The Second Report on 5G System Trials in Japan

2019

June 14, 2019

5G Trial Promotion Group
Fifth Generation Mobile Communications Promotion Forum

Contents

Preface

Mr. Gaku NAKAZATO

Director for New-Generation Mobile Communications Office, Ministry of Internal Affairs and Communications (MIC)

I am very much pleased with the release of "The Second Report on 5G System Trials in Japan 2019".
MIC has started six 5G field trial projects since May 2017. Each project set more advanced technical goals in terms of eMBB/URLLC/mMTC, and did verification for the second year in more application fields at more sites than in the first year.
The details are described in this report.

5G commercialization in Japan is just around the corner. MIC assigned the first 5G frequencies to the four telecom carriers in April 2019.
With those related movements, I am sure 5G will be launched smoothly and a lot of people around the world coming to the Olympic and Paralympic Games Tokyo 2020 will be able to enjoy not only exciting games but also 5G applications and services inside or outside the venues.

I welcome your suggestive comments and look forward to seeing you at Tokyo 2020.

Dr. Kohei SATOH

Secretary General, The Fifth Generation Mobile Communications Promotion Forum (5GMF) and Executive Counsellor, Association of Radio Industries and Businesses (ARIB)

5GMF has begun its activities bringing together participants from industry, academia and government, promoting cooperation and collaboration among experts and specialists in a wide range of fields not limited to information and communications.

The "5G Trial Promotion Group (5G-TPG)" was established in January 2016 to study plans and frameworks for performing "Comprehensive field trials for 5G systems" in Japan, and summarized the outcomes as the first edition Report including 5G trial concepts, contents and plans of "5G Utilization Projects" in September 2017.

5G-TPG developed and published the "First Report on 5G System Trials in Japan" in March 2018 as a result of adding the overview and plans of the "5G Comprehensive Field Trials" led by the Ministry of Internal Affairs and Communications to its first edition Report. Many partners in various utilization fields called "Verticals" participate in the trials as well as those related to the mobile communications industry to create a new market through actualization of 5G.

The practical 5G Comprehensive Field Trials has started since May 2017, and it is expected that more partners in various fields will participate in these field trials. Therefore, 5G-TPG publishes this report containing detailed and recent results during these field trials.

Dr. Yukihiko OKUMURA
Leader of 5G Trial Promotion Group (5G-TPG), The Fifth Generation Mobile Communications Promotion Forum (5GMF)

To support Japanese 5G system trials/field trials, the 5G-TPG was established as a cross-organizational group within 5GMF in January 2016. For promoting 5G system trials smoothly and efficiently, the 5G-TPG is undertaking the following activities:

- Collecting information on international 5G system trials and sharing it to 5GMF members
- Announcement of activities and outcomes of 5G system trials conducted by 5GMF members to outside
- Exchanging information on 5G system trials among foreign 5G promotion forums, and promoting collaborations with the forums

From FY2017, the Ministry of Internal Affairs and Communications (MIC) "5G Field Trials" were started in Japan, and many stakeholders in various utilization fields participate in the trials as well as those related to the mobile communications industry to create a new market through actualization of 5G. In this report, the contents related to the FY2018 5G Field Trials were added as chapter 4 to the existing chapters, and it includes further outcomes in addition to the outcomes presented and exhibited at the 5G International Symposium 2019 held in January.

I hope this report will trigger further activities of the various field trial projects not only in Japan but also in the world, and expect that the actualization of 5G will contribute to the creation of new lifestyles and to the resolution of social problems. 5G-TPG will continue to timely publish reports with valuable outcomes of each trial project in the future.

Chapter 1 Introduction

The Fifth Generation Mobile Communications Promotion Forum (5GMF) is publishing this report in order to provide information on the desired test contents and plans of the upcoming 5G system trials in Japan, which the 5GMF is facilitating. The 5G Trial Promotion Group (5G-TPG) was formed in order to further study these points and the results published here and represent the outcome of their work.

Chapter 2 groups more than 40 proposals from the 5G Utilization Project, generated mainly from members of the 5G-TPG, into following six broad categories that were decided upon after discussion by the 5G-TPG:

- Entertainment
- Safe and secure society prevented from crime and natural disasters
- Logistics, agricultural and fisheries, offices, factories
- Remote controlled and managed devices such as robots and drones
- Connected cars, autonomous and remote driving
- High data-rate and reliable communication for high speed mobile

These utilizations of 5G as described by the 5G Utilization Project come out of the technological foundations of 5G technology, which are described in the published 5GMF White Paper, “5G Mobile Communications Systems for 2020 and Beyond”. An overview of the 5G Utilization Projects is provided in the 5GMF White Paper.

Other 5G Utilization Projects in the same field and the broader fields in addition to the 5G Utilization Projects described in the 5G-TPG’s report can be proposed and will being investigated by 5GMF. The Ministry of Internal Affairs and Communications (MIC) Round-table Conference on Radio Policies 2020 Report discussed nine different fields where vertical industries (industries exploiting 5G) are categorized as the utilization field of the next generation mobile services. (see Fig. 1)

Chapter 3 introduces content, plan, and outcome of “5G Field Trials in the first year (2017-2018)” that the MIC has started from the fiscal year 2017 for three years. In the 5G Field Trials, six groups evaluate 5G system performance such as eMBB (enhanced Mobile Broad Band), mMTC (massive Machine Type Communication), and URLLC (Ultra Reliable and Low Latency Communication) in various locations all over Japan in addition to Tokyo. Many partners in various utilization fields participate in the trials as well as those related to the mobile communications industry to create a new market through actualization of 5G.

Chapter 4 introduces content, plan, and outcome of “5G Field Trials in the second year (2018-2019)” with six groups at more locations throughout Japan following the first year.

Fig. 1 Nine fields from the MIC Round-table Conference on Radio Policies 2020 Report.

This figure provides examples of some practical uses of beyond uses for smartphone consumers, including health care, agriculture, finance, transportation, and various other industrial uses. By unearthing basic needs of industrial applications, such as improving operation efficiency of various industries or making connections increasingly convenient as well as confronting new problems of an advanced industrial nation like Japan, such as a low birth rate rapidly aging society or the decrease in the working population, 5G will not only promote market and industrial growth but will become another tool to help solve social issues.

However, if only those involved in wireless industries attempt to lead 5G R&D and promotion, it will be impossible to uncover the true needs of a diverse range of industrial applications. And it is important to look for specific recommendations and receive proposals from those industries who will actually use these applications. Therefore, we also held application ideathons at public events, which gave us the opportunity to bring new ideas to the forefront of our vision. (see Fig. 2)

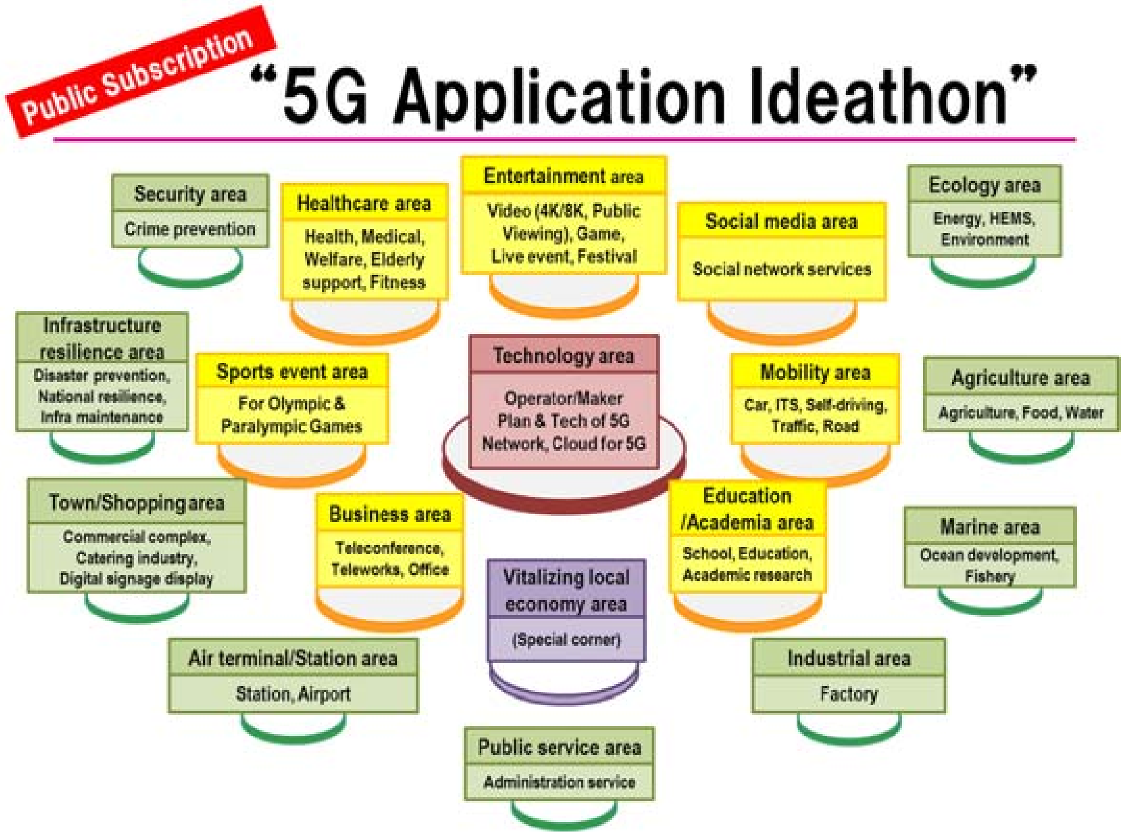


Fig. 2 Public 5G application ideathons.

Looking at Fig. 2, the middle section shows how experts in in wireless industries introduce 5G technologies in ways that are easily understood by the general public. Surrounding that are various other industrial applications of 5G. As the awareness of these technologies is high among those using ICT, the quality of ideas among the collected proposals was very good. This means there is a high level of public understanding among those who use these industrial applications.

In addition, user surveys were conducted by the 5GMF Application Committee. The ways of thinking of the generation of smartphone natives opened a "different dimension" of new ideas from newly discovered needs, beyond the needs of vertical industries. Therefore, we need to add an additional area in Fig. 2, a "smartphone native student area" that must also be researched.

The public 5G ideathons are one way to collaborate with the public to uncover the real needs of users as well as encourage more awareness generally about 5G. Therefore, as the number of these meetings increase, discussions around 5G will also deepen, ultimately increasing the general public's awareness in 5G.

Chapter 2　5G Utilization Project

Please refer to “The First Report on 5G System Trial in Japan 2018 Rev.1 (April 27, 2018)” on the 5GMF website (URL is below) for the details of this chapter:

https://5gmf.jp/en/whitepaper/the_first_report_on_5g_system_trials_in_japan_2018_rev1/

【Overview】

The 5G Utilization Projects in this section “Entertainment” foresee 5G’s ultra-high speeds, its high capacities, and ultra-low latency will provide users with experiences up until now they have been unable to enjoy.

What this means in concrete terms is offering users ultra-high definition 8K video transmissions including live broadcasting/multicasting and high-presence multimedia data transmissions in which videos are taken by multiple cameras from multiple different points of view, which meet user needs.

Video and data will be delivered to users not only through devices like smartphones and tablets but through the use of head mounted displays and large high-definition signage that require ultra-high-speed data transmissions.

These services will be offered where users congregate, such as concert or event venues, stadiums and race tracks like those used at the Olympics. These services will also be able to offer users the chance to experience and participate in events remotely that they cannot attend in person.

In addition, utilizing virtual reality, history and art museums will also be able to provide remote experiences, hold remote chats from multiple locations, and hold remote competitions and games and as well as provide full body experiences from festival locations.

It is planned to provide some of the above-mentioned services as part of a new entertainment experience to be able to more deeply enjoy the 2020 Tokyo Olympics and Paralympics.

Chapter 3　5G Field Trials in Japan 2017-2018

Please refer to "The First Report on 5G System Trial in Japan 2018 Rev.1 (April 27, 2018)" on the 5GMF website (URL is below) for the details of this chapter:

https://5gmf.jp/en/whitepaper/the_first_report_on_5g_system_trials_in_japan_2018_rev1/

【Overview】

The 5th generation mobile communication system 5G is a next generation mobile communication system having features such as "ultra-high speed/large capacity", "large number of connections", "ultra-low latency" etc., which further developed the existing system. It is expected that 5G will be realized as an ICT base of the advanced information society at an early stage.

In recent years, in Japan, activities related to research and development and international standardization of technologies and functions supporting 5G, such as radio access network technologies and others, are rapidly accelerating toward the actualization of 5G in 2020.

From this fiscal year 2017, the Ministry of Internal Affairs and Communications (MIC) "5G Field Trials" has been started, and many stakeholders in various utilization fields participate in the trials as well as those related to the mobile communications industry to create a new market through actualization of 5G.

In this chapter, each group leader promoting the 5G field trial will introduce the content, plan, and outcome of each trial.

Table.3.5G Field Trials in FY2017

	Responsible organization	Main partners	Field	Main locations	Technology
I	NTT DOCOMO	･TOBU TOWER SKYTREE ･ALSOK ･Wakayama Pref.	･Sightseeing ･Smart cities ･Telemedicine	･Tokyo ･Wakayama	eMBB
II	NTT Communications	･Tobu Railways ･Infocity	･Transport	･Tochigi ･Shizuoka	eMBB
III	KDDI	･Obayashi Corp. ･NEC ･Toyota IT Center	･Construction ･Connected car	･Saitama	URLLC
IV	ATR	･Naha City ･Keikyu Railways	･Entertainment	･Okinawa ･Tokyo/HND	eMBB
V	Softbank	･Advanced Smart Mobility Co., Ltd. ･SB Drive Corp.	･Transport	･Ibaraki	URLLC
VI	NICT	･Itoki ･Sharp ･Softbank	･Logistics ･Smart office	･Miyagi ･Kanagawa ･Osaka	mMTC

Chapter 4　5G Field Trials in Japan 2018-2019

4.1 Overview

From last fiscal year (FY2017), the Ministry of Internal Affairs and Communications (MIC) "5G Field Trials" were started in Japan, and many stakeholders in various utilization fields participate in the trials as well as those related to the mobile communications industry to create a new market through actualization of 5G. In this chapter, each group promoting the 5G Field Trial introduces the content and outcome of each trial that were conducted in FY2018 as summarized in Table 4.1.1.

Table 4.1.1 5G Field Trials in FY2018

Technology	Responsible Organization	Main Partners	Trial Overview	Main Trial Locations
eMBB (4.5, 28GHz)	NTT DOCOMO	• TOBU TOWER SKYTREE • ALSOK (Security) • Fukui Pref. • Wakayama Pref. • Aizu-Wakamatsu City	• AR/VR content • Monitoring and Security • Medical Services	• Kyoto • Gunma • Tokushima • Wakayama
eMBB (4.5, 28GHz)	NTT Communications	• Tobu Railway • West Japan Railway Company • Infocity (Contents Company)	• Transport (High speed railway)	• Ibaraki • Tokyo
eMBB (28GHz)	ATR (Research Corporation)	• Kyushu Institute of Tech. • Keikyu Railways • Waseda Univ. • Maehara elementary school	• Smart factory • Station • School education	• Fukuoka • Haneda Airport International Terminal Station
URLLC (4.5, 28GHz)	Softbank	• Advanced Smart Mobility Corp.	• Transport • Car remote control	• Yamaguchi • Shizuoka
URLLC ×eMBB (3.7/4.5,28GHz)	KDDI	• Obayashi Corp. (Construction) • NEC (Appliance manufacturer) • The Univ. of Tokyo.	• Remote Construction • Drone surveillance	• Osaka • Nagano • Hiroshima
mMTC (4.5GHz)	Wireless City Planning	• Pacific Consultants (Construction consultant) • NICT (National institute) • Higashihiroshima City	• Smart highway • Smart office	• Aichi • Hiroshima

4.2 Demonstration experiment on 5G ultra high bit-rate communication in outdoor environments - Entertainment / Smart City / Workplace / Medical applications -

- Responsible organization: NTT DOCOMO, INC.
- Partners: TOBU RAILWAY Co., LTD., NEC Corporation, Sharp Corporation, INFOCITY Inc., Kyoto Prefecture, Ericsson Japan K.K., Intel K.K., Mitsubishi Electric Corporation, Fukui Prefectural Dinosaur Museum, Panasonic Corporation, Aizu Wakamatsu City, Fujitsu Limited, NIPPON TELEGRAPH AND TELEPHONE CORPORATION, Tokushima Prefecture, SOHGO SECURITY SERVICES CO.,LTD. (ALSOK), Wakayama Prefecture, Wakayama Medical University, NTT Bizlink, Inc., NTT Communications Corporation, Maebashi City, Maebashi Municipal Fire Department, Maebashi Institute of Technology, TOPIC, Inc., Maebashi Red Cross Hospital, Plat Ease Corporation

4.2.1 Introduction

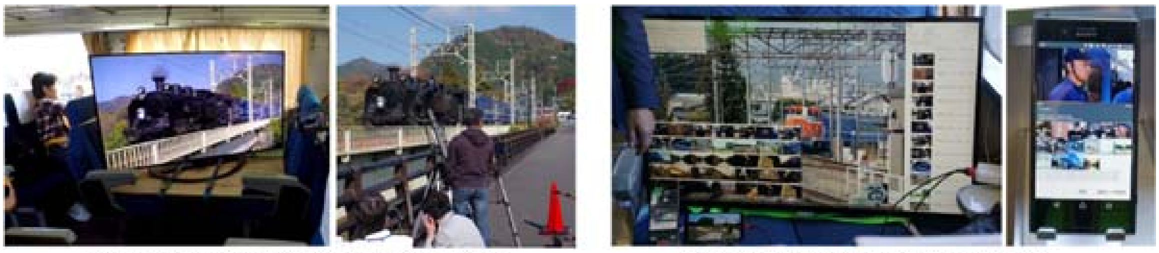
NTT DOCOMO (DOCOMO), working with 25 partner organizations from local municipalities, private firms, and universities, conducted 11 field trials between October 2018 and March 2019 in order to demonstrate uses of the Fifth Generation mobile communication system (5G) as part of Ministry of Internal Affairs and Communications (MIC)'s 5G Field Trials [1].

This section introduces results of DOCOMO's 5G field trials on ultra high bit-rate communication in outdoor environments for entertainment, smart city, workplace, and medical applications that are conducted in many locations across Japan with 5G prototype wireless devices in the 4.5 GHz band and the 28 GHz band [2],[3].

4.2.2 5G System Performance Evaluations in Entertainment Application

4.2.2.1 Ultra High Definition Video Transmission to Steam Locomotive Using 5G

This trial, with the goal of creating new tourism related activities, was held from Monday, November 12 to Friday, November 16, 2018 in cooperation with Tobu Railway by using a regularly running Tobu Railway steam locomotive [4]. 5G communications area, with the cooperation of NEC, utilizing both the 4.5 GHz band and the 28 GHz band was provided on the Kinugawa Bridge section of the Kinugawa Line in order to carry out the following HD video delivery demonstration. An 8K video camcorder, used with the cooperation of Sharp, captured live video of the steam locomotive which was then transmitted into the train carriage in real time, which can create a new way for tourists who are riding on the steam locomotive to enjoy the trip. In addition, the use of a 4K content delivery system, with the cooperation of Infocity, was demonstrated by downloading several 4K video files to many smartphones and notebook PCs simultaneously on the train.



Using 5G to transmit 8K live video of the outside of the steam locomotive to the inside of the train carriage

View of content transmitted by the 4K video content delivery system

Fig. 4.2.2.1 New tourism experiences while riding steam locomotive with the realization of the delivery of HD Video

4.2.2.2 Attracting Tourism through the Use of 5G and 8K Video

This trial, with the goal to demonstrate services to attract tourists to regional tourism sites, was conducted around the area of Arashiyama in Kyoto, with the cooperation of Kyoto Prefecture, from Thursday, December 13 to Friday, December 14, 2018. An 8K video camera, used with the cooperation of Sharp, recorded two channels of 8K video of the Togetsu Bridge and transmitted the two views in real time to the opposite side of the Katsura River to be viewed there. Participants in this trial were given a questionnaire, and 97 percent answered that they indeed wanted to see this tourist attraction in person, their interest being increased due to the clear 8K video they had just viewed. This trial demonstrated that 5G can bring the possibility of easily transmitting 8K video, even in tourist areas that are densely populated or where wired networks would cause issues, in order to contribute to promoting tourism. This trial used an Ericsson Japan's 28 GHz-band 5G base station as well an Intel's 28 GHz-band 5G mobile station. These two mobile stations were used to test data transmissions. By using 364.5 MHz bandwidth, data was transmitted at average bit-rate of 2.5 to 3.2 Gbps per base station. When converted to 800 MHz bandwidth, the average bit-rate was 5.0 to 6.4 Gbps, which results in achieving this trial's technical objective.

Transmission of 2-channel 8K video to the opposite side of Katsura River

Tourists considering tour courses by watching 8K video

Fig. 4.2.2.2 Attracting tourism to the Arashiyama area via 8K video during Kyoto Arashiyama Hanatouro 2018

4.2.2.3 Live Video Transmission of Wheelchair Basketball Game Using 5G

This trial demonstrated transmission of multiple viewpoint HD live video, with the cooperation of Mitsubishi Electric, of a wheelchair basketball game on January 13, 2019.

5G communication area was provided at an arena using Mitsubishi Electric's 28 GHz 5G base station. Inside the arena two 4K cameras and one 180-degree camera were installed and video they took was transmitted via two mobile stations to the spectator seating area and the arena lobby. Spectators could experience the exciting action on the court from multiple angles as well as from areas on the court where their seats had an obstructed view, realizing a new way to enjoy spectator sports. 96 percent of participants said this was a satisfying experience.

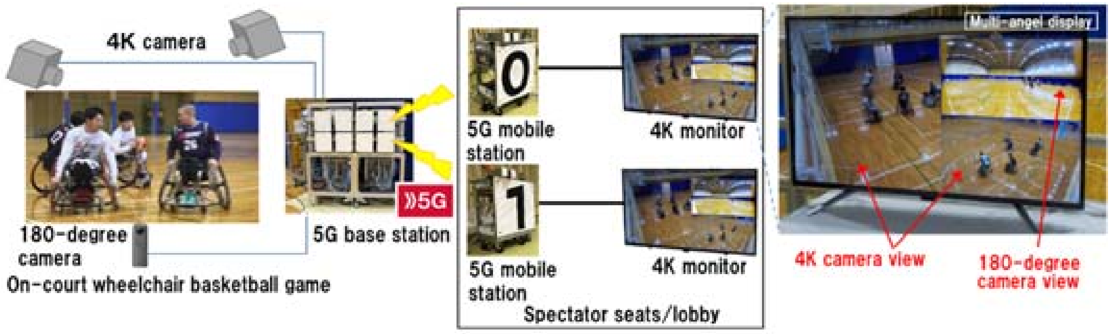


Fig. 4.2.2.3 Experiencing the atmosphere of a wheelchair basketball game via multi-angle HD video

4.2.2.4 Visiting a Museum Remotely Using 5G and Virtual Reality Technology

The ability to remotely experience a museum using VR technology was demonstrated with the cooperation of the Fukui Prefectural Dinosaur Museum on February 4, 2019. This trial connected the museum with PLAY 5G in Tokyo Soramachi, Tokyo Skytree Town via an exclusive network, with Ericsson Japan's 28 GHz-band 5G base station and Intel's 28 GHz-band 5G mobile station placed inside the Museum used to deploy a 5G communication area on the museum's display floor. The communication environment included, with the cooperation of Panasonic, a video delivery system with a variable-rate video encoding, which successfully allowed for transmission of bidirectional 4K video. Specifically, a video taken by a 360-degree 4K live camera with a 5G mobile station at the museum could be delivered when it moved with a museum researcher walking around the museum acting as a guide. Visitors at PLAY 5G in Tokyo Soramachi, Tokyo Skytree Town were able to participate in the bidirectional real time video transmission and could take part in interactive conversations with the museum researcher. They were also excited to experience the museum environment while using a VR head mounted display, including seeing with their own eyes a powerful dinosaur skeleton that they would normally not be able to see, which lead to surprised outbursts from participants. This same demonstration was held from locations in Tokyo in December 2018 as well.

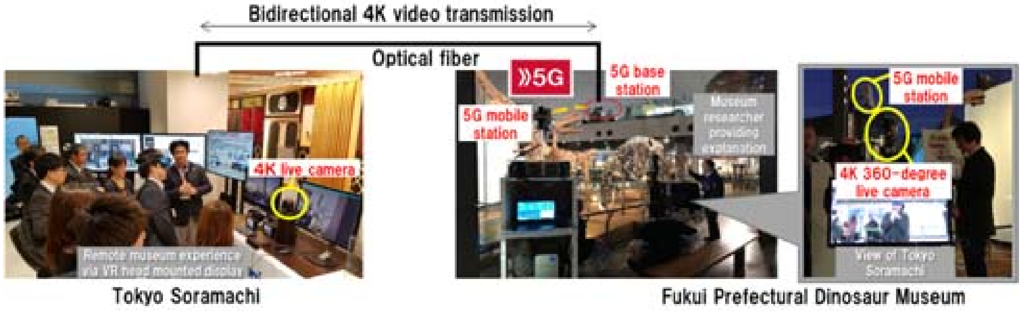


Fig. 4.2.2.4 Experiencing a museum in a remote location realized by bidirectional real time 4K camera and VR technology

4.2.2.5 Live Viewing of Tourism Event Using 5G

This trial demonstrated the ability to conduct live viewing of a tourism event, with the cooperation of Aizu Wakamatsu City, at the Tsurugajo Castle, Aizu Wakamatsu City, on Friday February 2, 2019. Ericsson Japan's 28 GHz-band 5G base station was installed in the castle keep and Intel's 28 GHz-band mobile station was placed in the castle tower, while with the cooperation of Sharp, an 8K video camera was placed in the tower. The live video of Aizu-Erousoku (candle with picture) Festival, which was held on the day of the trial, was taken and people in the keep could watch an 8K live stream of the festival. Through the utilization of 5G, 8K video transmission environment could be immediately constructed in a cultural facility where it would otherwise be difficult to lay a cable. In addition, the HD viewing area became popular as visitors could view patterns of the lanterns that could only be seen from above. A survey showed 93% of participants stated they now wanted to go to the top of the tower, as well. This demonstrated that the offering of new experiences contributed to increasing interest in tourism in the region.

Fig. 4.2.2.5 8K live viewing using 5G in Aizu-Erousoku Festival

4.2.2.6 Cheering on Athletes at Sports Event from Remote Location in Real Time Using 5G

The ability of supporters to cheer on athletes at a sporting event from a remote location was demonstrated, with the cooperation of Fujitsu, in Kawasaki City, Kanagawa on

Sunday March 3, 2019. The specific event where the trial was conducted was the PK Championship, which was held at Fujitsu Stadium Kawasaki. The spectators located off site were served by a Fujitsu's 4.5 GHz-band 5G wireless device and a NTT Distributed Smart Antenna System (D-SAS), which was used to create a highly efficient Wi-Fi as well as a wavelength-division-multiplexed passive optical network (WDM-PON) system, which connected to the stadium via a fixed-line VPN. With the cooperation of Infocity, three 4K cameras were installed in the stadium while a 2K camera was placed where the supporters were located, which enabled a bidirectional real time communications network utilizing 5G to allow for supporters to cheer on the participating athletes from their remote location. Players said that they "received power from the cheers of their supporters" while fans said "The competition seemed more exciting because I felt our cheers were actually heard on the pitch." 93% of participants said in a survey that they had gained interest in this style of supporting athletes from a remote location. Additionally, fixed wire communication between two points was used as an assumed 5G core network to demonstrate the realization, with the cooperation of NTT, of an application of network slicing technology to separate transmission of side content, such as information on results and video archives, from the above four camera transmissions while guaranteeing quality on the same bandwidth.

Fig. 4.2.2.6 Realization of real time remote support of a sports event using 5G

4.2.3 5G System Performance Evaluations in Smart City Application

4.2.3.1 Car Security with 5G

Security applications utilizing 5G were demonstrated, with the cooperation of ALSOK, in Kamiyama Town, Tokushima Prefecture on Friday January 25, 2019. This demonstration used NEC's 28 GHz-band 5G wireless device to transmit images from four cameras installed on a vehicle that were then synthesized to create a "flying view" around the vehicle, an image which can then be viewed from any viewpoint. It was confirmed that the transmitted images could view an area of about 35 meters around the vehicle, including other surrounding vehicles as well as the ability to determine the posture and clothes of pedestrians in the area. In the future, this type of "flying view" video can be sent to a control center which will be able to provide services to protect drivers such as detecting nearby vehicles that are being driven recklessly. It will also be able to provide community security services such as detecting suspicious individuals or lost children. Other expected services include the ability to provide support to security personnel rushing en route to an incident or providing information to relevant organizations in such a situation.

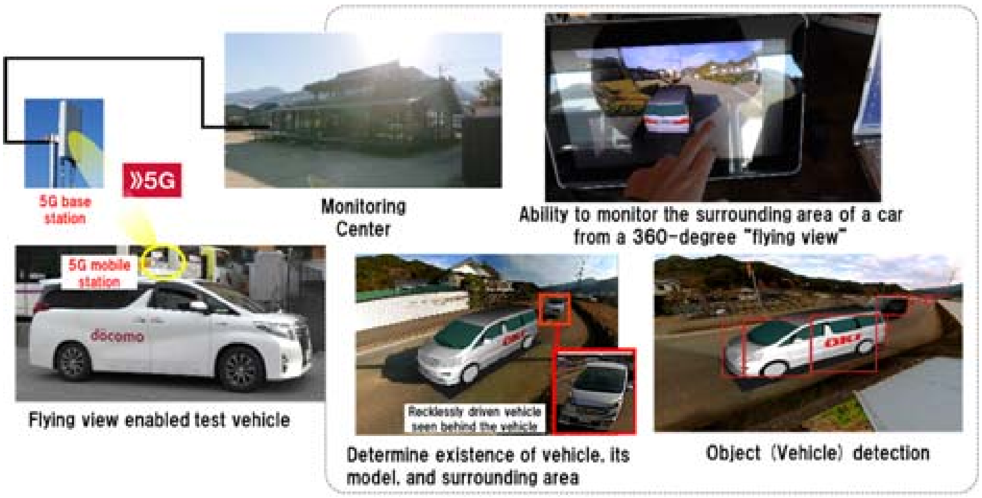


Fig. 4.2.3.1 Realization of car security via flying view using 5G

4.2.3.2 Community Security Services Using 5G

Community security services were demonstrated, with the cooperation of Aizu Wakamatsu City, ALSOK, and NEC, in Aizu Wakamatsu City, Fukushima Prefecture, for three days from Monday February 4 to Wednesday February 6, 2019. This trial placed a 4K camera at a high location on the Tsurugajo Castle tower which transmitted video it took to a control center on the ground via NEC's 4.5 GHz-band 5G wireless device. It was verified that these 4K video transmissions could be analyzed by AI to quickly recognize someone who had fallen due to an illness or other medical condition 85 meters away from the installed camera. This trial also aimed to demonstrate the ability to provide highly efficient security services via smart glasses, so video from security personnel was shared with a control center via 5G. The control center identified the fallen individual via facial recognition and his identity was displayed on the security personnel's smart glasses, which was sent via 5G in one sequence, verifying the viability of this type of security operation.

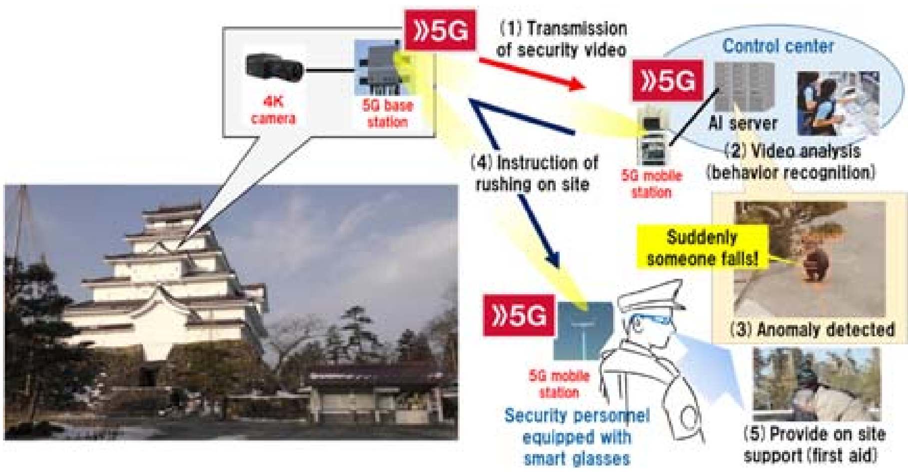


Fig. 4.2.3.2 Realizing community security services using 5G

4.2.4 5G System Performance Evaluations in Medical Application

4.2.4.1 Advanced Remote Diagnostics Using 5G

In a continuation from trials held the year prior to the ones described in this booklet

[5], an advanced method of remote diagnosis procedures was demonstrated in order to solve the issue of a difference in service levels of medical care between urban and non-urban areas, with the cooperation of Wakayama Medical University and Wakayama Prefecture, from Wednesday January 16th to Thursday January 24, 2019. NEC's 4.5 GHz-band 5G base station was placed twelve meters above the street level in the Miyama district of Hidakagawa Town, Wakayama in order to provide a 5G communications area around a local medical clinic. While in the previous year remote diagnoses processes were trialed at this clinic, a new way of doing doctor's house calls were tested this year thanks to an entire 5G communication area around the clinic. Specifically, this meant that the clinic physician could connect via 5G to specialists at the Wakayama Medical University while at patient's house and, with the cooperation of NTT Bizlink, could use a 4K teleconference system to facilitate operation of medical equipment and the formulation of a treatment plan. The specialist doctor could see images from a close-up 4K camera and the output from an ultrasonic diagnostic device that was shared via 5G and confirm a diagnosis in real time. These tools were well received, with specialists stating that "This system made it seem as if the patient was right in front of me and I could diagnose the patient as if they were actually next to me." And that "I am going to want to use these tools everyday as they will allow me to quickly discover diseases like heart failure."

Activities were held for an additional application of the remote diagnostic support system from the medical field: remote education. Specifically, at a local medical clinic a young doctor operated an endoscope which, through the 5G network, could send images to a specialist doctor at the Wakayama Medical University in real time, allowing the specialist to provide advice on how to use it smoothly, for example, on when to turn the scope, when to stop it, and what points to look for when making a diagnosis.

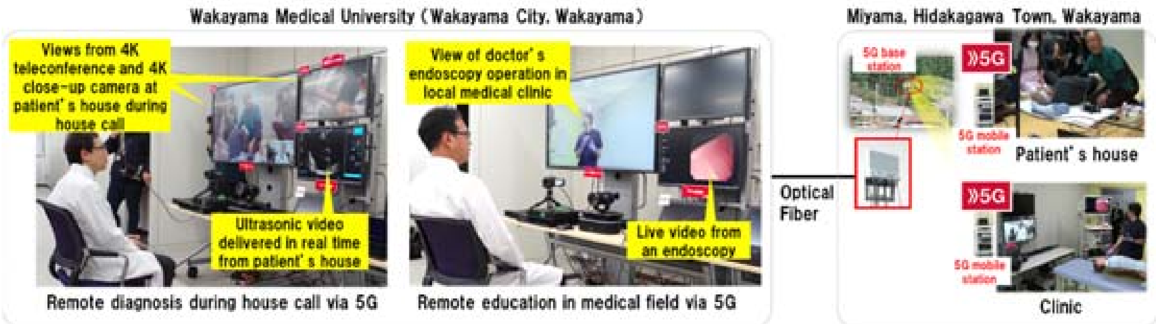


Fig. 4.2.4.1 Realization of house calls as well as remote education of doctors in local medical clinic using 5G

4.2.4.2 Solutions to Make Emergency Care Transport More Efficient Using 5G

Japan's first use of 5G for emergency medical care was demonstrated in this trial, with the cooperation of Maebashi City, Maebashi Municipal Fire Department, TOPIC, and Maebashi Red Cross Hospital, in Maebashi City, Gunma on Friday February 15, 2019. The purpose was to decrease the time needed to take appropriate action during the transport of a patient in a time sensitive situation by connecting via 5G an ambulance, doctor car, and the emergency hospital in order that information on the patient's condition could be shared among all three via HD video. NEC's 28 GHz-band 5G base station was installed on the 12th floor of the Maebashi City Hall, which created a 5G communication area around the city hall and the Gunma Prefectural Building. NEC's 28 GHz-band 5G mobile stations were placed on the roofs of the Maebashi Municipal Fire

Department's ambulance and DOCOMO's test vehicle, which was transformed into the doctor car. This trial was an implementation of a previous emergency transportation scenario. The patient was transported in the ambulance until reaching the docking point with the doctor riding in the doctor's car en route to the hospital, with a bedside monitor, an overhead view camera and a close-up camera video packed together in a 4K video that via 5G is shared to the doctor's car as well as with the emergency hospital which will receive the patient. The doctor riding in the doctor car could check on the status of the patient, such as loss of blood or other indicators, while being able to instruct emergency personnel on sufficient procedures to treat the patient inside the ambulance. It was also successfully verified that the emergency hospital could access the patient's previous medical history from the Individual Number card (My Number) system offered by Maebashi Institute of Technology. Next, once reaching the docking point the patient was transferred to the doctor car, which was equipped with an ultrasonic diagnostic apparatus and 12-lead electrocardiogram, the overhead view and close-up cameras, all packed into a 4K video which, via 5G, could be shared between the doctor car and the emergency hospital, and it was confirmed that the doctor in the doctor car and those at the emergency hospital could provide advice and the patient could be registered at the hospital while en route to there. The system was popularly received, with doctors who participated providing feedback such as "The video seen with 5G was clear and the information was detailed," "Up until now we depended on voice communication when a patient was being transported in the ambulance and we necessarily had to speculate concerning the condition of the patient, but with this system has realized a situation where the emergency patient is for all practical purposes already at the hospital," and "There is a very deep understanding that comes from this situation when what is happening inside the ambulance can be faithfully reported to those outside the ambulance." It was confirmed that this solution was able to increase the survival rate of patients.

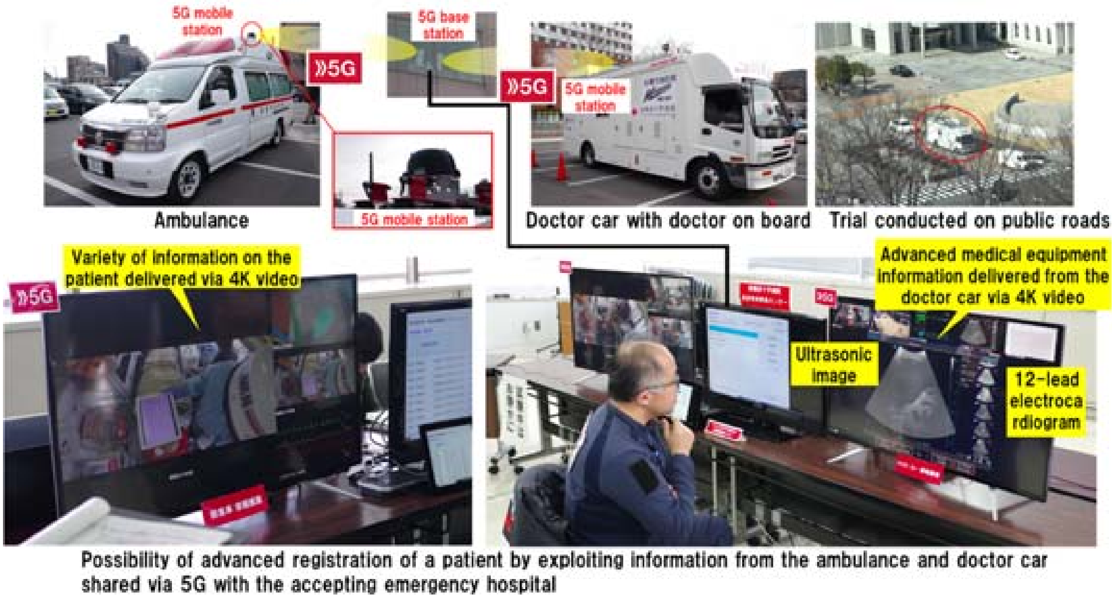


Fig. 4.2.4.2 Realization of efficient emergency patient transport using 5G

4.2.5 5G System Performance Evaluations in Workplace Application

4.2.5.1 Moving Satellite Office Using 5G

The use of 5G to create a moving satellite office where work could be done while in a moving environment as if in their own office was demonstrated, with the cooperation of Plat Ease and Panasonic, in Kamiyama Town, Tokushima on Wednesday January 23, 2019. For this trial, a 5G mobile station was installed on a moving test vehicle and those inside the vehicle participated in a mock remote meeting, with a 4K 360-degree live camera transmitting video via 5G to head mounted displays worn by those in the car. It was demonstrated that with this solution those in the car could participate in the meeting as if they were actually in the meeting room. Additionally, 4K video was also uploaded to the meeting room from inside the moving satellite office, allowing participants in the meeting room to feel as if those in the moving satellite office were actually in the room with them. This trial also verified that the large files for video editing (in the Mezzanine file format) utilized by Plat Ease in its everyday work could be smoothly downloaded and uploaded from the moving vehicle using 5G. It is thought that by being able to efficiently manage time with the realization of a moving satellite office that will allow work to continue while employees are commuting or on a business trip will bring about a revolution in the ways of work.

Fig. 4.2.4.1 Realization of moving satellite office using 5G

4.2.6 Conclusion

This section introduced results of NTT DOCOMO's 5G field trials on ultra high bit-rate communication in outdoor environments for entertainment, smart city, workplace, and medical applications that were conducted in many locations across Japan with 5G prototype wireless devices in the 4.5 GHz band and the 28 GHz band for the MIC's 5G Field Trials.

NTT DOCOMO's progress on the implementation of the 5G Field Trials in 2018 continued from its activities during the previous year by demonstrating uses to support regional revitalization within the four applications mentioned above, especially in the field of medical application with the first demonstrated use of a 5G enhanced solution in emergency transportation when 5G was used to improve communication sharing between ambulances, doctor cars, and hospitals while patients were being transported to the hospital which led to a confirmed improvement in patient survival rates. Additionally, an application of 5G towards remote medical care was demonstrated when 5G portable base stations were utilized to allow specialists at a major urban hospital to assist local clinic doctors when making a house call. In the field of entertainment applications of 5G's ultra-high bit-rate communication and portability were demonstrated with the transmission of high definition video at local events and tourist spots. Successful demonstrations of 5G in the field of smart city application included the use of free viewpoint video transmissions for use in security solutions. Additionally, new activities during the 2018 demonstrations in the field of workspace application included the realization of a mobile environment that facilitated the sending and receiving of large files needed for video editing as well as being able to hold meetings to discuss the files, both of which demonstrated how 5G is expected to bring about a revolution in the ways of work.

References

[1] MIC, "Start of FY2018 5G Comprehensive Demonstration Test", http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/2018_09_14_01.html, Sep 14, 2018.

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[4] NTT DOCOMO and TOBU Railway, "Succeed in Ultra-High-Definition Live Video Transmission to SL TAIJU Using 5G", https://www.nttdocomo.co.jp/binary/pdf/info/news_release/topics_181128_01.pdf, November, 2018.

[5] NTT DOCOMO, "DOCOMO's Results of MIC 5G Field Trial in FY2017", https://www.nttdocomo.co.jp/binary/pdf/corporate/technology/rd/topics/2017/topics_180326_03.pdf, March, 2018.

4.3 Demonstration experiment on 5G high bit-rate communication with high mobility - Entertainment / Transportation Field -

- Responsible organization: NTT Communications Corporation
- Partners: NTT DOCOMO, INC., NEC Corporation, TOBU Railway Co., LTD., West Japan Railway Company, INFOCITY, Inc., Nippon Telegraph and Telephone Corporation, Sharp Corporation, Panasonic Corporation

4.3.1 Introduction

This section introduces two 5G field trials conducted by NTT Communications with many partner companies as part of Japan's Ministry of Internal Affairs and Communication's 5G Field Trials in fiscal year 2018 [1].

Among the activities continuing from the previous year in the field of entertainment were trials held concerning the delivery of high-definition video to trains in urban. New trials were held this year in the field of transportation, demonstrating safe railway management through the monitoring of deteriorating infrastructure.

4.3.2 High-definition video delivery to high mobility

This trial demonstrated that high-presence, high-definition images such as competition video and tourist content of the Tokyo Olympic and Paralympic Games could be transmitted to passengers in high mobility such as trains and buses via 5G in urban environment.

Period: December 17-21,2018
Place: Tobu Skytree Line (near Kasukabe Station)
Frequency: 4.4 GHz – 4.9 GHz band and 27.0 GHz - 29.5 GHz band

Fig.4.3.2.1 shows Overview of the demonstration experiment.

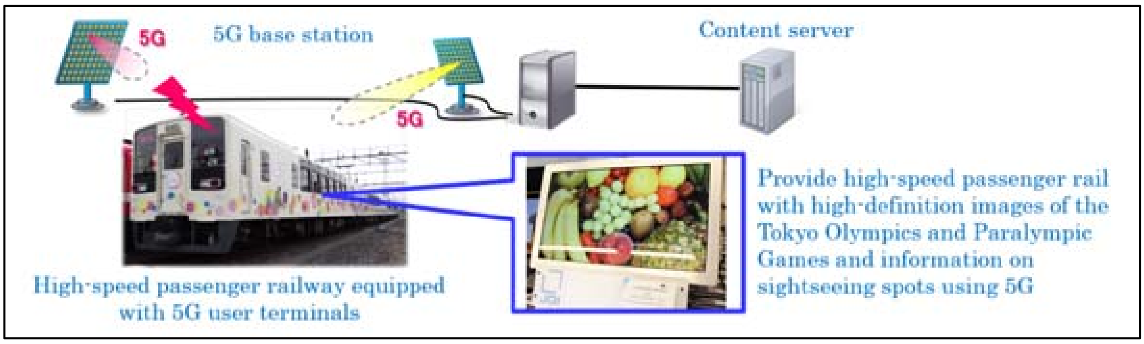


Fig.4.3.2.1 Overview of high-definition video delivery to high mobility in Tobu Skytree Line

We built 5G communication areas of 4.5 GHz and 28 GHz in the curved section near Tobu Skytree Line Kasukabe Station. In the 28 GHz band, two base stations were installed, and handover was also performed. Base stations are installed in different directions in the 4.5 GHz and 28 GHz bands. The 5G mobile station was installed in the window of the crew room of the Tobu Skytree Train.Fig.4.3.2.2 shows the arrangement of base stations.

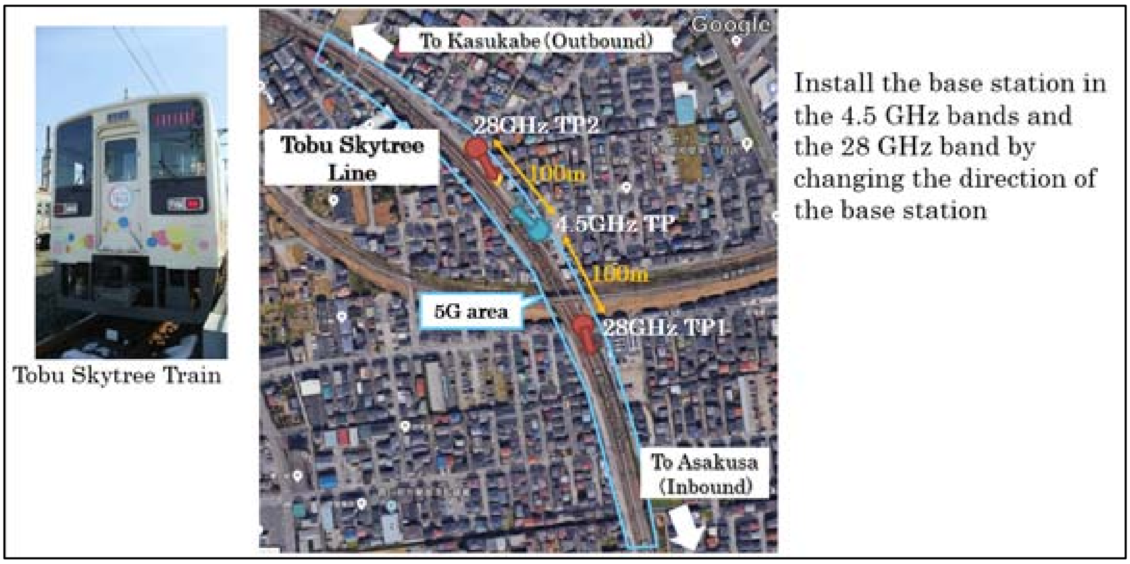


Fig.4.3.2.2 Arrangement of base stations at the experimental site of Tobu Skytree Line

In the 5G transmission characteristics evaluation in the 4.5 GHz band (bandwidth 100 MHz), the mobile station simulating the user terminal was placed at the head of the inbound train, and the characteristic measurement was performed under an environment of 60 km / h or more. Fig.4.3.2.3 shows the test results. The maximum throughput achieved approximately 540 Mbps in total for two layers. Also, the target of 240 Mbps or more was maintained for 15 seconds (about 246 m) on the outbound-train.

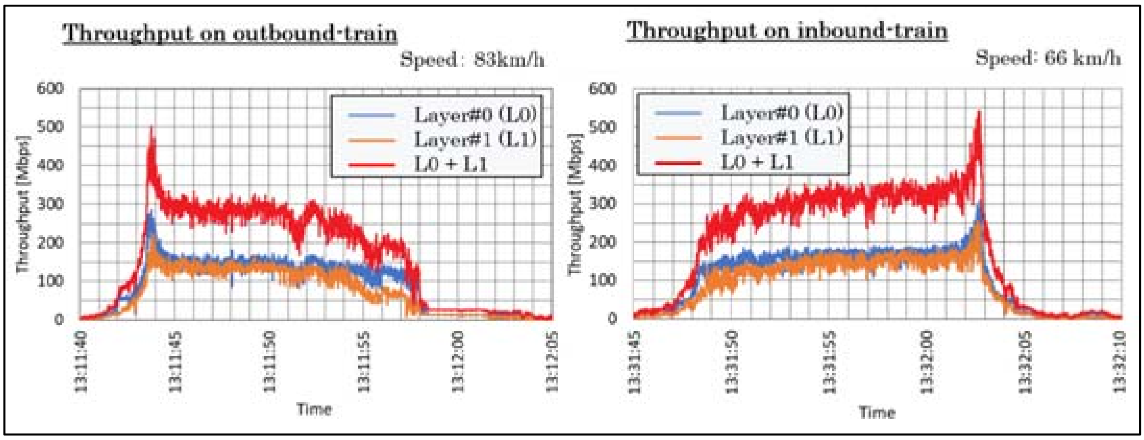


Fig.4.3.2.3 Throughput in 4.5 GHz band

In the 28 GHz band (bandwidth 700 MHz), the mobile station was placed at the head of outbound train. Fig.4.3.2.4 shows the test results. The maximum throughput achieved 991 Mbps near TP1, and 1096 Mbps near TP2 after handover.

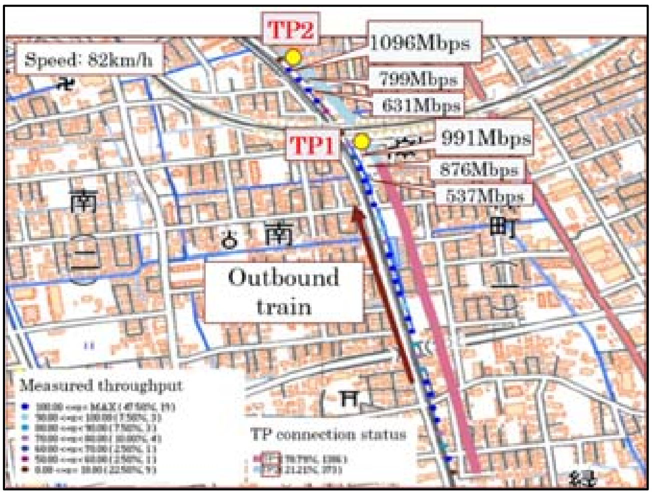


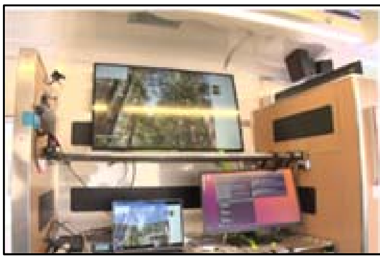
Fig.4.3.2.4 Throughput in 28 GHz band (bandwidth 700 MHz)

As the demonstration of 4K high-definition video delivery in the 4.5 GHz band, a hybrid type hi-definition video delivery was conducted. We downloaded 4K video to a cache server in the train via 5G and confirmed that it was possible to watch video stably with 40 smartphones in cooperation with Passive Optical Network (PON) and cooperative wireless LAN system. Fig.4.3.2.5 shows the results of downloading video files via 5G.

Results of video files downloaded via 5G	
Total size	375.487 MB
Maximum throughput	345.145 Mbps
File number	15
Video length	4 minutes 49 seconds

Fig.4.3.2.5 Results of video files download via 5G in hybrid type

Also, another demonstration of video streaming of 4K / H.265 video by Real-time Transport Protocol (RTP) was conducted. Uncompressed 4K video files ware encoded in H.265 in real time, distributed by streaming via 5G. We gradually increased the video transmission bit rate, confirmed that could watch 20 Mbps 4K / H.265 video for about 20 seconds. Fig.4.3.2.6 shows the results of streaming type video delivery.



Results of Streaming type video delivery	
Maximum bit rate	around 20 Mbps
Playback length	around 20 seconds

Fig.4.3.2.6 Results of Streaming type 4K video delivery via 5G

Further, the demonstration of 8K high-definition video delivery was conducted in the 28 GHz band. 8K video data was transmitted by HTTP Live Streaming (HLS) from the

HLS distribution server arranged on the track side via 5G. In the train car, 8K video date is encoded with a real-time decoder and displayed on a 60-inch 8K display.
Fig.4.3.2.7 shows the state of the 8K video transmission test when traveling in the outbound direction of the railway (facing the beam). It was unstable for about 15 seconds after the 8K video was first displayed, but thereafter it was confirmed that the video was viewed stably for about 25 seconds.

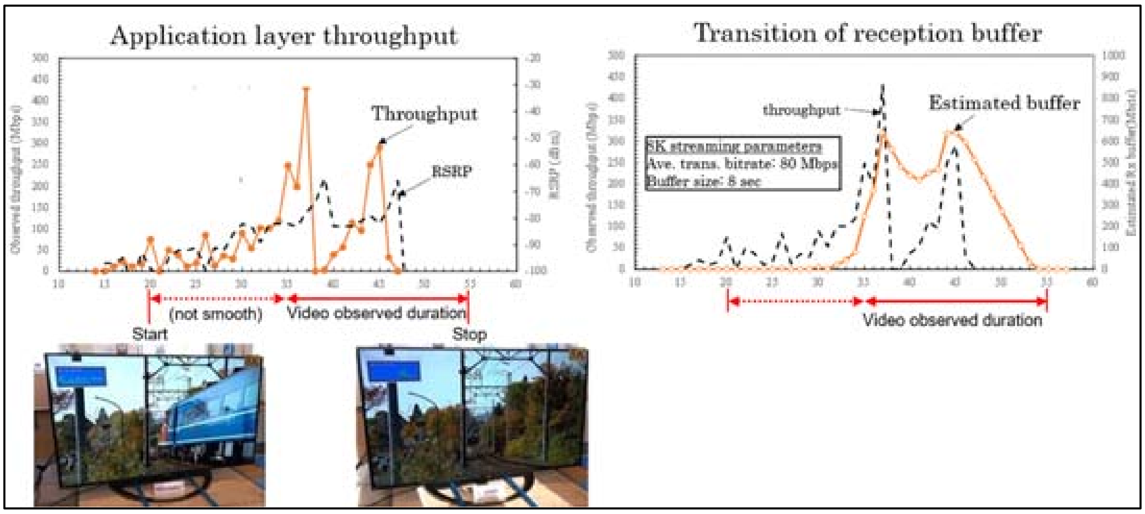


Fig.4.3.2.7 Results of 8K video streaming

4.3.3 Railway infrastructure monitoring for safe railway management

It was demonstrated that train rails and traveling area were taken in high definition from the high-speed train, and the video was uploaded via 5G to the monitoring center etc. in real time.

Period: February 18-22,2019
Place: JR Kyoto Line（near Takatsuki Station）
Frequency: 27.0 GHz - 29.5 GHz band

Fig.4.3.3.1 shows Overview of the demonstration experiment.

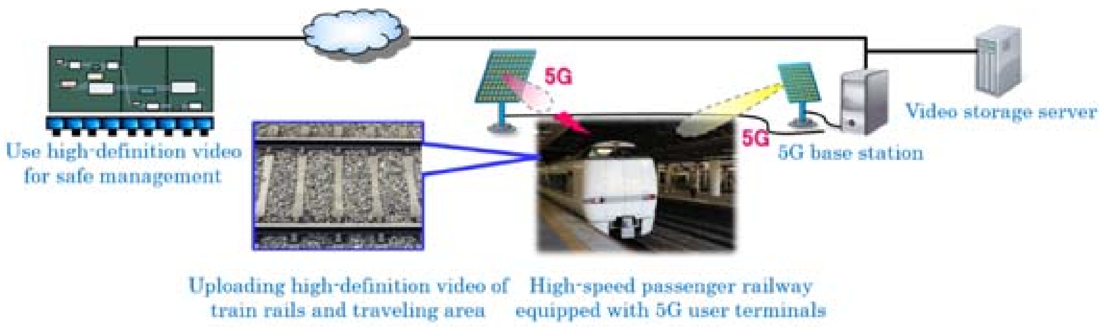


Fig.4.3.3.1 Overview of high-definition video uploading in JR Kyoto Line

We built 5G communication areas of 28 GHz near JR Kyoto Line Takatsuki Station. Four base stations were installed on the road along the railway. The 5G mobile station and cameras were installed in the cabins of JR Kyoto Line / Limited Express "Konotori". Fig.4.3.3.2 shows the arrangement of base stations.

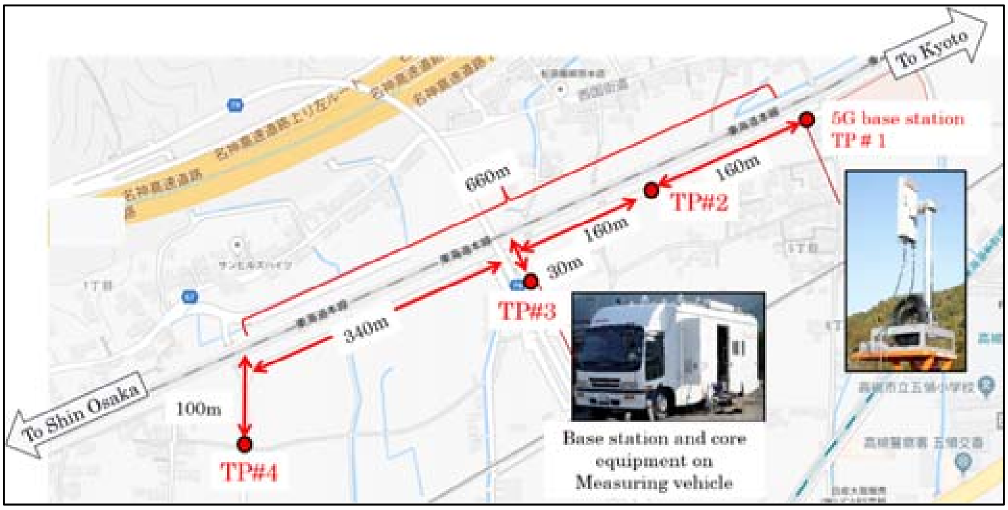


Fig.4.3.3.2 Arrangement of base stations at the experimental site of JR Kyoto line

Fig.4.3.3.3 shows 5G transmission characteristics to a train traveling at about 110-120 km / h. Maximum throughput of about 1.2 Gbps (bandwidth 700 MHz) was observed around TP4, and the average throughput of 1 Gbps or more (bandwidth 800 MHz conversion) was achieved in two seconds immediately after entering the TP4 area and three seconds immediately after entering the TP2 area.

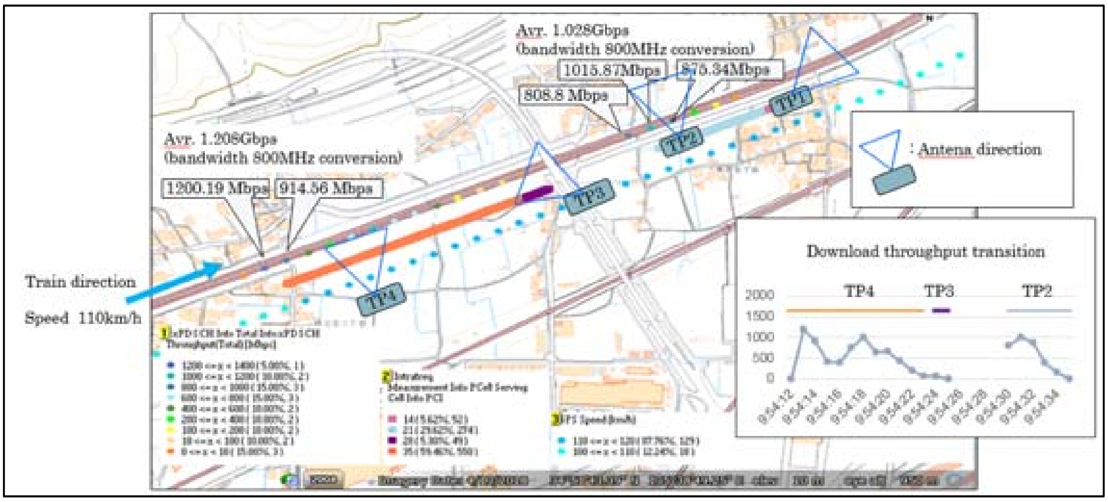


Fig.4.3.3.3 Download throughput distribution

Also, in the transmission characteristic test of the upload from the train, maximum throughput of 240 Mbps (bandwidth 700 MHz) was observed.

As an experiment of the use case, to efficiently detect rail flaws and distortions, we transmitted by uploading an image of train rails taken by a 4K high-frame rate camera from a running train. To identify the detailed condition of rails from the train running at 120 km / h, the close-up videos of the rails at 4K / 230 fps were taken. In the demonstration, it was possible to transmit the video with a bit rate of 20-30 Gbps and a length of about 1 minute, in 7 seconds passing through 5G area. In the video, we could clearly read the control numbers written on railroad ties.

Also, the traveling area was taken with a 4K live video camera from the running train, and the 4K video was encoded by variable rate video coding and transmitted via 5G uplink. It was demonstrated that the state of the traveling area could be confirmed in real time.

Fig.4.3.3.4 shows demonstration results of these two use cases for safe railway management.

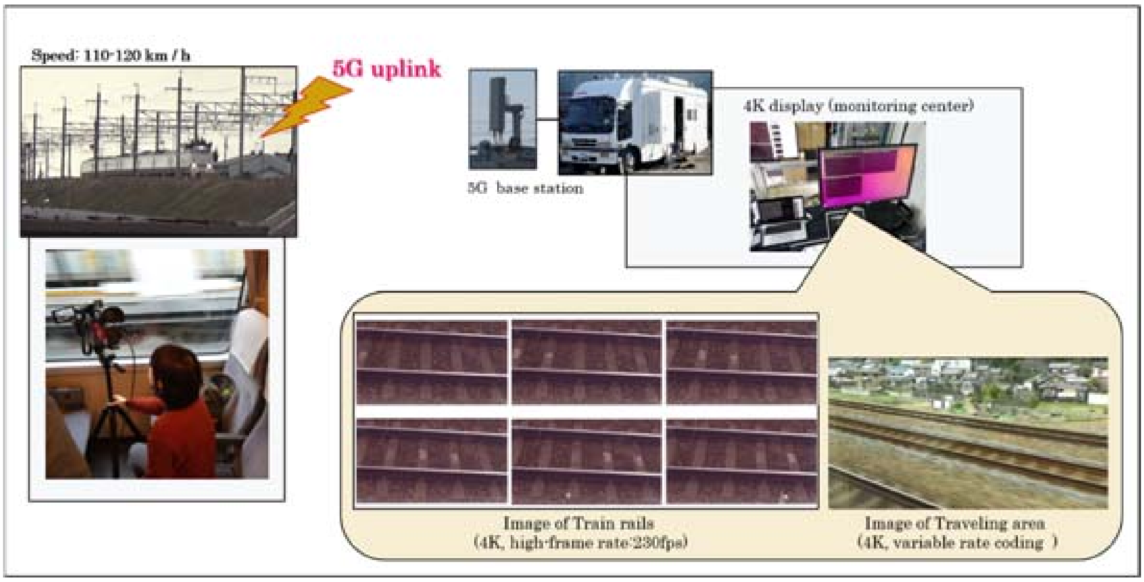


Fig.4.3.3.4 Two use cases for safe railway management

4.3.4 Conclusion

Realization of 5G high-bitrate communication in 4.5GHz and 28GHz was verified assuming high mobility such as cars and railways traveling at 60-120 km / h, in urban or rural environments. It was confirmed that 4K / 8K high-definition video content was transmitted to the train traveling at 60 km / h in urban near Tobu Skytree Line Kasukabe Station, and the video content was watched on a display or smartphone. It's considered to provide high-definition video such as the latest news of the 2020 Tokyo Olympics and Paralympics timely for a passenger of high-speed train by high-bitrate communication of Gbps order in the high-speed movement environment. Also, in suburban near JR West Takatsuki Station, it was confirmed that high-definition video of infrastructure equipment such as the train rails was delivered via 5G uplink from a train traveling at 120 km / h. It is expected to contribute to the safe railway management by allowing the state of the rails and the areas around them to be monitored efficiently in real time.

References

[1] MIC, "Start of FY2018 5G Comprehensive Demonstration Test", http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/2018_09_14_01.html, Sep 14, 2018.

4.4 5G Field Trials Utilizing High Speed Uplink Capability - application to automobile services, remote control of construction machinery, real time 4K video transmission from a drone, real time transmission of high frame rate video in a golf tournament, and Operation assistance of a snowplow vehicle-

- Responsible organization: KDDI Corporation
- Partners: TOYOTA InfoTechnology Center Co., Ltd., Obayashi Corporation, NEC Corporation, The University of Tokyo (Nakao Lab.), Fukuyama-city, Commerce Industry and Labor Bureau of Hiroshima Prefecture, TV Asahi Corporation, Hakuba village, Ritsumeikan University, Kanai doryoukou.

4.4.1 Introduction

The Ministry of Internal Affairs and Communications (MIC) started "Field Trials of fifth Generation Mobile Communication System" in the FY 2017, towards the realization of the Fifth Generation Mobile Communication System (5G). Partners of the trials include telecommunication operators as well as "verticals" to be involved in a variety of 5G use cases.

In FY 2018, MIC carried out Field Trials of 5G again, and KDDI and partners participated in the trials. [1] From October 2018 to March 2019, evaluation of 5G radio performances in various environment conditions, and verifications of five 5G use cases utilizing ultra-high-speed uplink capability in 3.6 GHz-4.2 GHz, 4.4 GHz-4.9 GHz or 28 GHz bands were carried out. This section introduces the results of the trials.

4.4.2 Technical targets and use cases

The technical targets of the trials were to realize ultra-high-speed uplink communication in 3.6 GHz-4.2 GHz, 4.4 GHz-4.9 GHz or 28 GHz bands as shown below, by using user equipment (UE) in motion at less than 60 km/h.

(i) Uplink capability of 300 Mbps (2 Gbps per base station) on average from UE in 28 GHz (assuming bandwidth of 800 MHz).
(ii) Uplink capability of 75 Mbps (250 Mbps per base station) on average from UE in 4.5 GHz (assuming bandwidth of 100 MHz).

Following three points were addressed in the trial.

A) Verification of use cases taking advantage of high speed 5G uplink capability from UE.
B) Performance evaluation of 5G uplink capability in each use case.
C) Identification of the advantage of 5G in each use case.

Five use cases are verified in the trial. Table 4.4.2.1 shows partners, trial locations, and frequency bands of each use case.

Table 4.4.2.1 Overview of Trials in FY2018

Use Cases	Partners	Trial locations (City/Prefecture)	Frequency bands
Application to automobile services	TOYOTA InfoTechnology Center	Shinjuku/Tokyo	4.5 GHz 28 GHz
Remote control of construction machinery	Obayashi Corp., NEC	Ibaraki/Osaka	28 GHz
Real time 4K video transmission from a drone	The University of Tokyo, Fukuyama-city, Commerce Industry and Labor Bureau of Hiroshima Pref.	Kashiwa/Chiba, Fukuyama/Hiroshima, Onomichi/Hiroshima	28 GHz
Real time transmission of high frame rate video in a golf tournament	TV Asahi Corp.	Chonan/Chiba	28 GHz
Operation assistance of a snowplow vehicle	Hakuba village, Ritsumeikan Univ., Kanaidoryoukou	Hakuba/Nagano	3.7 GHz 28 GHz

Table 4.4.2.2 shows the results of uplink throughput in each use case. It was confirmed that the technical targets as shown in (i) and (ii) in section 4.4.2 were achieved in every use case.

Table 4.4.2.2 Uplink throughput of each use cases

Use Cases	Frequency bands	Uplink throughput	
		Measured value	Value converted in bandwidth specified by the technical target
Application to automobile services	4.5 GHz	188.4 Mbps@100 MHz	188 Mbps
	28 GHz	95.3 Mbps@100 MHz	762 Mbps
Remote control of construction machinery	28 GHz	159.8 Mbps@100 MHz	1278 Mbps
Real time 4K video transmission from a drone	28 GHz	330 Mbps@700 MHz	377 Mbps
Real time transmission of high frame rate video in a golf tournament	28 GHz	330 Mbps@700 MH	377 Mbps
Operation assistance of a snowplow vehicle	3.7 GHz	76 Mbps@100 MHz	76 Mbps

Each use case was verified in different surrounding conditions from the viewpoint of radio propagation characteristics. Table 4.4.2.3 shows places and environment conditions of each use case.

Table 4.4.2.3 Environmental conditions of the trials in FY2018

Use Cases	Places	Conditions	
		Blockages	Other factors
Application to automobile services	Road	Buildings, and tree leaves	
Remote control of construction machinery	Construction field		
Real time 4K video transmission from a drone	Ground - Air	Buildings	
Real time transmission of high frame rate video in a golf tournament	Golf field	Tree leaves	
Operation assistance of a snowplow vehicle	Road	Tree leaves	Snow

4.4.3 Overview of Trials

4.4.3.1 Application to automobile services

Field trials of automatic detection of pedestrians and obstacles were conducted by image analysis of 4K video captured and transmitted from a moving automobile via 5G. The transmission of 4K video from a moving automobile in real time is made possible by using 5G and cannot be realized by 4G.

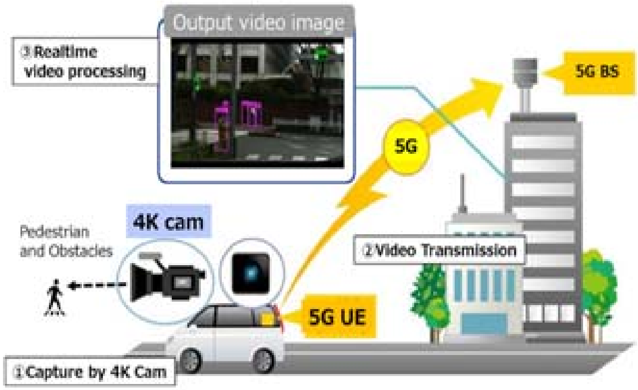


Fig. 4.4.3.1 Overview of trial for automobile services

In FY 2018, 5G radio performances were measured for this trial in Shinjuku, Tokyo. Fig. 4.4.3.2 shows the area of the field trial and the driving routes. Fig. 4.4.3.3 illustrates the seasonal fluctuation of UL SINR (Signal to Interference Noise Ratio) measured in 4.5 GHz and 28 GHz.

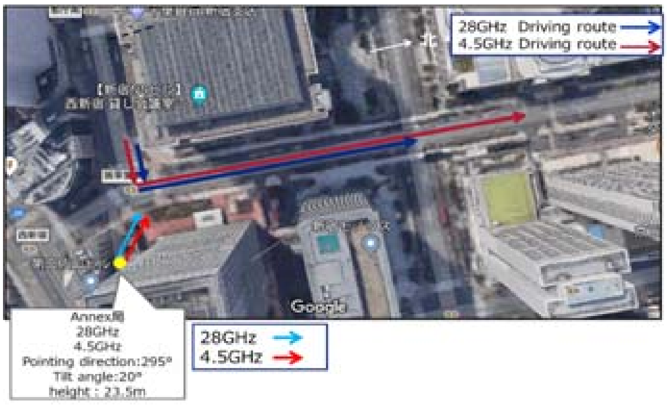


Fig. 4.4.3.2 Field trial area and driving route

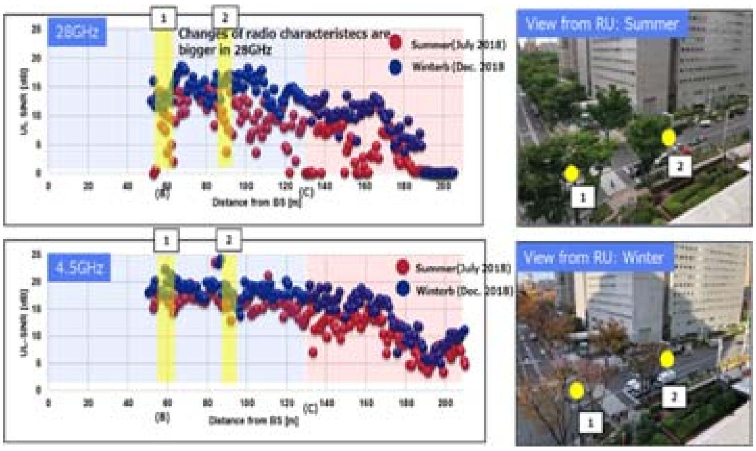


Fig. 4.4.3.3 Measured UL SINR's in 28GHz and 4.5GHz

UL SINR varies depending on frequency bands and seasons. The results are summarized in Table 4.4.3.1.

Table 4.4.3.1 Results of UL SINR measurement

Frequency bands	Summer	Winter	Diff
28 GHz	8.7 dB	15.9 dB	7.2 dB
4.5 GHz	16.5 dB	19.9 dB	3.4 dB

The values in Table 4.4.3.1 are medians in the areas in yellow in Fig. 4.4.3.3, where the line of sight (LOS) between the base station and the UE was not secured due to blockage by tree leaves. It was observed that UL SINR's in winter were better than those in summer due to defoliation of leaves, and that 4.5 GHz band is less susceptible to leaves than in 28 GHz.

Fig. 4.4.3.4 shows the result of recognition using 4K and 2K, respectively. It was confirmed that obstacles including pedestrians could be recognized from further distance by using 4K than by using 2K.

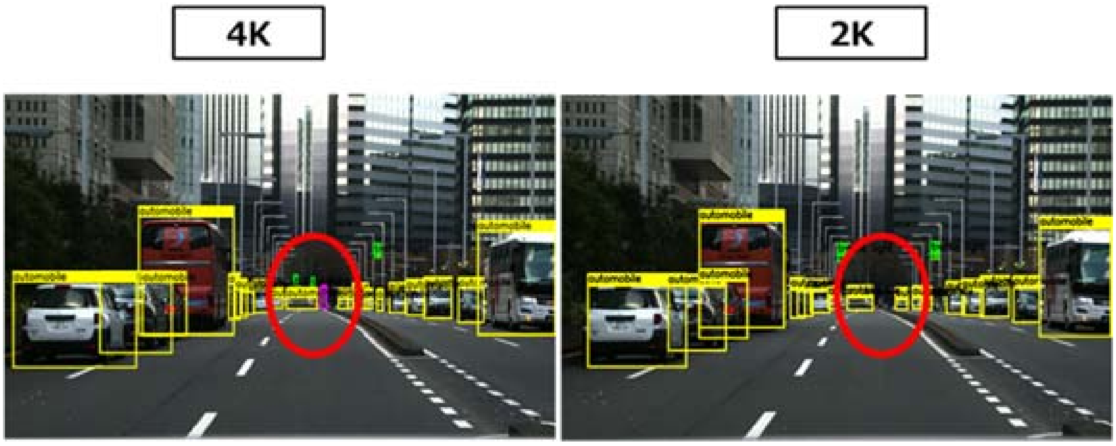


Fig. 4.4.3.4 Comparison between 4K and 2K

4.4.3.2 Remote control of construction machinery

In the trial, the application of 5G to remote control of construction machinery in recovery from landslide disaster is verified, which is expected to realize safe environment for operators as well as prompt recovery from disasters. The trial configuration is shown in Fig. 4.4.3.5.

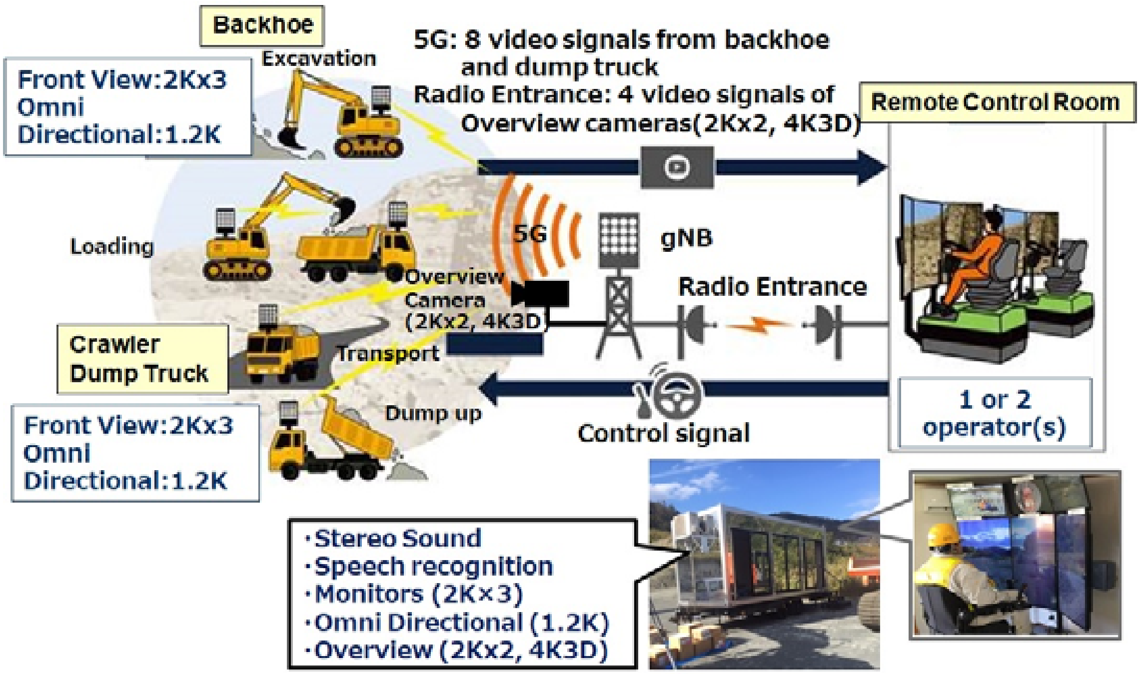


Fig. 4.4.3.5 Trial configuration for remote control of construction machinery

In the trial, in order to improve efficiency of remote control to that of manned maneuver operation as close as possible, following measures were adopted.

(i) Delivery of multiple video streams (three 2K + one 1.2K per machinery) to the remote control room.
(ii) Delivery of sound and vibration to the remote control room, in addition to video.
(iii) Reduce E2E latency less than 100 ms.

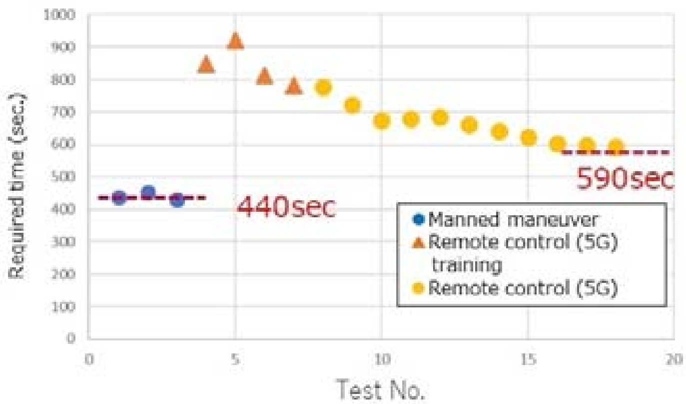
Reduction of E2E latency is essential from the viewpoint of improving operation efficiency. In the trial, considering the tradeoff between video quality and processing time required for coding/decoding, 2K video was adopted instead of three dimensional 4K video used in the trial last year. As a result, E2E latency of 80ms indoors and 100 ms in the field were realized, in contrast to 600 ms in the trial last year.

In the trial, following conditions were adopted, assuming the applications to recovery from landslide disasters.

- A) gNB on a high elevation work vehicle and remote control room on a trailer house were used, so that they can be moved easily to the disaster site.
- B) Use of radio entrance as B/H, assuming fiber is not available.
- C) Use of IP "Surrogate" to control construction machinery (versatile remote control unit developed by Obayashi Corp.).
- D) Realistic operation environment by delivering sound and vibration.
- E) Antenna direction was controlled by "Sky juster" developed by Obayashi Corp..
- F) The testing to control two machines by one operator was also tested successfully (Crawler dump truck was controlled by speech).

To compare the efficiency of this remote control system with manned maneuver, required time to perform the following cycles three times was measured as shown in Fig. 4.4.3.6.

1. Excavation by backhoe → Loading to crawler dump truck → Transport → Dump up.
2. Three bucketful of earth and sand (about 2 m^3) was transported by 40 m.



Comparison of required time

	Required time (sec)	Ratio	
Manned Maneuver	440	1	Average
Remote Control (5G)	590	1.34	Converged

Fig. 4.4.3.6 Result of trial test

Following result was obtained by the trial.

- 34% more time is required to perform the same task by remote control than by manned maneuver.
- In general, efficiency of remote control is around 50～60% as compared with manned maneuver. It turned out that the result of this time proves more efficient than other existing remote control systems using Wi-Fi.

4.4.3.3 Real time 4K video transmission from a drone

Transmission of real time 4K video from a flying drone is expected to be utilized in various fields. The potential applications will include detection of suspicious persons, adding new values to entertainments, disaster relief and so on. In the trial, two use cases, person detection from sky and virtual flight experience were verified.

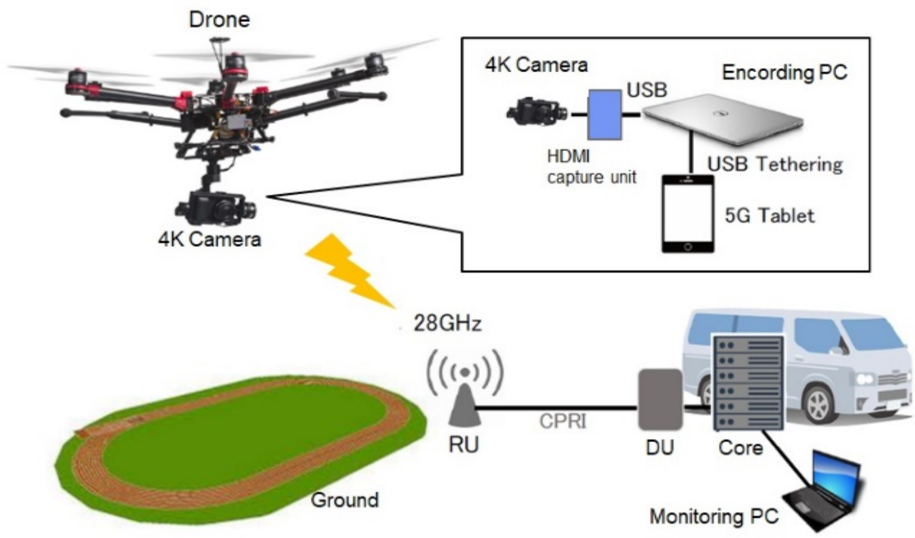


Fig. 4.4.3.7 Network configuration

5G performance was evaluated in 28 GHz in the 5G area constructed in Kashiwa 2 campus of the University of Tokyo and RSRP (Reference Signal Received Power) was measured at various altitudes lower than 150 m, as shown in Fig. 4.4.3.8. Simulation was also performed to estimate the RSRP and it was confirmed that the measurement results matched the simulated results as shown in Fig. 4.4.3.9. It was also confirmed that the radio performances of 15 Mbps required for 4K transmission was satisfied at all altitudes except for some spots.

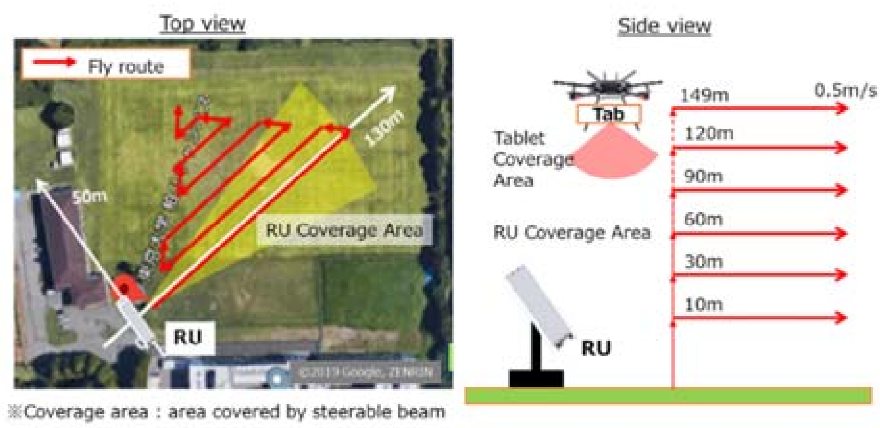


Fig. 4.4.3.8 5G coverage area and fly route

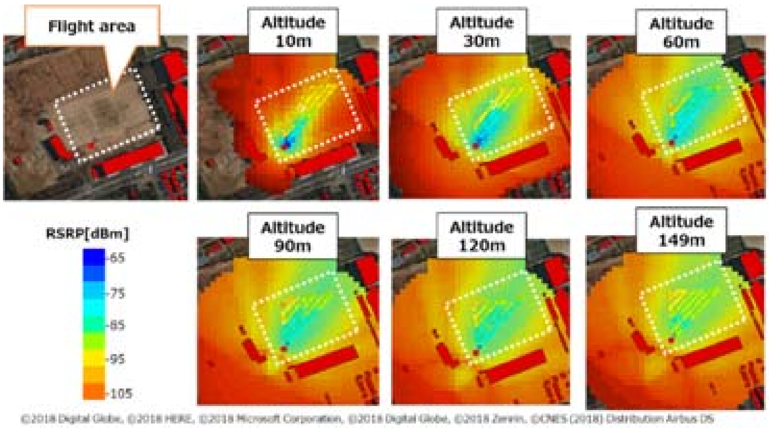


Fig. 4.4.3.9 RSRP distribution (simulation and measurement)

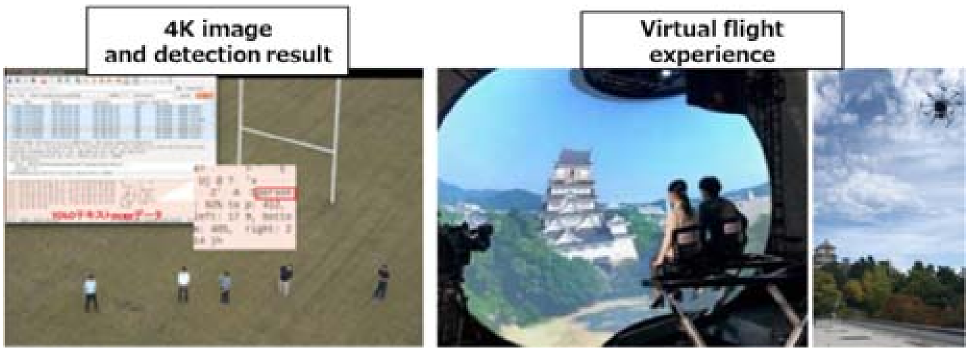


Fig. 4.4.3.10 Result of trials

4.4.3.4 Real time transmission of high frame rate video in a golf tournament

For sports casting today, transmitting a video by portable radio system (including Field Pickup Unit) is one of common manners. However, current system doesn't have enough capability or capacity to transmit 4K video.

The objective of this trial is to validate if 5G can transmit two types of 4K video in uplink in a real environment. One is "TV broadcast quality" 4K video (60 fps/100 Mbps), and the other is "TV broadcast quality" 4K high frame rate video (120 fps/200 Mbps). These videos are currently transmitted via optic fiber; 5G is expected to be an alternate solution, and also to increase camera work flexibility, taking advantage of radio access mobility.

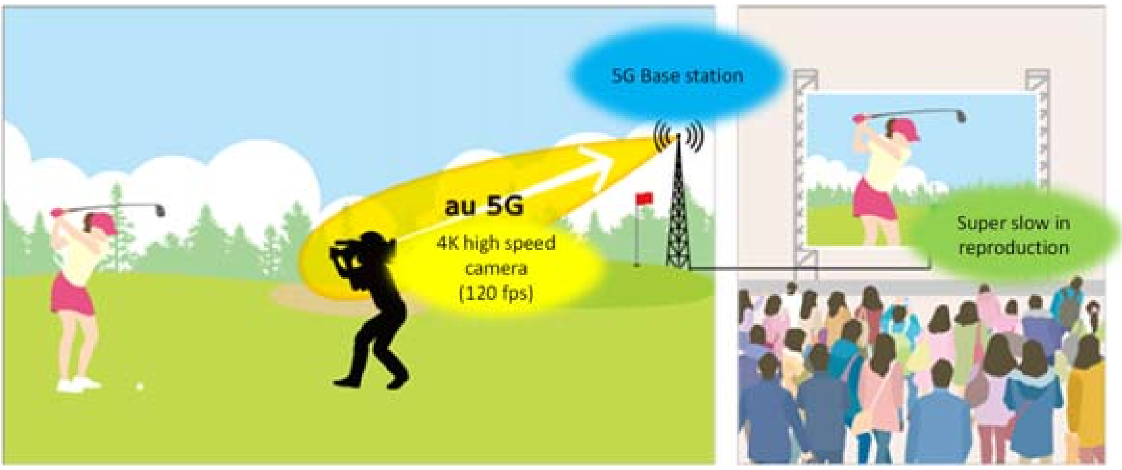


Fig. 4.4.3.11 Image of the use case in this trial

The trial took place in 18th hole of Great Island Club golf course, Chousei-gun, Chiba prefecture. Equipment configuration and location is shown in Fig. 4.4.3.12.

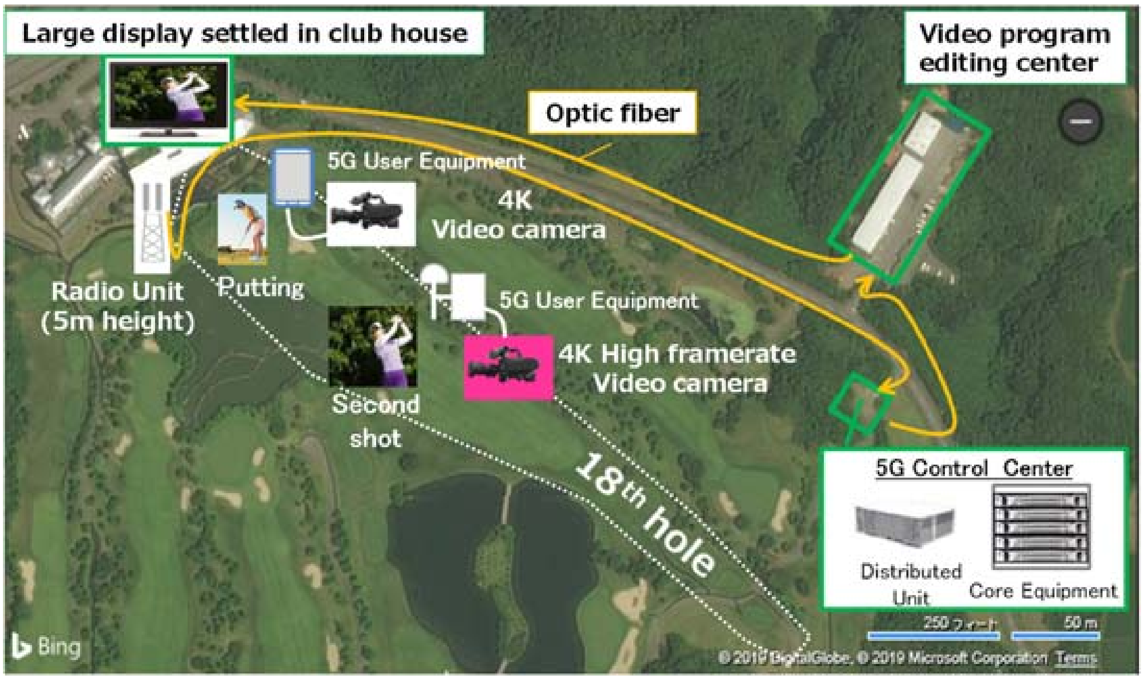


Fig. 4.4.3.12 Equipment configuration and location

Radio Unit (RU) was located on a camera tower beside the putting green. Two cameras were located in the course; one was beside the putting green with 5G UE, the other, which is 4K high frame rate camera, was in the middle area of the course, also with 5G UE to capture the second shot.

To secure enough capacity for required uplink throughput, two cells were created, and assigned for each UE. (Fig. 4.4.3.13)

5G performance was validated by using tablet type UE at the points sown as ① - ⑧.

Fig. 4.4.3.13 Cells and measurement points

As a result, it was verified that tablet type UE was able to satisfy the required uplink throughput for “TV broadcast quality” 4K video (100 Mbps) at putting green ① and ②. For the second shot, Customer Premises Equipment type UE with more uplink RF power was used, and the “TV broadcast quality” high frame rate video was transmitted in real time via 5G at 200 Mbps. The video was reproduced as super slow 4K video at an editing center, and was also demonstrated on a large display in the club house.

Fig. 4.4.3.14 The super slow 4K video demonstration

4.4.3.5 Operation assistance of snowplow vehicle

To carry out snow removal work safely and quickly is a business of vital importance in the area of heavy snowfall. The objective of the trial was to verify the potential of 5G for operation assistance of snowplow vehicle in those areas. For that purpose, the 5G area was constructed in Hakuba, Nagano, using both 3.7 GHz and 28 GHz.

The effect of snow on the radio performance was evaluated in 28 GHz. UE antenna used for measurement was installed inside a car moving at about 10 km/h as shown in Fig. 4.4.3.15. Dry snow was falling continuously during the measurement, and the amount of snowfall was 11 cm per day. In the condition above, the downlink throughput was over 500 Mbps within about 70 meters from the base station, which was 600 Mbps lower than that without snowfall. RSRP was 7 dB lower than that without snowfall. These degradations were considered to be caused by the snow attached to the surface of the base station antenna.

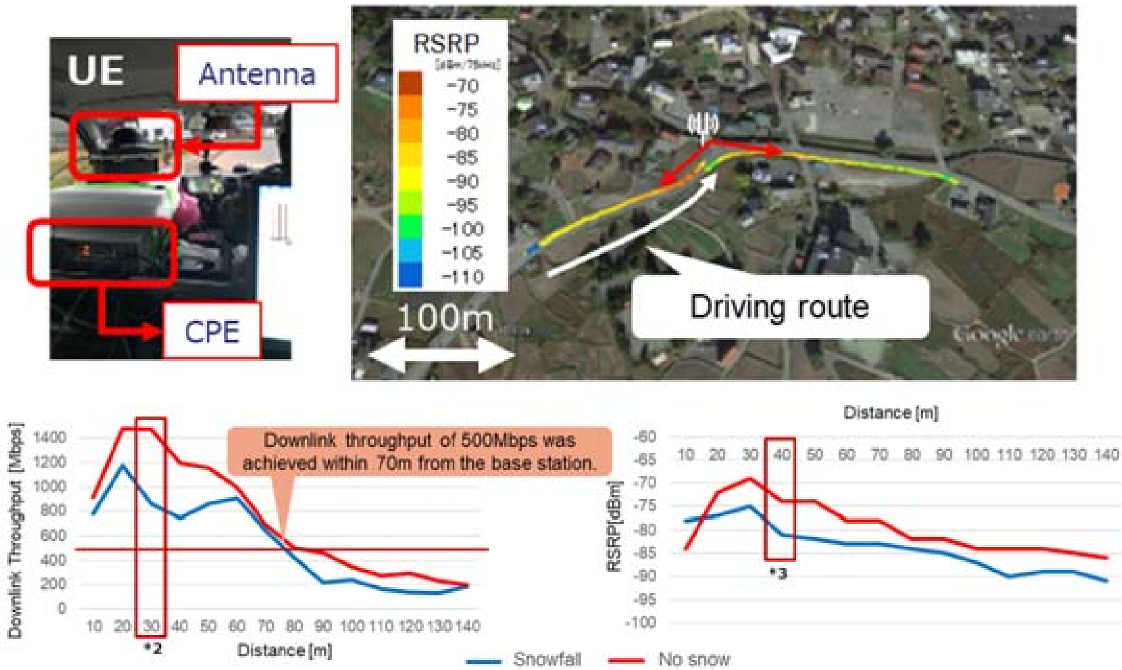


Fig. 4.4.3.15 Experimental results using 28 GHz

In snowplow operation, there is often a risk that a snowplow vehicle may damage manholes and curbs since they are under the snow and invisible from a vehicle operator. In this trial, the file containing images of manholes and curbs taken in summer were downloaded to a tablet inside a snowplow vehicle. When the snowplow vehicle approaches manholes or curbs, the image in summer is displayed on the tablet, thus the operator can be aware of the existence of structures under the snow and can avoid damages to them.

Even when it was snowing, the achieved throughput was between 600 Mbps and 850 Mbps (at TCP) at multiple points. It was confirmed that a large image data of 500 MB could be downloaded in about six seconds using 28 GHz.

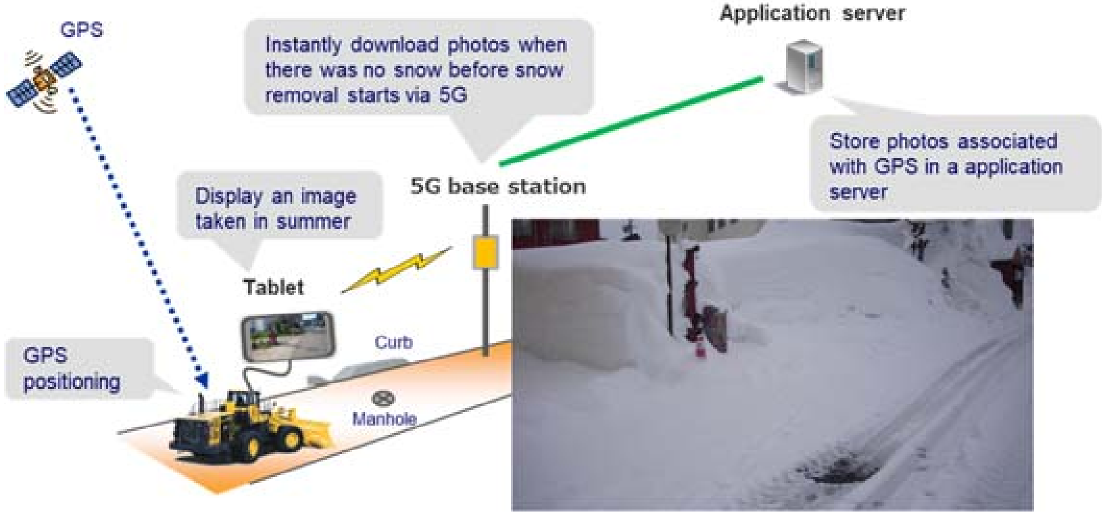


Fig. 4.4.3.16 Operation assistance system

Finally, the use case of uploading the scene after the snowplow operation in real time from a car following the snowplow vehicle in 4K video (30 fps, 20 Mbps at UDP) was verified. The testing was performed in 3.7 GHz band and the results are shown below. In the testing, antennas were installed on the top of the car moving at about 10 km/h. Within about 350 meters from the base station as shown in Fig. 4.4.3.17, the uplink throughput of 23 Mbps required for 4K video transmission was achieved, and 4K video was successfully displayed in real time.

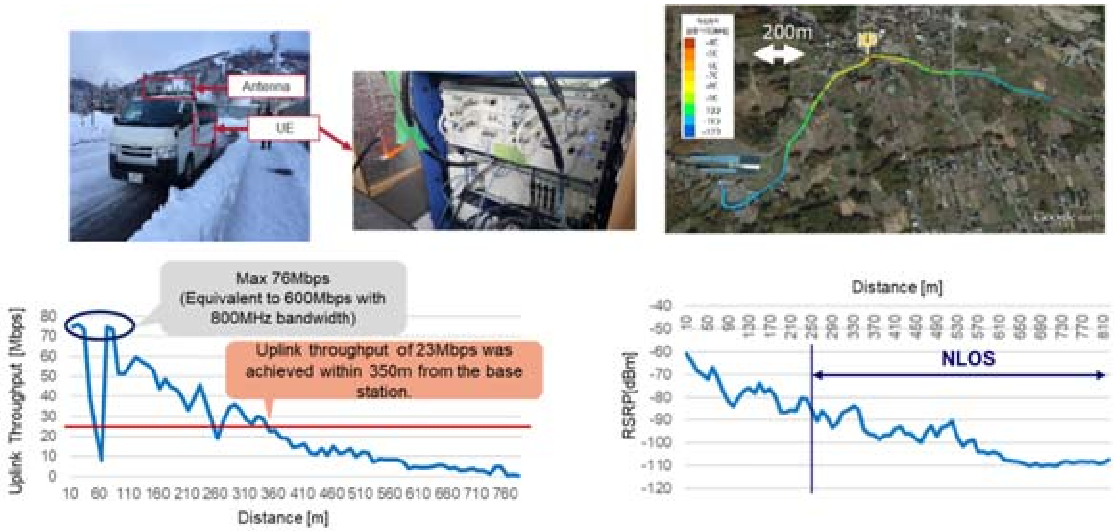


Fig. 4.4.3.17 Radio performance in 3.7 GHz

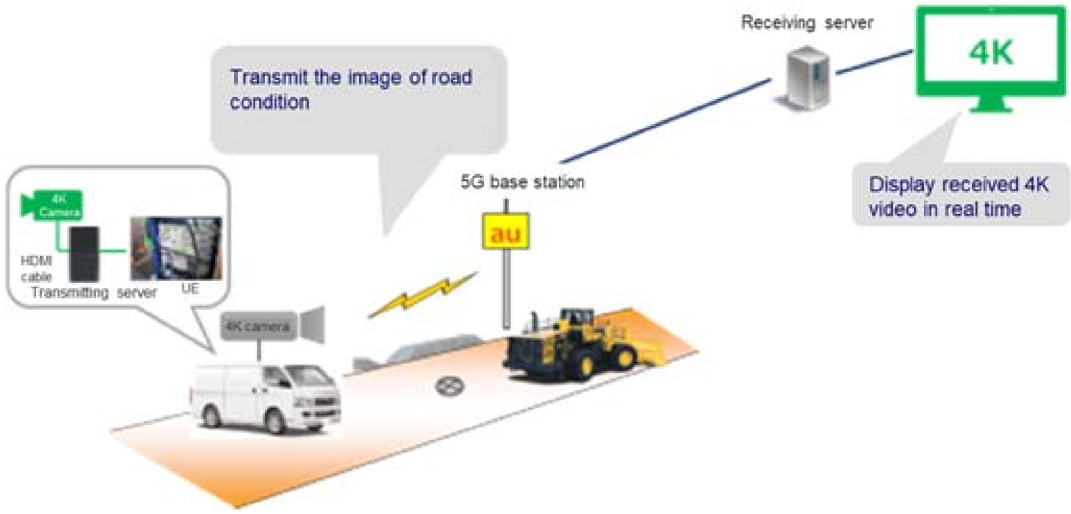


Fig. 4.4.3.18 4K video upload system

4.4.4 Conclusion

This section provides an overview of the trials utilizing high speed uplink capability of the 5G system trials in FY 2018. The results of these trials were published in [2]-[6].

References

[1] MIC, “Start of FY2018 5G Comprehensive Demonstration Test”, http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/2018_09_14_01.html, Sep 14, 2018.
[2] KDDI, “KDDI to start 5G System Trials by MIC in FY 2018” (in Japanese), https://news.kddi.com/kddi/corporate/newsrelease/2018/09/14/3384.html, Sep. 14, 2018.
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[6] KDDI, “Success in operation assistance of a snowplow vehicle using 5G by KDDI Corp. and Hakuba village” (in Japanese), https://news.kddi.com/kddi/corporate/newsrelease/2019/01/17/3561.html, Jan. 17, 2019.

4.5 5G Field Trials in Indoor Environments - For improvement of safety and security in a station, ICT education at schools, and improvement of layout flexibility in a factory-

- Responsible organization: Advanced Telecommunications Research Institute International (ATR)
- Partners: KDDI Corporation, Keikyu Corporation, Panasonic Corporation, WASEDA University, Koganei City Board of Education（Maehara Elementary School）, Kyushu Institute of Technology, DENSO Corporation

4.5.1 Introduction

The Ministry of Internal Affairs and Communications (MIC) has been leading the 5G Field Trials since 2017 to create new markets using 5G systems [1]. As part of trials, 5G testing was carried out in 28 GHz in indoor environment and it was confirmed that the ultra-high-speed communication exceeding 2 Gbps per base station on average was achieved, using 10 or more user terminals. This section describes 5G system performance evaluations and use cases verified in the trial.

4.5.2 Use cases, partners and locations of the trial

Following three use cases were verified in the trial.

1. In a train station of an international airport, improving convenience, safety and security is essential for increasing number of inbound travelers. In the trial, 5G was used to transmit 4K video from monitoring robots to a remote monitoring site, where an emergency was detected by monitoring the 4K video. Providing travel guidance of 4K video clips and language translation using 5G tablet were also verified in the trial.
2. In a school, ultra-high-speed transmission capability of 5G was utilized to download and stream educational materials consisting of rich 4K video contents, anticipating to vitalize a class.
3. In a factory, changing layout of production lines necessarily requires complicated changing wiring of signal cables, which may result in inefficiency associated with layout change. In the trial, in order to increase flexibility of layout, replacing signal cables with 5G was verified by interconnecting an industrial robot, 3-dimensional (3D) scanner and a controller by 5G. The large data of 100 MB generated by 3D scanner was sent to the controller, taking advantage of stable and large upstream throughput of 5G.

Smart Station　　Smart School　　Smart Factory

Fig.4.5.2 Conception of three trials

The following table shows the locations and partners of above three use cases.

Table.4.5.2 Locations and Partners of Trials

Use cases	Place	Partner	Location
Enhance security and safety in a train station	Haneda International Airport Terminal Station (Keikyu Line)	KDDI Corporation, Keikyu Corporation, Panasonic Corporation, WASEDA University	Ota-Ku, Tokyo
Distribution of rich contents in a class	Maehara Elementary School	KDDI Corporation, Maehara Elementary School	Koganei City, Tokyo
Increasing layout flexibility in a factory	Kitakyushu factory (DENSO Kyushu)	KDDI Corporation, Kyushu Institute of Technology, DENSO Corporation	Kitakyushu City, Fukuoka

4.5.3 Field trials in Station

4.5.3.1 The transmission characteristics evaluation

The radio performance in 28GHz including throughput was evaluated using the test environment constructed in the Haneda International Airport Terminal Station. The size and shape of the station platform are typical for many subway stations.

At each measuring point, downlink throughput was measured six times, turning the direction of tablet by 60 degrees, i.e. 0, 60, 120,...300 degrees. The result shown in Figure 4.5.3.1 indicates that at some point the throughput becomes maximum when the tablet is not right facing the RU. In the station, parts of area are in non-line of sight (NLOS) conditions, blocked by pillars, walls, and escalators. It was observed, however, that 5G communication was possible in some NLOS areas, if the reflected radio waves could be received.

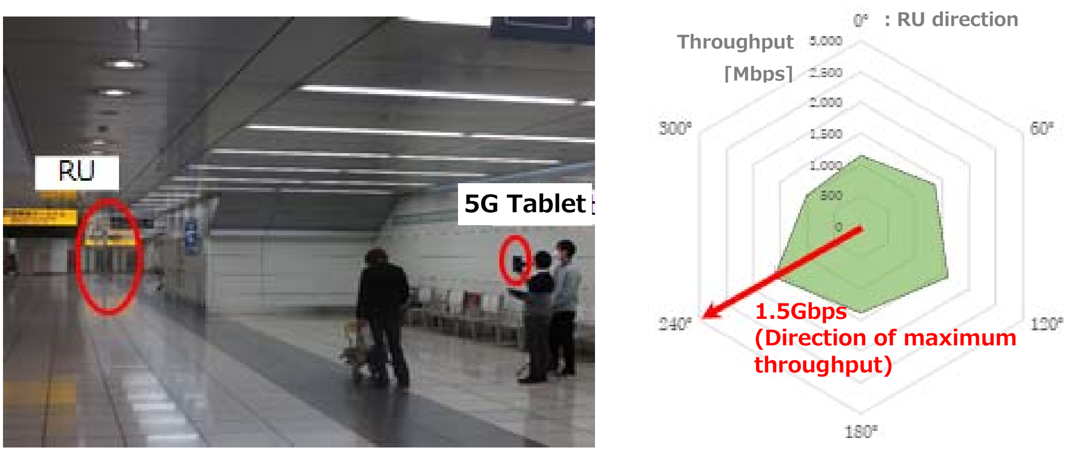

Fig.4.5.3.1 Example of measurement point and result of throughput

4.5.3.2 Applications of Smart Station

The following two applications were tested in the trial.

・Remote monitoring : A robot patrols in the station and sends video of what is happening in the station by 4K video to the remote monitoring site. At the monitoring site, the video is checked using VR goggles to see if there is any anomaly, including a sick passenger, a suspicious behavior, etc.

・Language translation with travel guidance : By using the 5G tablets with language translation applications, a station staff can answer the questions of foreign travelers, and can provide travel guidance including 4K video clips.

Fig.4.5.3.2 Scene of evaluation in Station

In the station environment, the radio performance is not spatially uniform, and varies depending on the location. Even a small displacement may cause big changes in throughput. In order to prevent interruption in this circumstance, the advantage of an adaptive-rate-control video encoder was verified in the trial, which controls the video quality according to the available data rate. Fig.4.5.3.3 shows a robot used in the trial and the coding rate of the adaptive-rate-control video encoder employed in the trial.

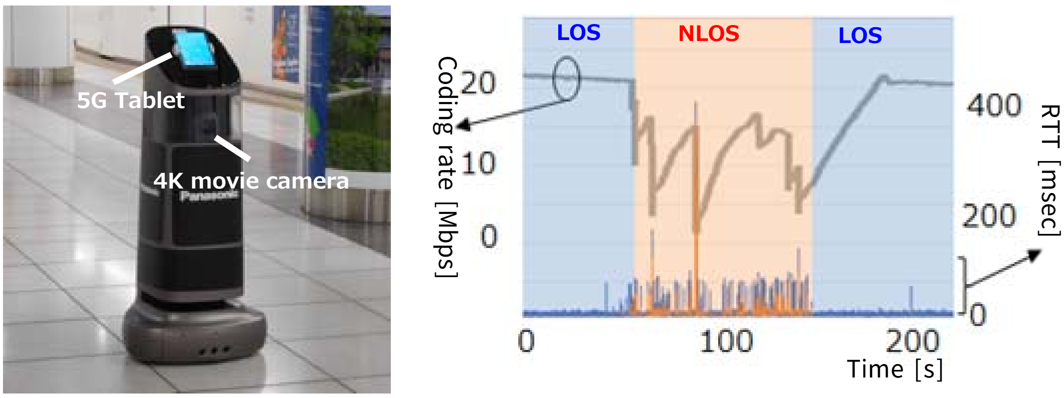

Fig.4.5.3.3 Moving robot with 4K video camera and video coding rate control verification result

4.5.4 Field trials in School

4.5.4.1 The transmission characteristics evaluation

Indoor test environment in 28GHz was constructed in a gymnasium in Maehara elementary school in Tokyo and the radio performance was confirmed. The total downlink throughput was over 2Gbps/800MHz *1 using 20 tablets simultaneously. The results were influenced by the relative locations and directions of base station and tablet antennas, since the antenna of tablet has directivity. The following are measured results and the tablet placement.

*1: In the trial, the throughput was measured in 700 MHz bandwidth and was converted to that in 800MHz, as specified in the technology target.

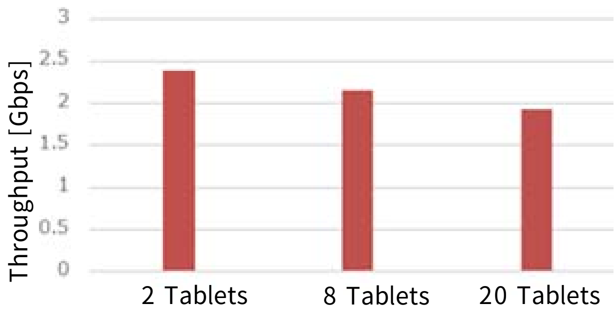

Fig.4.5.4.1 Measured results and tablet placement *2

*2：Each 5G tablet is oriented in the direction toward RU.

4.5.4.2 Comparison between 5G and Wi-Fi

In the trial, twenty 5G and Wi-Fi tablets were used respectively for download and streaming of 4K video, in order to compare the differences between 5G and Wi-Fi. As a result, the average download time for 5G was 17 seconds and all the 5G tablets finished download within 25 seconds, while it took 101 seconds on average by Wi-Fi. In streaming, all students could watch without interruption with 5G to the end, while most students experienced interruption with Wi-Fi.

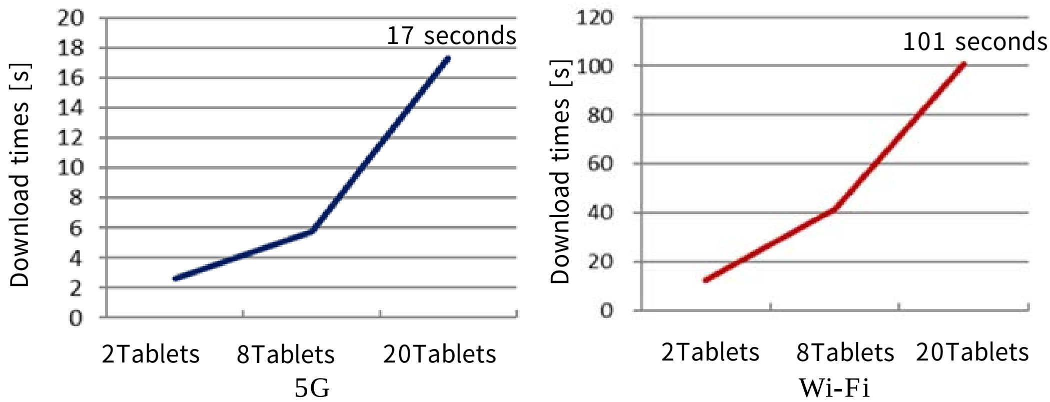

Fig.4.5.4.2 Results of download time

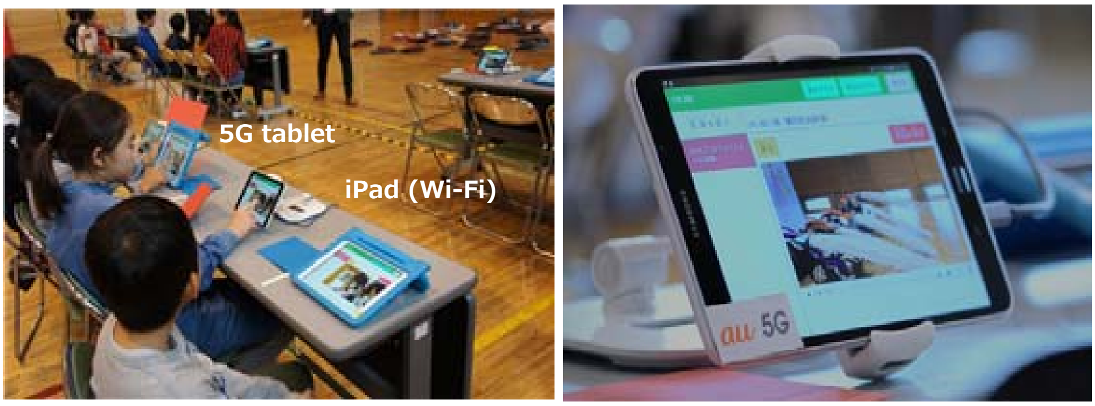

Fig.4.5.4.3 Scene of evaluation in School and Screen example used in evaluation

4.5.5 Field trials in Factory

4.5.5.1 The radio performance evaluation

In the trial, in order to confirm the impacts of machinery in a factory on 5G radio performances, the throughput was measured both when the machinery was working and when it was not working in the factory. From the measurement results, it was observed that the throughput was not affected by the operating machinery in the factory. Fig.4.5.5.1 illustrates the typical throughput when the machines are working. In the trial, the UL throughput over 100Mbps required for transmitting 3D scanner data was attained within 40m from the antenna of 5G base station.

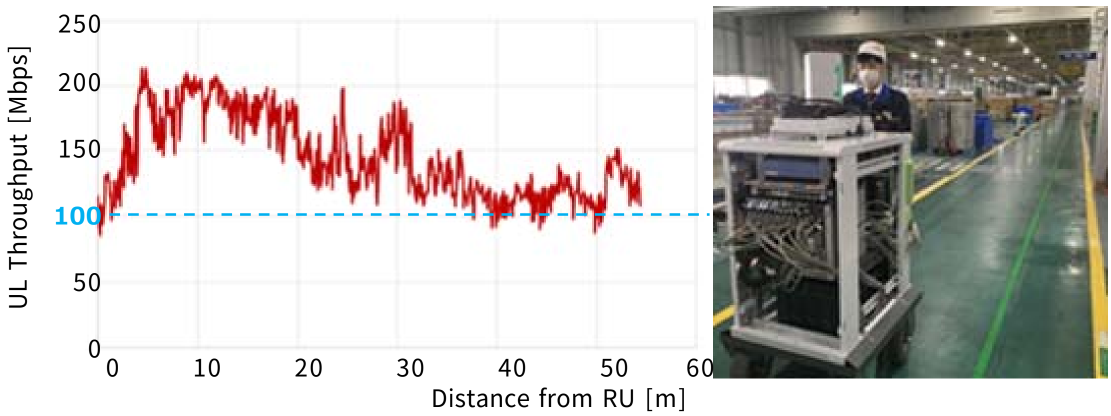

Fig.4.5.5.1 Measured result and measurement scene

4.5.5.2 Application of 5G to robot control

The system configuration for trial is shown in Fig.4.5.5.2. The position of parts was measured by the 3D scanner and was sent to the control PC. The PC controls the industrial robot to pick up the parts firmly by referring to the position information fed by 3D scanner, even if there is a displacement of the parts on a belt conveyer. By using 5G, these devices can be interconnected without complicated wiring of cables, and large volume data of 100MB can be sent from the 3D scanner, which will realize flexible layout change in a factory.

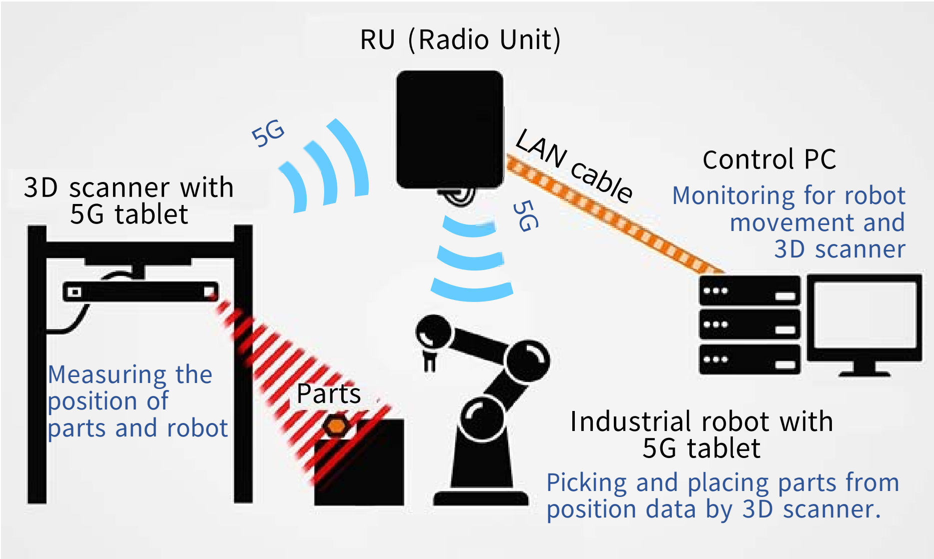

Fig.4.5.5.2 System diagram in the factory

Fig.4.5.5.3 shows the visualized image using the measurement results of 3D scanner and the uplink throughput from the 3D scanner.

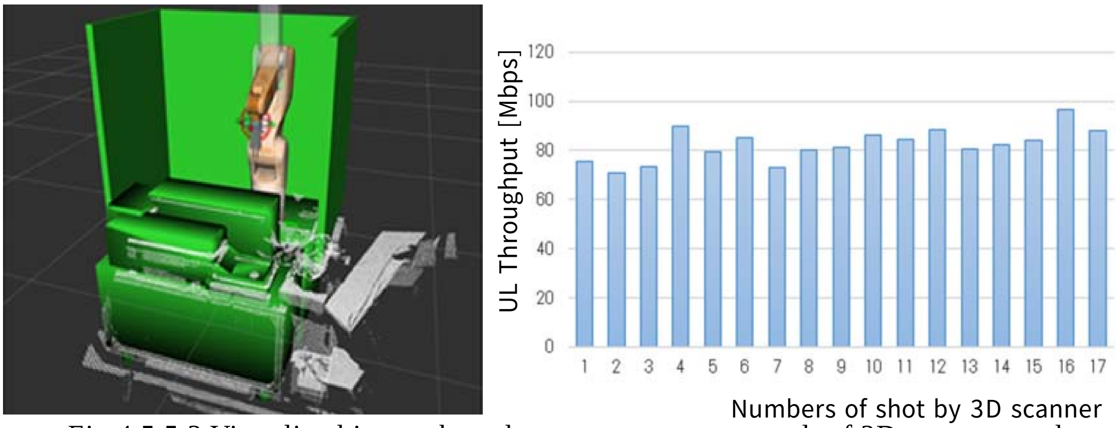

Fig.4.5.5.3 Visualized image based on measurement result of 3D scanner and uplink throughput from the 3D scanner

Recently, it often becomes necessary to change layout of machinery in factories in order to cope with small quantity of productions of a variety of products. It is desirable to reduce the down time associated with relocation of equipment as small as possible. In the trial configuration this time, the robot can start the same work as before the relocation automatically with minimal down time, using the position information of parts and a robot posture, measured by 3D scanner. In this trial, it was proved that the robot was able to be relocated and to be restarted in about 10 minutes after shut down.

Before relocating After relocating

Fig.4.5.5.4 Before and after relocating the industrial robot

4.5.6 Conclusion

This section described performance evaluation testing carried out in FY2018 for indoor applications by utilizing the eMBB capability of 5G in the 28 GHz band.

The radio performances in the 28 GHz band in indoor environment were evaluated by the 5G trial equipment. In the testing at the train station, it was observed that 5G communication was possible even in the NLOS regions, if reflected radio waves could be received. The aggregate sector throughput in the school was over 2Gbps using 20 user equipment. In the factory, it was confirmed that the coverage in which UL throughput was over 100Mbps reached up a few ten meters.

The trial evaluation results of 5G system performance showed that 5G can provide application which need ultra-high-speed communication such as HD video and 3D position data.

References

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4.6 5G Demonstration experiment on 5G ultra low latency communication for assisting autonomous driving - Truck platooning applications -

- Responsible organization: SoftBank Corp.
- Partners: Advanced Smart Mobility Co., Ltd.

4.6.1 Introduction

Research and development are underway towards the commercial roll-out of the Fifth Generation Mobile Communication System (5G) in 2020. 5G supports not only an enhanced Mobile Broadband (eMBB) but also Ultra Reliable and Low Latency Communication (URLLC) and massive connections for Machine Type Communication (MTC), massive-MTC (m-MTC). Especially, URLLC and m-MTC would potentially expand the mobile communication market to the new areas, such as mission critical and networked industrial applications. It is therefore urgent to identify new and concrete use cases as applications utilizing 5G.

In Japan, the Ministry of Internal Affairs and Communications (MIC) began its 5G Integrated Verification Trials in 2017 [1]. This trial not only attempts to demonstrate the technical evaluation of 5G systems for their future commercial roll-out, but also to invite vertical industries and a telecommunication industry to participate the trials with a view to assessing potential 5G applications and use cases.

SoftBank Corporation actively participates the MIC's trials as a member of the Trial Group V, which focuses a 5G URLLC aspect. This section introduces the Group V's activities, including the use case of truck platooning utilizing 5G networks.

4.6.2 Utilizing 5G for Truck Platooning

Truck platooning is the electrical linking of two or more trucks in convoy. They move on the highway together as a single vehicle group to reduce fuel consumption and CO_2 emission as well as to achieve more efficient use of roads, i.e. to improve road traffic capacity, e.g. the number of vehicles per km. The research and development of truck platooning is currently being conducted all over the world to this end.

Truck platooning can solve several social problems, such as 1) CO_2 emission, 2) traffic congestion and 3) aging drivers and their severe work environment. If platoons drive with a shorter inter-vehicle distance, air resistance affecting vehicles could be reduced, resulting in lower fuel consumption and less emission of CO_2 into the atmosphere. For example, it has been demonstrated that 3 trucks running in a platoon, driving at 80 km/h while separated by the distance of 4 meters, decreases those vehicles' fuel consumption by 15% [2]. If the distance between the trucks further reduces to be only 2 meters, there could be fuel savings of 25%. At the same time, this would also lead to an increase in the capacity of roads while mitigating traffic congestion. This would result in further CO_2 reductions. In addition, Japan has problems with declining birthrate and aging population. Labor shortage arising from the problems leads to the aging of drivers and their overworking. These are becoming more crucial social issues, since these increase traffic accidents and severe working environment. It is also expected that stress of the driver be reduced, and safety be improved by the introduction of the truck platooning.

Adaptive Cruise Control (ACC) measures a distance between a lead vehicle and a trailing one by using radar and keeps an inter-vehicle distance safe, corresponding to its vehicle speed. ACC is widely introduced in automotive vehicles, including trucks, to help to improve safety on the roads. There is, however, a large time delay from the instant that the deceleration of the vehicle ahead begins and that the distance between the lead and trailing vehicles becomes shorter. It further takes a larger delay until the deceleration of the trailing vehicle begins. So, in general, the longer inter-vehicle distance is needed to prevent a collision by using ACC alone. On the other hand, a

Cooperative ACC (CACC) can significantly improve the controllability when the vehicle ahead suddenly brakes, because the CAAC controls vehicle speed by transmitting the speed and acceleration data of the vehicle ahead to the following vehicles. In addition, CACC provides stable running without hunting (fluctuation of inter-vehicle distance) due to its shorter latency. To realize further improvement in fuel economy and to increase road traffic capacity, less inter-vehicle distance and larger numbers of vehicles in the truck platooning is necessary without compromising safety. The application of 5G URLLC to the area of truck platooning is highly expected since 5G provides ultra-low latency and high reliability.
In truck platooning, it also requires surveillance video transmission from trailing trucks to a human driver in a leading truck to ensure the safety operation of truck platooning. For this purpose, high bit rate video signal transmission with low latency is needed. This is a unique requirement of truck platooning. Only 5G could support this requirement.

4.6.3 Use cases in truck platooning

The Group V is working on two use cases to demonstrate 5G's ultra-low latency capabilities as follows; (1) communications between vehicles for platooning, (2) communication for remote monitoring / control of platoon from a remote site.

These use cases are shown in Fig.4.6.3.1 and Fig.4.6.3.2.

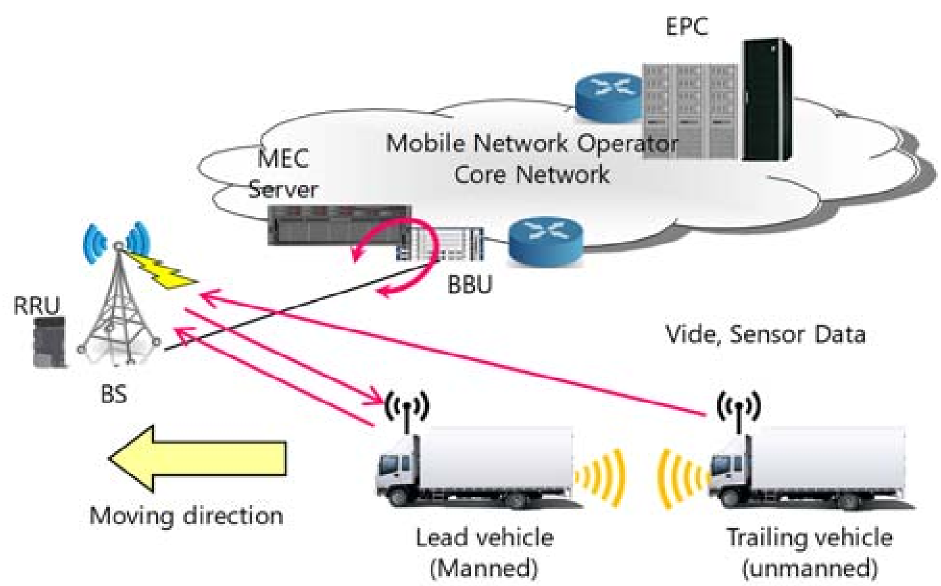

Fig.4.6.3.1 Use Case 1: Communications between vehicles in Truck platooning

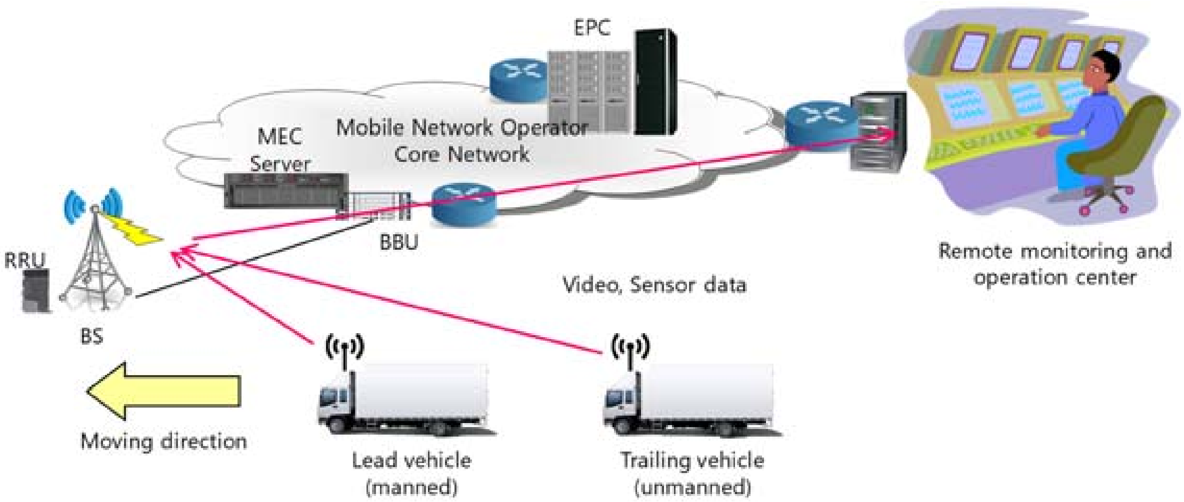

Fig.4.6.3.2 Use Case 2: Remote monitoring / control for truck platooning

Communication Requirements for these use cases can be classified into two categories; (1) low capacity and low latency communication and (2) high capacity and low latency. The first category is required for vehicle control system, which transmits and receives information of vehicle speed, acceleration and vehicle positioning. This category also requires high reliability. The second category is required for video monitoring system for platooning, which transmits and receives video streams to monitor areas around the trailing vehicles.

Fig.4.6.3.3 shows three types of communication for platooning; (1) V2N2V (Vehicle-to-Network-to-Vehicle), (2) V2V (Vehicle-to-Vehicle) Direct / Sidelink and (3) V2N (Vehicular-to-Network).

V2N2V is a vehicular-to-vehicular communication link via a base station to connect the vehicles. V2V direct is a communication link, which directly connects the vehicles. V2N is a communication link which connects the vehicles to a mobile network. The V2N2V link (1) provides relatively low latency and stable communication with the support of a base station. The V2V direct link (2) provides lower latency communication, being compared with the link V2N2V (1), but has a possibility of less reliable communication due to the interrupt of radio waves by other vehicle going in between the two trucks. The V2N link (3) is required for a remote monitoring of vehicles and a remote operation of vehicles. The link has a large latency which mainly comes from the mobile core network.

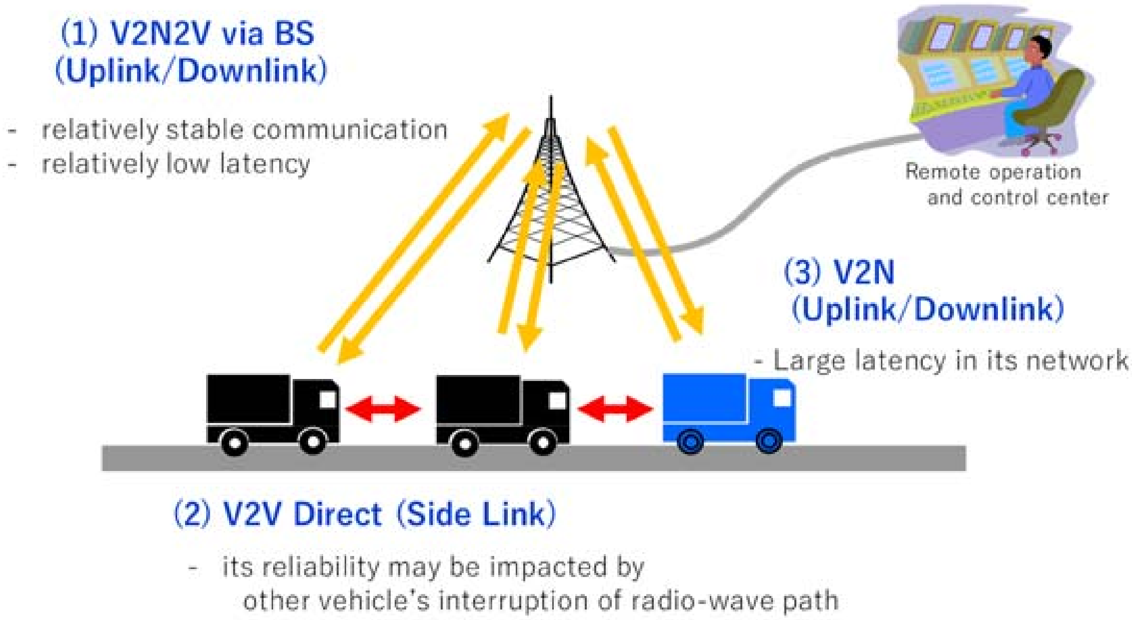

Fig.4.6.3.3 Types of communication in platooning

4.6.4 5G System Performance Evaluations in Truck Platooning Application

4.6.4.1 System configuration

5G communication test equipment was evaluated with big trucks in Ibaraki-prefecture, Japan, considering rural radio environment for platooning, e.g. a highway in a rural area. Field trials were performed for Vehicular-to-Network (V2N) and Vehicular-to-Vehicular (V2V) direct communications. (Figs.4.6.4.1)

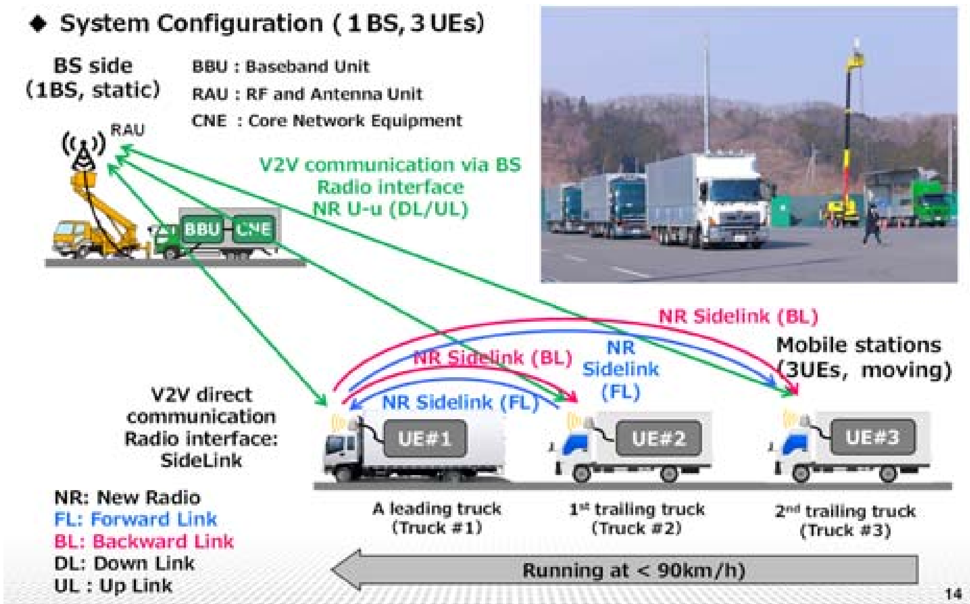

Fig.4.6.4.1 Field trial test environment for V2N communications

Figures 4.6.4.2 and 4.6.4.3 show 5G-NR based BS prototype and 5G-NR based UE (User Equipment) prototype, including side link function.

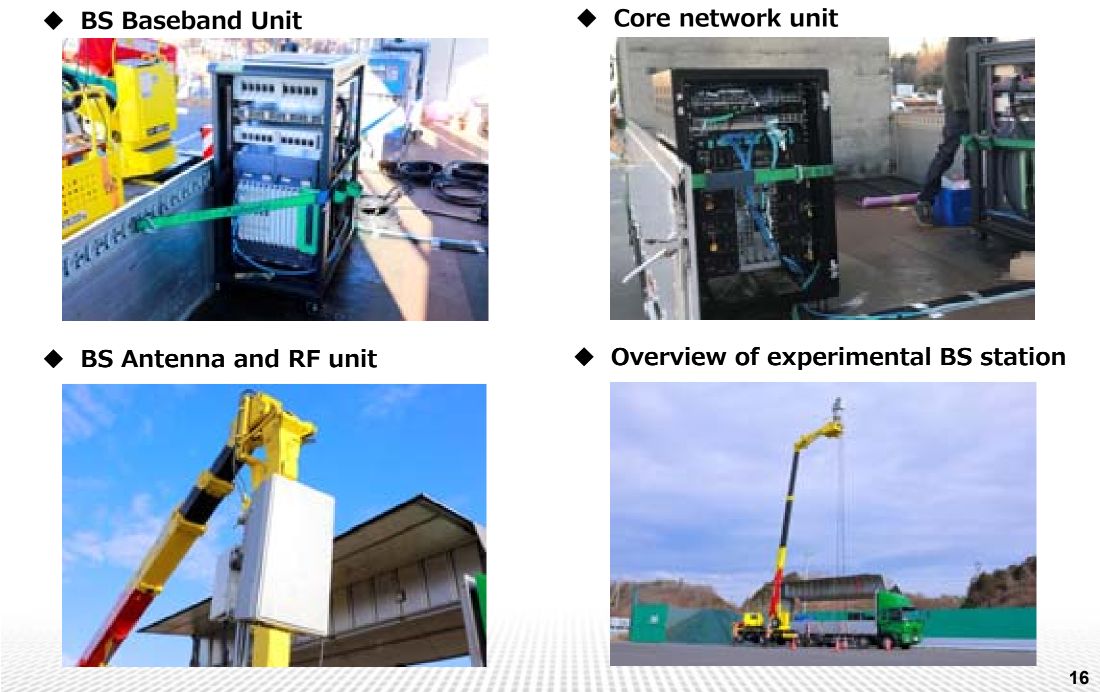

Fig.4.6.4.2 5G-NR based BS prototype

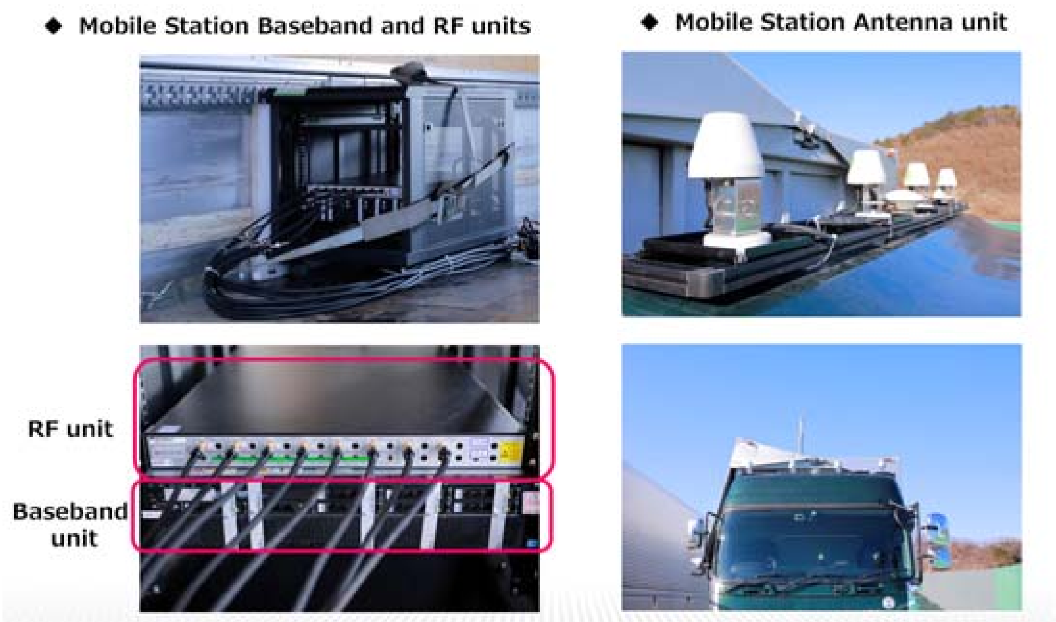

Fig.4.6.4.3 5G-NR based UE prototype

4.6.4.2 transmission latency performance of 5G-NR U-u (uplink and downlink)

Figure 4.6.4.4 shows one-way transmission latency performance of 5G Uplink and Downlink (over the air), and round-trip IP-layer latency.

The figure shows that both Uplink and Downlink one-way latency satisfy their requirement of less than 1ms. It also shows that IP-layer latency is less than 1ms (round-trip is less than 2ms).

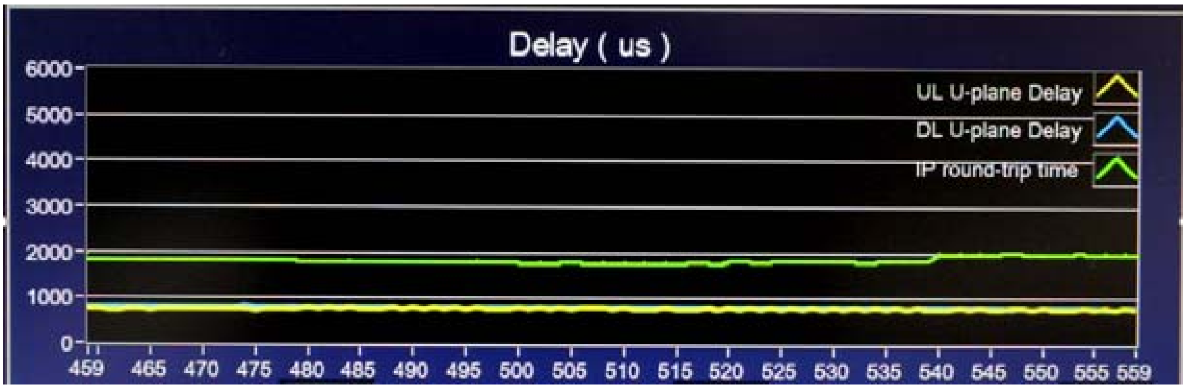

Fig.4.6.4.4 transmission latency of Up- and Down-link

4.6.4.3 transmission latency performance of 5G-NR sidelink

Figure 4.6.4.5 shows one-way transmission latency performance of 5G sidelink (over the air), and round-trip IP-layer latency.
The figure shows that sidelink one-way latency satisfy its requirement of less than 1ms. It also shows that IP-layer latency is less than 2 ms (round-trip is less than 4 ms).

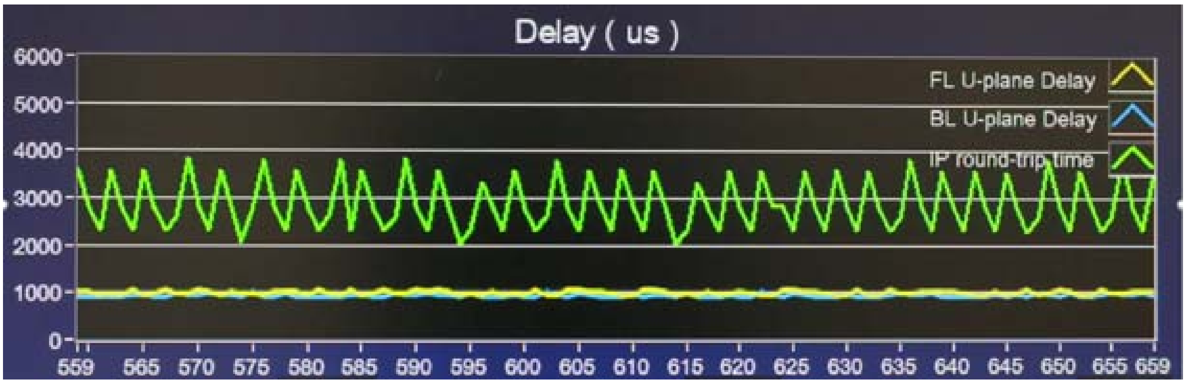

Fig.4.6.4.4 transmission latency of sidelink

4.6.5 Vehicle control message transmission over 5G sidelink

4.6.5.1 System configuration

Figure 4.6.5.1 shows system configuration of vehicle-control message transmission trial. The vehicle-control messages, including acceleration, braking and position messages, are transmitted over 5G sildelink.

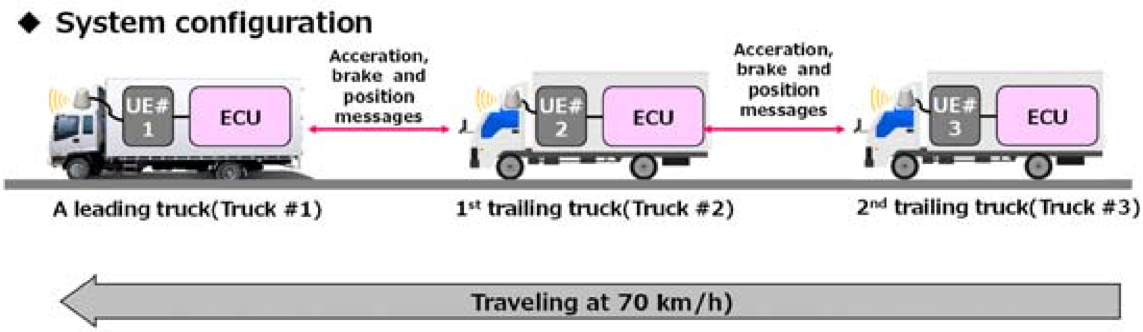

Fig.4.6.5.1 System configuration of vehicle-control message transmission trial

4.6.5.2 Field Trials on Shin-Tomei express high-way

5G Truck platooning field trials were carried out on a real highway to assess the reliability and low latency capability of 5G. Inter-vehicle distance was set 35 m, according to national traffic regulation. The speed of trucks was set to 70 km/h, which is an upper limit of truck speed on highway. Overall test course length was 14 km. Figure 4.6.5.2 depicted the trials on the highway.

Fig.4.6.5.2 Vehicle-control message transmission trial over 5G on Shin-Tomei express highway

Fig.4.6.5.3 5G Truck Platooning trial on Shin-Tomei express highway

It was confirmed that 5G ultra-reliable and low latency communication system was able to provide message transmission capabilities for 8 minutes without human driver assistance.

Figures 4.6.5.4 shows latency performances recorded inside ECU (Electronic Control Unit) of the trucks, for 4G LTE-based up- & down-link and 5G sidelink. Being compared 5G latency with that of 4G LTE, 5G sidelink can reduce around 50 ms of latency.

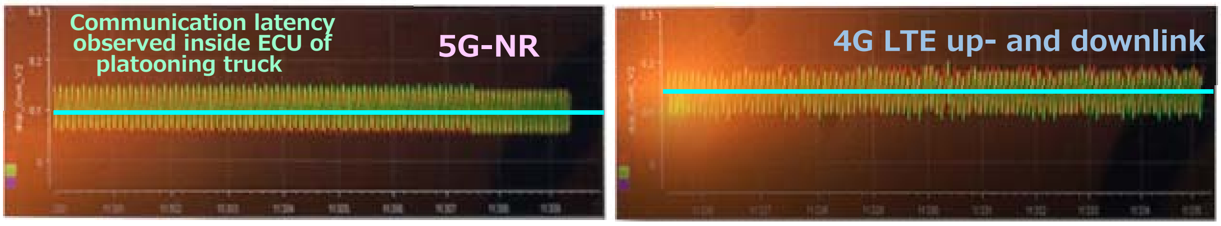

Fig.4.6.5.4 Communication latency observed inside ECU (5G-NR left and 4G-LTE right)

4.6.6 Conclusion

Performance evaluation of 5G URLLC was carried out in real express high-way to assess 5G URLLC applying to track platooning. Two use cases of (1) low capacity and low latency communication for vehicular control and (2) high capacity and low latency for video monitoring, were considered. The results show that both of these communication requirements could be met with 5G capability. 5G field trials were performed on a real highway. It was proven that 5G URLLC capability was able to meet the requirements of truck platooning.

References

[1] MIC, “Start of FY2018 5G Comprehensive Demonstration Test”, http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/2018_09_14_01.html, Sep 14, 2018.

[2] Aoki Keiji, “Achievements in Automated Truck Platooning,” ITS Japan, ITS Symposium, December 2012.

4.7 Field Trials of Massive Simultaneous Connections using 5G
- For Smart Highway and Smart Office -

- Responsible organization: Wireless City Planning Inc.
- Partners: PACIFIC CONSULTANTS CO., LTD., MAEDA CORPORATION, Aichi Road Concession Co., Ltd. Higashihiroshima City, National Institute of Information and Communications Technology, SHARP CORPORATION, ITOKI CORPORATION.

4.7.1 Introduction

Research and development on the Fifth Generation Mobile Communication System (5G) is ongoing, with the aim of commercialization by 2020. 5G is expected to be the foundation of the next generation society by providing enhanced mobile broadband (eMBB), ultra-reliable and low latency communication (URLLC) and massive machine type communication (mMTC) services. eMBB service will be applied to next generation smart phones as well as new types of entertainment, i.e., 4K/8K videos, virtual and augment reality, and gaming. On the other hand, URLLC and mMTC services will create new markets such as connected cars, IoT (internet of things), factory automation and so on.

Ministry of Internal Affairs and Communications of Japan started a three-year plan in 2017 to carry out field trials to promote 5G. [1] In these trials, a wireless system using 5G is evaluated in 5G candidate spectrums, i.e., 3GHz, 4GHz and 28 GHz bands. At the same time, the 5G wireless system is applied to many new markets with various industrial partners to show the possibilities of 5G. This chapter is an overview of the trials for 5G mMTC services. In our trials, 5G mMTC is applied to smart highways and smart offices.

4.7.2 Realizing IoT with 5G

There are two key factors to realize IoT with 5G. First, it is necessary to develop a wireless transceiver that is suitable for multiple simultaneous connections. Fig.4.7.2.1 shows a 5G mMTC wireless transceiver that we have developed for IoT. In order to realize the simultaneous multiple connections, we implemented a cut-to-edge technologies called as grant free access and NOMA (non-orthogonal multiple access) [2]. With these technologies, it is possible to accommodate 1 million devices in a single cell.

Second, it is important to extend the mobile network coverage not only for human beings but also for things, i.e., sensors, devices, machines, vehicles and so on. In current mobile network for smart phones, base stations are built at populated areas. However, in the era of IoT, a mobile network need to be expanded to remote areas such as mountainous construction sites, agricultural field, underground mines, and so on. Fig.4.7.2.2 shows an ad-hoc 5G system we have developed to expand the mobile coverage. The ad-hoc 5G system can be easily set up wherever mobile coverage is required as all necessary functions are installed in a compact frame.

Specifications

- Wireless
  - 4.7GHz
  - Grant-free access
  - NOMA
- Others
  - Small form factor (125x75x60mm)
  - Battery drive

Fig.4.7.2.1 5G mMTC wireless transceiver

Specifications

- Wireless
  - 4.9GHz
  - Massive MIMO
- Others
  - Small foot print (2.1x1.7m)
  - Max 5m height
  - Edge computing

Fig.4.7.2.2 Ad-hoc 5G System

4.7.3 Smart highways with 5G

Highways, also known as motorways in UK or autobahns in Germany, are very important social infrastructures connecting cities. A highway authority places sensors and cameras to collect data/information along the highways. For example, the traffic authority can monitor traffic volume, accidents, weather conditions from them to manage the traffic flow. The authority also checks the health condition of the infrastructures such as bridges, tunnels, and viaducts. With current technologies, they are very expensive because they need to install electric power lines and wired communication lines. Therefore, the devices cannot be placed in many locations. 5G will solve these problems. 5G provides broadband services with low latency and massive connections in a wireless way. Also, the recent advancement of device technologies allows us to power them wirelessly using high capacity batteries or solar panels. In the near future, a highway authority can collect so many data from so many devices connected by 5G. This big data will help the authority to manage the highway in a cost-efficient manner. We call this concept, “smart highway” in this article.

To prove this concept, we carried out an experiment at a highway located in Aichi prefecture in Japan. We conducted three experiments along the highway. The first experiment is for the health monitoring of a bridge. Many sensors are installed at the bridge beams and bridge piers as you can see in Fig.4.7.3.1. The sensors are called as accelerometers, which measure the small displacement of the beams and piers. In a current system, a wireless LAN with multi-hop configuration is used for collecting data from many sensors. However, it is useless because one cannot collect enough data to analyze the deterioration of the bridge in real time due to the limited data rate. In this experiment, 5G mMTC wireless transceivers, shown in Fig.4.7.2.1, are used to collect data from the accelerometers. It is shown that real time monitoring of the bridge condition is possible using the 5G based system.

In the second experiment, 4K cameras were placed at an intersection of the highway to monitor the road condition. It is a painstaking task for a highway authority to check the image from the cameras by human eyes. AI (artificial intelligence) is a useful technology to check an abnormal phenomenon from the image. One can check the phenomena in a wide area with 4K. However, it requires high data rate communication to import the image into the AI system. We employed the ad-hoc 5G system to import the image from 4K camera to the AI system as shown in Fig.4.7.3.2. It is shown that a small fallen object on the road can be automatically detected by using the 5G based 4K-AI monitoring system.

The third experiment is for a traffic jam monitoring. Usually, traffic counters are used for the monitoring. However, it is very expensive to install them as we need to install power and communication lines in advance. We developed a traffic counters using wireless communication and solar panel as shown in Fig.4.7.3.3. Therefore, one can place the counters in various places without special arrangement for power and communication lines. We installed 5 traffic counters along the highway as shown in Fig.4.7.3.3. As a result, we can monitor the length of the traffic jam more precisely compared to the existing expensive traffic counter that is located in a very limited place.

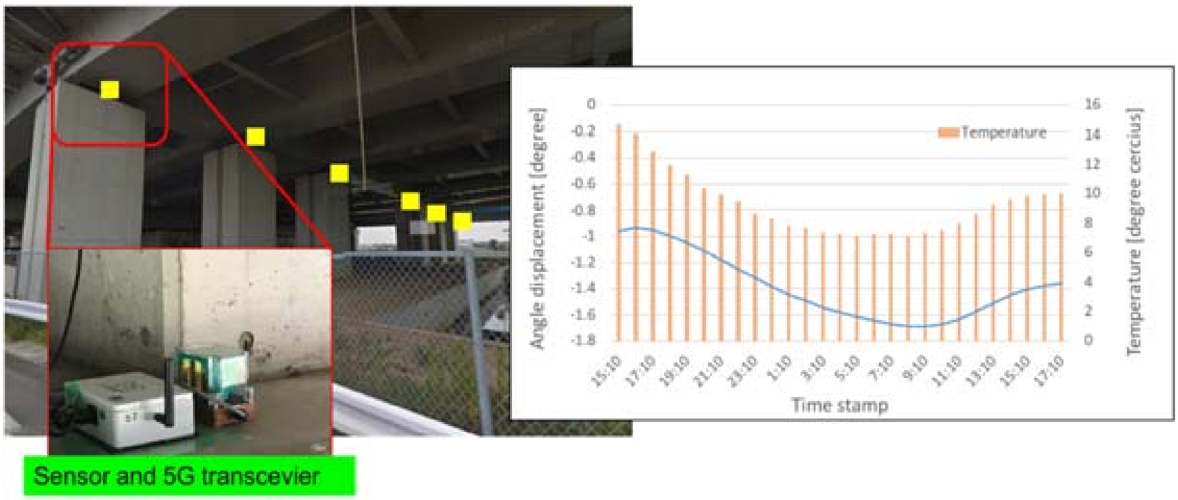

Fig.4.7.3.1 Health monitoring of highway bridge.

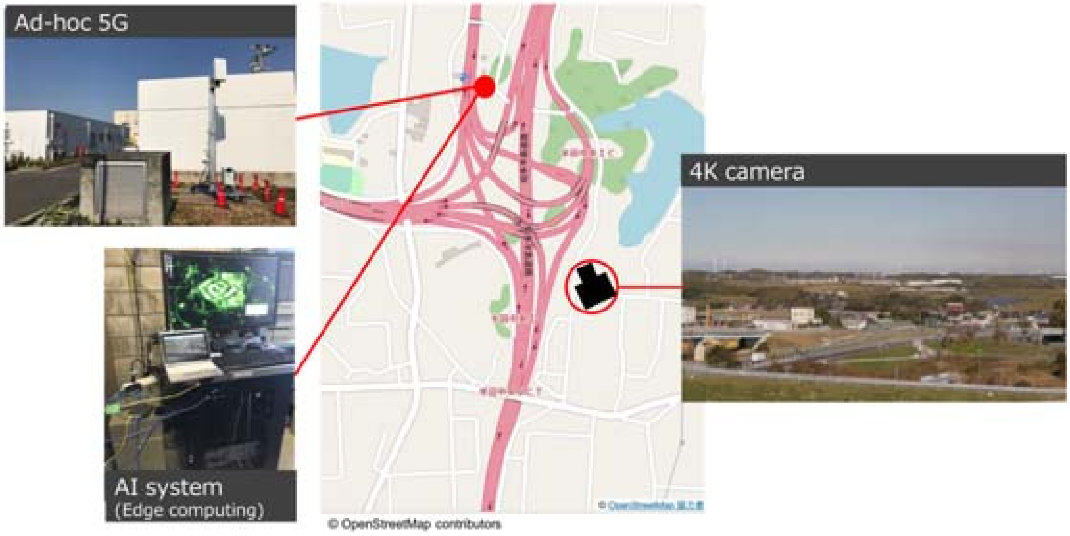

Fig.4.7.3.2 Road monitoring at highway intersection.

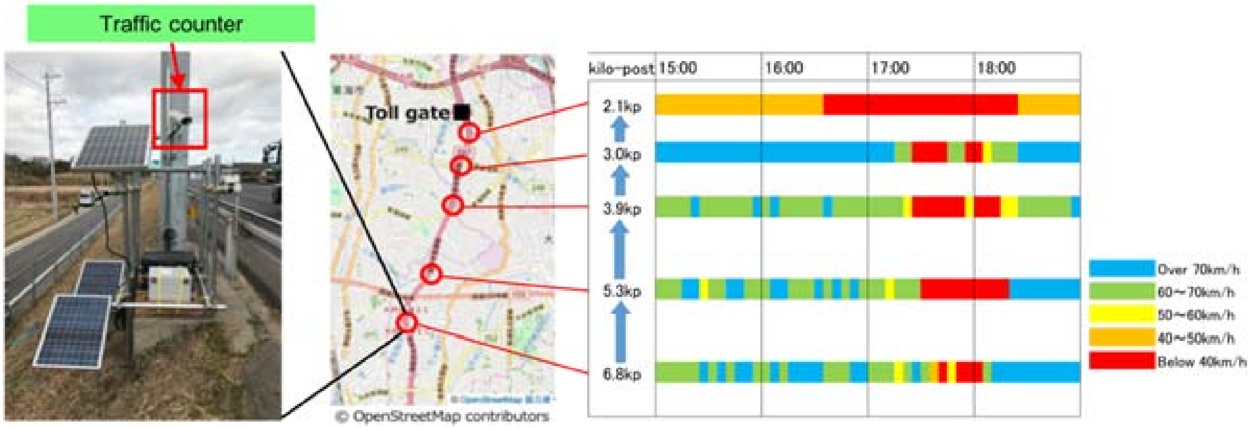

Fig.4.7.3.3 Traffic jam Monitoring using traffic counters.

4.7.4 Smart Offices with 5G

In this smart office experiment, which is conducted in Higashi-Hiroshima city office in Japan, we evaluated two concepts in a future office. The first concept is "healthy workplace". Many sensors are installed in office furniture such as desks and chairs to monitor the heart beats, pulses, breathings, stresses of the office workers when they are working. At the same time environmental sensors are employed to measure the temperature, humidity, air-pollution in the workplace. The collected data is used for analyzing the relation between the health condition of the workers and the environmental indicators. The 5G mMTC wireless transceivers are used to collect the data from these sensors as shown in Fig.4.7.4.1.

The second concept is "virtual office". The role of the workplace is changing recently. Many people tend to work from home for their personal reasons. They want to work from home as if they are in their office. The virtual office concept is useful in the case of a disaster because the information obtained in a disaster site can be shared with the headquarter for quick recovery. Advanced IT tools such as 4K/8K image/video and virtual and augmented realities are very useful for this purpose. We connected these tools using various wireless technologies to provide the virtual office service in this experiment.

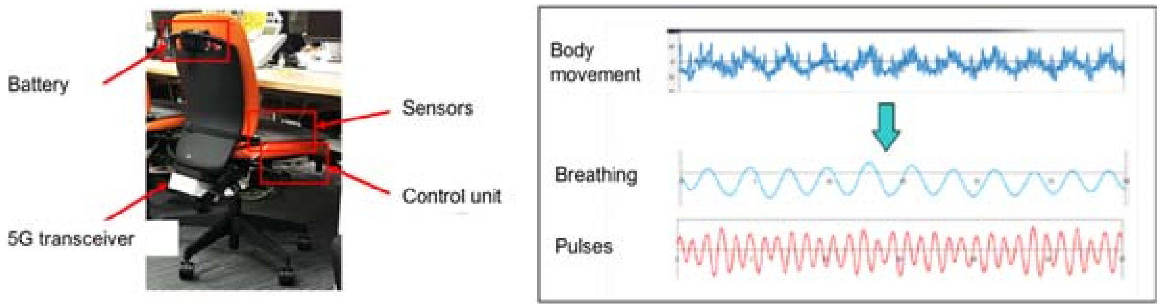

Fig.4.7.4.1 The Smart Office Trial

4.7.5 Conclusion

In this chapter, we provided an overview of the experiment to realize IoT using 5G mMTC technology. We developed an mMTC wireless transceiver and an ad-hoc 5G system. A smart highway trial was held in collaboration with a highway authority to help them manage their traffic flow as well as the health monitoring of their infrastructure. Smart office trial was also being held in collaboration with Higashi-Hiroshima city office, in which the health conditions of the workers and working environment were being monitored. In both trials, we found that 5G is very useful to collect huge amount of data from many devices in a cost-efficient way.

References

[1] MIC, "Start of FY2018 5G Comprehensive Demonstration Test", http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/2018_09_14_01.html, Sep 14, 2018.

[2] Y.Okumura, 5G system trials in Japan, 6th global 5G event, Nov. 2018, Rio de Janeiro, Brazil, available at http://www.soumu.go.jp/menu_news/s-news/01kiban14_02000347.html.

[3] M.Moriyama et al., Efficient radio access for massive machine type communication, IEICE Tech. Rep., vol. 117, no. 297, SRW2017-56, pp. 5.

4.8 Summary

This chapter introduced the content and the outcome of MIC's "5G Field Trials" in this fiscal year 2018. From section 4.2 to 4.7, six groups showed the overview of 5G system performance evaluations by using eMBB, URLLC, and mMTC technologies in dense urban, urban, rural outdoor or indoor environment carried out all over Japan. The frequency bands used for the 5G Field Trials are 3.7 GHz, 4.5 GHz, and 28 GHz, which were allocated to the frequency bands for 5G commercial services starting in 2020, and many partners in various utilization fields participated in the trials as well as those related to the mobile communications industry to create a new market through actualization of 5G.

Moreover, MIC's "5G Utilization Idea Contest" from users and consumers' point of view was conducted in this fiscal year 2018 and 785 ideas were proposed all over Japan. 5G Field Trials adopting the new 5G utilization ideas that lead to solutions to regional issues and local revitalization will be conducted in fiscal year 2019.

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June 14, 2019