a research engineer in NTT DOCOMO 5G Laboratory. His current interests include wireless transmission technologies for 5G fifth generation mobile communications system. He received the IEICE Young Engineers Award in 2009 and also received APMC 2014 Prize in 2014. He is a member of IEICE and IEEE.

Kazushi Muraoka received the B.S. degree in computer science, the M.S. degree, and the Ph.D. degree in communications and integrated systems, all from Tokyo Institute of Technology, Tokyo, Japan, in 2005, 2007, and 2013, respectively. He joined NEC Corporation in 2007, where he was engaged in research on cellular networks, cognitive radios, and wireless sensor networks. In 2014, he was a visiting researcher at University of California, Berkeley. Since 2018, he has been engaged in research on 5G mobile communication systems in NTT DOCOMO. His research interests include radio signal processing and radio resource management. He received the Young Researchers’ Award from IEICE in 2012. Dr. Muraoka is a member of IEEE.