General Report on 5G System Trials in Japan from 2017 to 2020

March, 2021

5G Trial Promotion Group

The Fifth Generation Mobile Communications Promotion Forum

Contents

Preface

Mr. IGARASHI Hirokazu

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

I am very pleased with the release of "General Report on 5G System Trials in Japan from 2017 to 2020".

MIC finalized its three-year 5G field trials project in March 2020 with enormous success. I felt that the main driving force for the trials in the first year was technology in many cases, but that the ones that took place in the last year were shaped and driven by real application needs that contributed to solving actual regional challenges. This is proof that social needs for 5G are emerging.

In this compilation booklet, we have explained what this project has addressed during its 3 years. I believe that the information contained in this booklet is helpful for understanding what 5G can do for society.

5G services in Japan were commercialized in March 2020. With the start of 5G services I am sure new markets will be created, and that it will make a significant contribution to solving social issues, such as labor shortages caused by Japan's low birthrate and aging population.

ICT is an essential part of our lives. The need for a new kind of lifestyle has been emerging ever since the COVID-19 pandemic started. ICT, and especially 5G, will be an enabler for a new era of both work styles and lifestyles. I hope the good practices presented in this booklet will help in the creation of a 'new normal'.

And last but not least, I would like to take this opportunity to thank everyone who has been involved in these field trials.

Mr. OHMURA Yoshinori

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

On behalf of 5GMF, I am great honor to release “The Third and Final in a series General Report on 5G System Trials in Japan 2020” by 5G-TPG (5G Trial Promotion Group).

5GMF was established in September 2014, to accelerate study of 5G systems in Japan and to facilitate collaboration with other countries, and contribution to international standardization at the ITU-R and other organizations. The 5GMF began its activities bringing together participants from industry, academia and government, promoting cooperation and collaboration among specialists in a wide range of fields not limited to information and communications.

The 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 has supported the 5G System Trials by MIC since 2017 and disseminated information on these trials domestically and globally as speakers to many workshops, academic symposiums and exhibitions etc.

In these trials, the 5G system performances were evaluated and radio wave propagation characteristics on especially 28 GHz band were measured in various application environments to solve social issues and apply to industrial fields. The possibility for the perspectives, it is observed clearly that the 5G system will be developed not only for communication but also as social infrastructure by utilizing new insights. Regarding new normal life for COVID-19 at this time, it is expected that the some useful functions of 5G systems can be utilized as the backbone of fields such as work from home, health care area, education, finance, and public services with a remote access.

I hope that this booklet will be useful for all the people concerned and interested to understand and utilize 5G systems globally. I would like to express sincerely thanks to all leadership and member of 5G-TPG who made it possible to release three booklets through vigorous activities over three years.

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 has been 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" as a three-year program 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. It can be said that such a large-scale program for the next-generation mobile communication system was a new challenge that we had never experienced for each mobile communication system of the past generations.

The 5G-TPG created the 5G-TPG Report, which could be considered its annual report, and distributed it as a booklet at the past Global 5G Events that have been held every six months around the world. The "General Report on 5G System Trials in Japan from 2017 to 2020" edited this time is third edition of 5G-TPG Report, and can also be considered as an integrated edition of all 5G-TPG Report so far, which includes outcomes of 5G field trials conducted from FY2017 to FY2019.

Commercial 5G services were started by operators in Japan towards the end of March, 2020. On the other hand, a new generation of mobile communication system has evolved about every decade in the past. It is expected that 5G will also spread and use of services will continue to expand in the next decade, and it is believed that the system integrated verification trials of 5G, discussed and implemented by the 5GMF and 5G-TPG over the five years from 2015 until commercial services began, will be a driving force behind this expansion.

Chapter 1 Introduction

The Fifth Generation Mobile Communications Promotion Forum (5GMF) was established in September, 2014, to promote implementation of 5th Generation mobile communications systems (5G). It proposed that system integrated verification trials of 5G linking wireless communication, network applications and user devices (UE), be conducted starting in FY2017, and established a task force and then a 5G trial promotion group to study specific content of such trials. The 5GMF is publishing this general report in order to summarize the activities in the preparatory stage of the 5G system trials in Japan that started in 2015, and the many various trials that were carried out over the three years from FY2017 to FY2019. In this chapter, the following sections describe the path taken by the task force/the promotion group in its activities on promotion of 5G system trials.

1.1 Preparation for System Trials on 5G

In September, 2015, the 5GMF planning committee established the System Integrated Verification Trial Initial Planning Task Force (called the “Initial Planning TF”) as a subcommittee, to draft a plan for conducting system integrated verification trials of 5G. Based on the results of hearings with 5GMF members, the Initial Planning TF created a draft plan enumerating trial items, details, equipment, and examples of applications and services that could be tested, for three categories of radio communication trials. These included a trial of high speed and capacity of the low-SHF band (below 6 GHz) communication, of high-speed and ultra-high-speed (ultra-low-latency) high-SHF band (over 6 GHz) communication, and of device-to-device communication with different types of wireless systems. Later, in January 2016, the 5G Trial Promotion Group (5G-TPG) was established within the 5GMF, to study a concrete plan and framework for conducting system trials across the various 5GMF committees, for technology, networks and applications. The 5G-TPG was composed of members elected from each committee (from 28 5GMF ordinary members as of June 2016). In the FY2016 preparation stage of the 5G-TPG activities schedule at the time (Fig. 1.1-1), the group promoted advance preparation and planning for conducting system integrated verification trials based on results from the Initial Planning TF, and in the FY2017 and later execution stage, the reorganized group promoted building the actual trial environments, selecting trial execution members and trial equipment, and executing the trials.

In the actual preparation stage, the 5G-TPG solicited proposals for concrete 5G utilization projects (suitable as trial themes) from the constituent members. After organizing the proposed projects in terms of trial content, trial environments, trial time-frames, related organizations and other factors, the results were published in a report (5G Utilization Project Plan – English Edition) in September, 2017. The report mentions a wide range of use cases in a total of 36 5G utilization projects, which are categorized into six fields such as Entertainment, Automobile-related, Crime prevention, and Disaster prevention. It lists trial environments associated with each use case, such as stadiums, shopping malls, theme parks, train stations, and airports; and gives specific locations with consideration for regional balance, and a desire to build trial environments in all regions, and not just the Tokyo area. The major contents of the report are introduced in Chapter 2 of this general report.

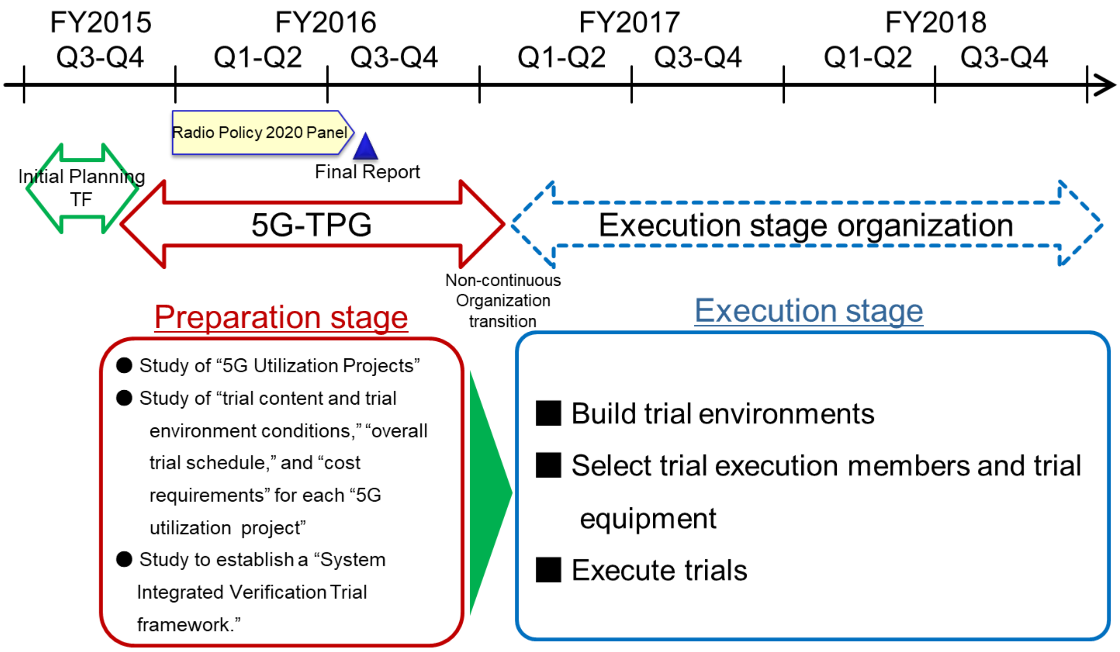


Fig. 1.1-1 5G-TPG activity schedule

1.2 Execution Stage for 5G Field Trials

The 5G-TPG later identified several projects desirable to execute as the system integrated verification trials of 5G at the beginning of FY2017, and began study with the goal of creating concrete execution plans and frameworks for each of the projects by the end of 2016.

On the other hand, the Ministry of Internal Affairs and Communications (MIC) had been promoting research and development on 5G radio communication technologies to realize ultra-high speed, high capacity, low latency and massive connectivity since FY2015. The basic framework for conducting the 5G Field Trials also incorporated this 5G research and development, and so called, "Technical Examination Service" work by the MIC, on systems that combined new applications and services envisioned for 5G, to identify any issues in implementing 5G systems and to perform studies necessary for creating the technical standards.

The trial items and content of these 5G Field Trials by the MIC also referred to the 5G-TPG report (5G Utilization Project Plan) mentioned earlier and conducted trials anticipating 5G utilization in various fields, while including study of the radio propagation characteristics of the new frequency bands for 5G and evaluation of system performance. After the MIC established the new trial framework, the 5G-TPG has continued its activities since FY2017, actively supporting implementation of the 5G Field Trials.

The 5G Field Trials begun in FY2017 were conducted for three years until FY2019, with participation from people in various utilization fields, to help create new markets through implementation of 5G. Each year, six trial groups conducted trials throughout Japan specializing on their respective themes. Technical objectives for ultra-high speed, high-capacity, low latency and massive connectivity were set for different areas; whether urban or rural, indoor or outdoor; and testing was done using the new frequency bands introduced for 5G (3.7/4.5/28 GHz), through collaboration among partners from a wide range of industries, application fields and participants involved in the mobile communications industry. Articles from each of the trial groups are included in this special feature, introducing specific themes tested in FY2019 and results from those trials.

Chapter 3 of this general report describes outcomes of "5G Field Trials for three fiscal years (FY2017-FY2019)" that were conducted by six trial groups in various locations all over Japan in addition to Tokyo. Those include the results of investigations on 5G radio propagation and evaluations on 5G system performance for eMBB (enhanced Mobile Broad Band), mMTC (massive Machine Type Communication), and URLLC (Ultra Reliable and Low Latency Communication) in addition to the outcomes of the field trials on nine types of use cases, which were conducted by many partners in various utilization fields participate as well as those related to the mobile communications industry to create a new market through actualization of 5G.

Chapter 2 5G Utilization Project

2.1 Overview

More than 40 proposals as the 5G Utilization Project were 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. 1-1)

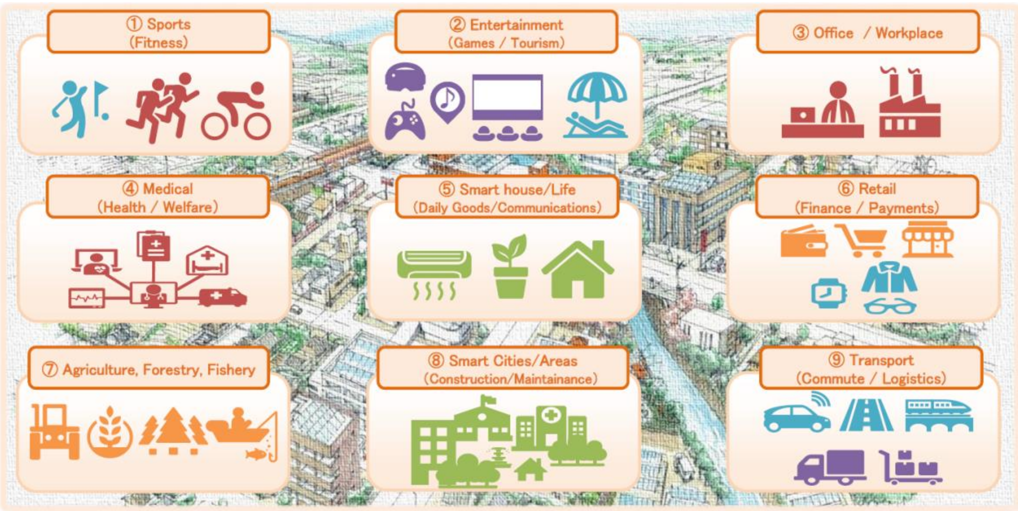


Fig. 2.1-1 Nine fields from the MIC Round-table Conference on Radio Policies 2020 Report.

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/

2.2 5G Utilization Projects

2.2.1 Entertainment

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.

5G utilization projects proposed in the field of “Entertainment” are as follows:

- Large Screen High Definition Signage Services
- Mobile Remote Meeting Systems
- Entertainment System inside Stadiums
- Offering Video and Data that Meets User Needs
- 5G and the “Exciting Stadium 2020”
- Heterogeneous Networks at Event Venues
- Using 5G to Create a Virtual Museum Experience
- Dynamic Hot Spot Services
- Experiencing Super Live Broadcasts of Japanese Festivals through Immersive Virtual Reality
- New Entertainment Experiences through Virtual Reality
- Live Broadcast and Transmission of HD Video
- Linear Video Streaming

2.2.2 Safe and Secure Society Prevented from Crime and Natural Disasters

The 5G Utilization Projects aim to help ensure a safe and secure society through the use of cameras and sensors to provide information, so that victims of disasters, accidents, or crimes can receive proper information and feedback, ensuring that this technology can help people feel secure in their lives in a safe society. 5G's special characteristics of ultra-high speeds, high capacities, and ultra-low latency can be used to collect data and provide feedback in real time. These capabilities can be used to offer many services to provide a safe and secure society for everyone.

5G utilization projects proposed in the field of "Safe and Secure Society Prevented from Crime and Natural Disasters" are as follows:

- Real Time Evacuation Guidance System
- Mobile Surveillance/Security
- Safety Systems with Video Surveillance Technology
- Providing Rich Contents to Airplanes and Ships
- Ensuring Communication with Shared Frequency Use during a Disaster
- Reference Themes

2.2.3 Logistics, Agricultural and Fisheries, Offices, Factories

The 5G Utilization Projects offer new lifestyles through broadly separated areas such as efficiency in logistics, an optimized heterogenous wireless environment, a network environment that can be used anytime anywhere, which can be offered do to the ability to freely choose from 5G special characteristics, such as multiple connections, ultra-high speeds, and high capacities.

In addition, with the 2020 Olympics and Paralympics in mind, new forms of entertainment will be offered through transmitting of high-definition video from new locations. Scenarios also include ways 5G technology will be able to offer new styles of work.

5G utilization projects proposed in the field of "Logistics, Agricultural and Fisheries, Offices, Factories" are as follows:

- Logistical Efficiency
- Using an Optimized Heterogeneous Wireless Environment
- A Network where It Is Possible to Keep the Same Environment Everywhere at Any Time

2.2.4 Remote Controlled and Managed Devices Such as Robots and Drones

The 5G Utilization Projects see the role of 5G in of remotely controlled and managed devices such as robots and drones in the following situations, remotely controlled robots, surveillance using camera-equipped robots or drones, autonomously cooperative distributed control of connected machines. They include the aspects such as the type of connected devices, HD cameras equipped for monitoring activities, as well as a way to deploy monitoring and control systems for edge computing.

From these scenarios, many different situations can be explored using 5G's special characteristics of high-speeds, high-capacity, and low-latency, a variety of new services can be imagined and created.

5G utilization projects proposed in the field of "Remote Controlled and Managed Devices Such as Robots and Drones" are as follows:

- Robot Monitoring and Remote Control
- Surveillance Using Camera-Equipped Robots
- Surveillance Using Camera-Equipped Drones
- Autonomously Cooperative Distributed Control of Connected Machines

2.2.5 Connected Cars, Autonomous and Remote Driving

The 5G Utilization Projects see that 5G's special characteristics, mainly ultra-high speeds and capacity, high reliability and low latency, will be able to explore new users by bringing about a safe and secure society through the use of connected cars, remote control and monitoring of railway cars, and autonomous driving.

The 5G mobile communication systems from, will be able to assist in autonomous driving through the collection of traffic information data and the creation of dynamic maps, services which can be offered through 5G's high speeds and capacity. In addition, the 5G offers the needed ultra-low latency, high capacity, high speed communications for autonomously driven cars (smart automobiles) or at a mining site with remote controlled, remotely monitored very large-scale construction vehicles.

Through these technologies, the large-scale growth in the autonomous vehicle market is anticipated, and users of advanced vehicles from family cars to large scale construction vehicles will be able to use the 5G network to help bring about a safer, and more secure and pleasant society.

5G utilization projects proposed in the field of "Connected Cars, Autonomous and Remote Driving" are as follows:

- Smart Automobiles (over the Horizon Accident Prevention)
- Delivery of High Capacity Maps for Use in Autonomous Driving
- Specialized Network for Connected Cars (Architecture)
- Valet Parking Systems in Large Scale Parking Lots
- Remote Management of Autonomous Driving
- Remote Controlled Operation of Large Vehicles at a Mining Site
- Platooning of Trucks

2.2.6 High Data-rate and Reliable Communication for High Speed Mobile

The 5G Utilization Projects will demonstrate the viability of high speed high quality transmissions to high speed moving vehicles, including trains, buses and aircraft and ships.

5G's special characteristics of ultra-high speeds, high quality, and low latency will offer devices which are moving at high speeds high speed broadband services, as well as management and monitoring services

New optimal services with applications can also be offered by integrating existing wireless systems and new wireless systems. The ultimate aim is to show the merits of 5G networks to both users of high speed vehicles as well as transportation firms.

5G utilization projects proposed in the field of "High Data-rate and Reliable Communication for High Speed Mobile" are as follows:

- Services for Railways
- Services for Buses
- Services to Ships and Airplanes
- Services on Public Transportation Vehicles Using Multiple Network Systems

Chapter 3 FY2017-2019 5G Field Trials in Japan

3.1 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. In Japan, the Ministry of Internal Affairs and Communications (MIC) has promoted efforts aimed at the realization of 5G, including research and development, international cooperation and standardization, allocation of frequencies to 5G, and the formulation of technical standards. As a part of this, with the aim of creating new markets through the realization of 5G, a three-year program of 5G Comprehensive Demonstration Tests (hereinafter referred to as “5G Field Trials”) was performed from FY2017 through FY2019 with the participation of stakeholders from various fields related to the use of 5G technology.

In the first year (FY2017) of the program, mobile phone operators proactively selected multiple themes and locations in which 5G is envisaged to be used in practice, and performed technical studies relating to the benefits of 5G with regard to speed, latency and connectivity.

In FY2018, 5G technical verification and performance evaluation tests were conducted for various use cases based on eight issues identified by the ICT Infrastructure Regional Development Strategy Study Group of the MIC. The MIC also organized a 5G Utilization Idea Contest with the aim of soliciting unique ideas from around Japan that provide solutions to various local problems. A total of 785 entries were received during October and November 2018. In December of the same year, primary screening was performed by the MIC’s Regional Bureaus of Telecommunications and Offices of Telecommunications (11 locations nationwide), and in January 2019, the leading proposals selected in primary screening were entered into a contest (secondary screening) held at the MIC. In the secondary screening, presentations were made by each proposer, and as a result of examination by a panel of judges, the overall grand prize was awarded to an entry from Shikoku, which proposed exploiting the characteristics of 5G to provide a better working environment, safer working conditions, and the transfer of skills from highly skilled workers. Other proposals also received awards, including the 5G Characteristic Utilization Award and the Regional Problem-Solving Award.

In FY2019, based on the results of previous technical verification and the results of the 5G Utilization Idea Contest, we conducted demonstrations at 23 locations nationwide with an emphasis on models that use 5G to help solve local issues.

In this chapter, Section 3.2 describes outcomes of 5G field trials on radio aspect including radio propagation/transmission and Section 3.3 introduces the contents and outcomes of 5G field trials shown in Tables 3.1-1, -2 and -3 by dividing them into nine use cases.

Table 3.1-1 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

Table 3.1-2 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

Table 3.1-3 5G Field Trials in FY2019

Technology	Target	Overview	Main locations	Organization
eMBB	Avg. 4-8 Gbps (base station) ※Avg.2-4 Gbps (user terminal)	1 Safety operation of crane work with high-definition images 2 Monitoring behavior at nursing homes 3 Realtime cloud-editing and relay of video 4 Passing down of traditional culture (remote education) 5 Livelihood support through sound visualization 6 Experience-based sightseeing with VR and Body Sharing 7 Advanced remote medical care 8 Advanced emergency transport	1 Ehime Pref. 2 Hiroshima city, Hiroshima Pref. 3 Sendai city, Miyagi Pref. 4 Tono area, Gifu Pref. 5 Tono area, Gifu Pref. 6 Naha city, Okinawa Pref. 7 Wakayama city, et al. 8 Maebashi City, Gunma Pref.	* NTT DOCOMO, INC. 1 Ehime University 2 Sompo Holdings, Inc. 3 Sendai Television Incorporated 4 CBC Creation Co., Ltd. 5 SUNCORPORATION 6 H2L Inc. 7 Wakayama Pref. 8 Maebashi city
	Avg. 1 Gbps (mobility)	1 Snow removal countermeasures 2 Driving assistance in dense fog 3 Round assistance on golf courses 4 Support for ensuring safety in underground railways	1 Eiheiji Town, Fukui Pref. 2 Oita Pref. 3 Nagano city, Nagano Pref. 4 Osaka city, et al.	* NTT Communications Corporation 1 Eiheiji Town 2 Oita Pref. 3 MIRAIT Corporation 4 ITOCHU Techno-Solutions Corporation
	Avg. 300 Mbps (Indoor)	1 Watching sports with togetherness in the stadium 2 Increasing efficiency in the dairy and livestock industries 3 Support for bloodhorse breeding industry	1 Higashiosaka city, Osaka Pref. 2 Kamishihoro town, Hokkaido 3 Niikappu town, Hokkaido	* Advanced Telecommunications Research Institute International 1 Jupiter Telecommunications Co., Ltd. 2 Tokachi Murakami Farm 3 Hidaka Keishuba Kyoudou Ikusei Kousha Corp.
URLLC	10 ms latency (End to End)	1 Evacuation guidance and traffic control in disasters 2 Truck platooning, Remote monitoring and control	1 Kitakyushu city, Fukuoka Pref. 2 Hamamatsu city, et al., Shizuoka	* Wireless City Planning Inc. 1 NIPPON SIGNAL CO., LTD. 2 Advanced Smart Mobility Co., Ltd.
	URLLC with Avg. 300 Mbps (terminal)	1 Support system for Mountain climbers 2 Operational support of sports (Slack line) 3 Tourism promotion using VR 4 Remote control of construction machines	1 Komagane city, Nagano Pref. 2 Obuse town Nagano Pref. 3 Minamiaso village, Kumamoto Pref. 4 Iga city, Mie Pref.	* KDDI CORPORATION 1 Shinshu University 2 Goolight Co., Ltd. 3 Tokai University. 4 OBAYASHI CORPORATION
mMTC	1 million devices/km^2 density	1 Safety management of workers in tunnels 2 Increasing efficiency in logistics through visualization	1 Hokkaido 2 Nerima-ku, Tokyo	* Wireless City Planning Inc. 1 TAISEI CORPORATION 2 NIPPON EXPRESS CO., LTD.

Under lines indicate that they are based on the 5G utilization idea contest.

3.2 5G Field Trials on Radio Aspect

3.2.1 Radio Propagation

3.2.1.1 Introduction

The frequency bands that have been allocated to firms for use upon the introduction of 5G in Japan include the 3.7 GHz band, comprised of 3.6 GHz to 4.2 GHz and the 4.5 GHz band, comprised of 4.4 GHz to 4.9 GHz, as well as the 28 GHz band, comprised of 27.0 GHz to 29.5 GHz. (The 3.7 GHz band and the 4.5 GHz band are collectively called the 4.5 GHz band.) Radio propagation characteristics of the 4.5 GHz band and the 28 GHz band were measured in the 5G Field Trials and the measurement results were evaluated, now that the technical requirements for the utilization of these new frequencies for 5G have been revealed. The following chart lists the locations where data on the radio propagation characteristics was obtained, the frequencies in which radio propagation effects where measured, as well as other environmental factors such as base station and mobile station antenna heights:

Table 3.2.1-1 Field Trial Environments

Location			Frequency band (GHz)	Base station antenna height (m)	Mobile station antenna Height (m)	Environment
No.		Address/Place				
1	-1	Shinjuku, Tokyo	4.5	8.6	2.6	City street, Urban Micro
	-2	Kayabacho, Tokyo	28	10	2.3	City street, Urban Micro
	-3	Wakayama	4.5	12	3	City street, Rural Macro
	-4	Arashiyama, Kyoto	28	1.8	1.8	City street, Rural Macro
2	-1	Fuji International Speedway	4.5, 28	30	2.6, 2.3	Racing circuit, Urban Micro/V2X
	-2	Tobu Kameido Line	4.5, 28	3.1	1.2, 1.4	Railway, Rural Macro
	-3	Suzuka Circuit	4.5, 28	10	0.8	Racing circuit, Urban Micro

3	-1	Shinjuku, Tokyo	4.5, 28	10	1.5	City street, Urban Micro
	-2			25	1.5	City street, Urban Micro
	-3			90	1.5	City street, Urban Macro
4	-1	Okinawa Cellular Stadium	28	16, 20	1.5	Baseball Stadium, Urban Micro
	-2	Haneda Airport International Terminal Station	28	2.8	1.5	Railway station, Indoor hotspot/ Indoor factory
	-3	Kamishihoro, Hokkaido	28	3, 6, 10	1.5	Cow shed, Indoor greenhouse/Indoor factory
5	-1	Test course, Ibaraki	4.5, 28	5	0.8	Vehicle test course, Urban Micro
	-2	Odaiba, Tokyo	4.5, 28	0.8	0.8	City street, Urban Micro/V2X
	-3	Telecom Center, Tokyo	4.5,28	60	3	City street, Urban Macro
6	-1	University Campus	4.5	2.1	1.5	Gymnastic hall, Indoor hotspot
	-2	Chiryu-shi	4.5	8	2.1	Bridge pier, Urban Micro
	-3	Hokkaido	4.5	3	2	Railway Tunnel under construction, Indoor factory
7	-1	Aizuwakamatsu	28	2.5	1.5	Sake brewery, Indoor greenhouse/ Indoor factory

Below are some examples of the test environments listed in the above chart.

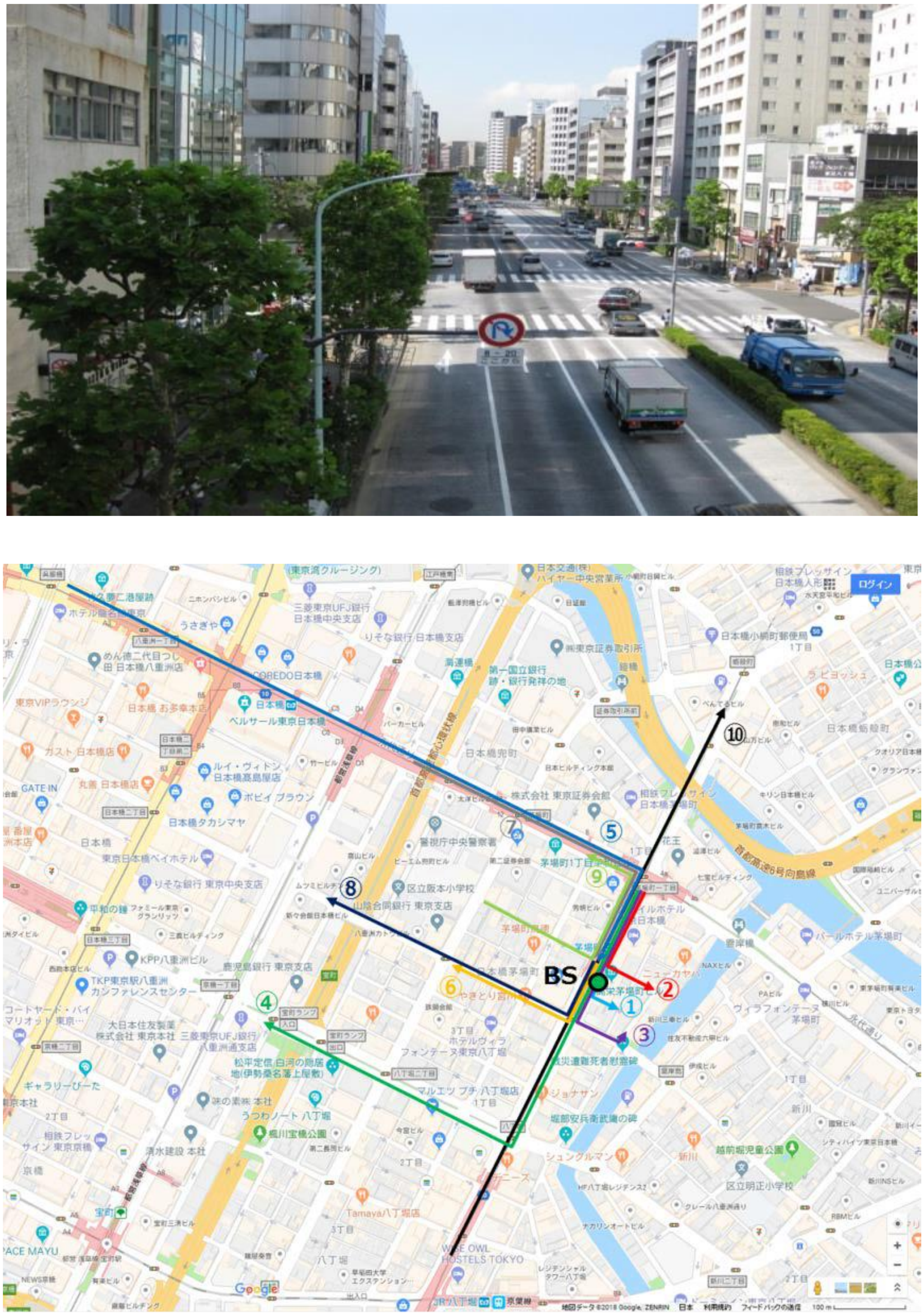


Fig. 3.2.1-1 Location No. 1-2 Kayabacho (Tokyo), 28 GHz band radio propagation measurement environment

Fig. 3.2.1-2 Location No. 4-3 Kamishihoro (Hokkaido), 28 GHz radio propagation measurement environment

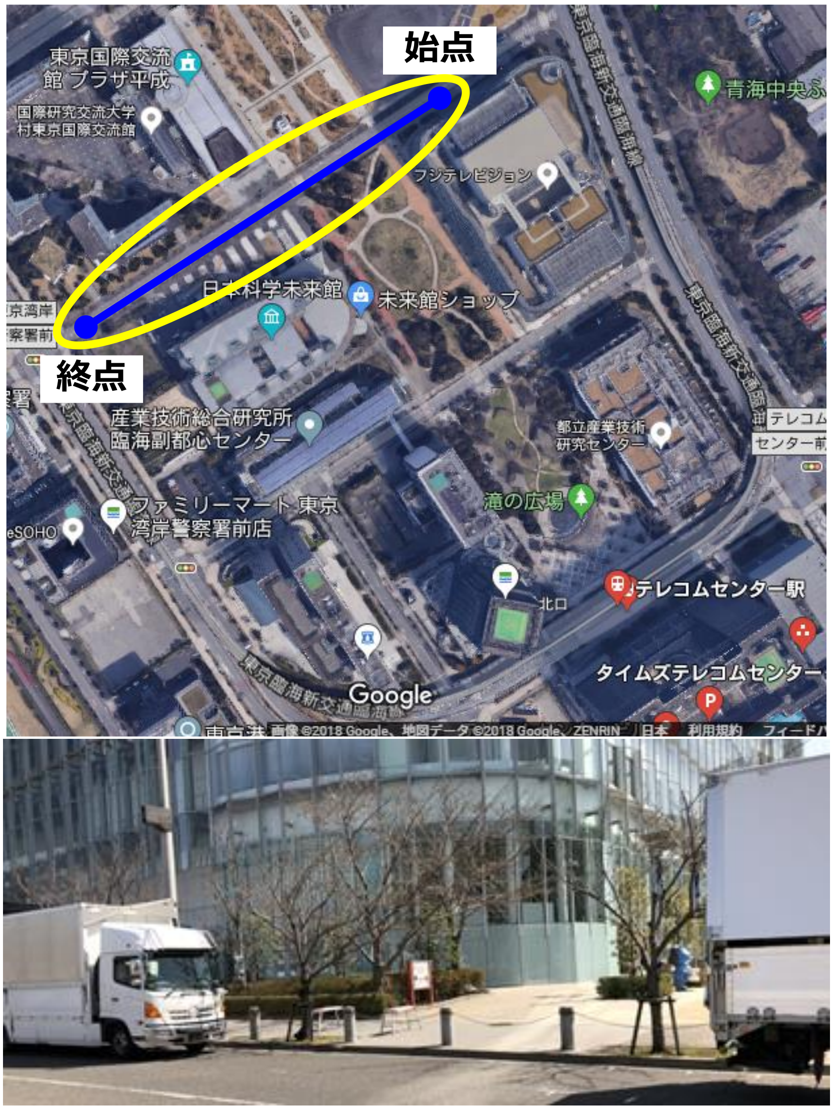


Fig. 3.2.1-3 Location No. 5-2 Odaiba (Tokyo), 4.5 GHz and 28 GHz radio propagation measurement environment

3.2.1.2 Survey Results

Propagation loss, K-factor, delay spread, angular spread, and Doppler spread were compared using the definitions of channel models in the ITU-R Report M.2412 as well as the 3GPP TR 38.901 for indoor factories (InF) and the definitions in the TR37.885 for Vehicle to Everything (V2X) environments at the locations noted in the previous section. The following sections provide the results of these surveys.

(1) Propagation Loss

Results from measurements of propagation loss obtained starting in 2017 are listed in Table 3.2.1-2. These results show that estimates of propagation loss using the ITU-R model can be said to be relatively accurate. However, the following issues need to be considered:

- In an UMi LOS environment, the propagation loss at the 28 GHz band from the influence of reflected waves was less than had been expected. However, in the case of trees acting as an obstruction, propagation loss was greater than expected, so it is necessary to calculate the value of losses due to trees.
- The model could not predict the propagation loss of transition area between LOS and NLOS.
- In an InH environment, the LOS model was adapted in areas with structures that included pillars which acted as obstacles. However, a new blocking model may be considered.
- When comparing model A and model B with frequencies under 6 GHz, estimates from model A were slightly more accurate.
- In outdoor environments, in a situation when the base station antenna height differed from what the model defined, if one needed to choose between the UMi and UMa model depending on the height of surrounding buildings, a more relatively accurate choice could be made based on the range of applications.
- In a stadium environment, for line of site transmissions the UMi model was accurate.
- In an environment that is similar to an open space such as a racing circuit or when the height of transceivers is low, such as in V2V environments, the two-pass model is a good fit, and for a standard model the 3GPP V2X model is a better fit than the ITU-R UMi model. However, in the V2X model the breakpoint has yet to be defined, so care is needed in regard to the loss of accuracy beyond this point.
- Concerning open spaces such as within a large station platform, a factory, or a cow shed, the 3GPP InF model is more accurate than the ITU-R InH model. However, the InF NLOS model is presupposed in the case of transmissions occurring in the same space, while the InH NLOS model should be applied when transmissions are sent and received in different spaces (rooms).
- Inside a tunnel environment, losses are the same as if in a free space. Even so, errors occur using the ITU-R_UMi model as the distance between transmission and reception increases.

Table 3.2.1-2 Propagation Loss Survey Results

Environment	Test Number	Comparing the ITU-R and 3GPP models：RMS errors [dB]					
		4.5GHz Model A or No Model		4.5GHz Model B		28GHz	
		LOS	NLOS	LOS	NLOS	LOS	NLOS
UMi	1-1	1.77	8.41	2.50	9.03		
	1-2					6.55	10.63
	2-1	5.78		7.43		7.24	
	3-1	12.53	4.21	10.73	7.11	7.1	4.17
	3-2	8.63	12.86	8.63	9.08	9.29	10.48
	4-1 (Tx1)					2.44	
	4-1 (Tx2)					1.40	
	5-2	5.58		7.60		5.91	
	6-2	4.54					
	6-3	17.7					
Uma	3-3	3.96	13.29	3.96	8.44	5.77	9.67
	5-3	4.42	10.10			3.33	
RMa	1-3	5.2	8.8				
	2-2	9.67				4.89	
InH	4-2					4.98	24.33
	4-3					5.47	8.55
	6-1	1.89		1.92			
	7-1					3.96	8.16
InF	4-2					3.82	4.31
	4-3					2.81	1.72
	7-1					3.30	2.68
V2X	2-1	3.97				3.37	
	5-2	7.6				7.6	

(2) K- Factor

Results from K-factor measurements obtained starting in 2017 are listed in Table 3.2.1-3. In this table K-factor ranges as defined by the ITU-R model, (average ±σ, with a standard deviation of σ) are listed. It can be understood from these results that in all environments K-factor values are smaller than in the ITU-R model. From this it is thought that in any environment reflected waves that are at the same level of direct waves will exist.

Table 3.2.1-3 K-Factor Survey Results

Environment	Test Number	K Factor [dB] Measurement values are at 50% in CDF		
		Measurement Value		Model Value
		4.5GHz	28GHz	
UMi	1-1	1.3		4~14
	1-2		0.2	
	2-1	3.4	1.5	
	3-1	1.5	1.0	
	3-2	-1.1	-2.6	
	4-1 (Tx1)		2.5	
	4-1 (Tx2)		3.0	
	5-1	2.3	0.9	
	5-2	1.5	1.5	
	6-2	1.47		
UMa	3-3	1.5	2.2	5.5~12.5
RMa	1-4		5.4	3~11
InH	4-2		-0.8	3~11
	6-1	0.95		
	7-1		-1	

(3) Delay Spread

Results from delay spread measurements obtained starting in 2017 are listed in Table 3.2.1-4. In this table the range of delay spread as defined by the ITU-R model, (average ±σ, with a standard deviation of σ) is listed. The following points are what can be determined from these results:

- The ITU-R model is accurate in either the UMi or UMa environments.
- In a V2V environment where the transceiver is at a low height values are lower in the UMi model.
- In an interior environment, an open space such as a large station platform or a factory in which strong reflective waves are prone to occur, values are higher than in the ITU-R InH model. In addition, this value is larger than the 3GPP InF model. Note: values in the InF model < values in the InH model.
- In cow shed-like indoor environments, the values were the median of the ITU_InH model and the 3GPP_InF model. Note: values in the InH model < values in the InF model.

Table 3.2.1-4 Delay Spread Survey Results

Environment	Test Number	Delay Spread [ns] Measurement values are at 50% in CDF				
		4.5GHz		28GHz		Model Value
		LOS	NLOS	LOS	NLOS	
UMi	1-1	49.0				○UMi ・4.5G_LOS: 20.0~114.8 ・4.5G_NLOS: 32.4~295.1 ・28G_LOS: 13.5~77.6 ・28G_NLOS: 20.4 ~213.8 ○UMa ・4.5G_LOS: 20.9 ~436.5 ・4.5G_NLOS: 158.5~955.0 ・28G_LOS: 17.8 ~371.5 ・28G_NLOS: 107.2~645.7 ○InH ・4.5G_LOS: 13.2 ~30.2 ・4.5G_NLOS: 30.9 ~56.2 ・28G_LOS: 12.9~29.5 ・28G_NLOS: 16.6~41.7 (note)4.5GHz is the value of model B
	1-2			30.2	58.9	
	2-1			27.5		
	3-1	79.4	52.5	31.6	138.0	
	3-2	39.8	75.9	39.8	83.2	
	4-1 (Tx1)			28.8		
	4-1 (Tx2)					
	5-1	27.5		102.3		
	5-2	9.1		11.5		
	6-2	0.06				
UMa	3-3	112.2	302.0	50.1	50.1	
	5-3	63.72	704.0			
RMa	1-4			14.4		
	2-2			46.5		
InH	4-2			151.4		
	4-3			63	35	
	7-1			47.9	50.1	

(4) Angular Spread

Results from angular spread measurements obtained starting in 2017 are listed in Table 3.2.1-5 and Table 3.2.1-6. In this table the range of angular spread as defined by the ITU-R model, (average ±σ, with a standard deviation of σ) is listed. The following points are what can be determined from these results:

Regarding base station angular spread:

- In environments around the base station, the value was larger than the ITU-R model, which was especially conspicuous in environments such as train station platforms and factories.

Regarding mobile base station angular spread:

- In UMi and UMa environments, values were in relative agreement with the ITU-R model, although a trend of somewhat smaller values can be seen.
- In interior environments, the values were larger than both the ITU-R InH model and the 3GPP InF model, and multiple strong reflective waves from the area arrived uniformly. Note: values in the InF model < values in the InH model.

Table 3.2.1-5 Angular Spread Survey Results (Base Station)

<table>
<tr><th rowspan="3">Environment</th><th rowspan="3">Test Number</th><th colspan="5">Angular Spread [°] Measurement values are at 50% in CDF</th></tr>
<tr><th colspan="2">4.5GHz</th><th colspan="2">28GHz</th><th rowspan="2">Model Value</th></tr>
<tr><th>LOS</th><th>NLOS</th><th>LOS</th><th>NLOS</th></tr>
<tr><td rowspan="6">UMi</td><td>1-1</td><td></td><td></td><td></td><td></td><td rowspan="10">○UMi
・4.5G_LOS：5.8~38.0
・4.5G_NLOS：8.9~58.9
・28G_LOS：5.2~34.7
・28G_NLOS：5.0~47.9
○InH
・4.5G_LOS：26.3~60.3
・4.5G_NLOS：
23.4~74.1
・28G_LOS：26.3~60.3
・28G_NLOS：23.4~74.1

(note)4.5GHz are values from Model B.</td></tr>
<tr><td>1-2</td><td></td><td></td><td>77.6</td><td>57.5</td></tr>
<tr><td>3-1</td><td>20.0</td><td>2.4</td><td>15.8</td><td>30.2</td></tr>
<tr><td>3-2</td><td>55.0</td><td>52.5</td><td>41.7</td><td>89.1</td></tr>
<tr><td>4-1 (Tx1)</td><td></td><td></td><td rowspan="2">10.0</td><td></td></tr>
<tr><td>4-1 (Tx2)</td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">InH</td><td>4-2</td><td></td><td></td><td>83.2</td><td></td></tr>
<tr><td>4-3</td><td></td><td></td><td>15.8</td><td></td></tr>
<tr><td>6-1</td><td>91.2</td><td></td><td></td><td></td></tr>
<tr><td>7-1</td><td></td><td></td><td>79.4</td><td>79.4</td></tr>
</table>

Table 3.2.1-6 Angular Spread Survey Results (Mobile Base Stations)

<table>
<tr><th rowspan="3">Environment</th><th rowspan="3">Test Number</th><th colspan="5">Angular Spread [°] Measurement values are at 50% in CDF</th></tr>
<tr><th colspan="2">4.5GHz</th><th colspan="2">28GHz</th><th rowspan="2">Model Value</th></tr>
<tr><th>LOS</th><th>NLOS</th><th>LOS</th><th>NLOS</th></tr>
<tr><td rowspan="9">UMi</td><td>1-1</td><td></td><td></td><td></td><td></td><td rowspan="14">○UMi
・4.5G_LOS：24.0~91.2
・4.5G_NLOS：25.7~123.0
・28G_LOS：20.4~81.3
・28G_NLOS：20.9~114.8

○UMa
・4.5G_LOS：40.7~102.3
・4.5G_NLOS：61.7~102.3
・28G_LOS：40.7~102.3
・28G_NLOS：38.0~63.1

○InH
・4.5G_LOS：26.9~70.8
・4.5G_NLOS：42.7~85.1
・28G_LOS：16.2~61.7
・28G_NLOS：29.5~85.1

(note)4.5GHz are values from Model B.</td></tr>
<tr><td>1-2</td><td></td><td></td><td>53.7</td><td>74.1</td></tr>
<tr><td>3-1</td><td>34.7</td><td>52.5</td><td>18.2</td><td>20.0</td></tr>
<tr><td>3-2</td><td>74.1</td><td>47.9</td><td>29.5</td><td>13.2</td></tr>
<tr><td>4-1 (Tx1)</td><td></td><td></td><td rowspan="2">14.5</td><td></td></tr>
<tr><td>4-1 (Tx2)</td><td></td><td></td><td></td></tr>
<tr><td>5-1</td><td>95.5</td><td></td><td>102.3</td><td></td></tr>
<tr><td>5-2</td><td>89.1</td><td></td><td>30.2</td><td></td></tr>
<tr><td>6-2</td><td>63.1</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">UMa</td><td>3-3</td><td>22.4</td><td>57.5</td><td>31.6</td><td>77.6</td></tr>
<tr><td>5-3</td><td>53.7</td><td>89.1</td><td>48.98</td><td>109.7</td></tr>
<tr><td rowspan="3">InH</td><td>4-2</td><td></td><td></td><td>104.7</td><td></td></tr>
<tr><td>4-3</td><td></td><td></td><td>27</td><td>77</td></tr>
<tr><td>7-1</td><td></td><td></td><td>81.3</td><td>104.7</td></tr>
</table>

(5) Doppler Spread

Results from Doppler spread measurements obtained starting in 2017 are listed in Table 3.2.1-7. The chart shows also shows the Doppler RMS. In addition, the values are standardized from the theoretical maximum of the Doppler spread. The following points are what can be determined from these results:

- In all environments, the Doppler spread was below the theoretical maximum.
- Doppler RMS values were also below the theoretical maximum, so the effect on moving vehicles in the surrounding area was small.
- Regarding NLOS environments, the differences between the values of the Doppler spread and Doppler RMS value were small so it is thought that the spatial extent of arrival waves is uniform.
- Regarding LOS environments at Haneda International Airport Terminal Station and the Aizu Wakamatsu Sake Brewery, the difference in values for Doppler spread and Doppler RMS were also not very large and it is thought that the large spatial extent of arrival waves is due to multipath-rich environment.

Table 3.2.1-7 Doppler Spread Survey Results

Environment	Test Number	Doppler Spread [fD_max] Measurement values are at CDF 50%			
		4.5GHz		28GHz	
		LOS	NLOS	LOS	NLOS
UMi	1-1	0.46 (0.92)	0.59 (0.81)		
	1-2			0.42 (0.90)	0.31 (0.57)
	2-1	0.28 (0.94)		0.25 (0.94)	
	3-2	0.31 (0.96)		0.30 (0.90)	
	4-1 (Tx1)			0.48 (0.56)	
	4-1 (Tx2)				
	5-1	(0.92)		(0.95)	
	5-2	(0.12)		(0.10)	
	6-2	0.21 (0.55)			
	6-3	0.35 (0.89)			
UMa	5-3	(1.03)	(1.21)	(1.11)	(1.14)
InH	4-2			0.63 (0.89)	0.84 (0.97)
	4-3			0.62 (0.85)	0.60 (0.75)
	6-1	(1.2)			
	7-1			0.67 (0.87)	

3.2.1.3 Summary

The results from propagation measurements starting in 2017 of the 4.5 GHz band and the 28 GHz band in different environments provides a comparison of values of 5G standards from the ITU-R model and the 3GPP model. The following can be said about an environment that complies to standards following the ITU-R scenario.

- The model was generally in agreement with the results found in propagation loss and delay spread.
- It must be taken into consideration that the K-factor values were smaller than what the model provided.
- It must be taken into consideration that the Doppler spread cannot reach its theoretical maximum.

- It must be taken into consideration that the angular spread is dependent on the surrounding environment.

In addition, the following can also be said about environments that are thought to be different than the ITU-R environment.

- Propagation values in V2X environments are more in agreement with the 3GPP_V2X model than the ITU-R_UMi model.
- Propagation values in factories, barns, and interior station platforms are closer to the 3GPP_InF model rather than the ITU-R_InH model.
- Propagation values inside tunnels are the same as in free spaces.

3.2.2 Examples of Radio Propagation/Transmission Trials

3.2.2.1 Introduction

This section describes some examples of the results of individual radio propagation or radio transmission trials in FY2017, assuming particular use cases or conducted in particular environments.

3.2.2.2 Trials for Long-Distance Transmission by NTT DOCOMO and Partners

In the long-distance transmission experiment, Base Station was placed at the Tokyo Skytree's observatory, at a height of 340 meters from ground level, while User Equipment (UE) was located on the roof of Tobu Railway's Asakusa station 1.2 kilometers away (Fig 3.2.2-1). Fig. 3.2.2-2 shows evaluation results in the long-distance transmission using 28 GHz band with 700 MHz bandwidth. DL and uplink (UL) maximum throughput were 4.5 Gbps and 1.5 Gbps, respectively. The 4.5 GHz band transmission characteristics were also evaluated in Shinjuku-Ward, Tokyo, where four UEs were used for the evaluation, and over 2.4 Gbps DL system throughput was measured.

Fig. 3.2.2-1 Trials for long-distance transmission

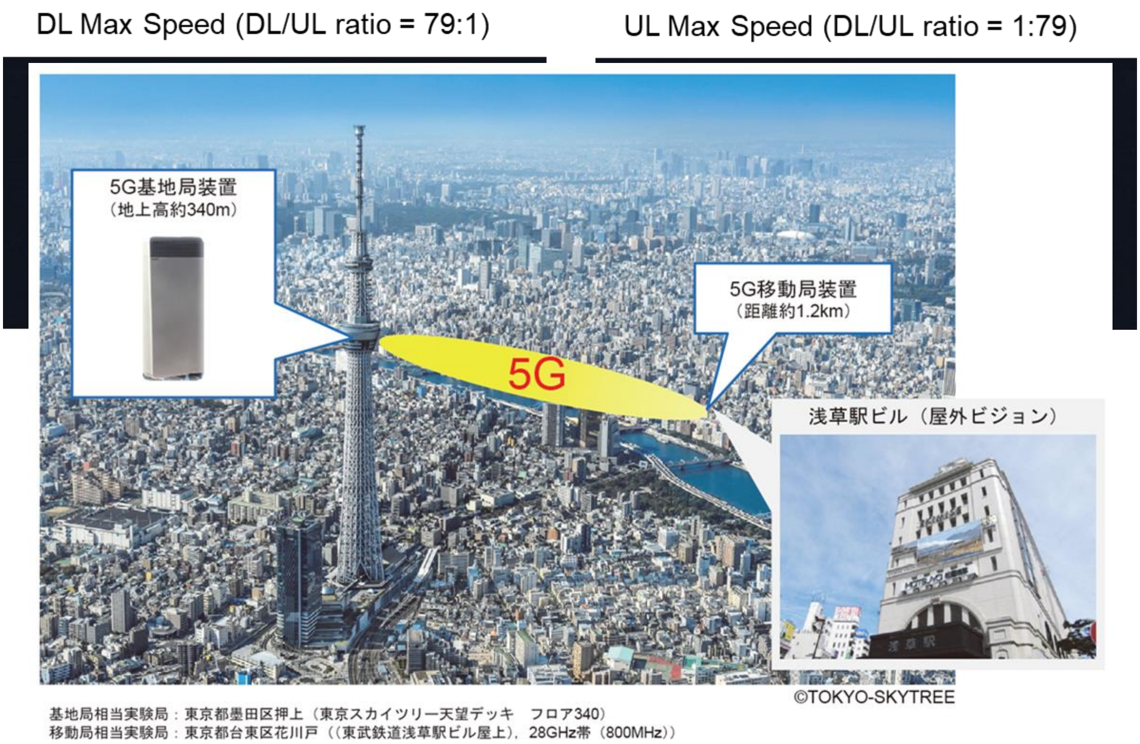


Fig. 3.2.2-2 Evaluation results in long-distance transmission

3.2.2.3 Trials for High Speed Communications with High Mobility by NTT Communications and Partners

5G radio prototype equipment of mobile station mounted inside measurement vehicle and transmission characteristic is evaluated with moving speed of more than 90 km/h in Fuji Speedway. Transmission characteristic evaluation is conducted in Fuji Speedway in February 2018. As shown in Fig. 3.2.2-3, 5G radio prototype equipment of base station is installed at the end of grandstand in Fuji Speedway, and mobile station antenna is mounted on the rooftop of measurement vehicle that runs a home straight with moving speed of more than 90 km/h.

Fig. 3.2.2-3 Evaluation environment of 5G transmission characteristic (Fuji Speedway)

Figure 3.2.2-4 shows an evaluation result of this trial. 2.241 Gbps throughput is achieved in 90 km/h. Ping RTT that is measured from the PC connected to Core to the PC at mobile station is almost 8 ms.

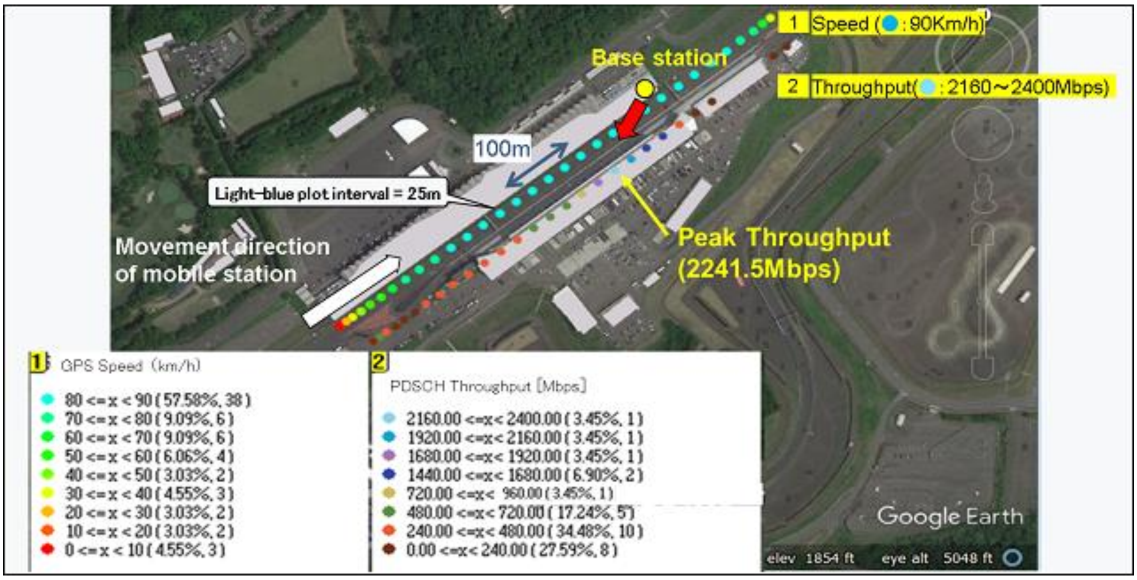


Fig. 3.2.2-4 Evaluation result

5G radio prototype equipment of mobile station is put on train and transmission characteristic is evaluated on the train with moving speed of more than 90 km/h near Ienaka Station of Tobu Nikko Line. As shown in Fig. 3.2.2-5, two base stations are installed in Ienaka station. Base station #1 is installed in northern end of the platform and base station #2 is located at a vacant lot in south area of the station building. Mobile station antenna is fixed in crew office area on the Skytree Train to receive the transmitted signal through front window, and the train travels with moving speed of 90 km/h.

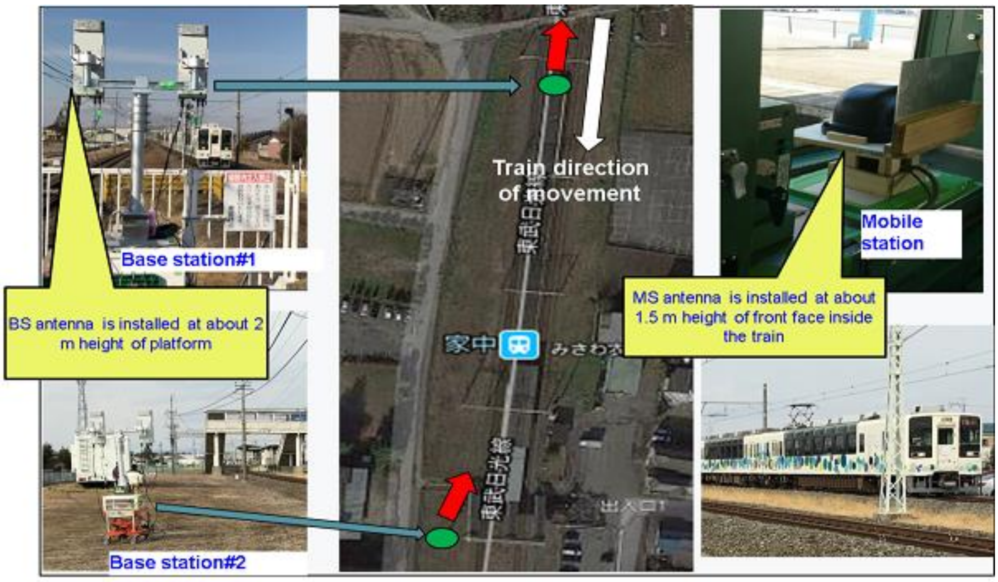


Fig. 3.2.2-5 5G field trial environment for transmission characteristic using train

Figure 3.2.2-6 shows an evaluation result of this trial. 2.077 Gbps throughput is achieved in 90 km/h. Ping RTT that is measured from the PC connected to Core to the PC at mobile station is almost 8ms.

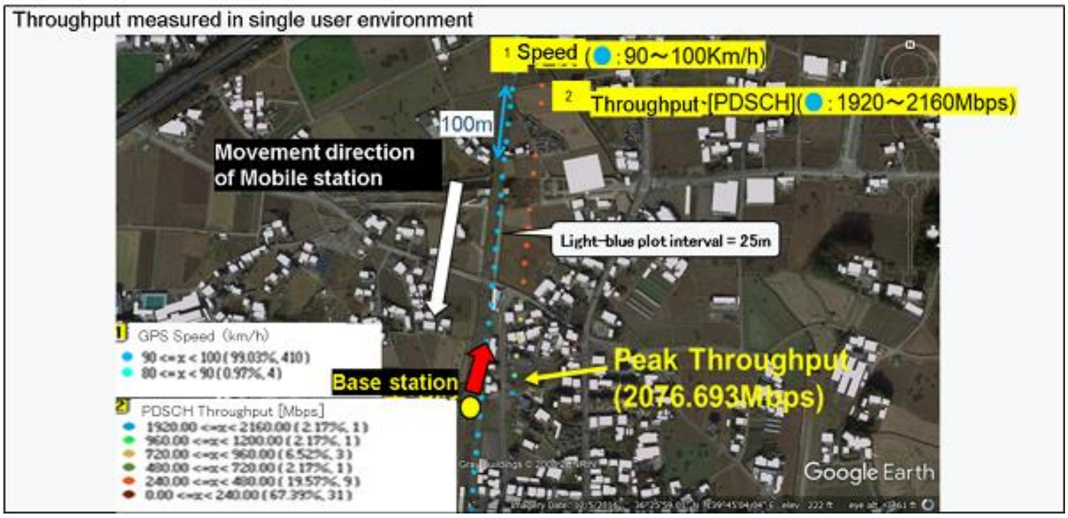


Fig. 3.2.2-6 Evaluation result

3.2.2.4 Trials for Connected Car by KDDI and Partners

In the trial, it is assumed that an instruction is given from a remote operator to a camera mounted on a vehicle moving at 60 km/h, to capture a video stream of the target object. Ultra-low latency is necessary so that the relative location between the target object and the camera will not change drastically from that of the moment when the instruction is given.

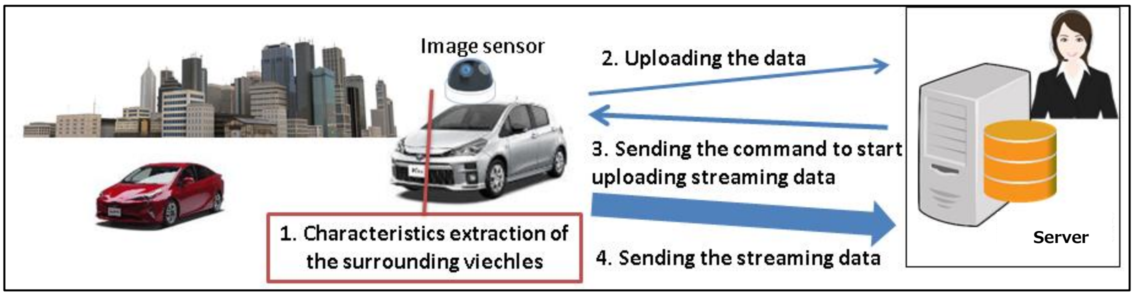


Fig. 3.2.2-7 Proposed trial for the Connected Car

In FY 2017, 5G radio performances were measured in two areas chosen for field trials for connected car applications. One represents urban area: Shinjuku in Tokyo, while the other represents suburban area: Ichinomiya in Aichi. (Figs. 3.2.2-8 and 3.2.2-9)

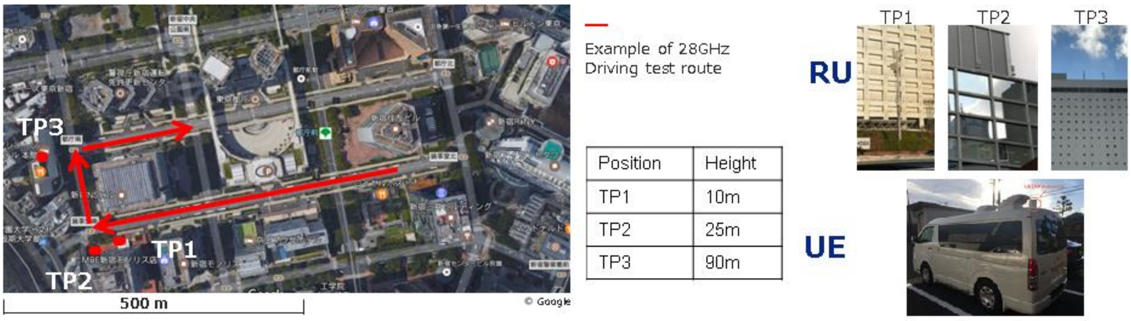


Fig. 3.2.2-8 Field trial area and locations of base stations in Shinjuku

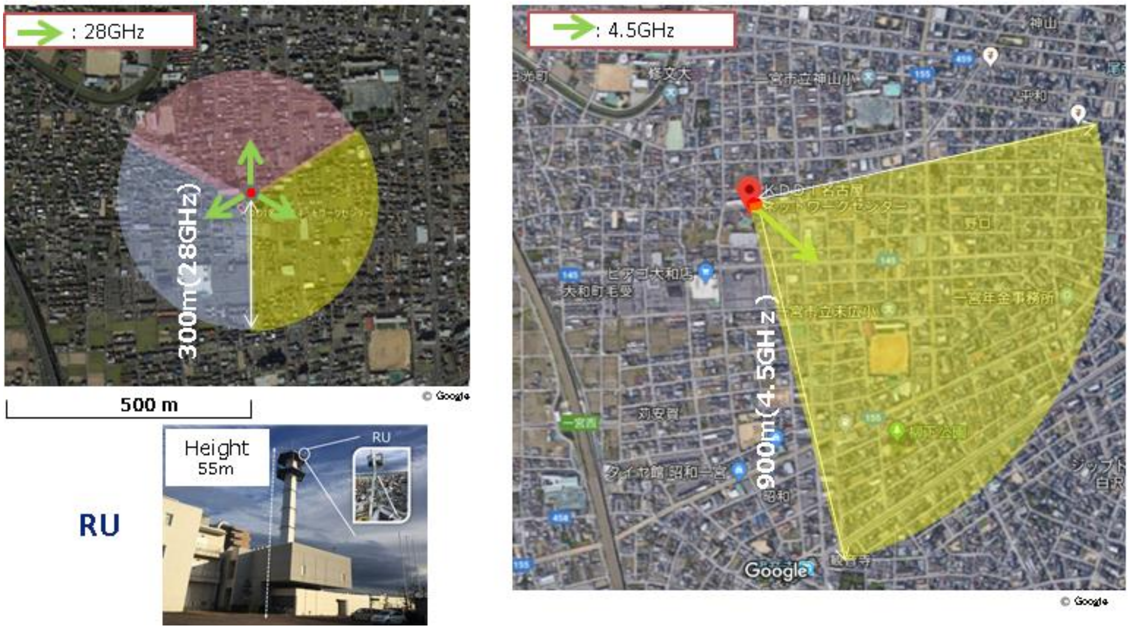


Fig. 3.2.2-9 Field trial area and locations of base stations in Ichinomiya

Figs. 3.2.2-10 and 3.2.2-11 illustrate sample radio performances in Ichinomiya in 4.5 GHz and 28 GHz.

In both 4.5 GHz and 28 GHz, following results are observed;

- Throughputs fluctuate according to the surrounding environment, including buildings and distance between BS and UE.
- Correlation between DL and UL throughput is observed.
- Throughputs are affected by blocking. The degradation is severer in 28 GHz than in 4.5 GHz.
- The median value of latency in one-way radio link is 0.935 ms in 4.5 GHz and 0.915 ms in 28 GHz, respectively, although latency increases according to channel quality degradation.

Fig. 3.2.2-10 Measured Result in 4.5GHz (Ichinomiya)

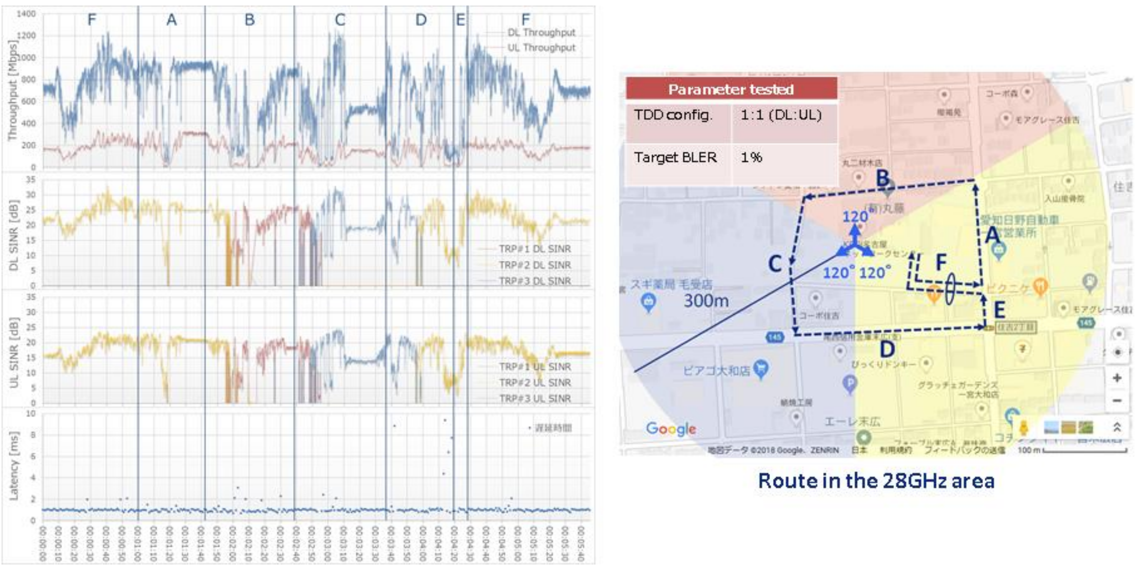


Fig. 3.2.2-11 Measured Result in 28GHz (Ichinomiya)

Degradation of 4.5 GHz is comparatively smaller than that of 28 GHz in “section 2”, where influence of surrounding buildings is susceptible.

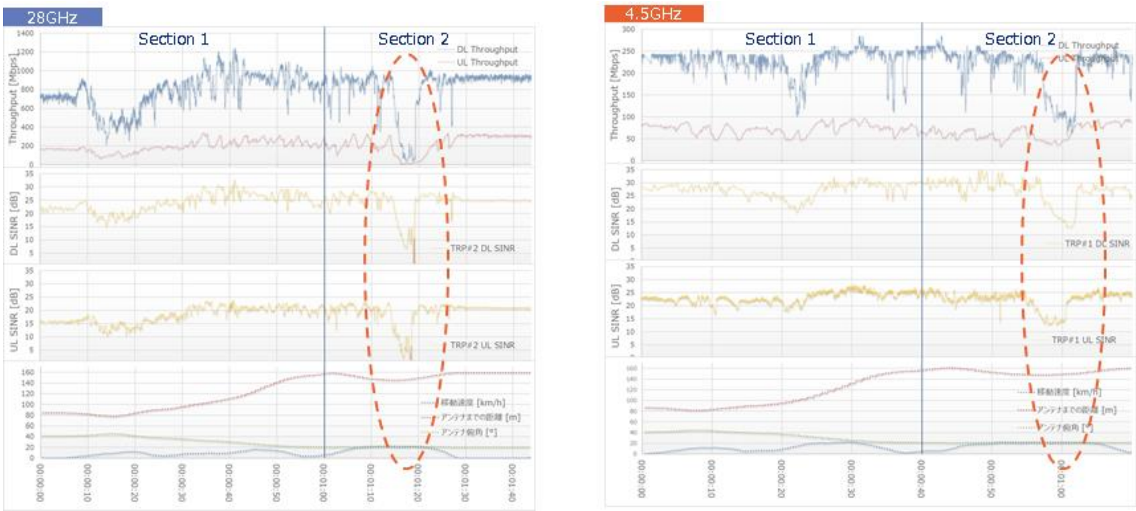


Fig. 3.2.2-12 Comparison between 4.5 & 28 GHz (Ichinomiya)

3.2.2.5 Trials in Stadium and Station by ATR and Partners

In connection with the stadium entertainment trial mentioned in Section 3.3.1.3(1), we conducted propagation measurements in a stadium using 28 GHz band which is assumed to be used in 5G. A heat map of propagation losses in the stadium is shown below. As there were few obstacles in the stadium, the propagation loss was close to free-space propagation loss.

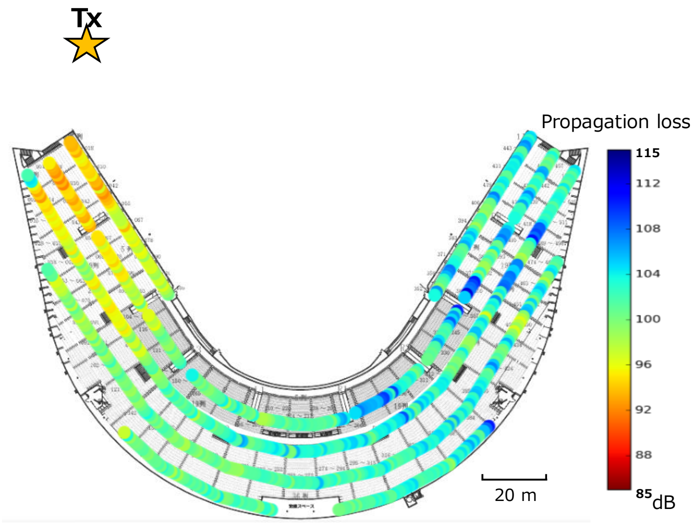


Fig. 3.2.2-13 Propagation loss in the stadium

In connection with the station application trial mentioned in Section 3.3.9.4(1), we measured 28 GHz band propagation in the station platform. Photographs of experimental scenery are shown in Fig. 3.2.2-14, and a heat map of propagation losses in the station platform is shown in Fig. 3.2.2-15. In a LOS area on the platform, the propagation loss was close to free-space propagation loss.

Fig. 3.2.2-14 Experimental site and experimental system

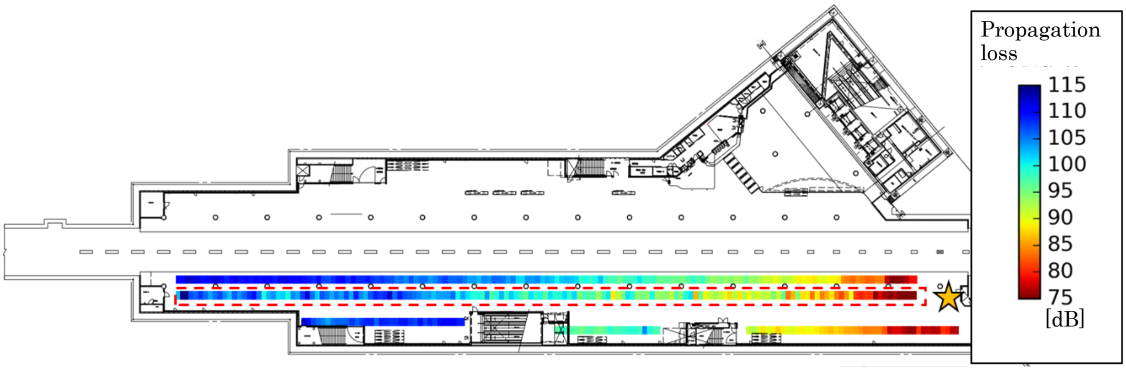


Fig. 3.2.2-15 Propagation loss in the station platform

3.2.2.6 Trials for Truck Platooning Applications by SoftBank and Partners

<u>Utilizing 5G for Truck Platooning</u>

Truck platooning is the electrical linking of two or more trucks in convoy. They move on the highway together as one group to reduce fuel consumption and CO2 emission as well as to achieve more efficient use of roads, i.e. to improve road traffic capacity. 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 CO2 emission, traffic congestion and 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 CO2 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 CO2 reductions. In Japan, the aging of drivers and overworking are becoming crucial social issues, since these increase traffic accidents and severe working environment. It is 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 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.

Trial Overview

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 Figs. 3.2.2-16 and 3.2.2-17.

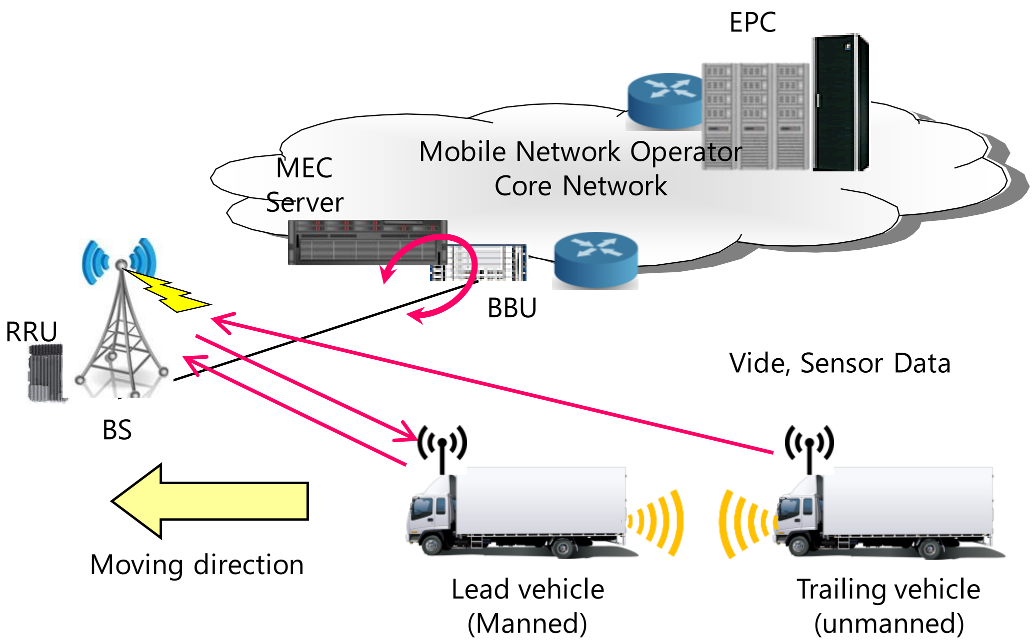


Fig. 3.2.2-16 Use Case 1: Communications between vehicles in Truck platooning

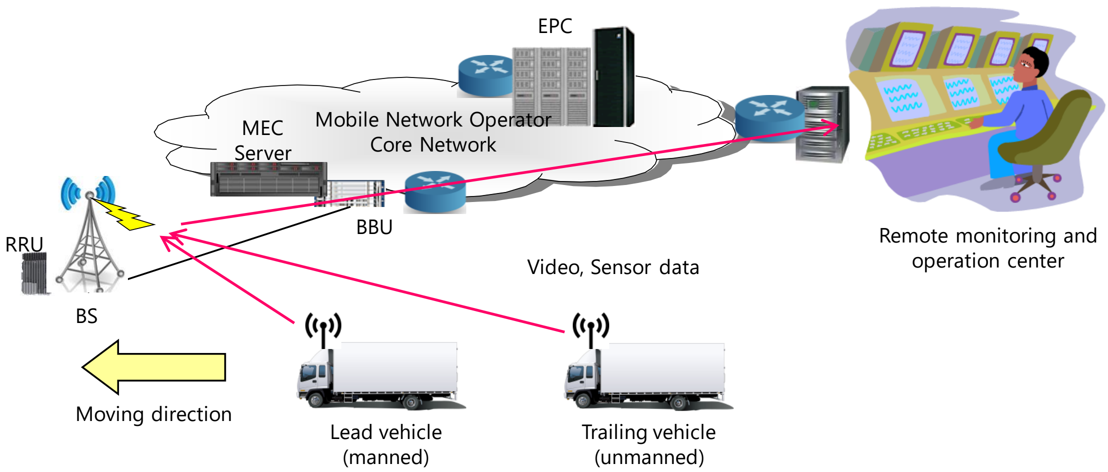


Fig. 3.2.2-17 Use Case 2: Remote monitoring / control for truck platooning

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. 3.2.2-18 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.

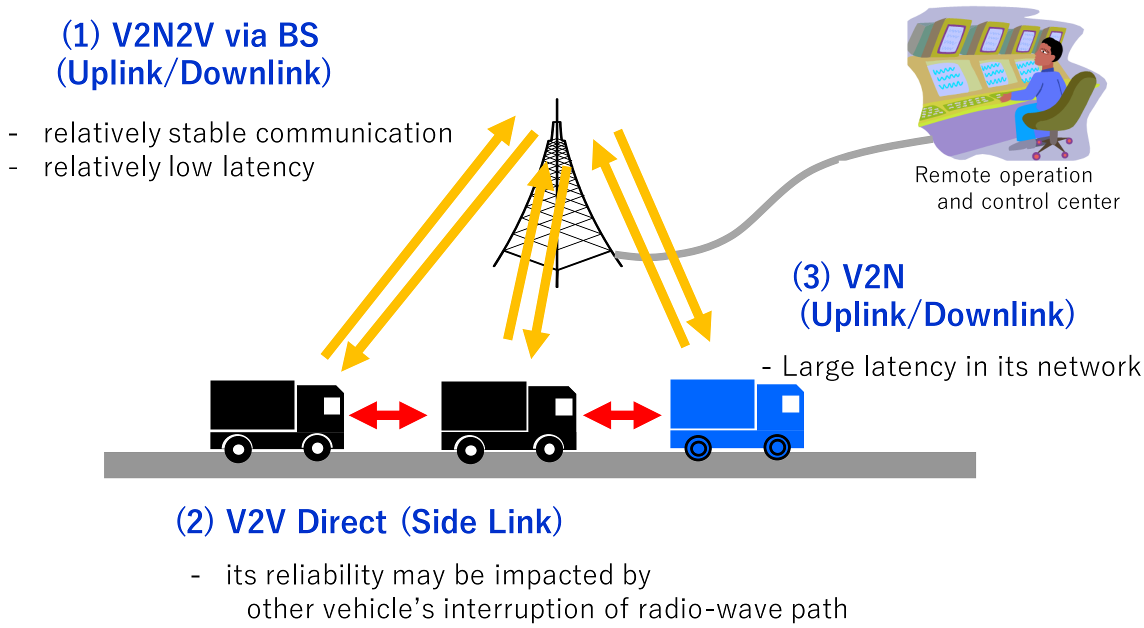


Fig. 3.2.2-18 Types of communication in platooning

Performance evaluations were being conducted in 2017 to assess 5G URLLC capabilities required for vehicle control in platooning and video monitoring around trailing vehicles. Specifically, communication links (1) and (2) above were tested by using the equipment listed in Table 3.2.2-1.

Table 3.2.2-1 Specification of the Test Equipment

Item #	Item	4.7GHz Equipment	28GHz Equipment
1.	Carrier Freq.	4.74 GHz	27.9 GHz
2.	Bandwidth	100 MHz	700 MHz
3.	Duplex	TDD	
4.	Radio Access	Downlink: OFDMA, Uploink：OFDMA	
5.	Sub-carrier interval	60 kHz	120 kHz
6.	Radio sub-frame length	0.125 ms	
7.	Data modulation scheme	Downlink：QPSK、16QAM、64QAM、256QAM Uplink：QPSK、16QAM、64QAM	
8.	Tx/Rx antenna configuration	BS: 64Tx/64Rx TUE: 4Tx/8Rx	BS: 4Tx/4Rx TUE: 2Tx/4Rx

Trial Results

5G communication test equipment was evaluated with big trucks in Tsukuba-city, 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. 3.2.2-19 and 3.2.2-20)

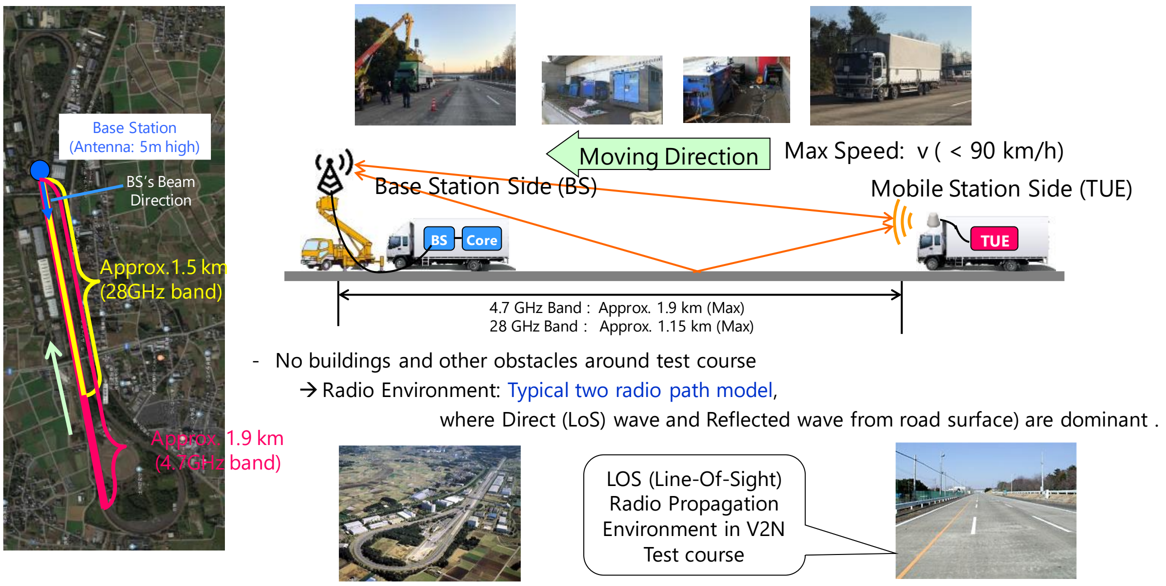


Fig. 3.2.2-19 Field trial test environment for V2N communications

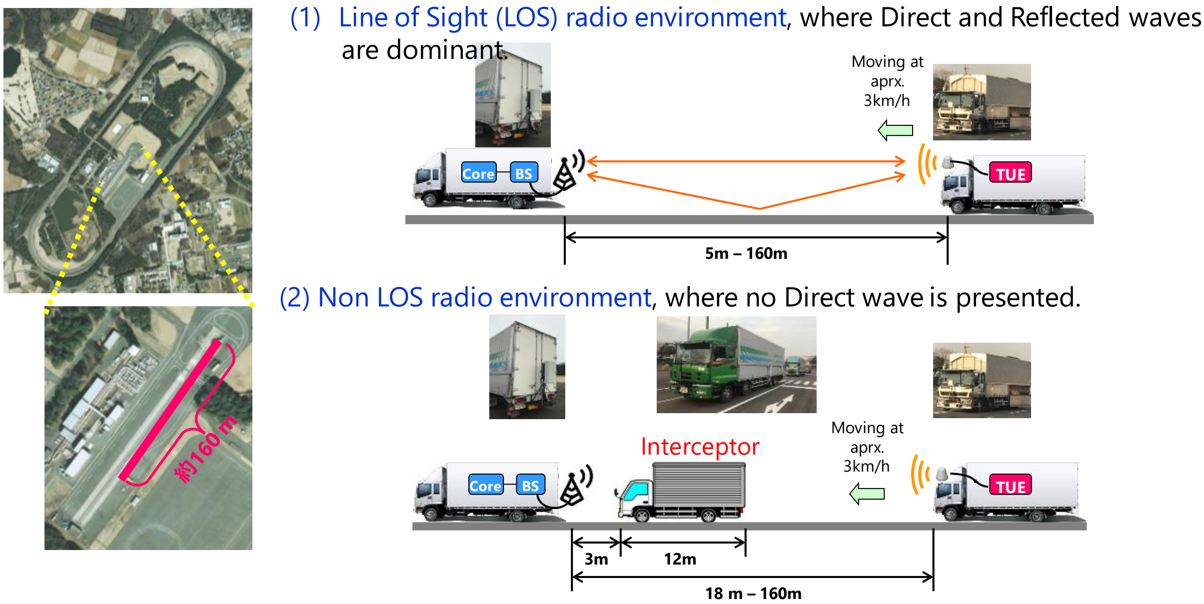
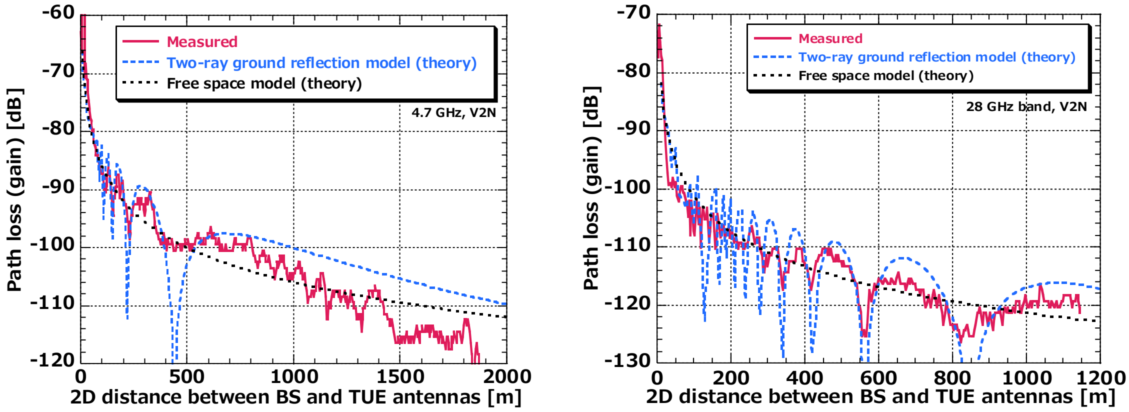


Fig. 3.2.2-20 Field trial test environment for V2V direct communications

Propagation environment evaluation

Radio propagation environments were evaluated at the test course. The evaluation was carried out to measure reception power strength by using Reference Signal (CSI-RS: Channel State Information – Reference Signal) which is periodically transmitted from Base Station in order to calculate propagation loss considering antenna gain, its pattern and feeder cable loss. Figs. 3.2.2-21 (a) and (b) show measured propagation loss in 4.7 GHz and 28 GHz bands, respectively.



(a) 4.7 GHz band (b) 28 GHz band

Fig. 3.2.2-21 Measured propagation loss at the test course.

It was found that at the test course path loss fluctuation well-meets that of two-ray ground reflection model.

Latency characteristics

Considering a 5G application to the vehicle control system in platooning, trial was conducted to test the latency characteristics of the 5G communication system. The trial was carried out on 4.7 GHz in a rural radio environment. The speed of the trucks was set from 0 km/h to 90 km/h. The results show that the over-the-air latency of 0.58 ms was achieved and demonstrated at the speeds of 87 km/h, as shown in Fig. 3.2.2-22.

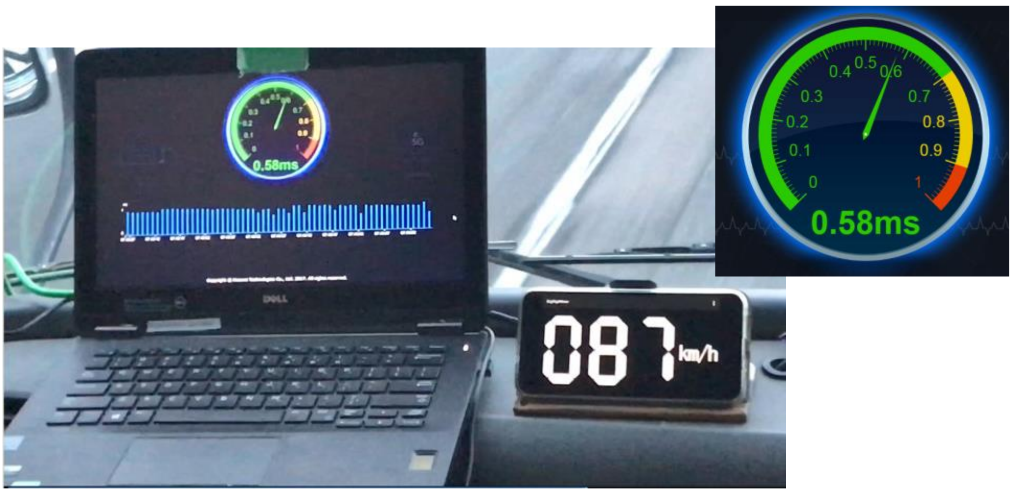


Fig. 3.2.2-22 Over-the-air Latency Characteristics

Figs. 3.2.2-23 and 3.2.2-24 show round trip delay performance of our 4.7 GHz 5G URLLC test equipment in V2N, i.e. via BS, communication for UE-BS (over-the-air delay) and UE-ICMP server (E2E delay), respectively. Fig. 3.2.2-23 shows that round trip delay over-the-air was less than 2 ms, independent from vehicle speed. It can be concluded that one-way over-the-air delay of less than 1 ms can be achieved. Fig. 3.2.2-24 shows that end-to-end round trip delay, including delay in network, i.e. between BS and core-network device, was less than 2.4 ms.

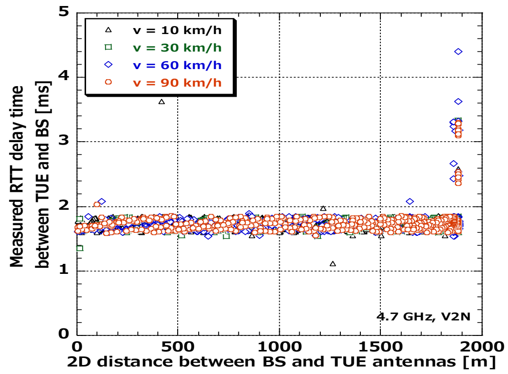


Fig. 3.2.2-23 over-the-air round-trip delay

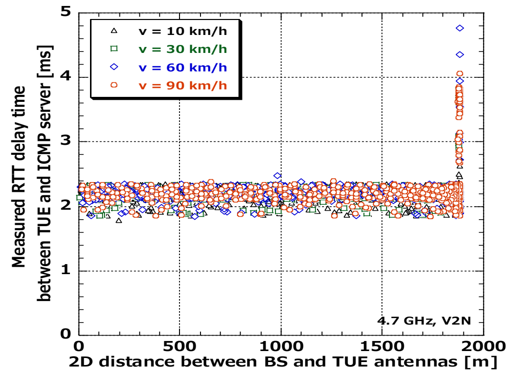
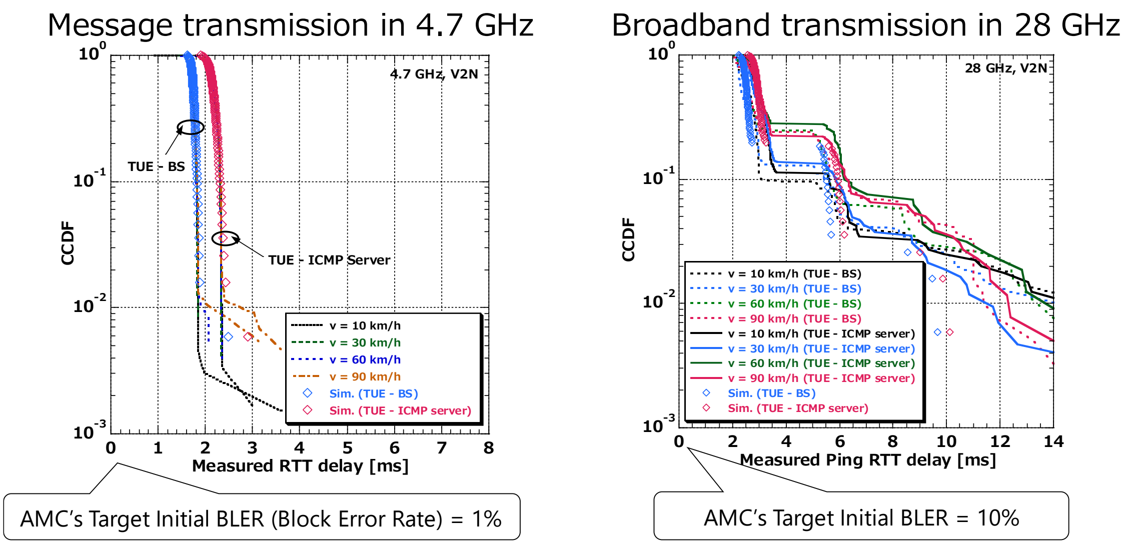


Fig. 3.2.2-24 End-to-End round-trip delay

Figs. 3.2.2-25 (a) and (b) are complementary CDF of the measured round-trip delay of our 5G test prototypes for 4.7 GHz and 28 GHz, respectively. The prototypes have different AMC's target initial BLERs (Block Error Rates) of 1% and 10 %, respectively.



(a) 4.7 GHz prototype (b) 28 GHz prototype

Fig. 3.2.2-25 Complementary CDF of our 5G test equipment

Figs. 3.2.2-25 (a) and (b) show that achievable round-trip time delay was different, due to the different target BLER tailored for message and broadband transmission, respectively.

Throughput characteristics

In truck platooning, it is required to monitor the surrounding of trailing trucks for safety driving. Field trial tests were carried out to assess the feasibility of low-latency and high capacity (or high throughput) communication systems by 5G. In the tests, V2V direct communication was evaluated. The inter-vehicle distance was 10 m. 28 GHz band is used since the band provides wider band width, e.g. a band width of 700 MHz. Fig. 3.2.2-26 shows traveled distance versus achieved throughput. This figure shows that the throughput of 2 Gbps is achieved.

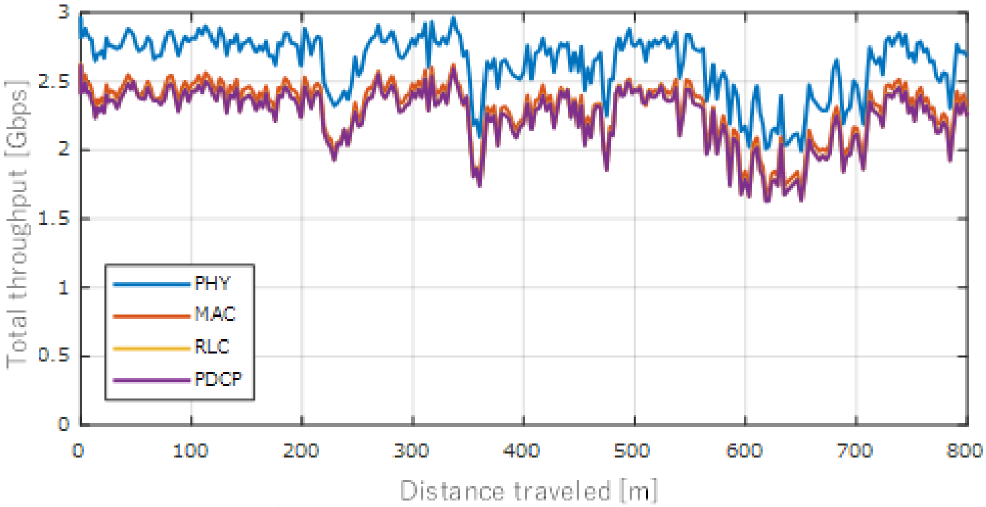


Fig. 3.2.2-26 Throughput characteristics

<u>Conclusion</u>

Performance evaluation of 5G URLLC was carried out in real automotive test course with a view to applying 5G 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 shows that both of these communication requirements could be met with 5G capability. Further tests on the reliability of 5G communication is planned towards complete platooning test.

References

[1] MIC, "Start of 5G Comprehensive Demonstration Test," http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/170516_02.html.

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

3.3 5G Field Trials on Nine Types of Use Cases

3.3.1 Use Case 1: Sports Application

3.3.1.1 FY2019 Field Trials by NTT Communications and Partners

- **Responsible organization:** NTT Communications Corporation

(1) Field Trial Utilizing 5G at a Golf Course to Assist with Golf Play

- **Partners:** MIRAIT Corporation, FUJITSU LIMITED, Nagano Keikyu Country Club Co., Ltd., NTT DOCOMO, INC.

This 5G field test was held at the Nagano Keikyu Country Club in Nagano City, Nagano Prefecture in November 2019. A 5G network transmitting over the 28 GHz frequency band was constructed at Hole 1 of the country club's golf course. This 5G network was utilized to transmit a video taken with a 4K 360° camera, and analyze with artificial intelligence to predict the golf ball landing spot as well as show the state of play with live video displayed on a next generation display golf cart. In a 5G environment with multiple base stations and multiple terminals, we succeeded in providing stable 4K live video transmission and a ball landing spot prediction service to a moving cart. This will make player turnovers more efficient. These services are expected to contribute to the economic revitalization of local areas, such as being an effective substitution for caddies when they are not available, and attracting golfers from both inside and outside the prefecture.

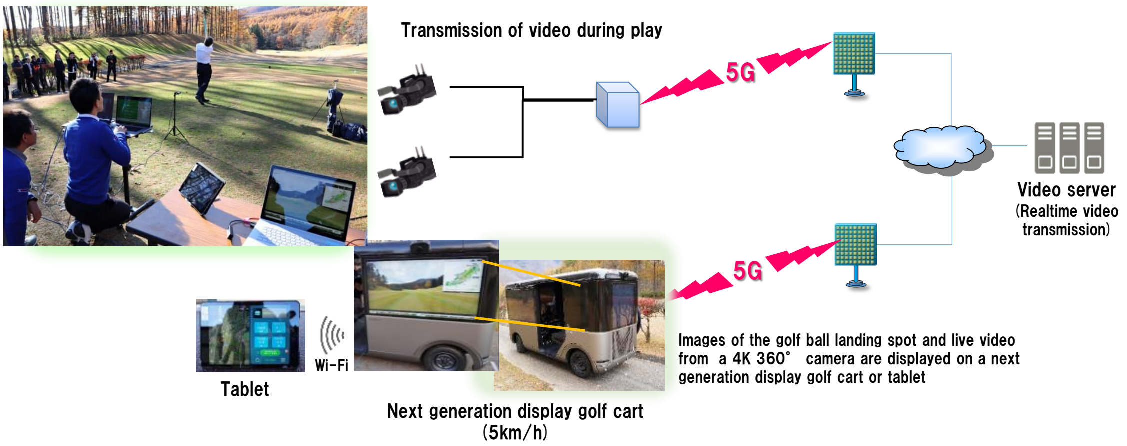


Fig. 3.3.1-1 Overview of the field trial utilizing 5G at a golf course to assist with golf play

Fig. 3.3.1-2 Pictures from the utilizing 5G at a golf course to assist with golf play field trial

3.3.1.2 FY2019 Field Trials by KDDI and Partners

- **Responsible organization:** KDDI Corporation

(1) Promotion of New Sports "Slackline"

- **Partners:** Goolight, Asobism, Japan Slackline Promotion Organization

The objective of this trial is to vitalize local society of Obuse town, which is well known among slackline enthusiasts, by promoting new sports "Slackline." There are some issues specific to promoting new sports. For example, viewers may not necessarily be familiar with the rules of the competition and may miss the highlight scenes. It is also necessary to provide a more immersive way to involve viewers and to make them feel closer to the sports, rather than just watching the game. To resolve these issues, a new kind of experience to enjoy sports was demonstrated by utilizing the high-speed uplink capability and low latency of 5G during the 2019 Slackline World Cup Japan Full Combo, held at Obuse General Park in Nagano Prefecture in September 2019.

In this trial, two 5G base stations using 28 GHz band were installed at five meters above the ground, and three 5G terminals were arranged as shown in Fig. 3.3.1-3. Using this testbed, two application tests were conducted.

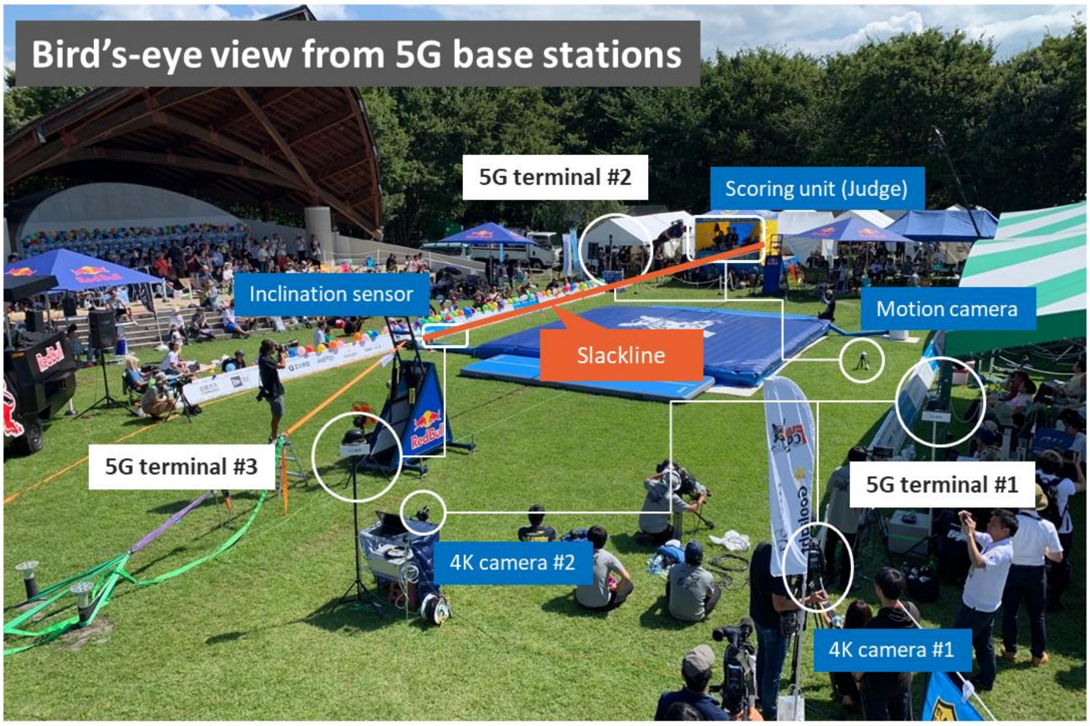


Fig. 3.3.1-3 Equipment layout

The overall system configuration of this demonstration is shown in Fig. 3.3.1-4. The system was divided into two systems: the video system and the vibration system.

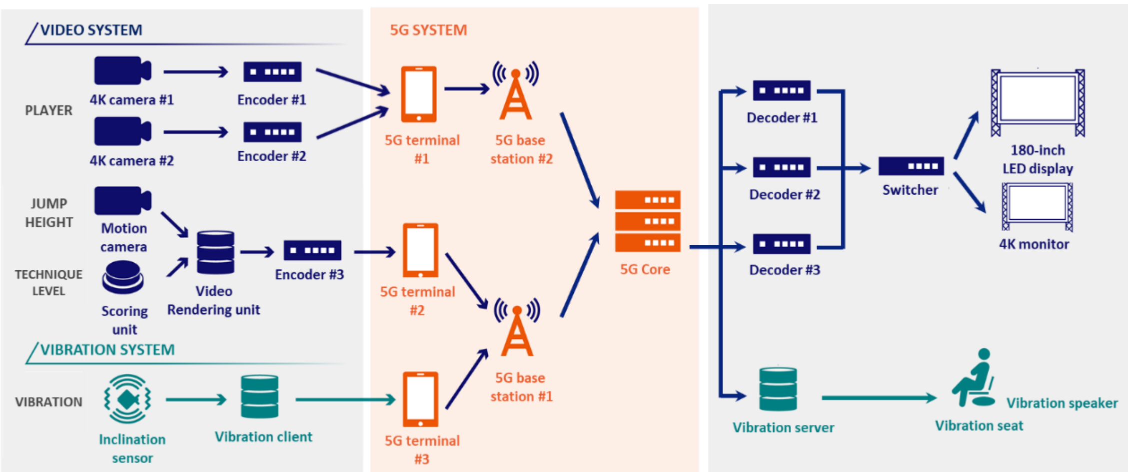


Fig. 3.3.1-4 System diagram

In the video system, height of jumps which were automatically measured from the motion camera images, together with the difficulty level of the technique and number of consecutive jumps, were visualized in the video rendering unit and transmitted via 5G terminal #2. 4K 60 fps high definition images of players were also transmitted via 5G terminal #1. These images were combined by the switcher and displayed on monitors in the venue in real time. Two sets of 4K cameras and encoders were prepared to shoot the players, and the angle was changed flexibly during the competition. 5G terminal #1 had a stable MAC throughput of over 100 Mbps (IP throughput of over 90 Mbps), and the End to End latency was 300 ms. This latency did not make viewers feel uncomfortable since most viewers did not see the competition scene itself and the display at the same time. These video helped viewers to better understand the competition.

As a result, the trial proved that it was effective to display important information including height, difficulty levels to be shared among viewers, in promoting competition and gaining fans for sports that are relatively new in origin and for which the rules and judging criteria are not widely acknowledged.

In the vibration system, the inclination sensor installed on the slackline detected the vibration that occurred at the moment a player touched the line, and the vibration information was delivered to the vibration seats via 5G in 41-50 ms. The low latency of 5G enabled the viewers to share a sense of unity with the competitors in front of them. The viewers who experienced the vibration seat commented, "I felt as if I were jumping on the slackline and felt united with the player. I feel like playing slackline myself."

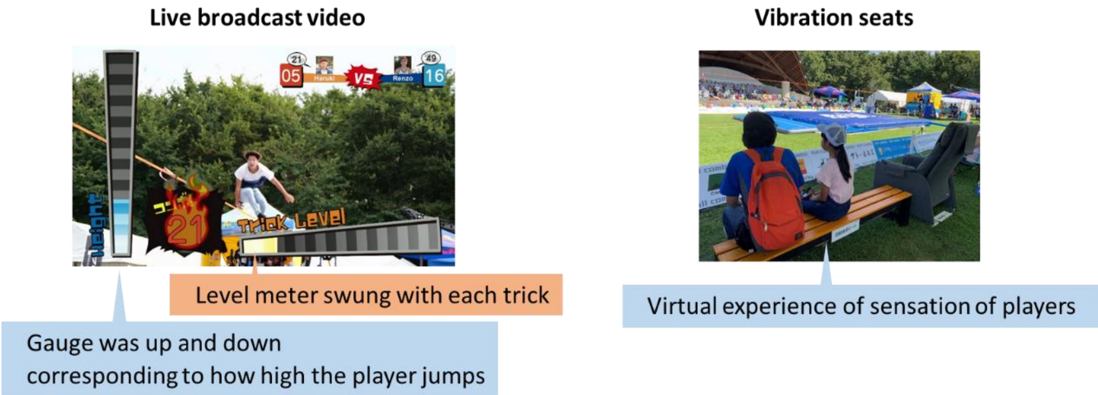


Fig. 3.3.1-5 Demonstration

As described above, by utilizing the large capacity and low latency of 5G, it has contributed to promote the understanding of competition which is important for the popularization of new sports, and to provide new and exciting experiences. 5G is expected to help vitalize the local community through promoting a community-based sports event like "slackline."

3.3.1.3 FY2019 Field Trials by ATR and Partners

- **Responsible organization:** Advanced Telecommunications Research Institute International (ATR)

(1) Enhance Sense of Unity between Players and Spectators

- **Partners:** KDDI Corporation, Jupiter Telecommunications, Data Stadium, Knows

This trial was held on October 19, 2019, in the au 5G Tag Rugby Exhibition Match at Hanazono Rugby Stadium. Tag Rugby is a team sport in which a player tries to take off tags from opponents, instead of tackles in rugby. In this trial, the data of players' vital sensor such as fatigue levels was transmitted to the server via 5G and superimposed on the 4K live video on the main screen and 5G terminals in the stadium. The spectators are encouraged to cheer players by swinging stick balloons. Each stick balloon has a vibration sensor that informs the server of how the balloon was hit, and the server calculates the cheering levels based on the vibration information. During the halftime of the game, the spectators competed for the level of swinging stick balloons. A sense of unity are enhanced between players and spectators and/or among spectators by sharing the information about players' activities and spectators' cheering levels. Figure 3.3.1-6 shows the overview of the trial configuration. In Fig. 3.3.1-7, part (a) shows the main screen which displays the tag rugby game, (b) shows the 5G terminal, and (c) shows the scene of cheering battles.

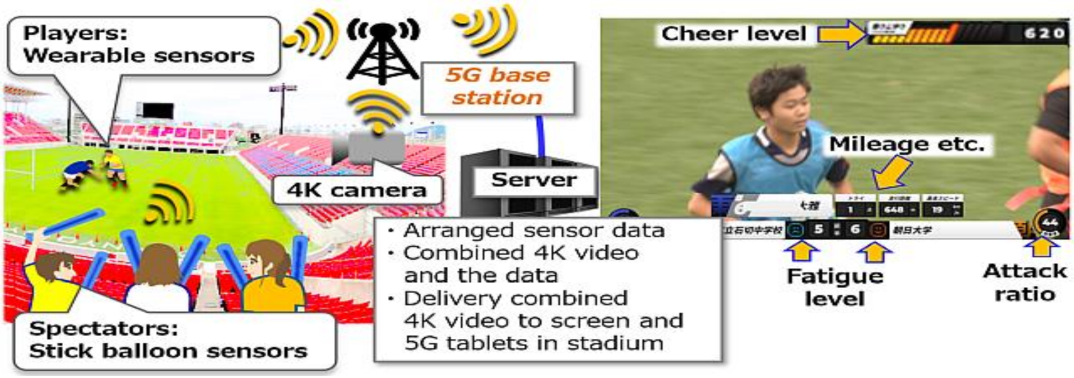


Fig. 3.3.1-6 Overview of watching sports bringing sense of unity between players and spectators

(a) Video on the main screen (b) Video on a 5G terminal (c) Cheering battle

Fig. 3.3.1-7 Snapshots of the field trial

The team leader of the data visualization system engaged in the trial said, "Not only in the professional sports, but also in amateur sports, did I feel the validity of providing brand new watching experience, such as live broadcasting with interactive rich content video, by utilizing 5G."

3.3.1.4 FY2018 Field Trials by NTT DOCOMO and Partners

(1) 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 Corporation, 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.

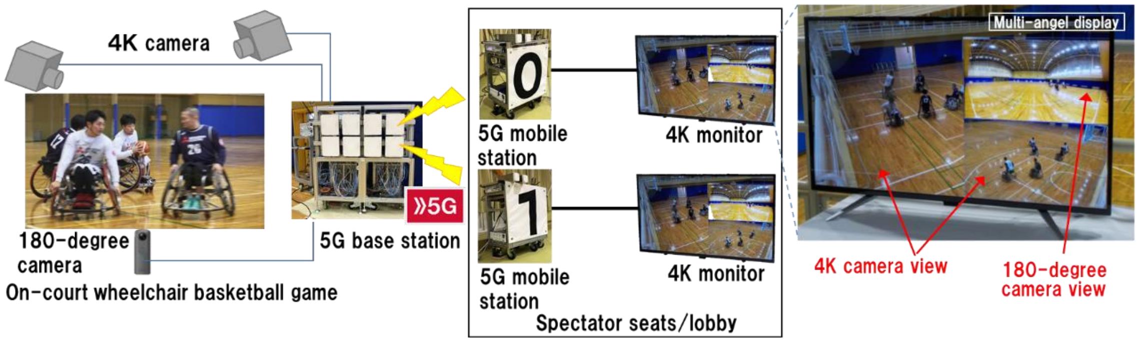


Fig. 3.3.1-8 Experiencing the atmosphere of a wheelchair basketball game via multi-angle HD video

(2) 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 LIMITED, 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. 3.3.1-9 Realization of real time remote support of a sports event using 5G

3.3.1.5 FY2018 Field Trials by KDDI and Partners

(1) 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 with TV Asahi Corporation 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.

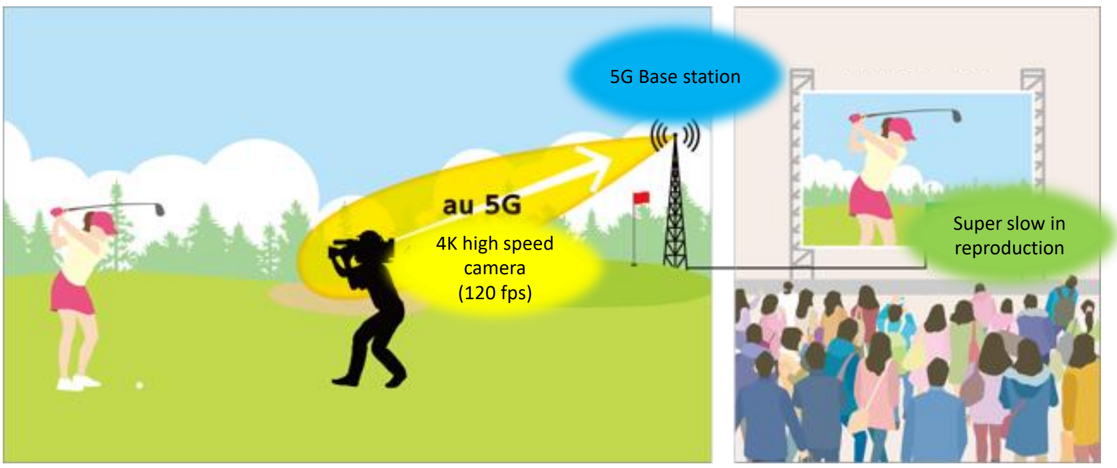


Fig. 3.3.1-10 Image of the use case in this trial

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. 3.3.1-11.

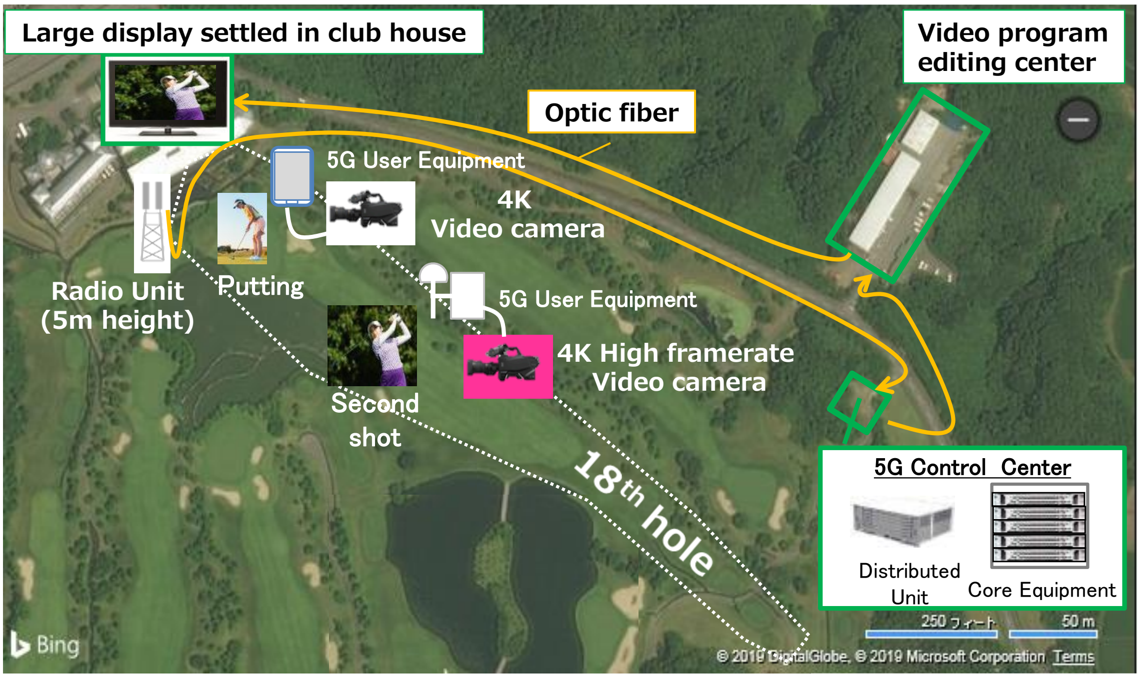


Fig. 3.3.1-11 Equipment configuration and location

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. (Figure 3.3.1-12)

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

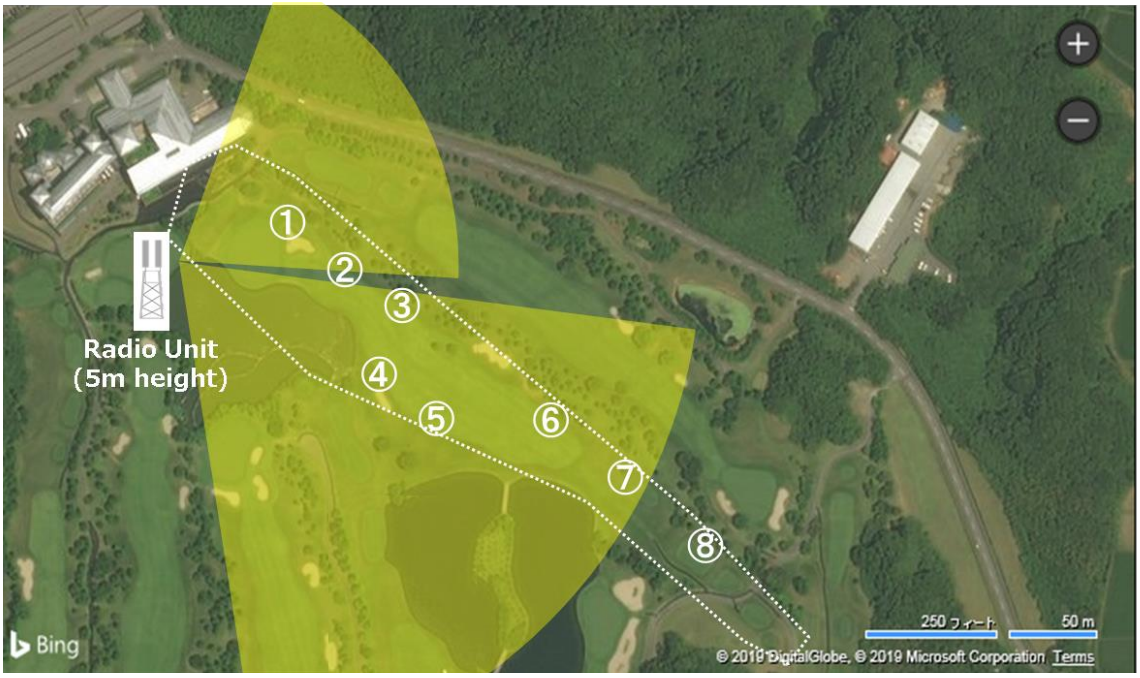


Fig. 3.3.1-12 Cells and measurement points

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. 3.3.1-13 The super slow 4K video demonstration

3.3.1.6 FY2017 Field Trials by ATR and Partners

(1) Stadium Entertainment

A 28GHz-band base station was built in the Okinawa Cellular Stadium, and a demonstration to simultaneously distribute 4K video to fifty 5G tablets was conducted in the stands during professional baseball games in March 2018 with the support of the Naha Board of Education, KDDI Corporation, and Okinawa Cellular Telephone Company. The viewers can select and view video from multiple cameras shot in the stadium. Figures 3.3.1-14 and 3.3.1-15 describe the overview and test configuration of the trials. Fig.3.3.1-16 shows the installation locations of fifty 5G tablets and the scene of the test.

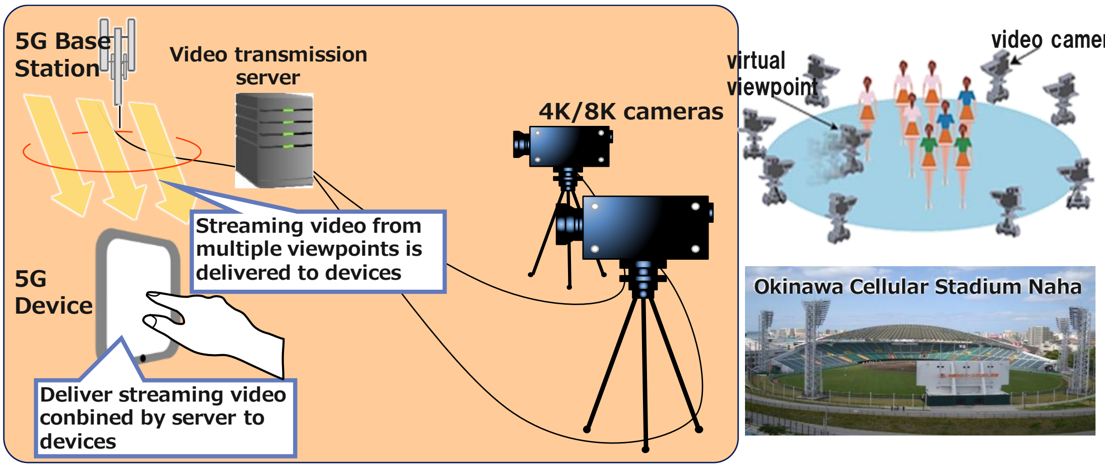


Fig. 3.3.1-14 Overview of the field trial to distribute 4K video in the stadium

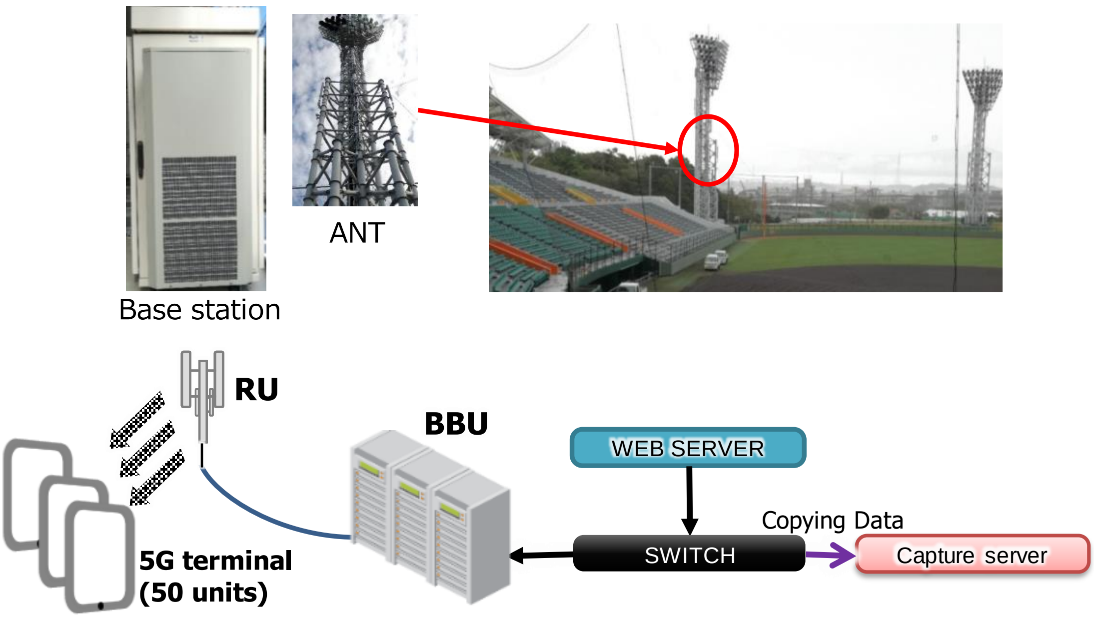


Fig. 3.3.1-15 Test Configuration

Fig. 3.3.1-16 Example of fifty 5G tablets set points and scene of test

In the future, it will be possible to watch real time and free viewpoint VR videos from different perspectives in the stadium or living room. We expect that this technology will expand the range of sports watching. The image of a free viewpoint video is illustrated in Fig.3.3.1-17.


Fig. 3.3.1-17 Image of a free viewpoint video

3.3.2 Use Case 2: Entertainment Application

3.3.2.1 FY2019 Field Trials by NTT DOCOMO and Partners

- **Responsible organization:** NTT DOCOMO, INC.

(1) Field Trial Utilizing 5G for Real Time Cloud Based Editing and Livestreaming Solutions in the Cloud

- **Partners:** Sendai Television Incorporated, Sony Business Solutions Corporation

This 5G field test was held in Miyagi Prefecture in December 2019. It verified the ability of a Docomo 5G preservice area in Miyagi utilizing the 4.5 GHz frequency band to carry out a service in which a 5G network would be used to transmit and edit video during the streaming of a live event. This trial confirmed that professionally filmed content could be transmitted without pause from four cameras (at speeds of 24 Mbps) placed at an outdoor event venue without the need of large scale relay equipment to an offsite location that was not a dedicated broadcast station but was equipped with specialized editing equipment and software.

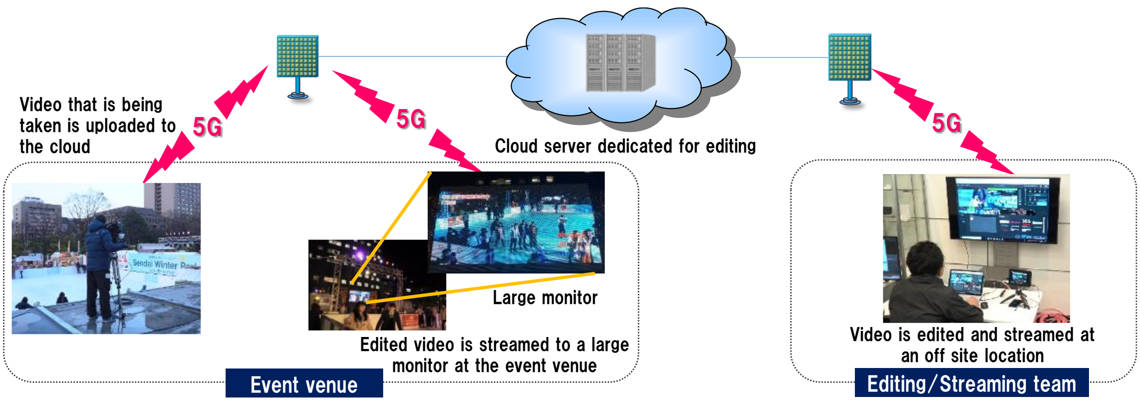


Fig. 3.3.2-1 Field Trial utilizing 5G for real time cloud-based editing and livestreaming solutions

Fig. 3.3.2-2 View of the off-site editing and switching

(2) Field Trial Utilizing 5G for Body Sharing to Promote Tourism in Okinawa Prefecture

- **Partners:** H2L Inc., IT Innovation and Strategy Center Okinawa

This 5G field test was held in Okinawa prefecture in February 2020. The goal of this test was to demonstrate the realization of a new form of tourism through services in which a virtual experience would allow participation in the same activities at a tourist site by those who could not visit it themselves. The trial location was an outdoor pool at the National Institute of Technology, Okinawa College, in Nago, Okinawa, where a 5G network was constructed via a portable base station that utilized the 4.5 GHz frequency band along with a robotic kayak with a 5G device installed. The robotic kayak in the pool was then connected to a remote-control master system at the DOCOMO 5G Open Lab ® OKINAWA, which is located within a 5G pre-service area. Trials were conducted on the transmission of high definition video as well as a virtual experience with the robotic kayak. Participants commented that the ability to view high definition video and control the robotic kayak remotely provided them a highly immersive sightseeing experience. This trial confirmed the possibility of realizing virtual tourist experiences in the future.

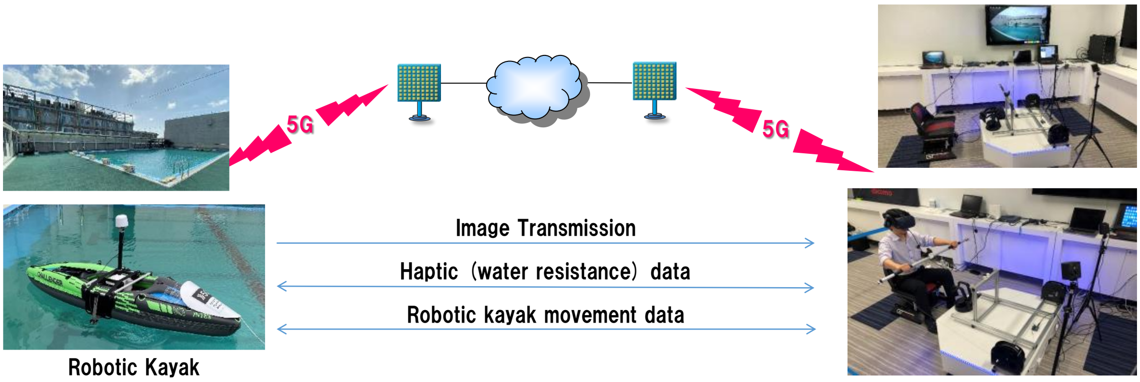


Fig. 3.3.2-3 System for field trial utilizing 5G to promote tourism

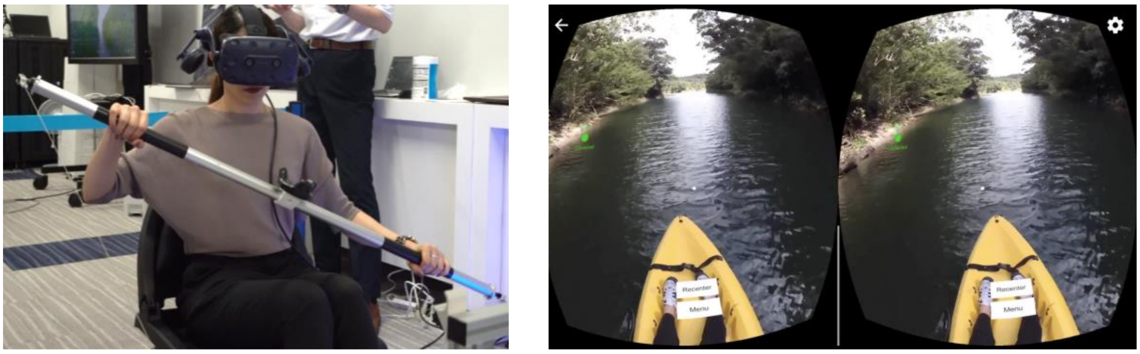


Fig. 3.3.2-4 Vision of a future virtual tourist kayaking experience utilizing 5G

3.3.2.2 FY2019 Field Trials by KDDI and Partners

- **Responsible organization:** KDDI CORPORATION

(1) Promotion of Tourism Utilizing High Definition Omnidirectional VR Video Images

- **Partners:** Tokai University, Air Camera, Agrid, Minamiaso Village

Promotion of tourism has been an important task for Minamiaso Village since the huge earthquake that hit the Kumamoto area in 2016. On another front, the Minamiaso area has a potential to attract more attention of tourists, if many off-limit spots can be appealed more positively, as represented by Mt. Aso crater, or a colony of rare plants. In this trial, in order to realize safe and environmental conscious tourism, high definition omnidirectional VR videos from drones were sent to tourists visiting these area through HMD (Head Mount Display) on a real- time basis, and examined the possibility of new attraction for tourism, and increase the attention of tourists to the Minamiaso area.

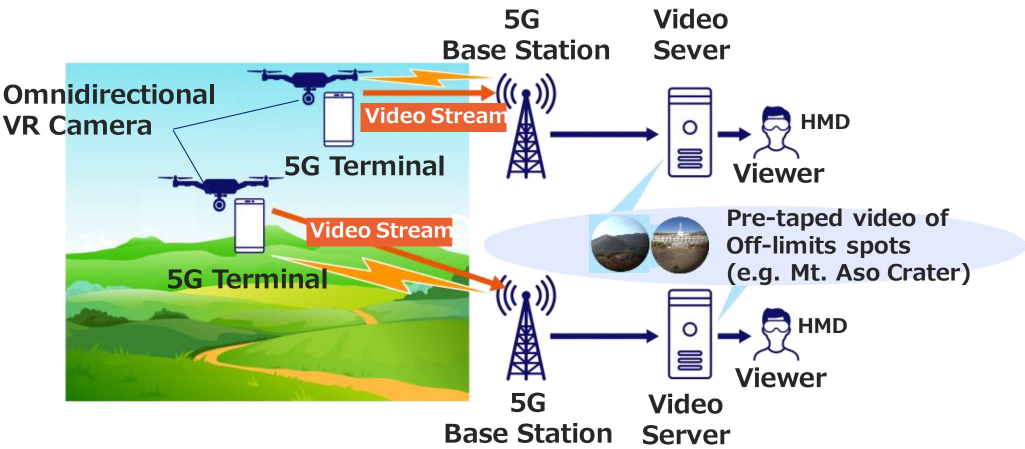


Fig. 3.3.2-13 Overview of the trial

The trial took place at the roadside station “Asobou no Sato Kugino” in Minamiaso village, in December 2019. Two 28 GHz 5G base stations were placed in the open space beside the roadside station, as shown in Fig.3.3.2-14.

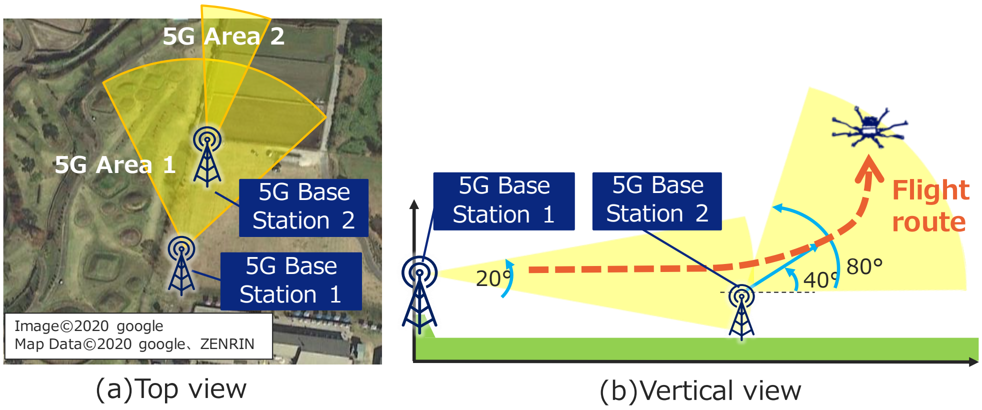


Fig. 3.3.2-14 5G area for the trial

First of all, the 5G radio performance was measured at several points in the area covered by two base stations, using one or two 5G terminals on the drone(s). From the measurement results, it was confirmed that the uplink IP throughput of 30 Mbps, which was required to transmit 4K omnidirectional VR video in the trial, was secured on the planned flight routes of the drones. However, in case two 5G terminals send data simultaneously in the area, it was observed that the aggregated uplink IP throughput was lower than that of one terminal, as shown in Fig. 3.3.2-15. The reason of this is considered to be the radio environment of one terminal being relatively worse than the other, causing the total efficiency of radio frequency usage became lower than that of one terminal in the better condition.

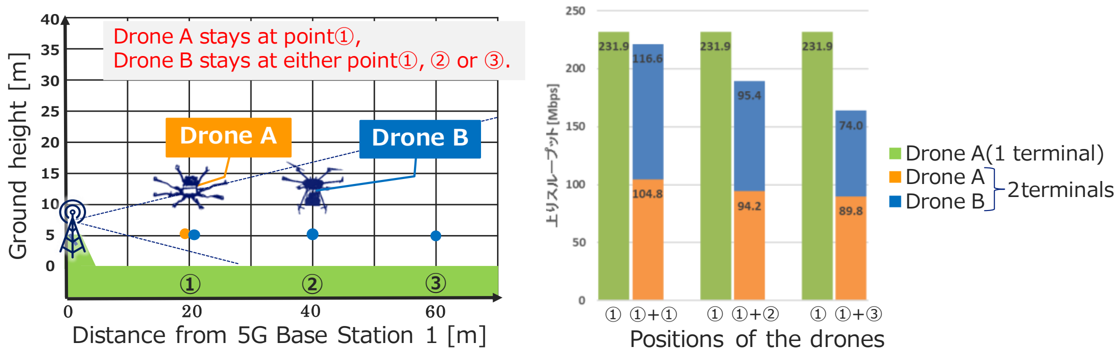


Fig. 3.3.2-15 5G performance test (two 5G terminals)

Next, the feasibility of the use case was verified. Two drones, each with one 5G terminal on board, flew over the area covered by the two 5G base stations, reached up to 67m distance from the base station at the farthest. High definition omnidirectional VR video stream from these drones was delivered to two viewers' HMD respectively without interruption, allowing viewers to enjoy a virtual flight experience. Pre-taped omnidirectional video contents including scenes of disaster area remains, in inaccessible areas, and in various seasons, were also included in the VR contents, to be switched back and forth by viewer's selection.

Mr. Fujiwara, CEO of roadside station company "Asobou no Sato Minami-Aso", who has been engaged in the local tourism in the area expressed, "In the past, sightseeing from a helicopter gained a popularity in this area, however, the service has been suspended because the noise caused a public nuisance. The trial this time is not a mere replacement of the service but can be more, since it's very gentle, and also provides the wide view that can be seen behind and below. This will be an advantage. Video quality was good enough, but it will be great with further upgrade."

Fig. 3.3.2-16 Snap shot of the trial

In the trial, remote piloting a drone via 5G was also verified at same site, taking advantage of ultralow latency on delivery of high definition video. The network configuration is shown in Fig.3.3.2-17. The pilot controlled the drone successfully to fly on the specified route, watching 4K resolution video alone in a remote disjuncture room, which was transmitted from the drone via 5G.

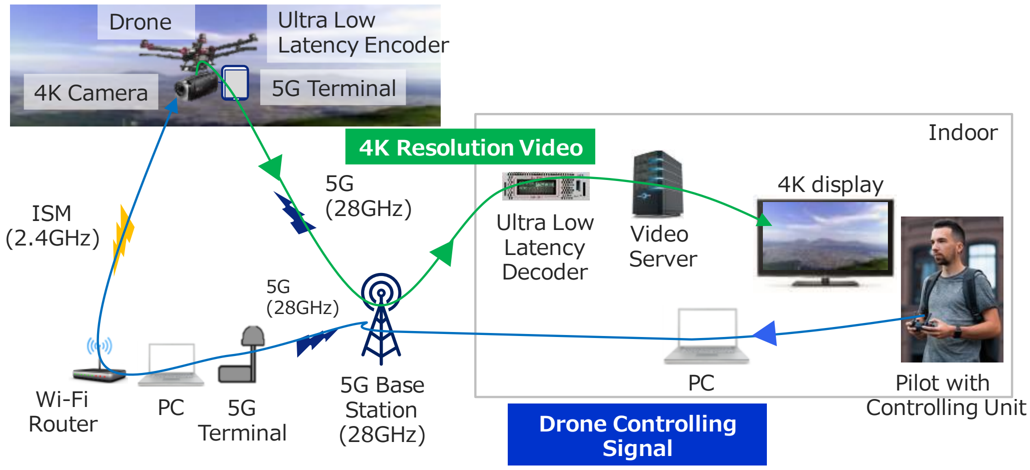


Fig. 3.3.2-17 Piloting a drone via 5G

The End to End latency of 4K resolution video delivery was 150ms, including 50ms for buffering at the decoder. The drone pilot engaged in the trial, Mr. Yaoita, CTO of drone engineering team "Agrid" commented, "I felt neither stress nor discomfort in controlling the drone remotely in this way and that the trial system can be adopted directly to drone competition race."

Fig. 3.3.2-18 Snap shot of the trial and the actual view via 5G

3.3.2.3 FY2017-2018 Field Trials by NTT DOCOMO and Partners

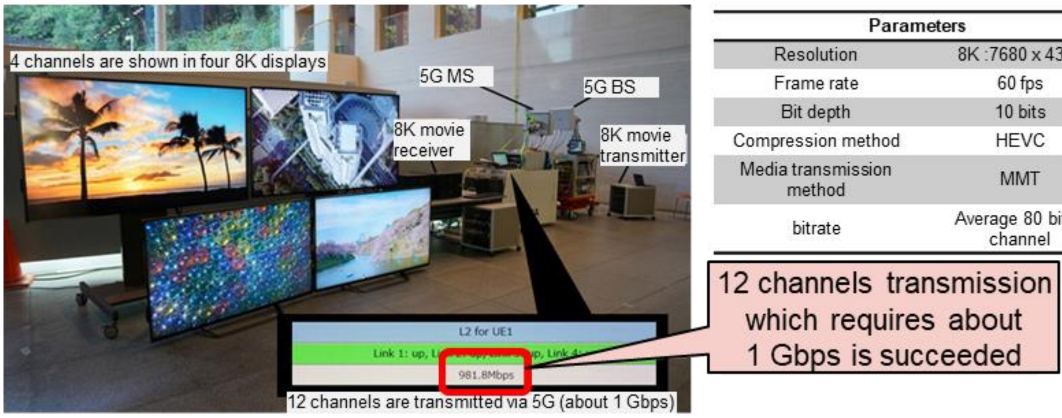
(1) 5G System Performance Evaluations for Entertainment Services

Figure 3.3.2-19 shows an overview of 5G system performance evaluations for proposed services in the fields of entertainment. Specifically, the dense urban areas such as stadiums during the Tokyo Olympics and Paralympics are being considered for the field of entertainment.

Fig. 3.3.2-19 5G system performance evaluations for entertainment services

<u>**Field Trials in FY2017**</u>

Assessments of high speed transmissions to deliver high definition high presence video will be carried out. In the trial with the cooperation of Sharp Corporation, 5G trial equipment systems could deliver 12 channel transmissions of 8K video as shown in Fig.3.3.2-20 [5]. Since 12 channels transmission of the 8K video requires about 1 Gbps, the larger number of channels can be realized by 5G capability over 10 Gbps. In addition, various kinds of entertainment services such as 4K high-resolution 360-degree camera video transmission, signage by low reflection display in the shopping mall, live transmission of multiple high-resolution 4K videos in the stadium, 3D video chatting by using mixed reality technology were evaluated through the 5G trial equipment.



Parameters	
Resolution	8K :7680 x 4320
Frame rate	60 fps
Bit depth	10 bits
Compression method	HEVC
Media transmission method	MMT
bitrate	Average 80 bits / channel

Fig. 3.3.2-20 8K video multi-channel transmission

References

[1] MIC, "Beginning the 5G Field Trials", http://www.soumu.go.jp/menu_news/s-news/01kiban14_02000297.html, May, 2017.

[2] NTT DOCOMO, "The State of Cooperative Activities and Progress in the MIC's 5G Field Trial", https://www.nttdocomo.co.jp/info/news_release/2017/05/19_01.html, May, 2017.

[3] Okamura, et al., "System Trials toward Actualization of 5th Generation Mobile Communication System 5G", MWE2017 WEIB, November, 2017.

[4] ITU-R M.2412-0, "Guidelines for evaluation of radio interface technologies for IMT-2020," Oct. 2017.

[5] NTT DOCOMO, "DOCOMO Achieves 12-Channel MMT Transmission of 8K Video via 5G System",

https://www.nttdocomo.co.jp/info/news_release/2017/11/07_01.html, November, 2017.
[6] NTT DOCOMO, "DOCOMO's Results of MIC 5G Field Trial in FY2017", https://www.nttdocomo.co.jp/binary/pdf/info/news_release/topics_180326_03.pdf, March, 2018.

(2) 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 Co., LTD. by using a regularly running TOBU RAILWAY steam locomotive [4]. 5G communications area, with the cooperation of NEC Corporation, 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 Corporation, 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. 3.3.2-21 New tourism experiences while riding steam locomotive with the realization of the delivery of HD Video

(3) 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 Corporation, 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. 3.3.2-22 Attracting tourism to the Arashiyama area via 8K video during Kyoto Arashiyama Hanatouro 2018

(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.

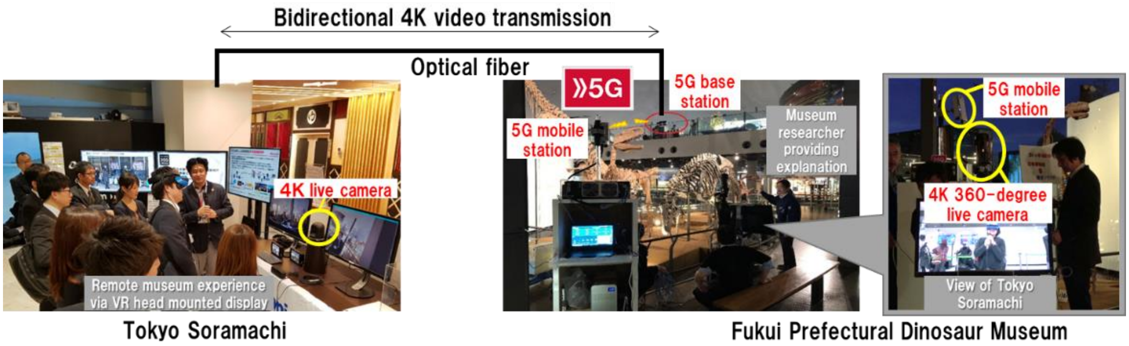


Fig. 3.3.2-23 Experiencing a museum in a remote location realized by bidirectional real time 4K camera and VR technology

(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. 3.3.2-24 8K live viewing using 5G in Aizu-Erousoku Festival

3.3.2.4 FY2017-2018 Field Trials by NTT Communications and Partners

(1) 5G Field Trial of High Speed Communications while Moving at High Speeds

The 5G trial described here tested the ability to use eMBB at transmission rates of up to 2 Gbps while moving at a speed of 90 km/h in urban or rural areas.

Specifically, a scenario was envisioned where users could access entertainment services that utilize high speed broadband of 2 Gbps on the 28 GHz band (with 800 MHz bandwidth) while travelling in a high-speed vehicle such as a bus or train utilizing 5G system benchmarks supported by NTT DOCOMO, INC. and cooperating partners in related fields. Trials were conducted on the Tobu Nikko Line of TOBU RAILWAY. The overview of 5G system performance evaluation shown in Fig. 3.3.2-25 was considered as entertainment services were being planned.

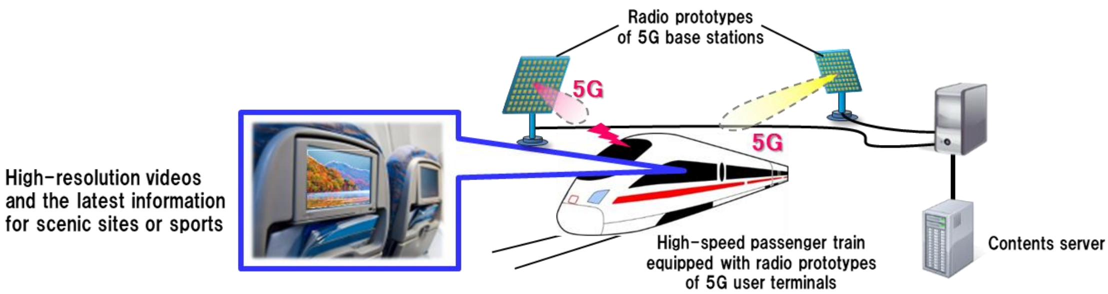


Fig. 3.3.2-25 Overview of 5G system performance evaluation

The delivery of high-presence and high-definition video contents, in both urban or rural areas to be used during the 2020 Tokyo Olympics and Paralympics, not only for spectators of sporting events but also for tourism, were tested using the 5G trial apparatus at the 28 GHz band on vehicles in high-speed environments traveling at over 90 km/h. The trial was conducted in February 2018 on the abovementioned Tobu Nikko Line (Details of the trial environment are described in Section 3.2.2.3).

<u>5G system performance evaluation for entertainment service</u>

As an entertainment service for railway passengers traveling at speeds of over 90km/h, railway operators are assuming a service that provides large-capacity contents of high-definition video according to a large number of users' request. After 5G transmission of super high definition video contents with 4K/8K is performed, the video contents are played back on display and smart phone.

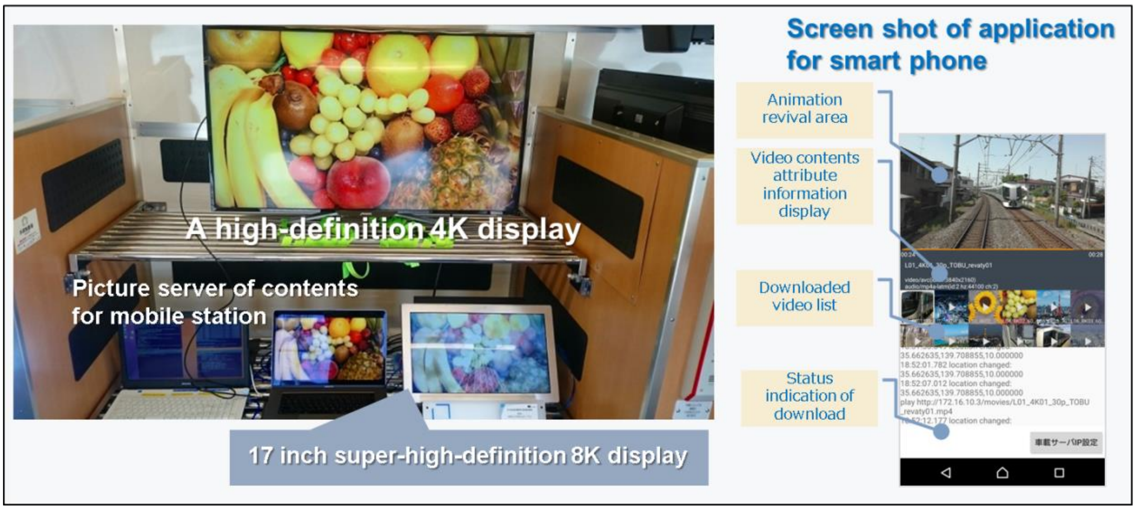


Fig. 3.3.2-26 High-quality video delivery service for high-speed moving vehicles

Actually connected time duration in high mobility of more than 90 km/h is almost 21 seconds, and total transmission quantity is 9.524 Gbit. In high speed mobility, the transmission bit-rate is changed by the distance between the base station and mobile station and RTT, and thus it's necessary to estimate and establish the quality of the contents in video delivery and required specification of 5G transmission by the most suitable balance.

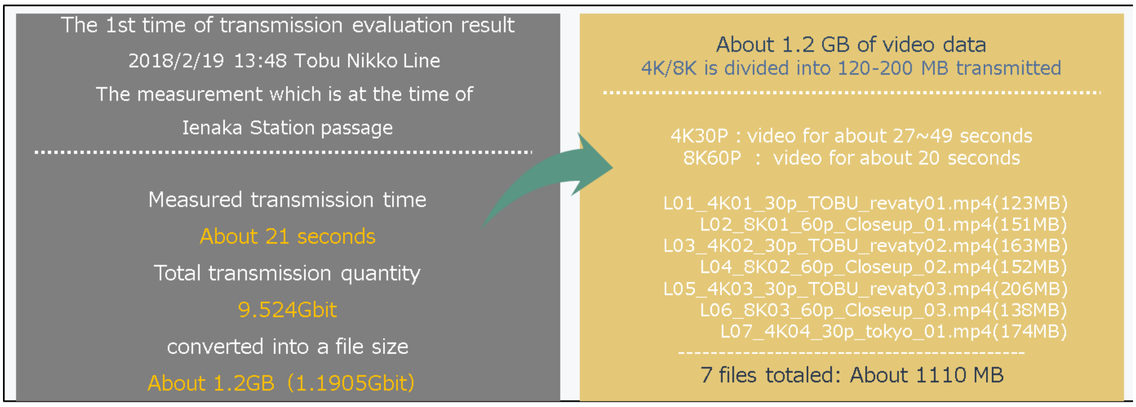


Fig. 3.3.2-27 Evaluation result

References

[1] MIC, "Beginning the 5G Field Trials", http://www.soumu.go.jp/menu_news/s-news/01kiban14_02000297.html, May, 2017.

[2] NTT DOCOMO, "The State of Cooperative Activities and Progress in the MIC's 5G Field Trial", https://www.nttdocomo.co.jp/info/news_release/2017/05/19_01.html.

[3] Okumura, et al., "System Trials toward Actualization of 5th Generation Mobile Communication System 5G", MWE 2017 WEIB, November, 2017.

(2) High-Definition Video Delivery to High Mobility

This trial with the cooperation of TOBU RAILWAY Co., LTD., NEC Corporation, Sharp Corporation and NTT DOCOMO, INC. 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

Figure 3.3.2-28 shows Overview of the demonstration experiment.

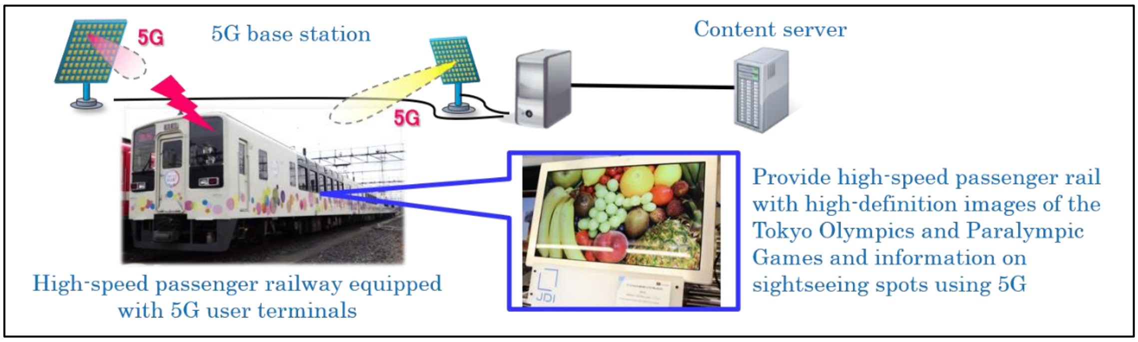


Fig. 3.3.2-28 Overview of high-definition video delivery to high mobility in Tobu Skytree Line

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. Figure 3.3.2-29 shows the arrangement of base stations.

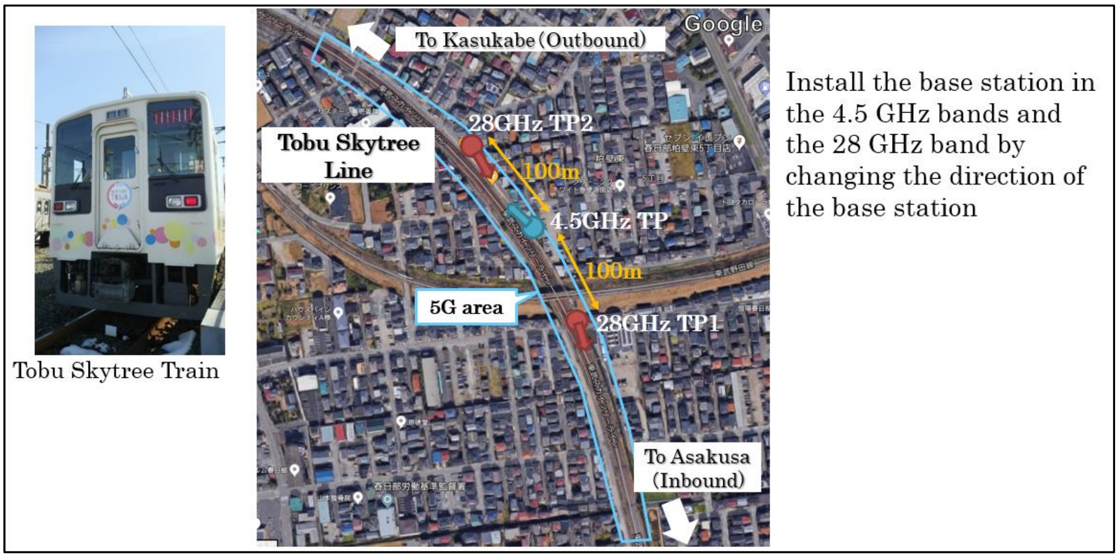


Fig. 3.3.2-29 Arrangement of base stations at the experimental site of Tobu Skytree Line

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. Figure 3.3.2-30 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.

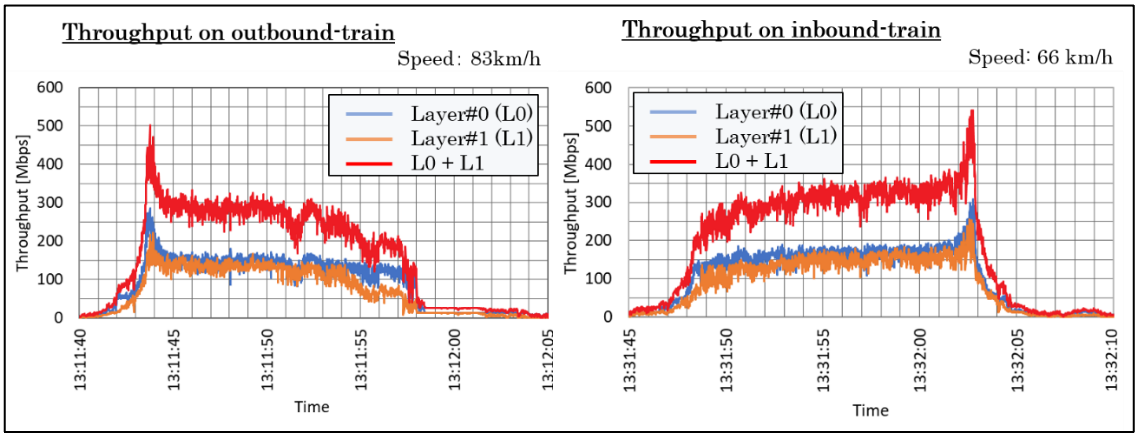


Fig. 3.3.2-30 Throughput in 4.5 GHz band

In the 28 GHz band (bandwidth 700 MHz), the mobile station was placed at the head of outbound train. Figure 3.3.2-31 shows the test results. The maximum throughput achieved 991 Mbps near TP1, and 1096 Mbps near TP2 after handover.

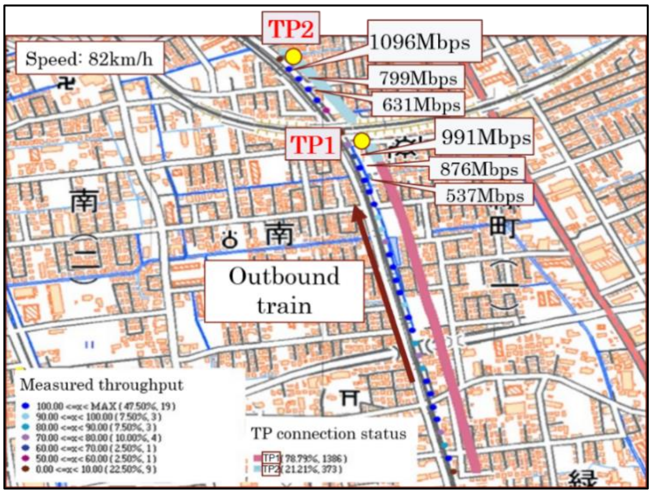


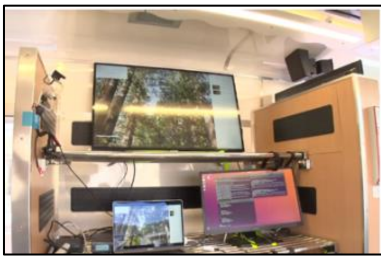
Fig. 3.3.2-31 Throughput in 28 GHz band (bandwidth 700 MHz)

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. Figure 3.3.2-32 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. 3.3.2-32 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. Figure 3.3.2-33 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. 3.3.2-33 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.

Figure 3.3.2-34 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.

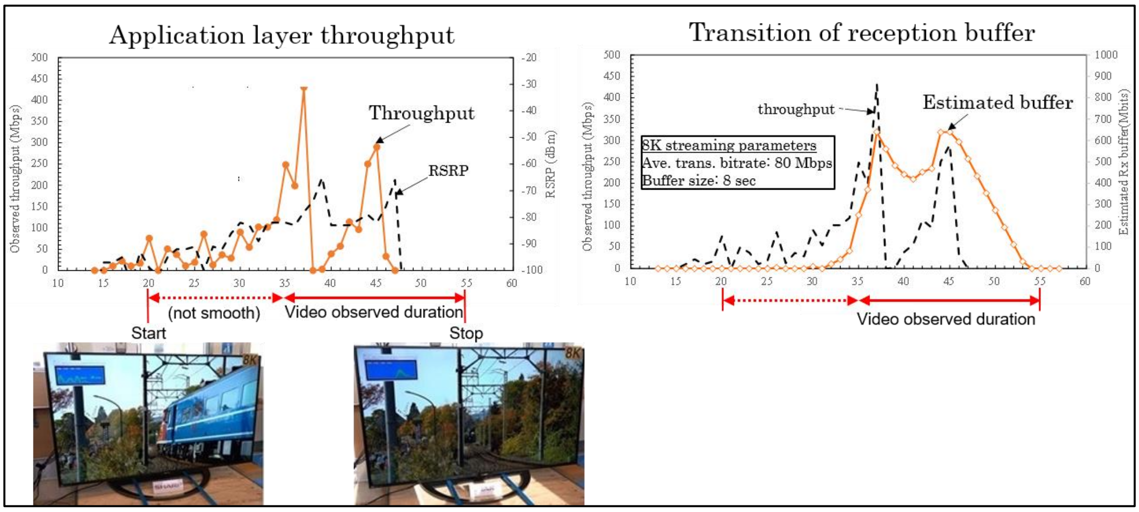


Fig. 3.3.2-34 Results of 8K video streaming

3.3.2.5 FY2017-2018 Field Trials by KDDI and Partners

(1) Real Time 4K Video Transmission from a Drone

Trials in FY2017

The objective of this trial is to verify the use case, in which 4K video stream will be delivered from a drone in the air. The video will be used effectively on the occasion of major events, natural disasters and so on. In FY2017, evaluation of 4G performance is carried out as an initial step with the University of Tokyo, as a base line to be compared with 5G.

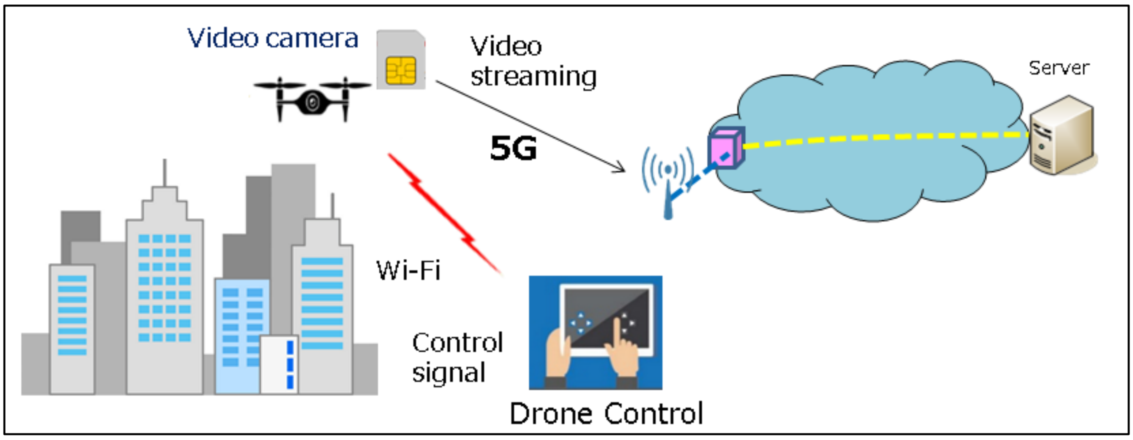


Fig. 3.3.2-35 Proposed trial for transmitting 4K video from a Drone

In FY 2017, preliminary testing using 4G/LTE was performed and it was revealed that it was difficult for 4G system to provide sufficient capability for 4K video uplink from drone in a stable manner.

Trials in FY2018

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 with the University of Tokyo, Fukuyama City, Commerce Industry and Labor Bureau of Hiroshima Prefecture.

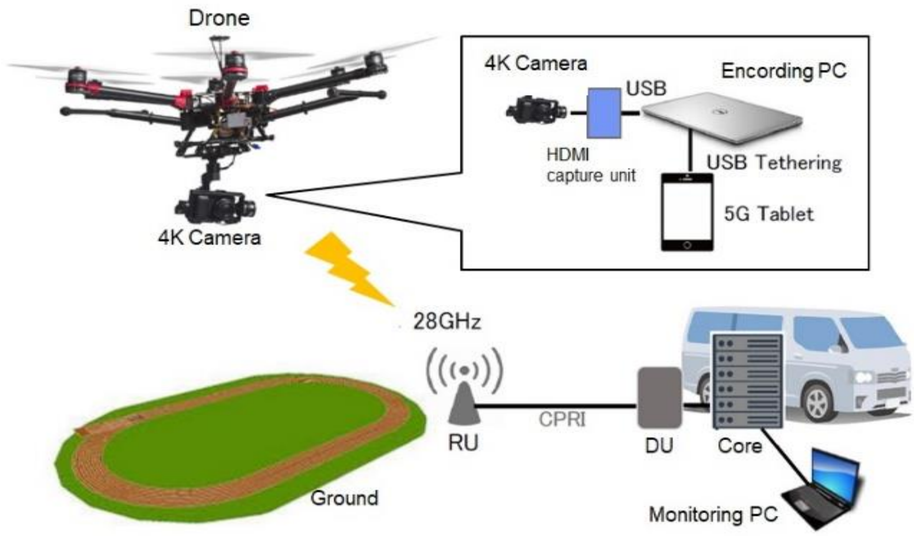


Fig. 3.3.2-36 Network configuration

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. 3.3.2-37 Simulation was also performed to estimate the RSRP and it was confirmed that the measurement results matched the simulated results as shown in Fig. 3.3.2-38 It was also confirmed that the radio performances of 15 Mbps required for 4K transmission was satisfied at all altitudes except for some spots.

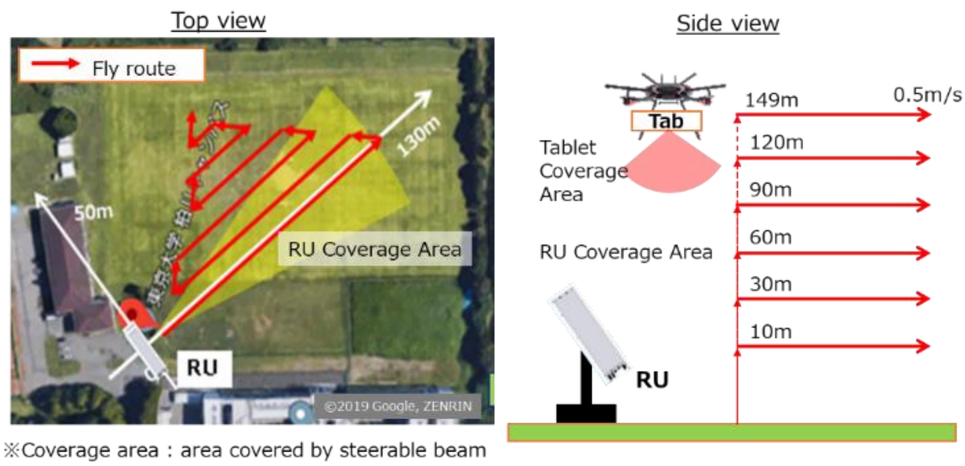


Fig. 3.3.2-37 5G coverage area and fly route

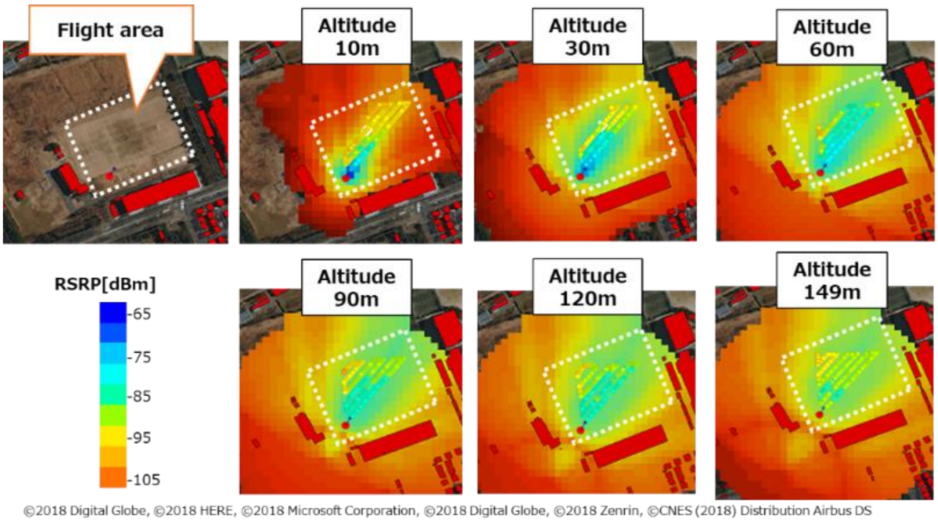


Fig. 3.3.2-38 RSRP distribution (simulation and measurement)

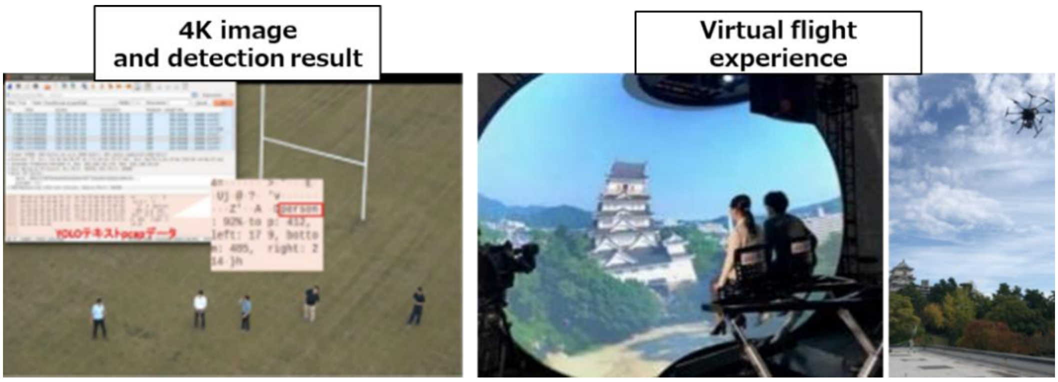


Fig. 3.3.2-39 Result of trials

3.3.3 Use Case 3: Office/Workplace Application

3.3.3.1 FY2019 Field Trials by NTT DOCOMO and Partners

- **Responsible organization:** NTT DOCOMO, INC.

(1) Filed Trial Utilizing 5G to Ensure Workplace Safety for Highly Skilled Workers

- **Partners:** Ehime University, Asakawa Shipbuilding Co., Ltd., Sumitomo Heavy Industries Material Handling Systems Co., Ltd., Ehime Prefecture

This 5G field test was held in Imabari city, Ehime Prefecture in December 2019. This trial demonstrated the realization of a safe operating environment utilizing a 5G radio device operating on the 28 GHz band to transmit high definition video to a crane operator cab of a blind spot from where the operator sits while he is slinging a load with the crane. The operator was able to sling loads safely around the blind spot while viewing high definition 2K video that was stably transmitted at low latencies with 50-60 Mbps to a display installed in his cab. In addition to providing the operator the ability to see the area around the blind spot other angles that were not usually visible were so now. One example is the ability to determine the center of mass of the load via the video from a camera hanging on the crane. This service is expected to increase safety during the operation of cranes at shipyards.

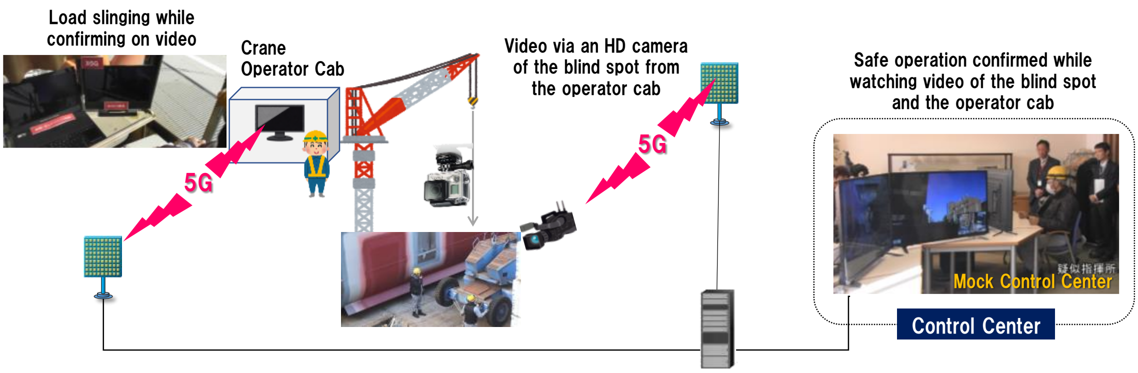


Fig. 3.3.3-1 Field Trial utilizing 5G to ensure workplace safety

Load being lifted after being slung

Image of the hanging overhead view

Working in the area of the operator cab's blind spot

Crane operator cab

Fig. 3.3.3-2 Pictures from the Field Test on Ensuring Workplace Safety

3.3.3.2 FY2018 Field Trials by NTT DOCOMO and Partners

(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 Corporation and Panasonic Corporation, 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.

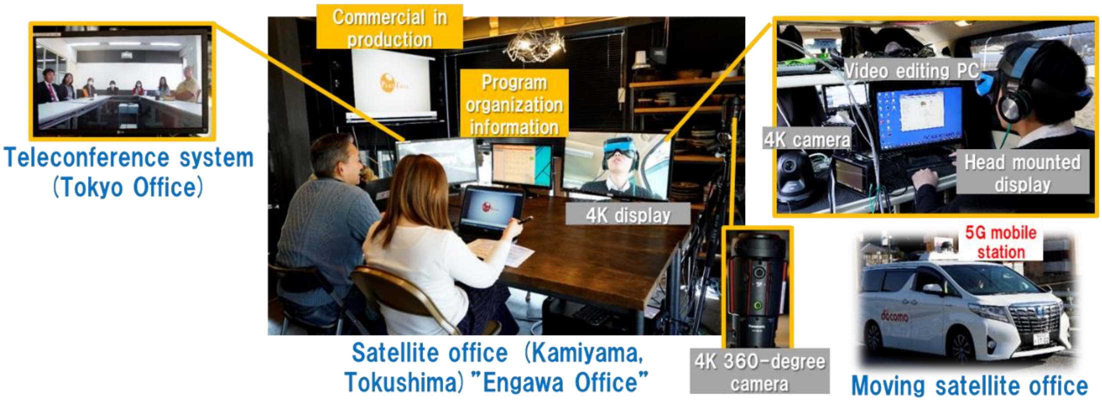


Fig. 3.3.3-3 Realization of moving satellite office using 5G

3.3.3.3 FY2018 Field Trials by ATR and Partners

(1) Field Trials in Factory

<u>The radio performance evaluation</u>

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. Figure 3.3.3-4 illustrates the typical throughput when the machines are working. In the trial, the UL throughput over 100 Mbps required for transmitting 3D scanner data was attained within 40m from the antenna of 5G base station.

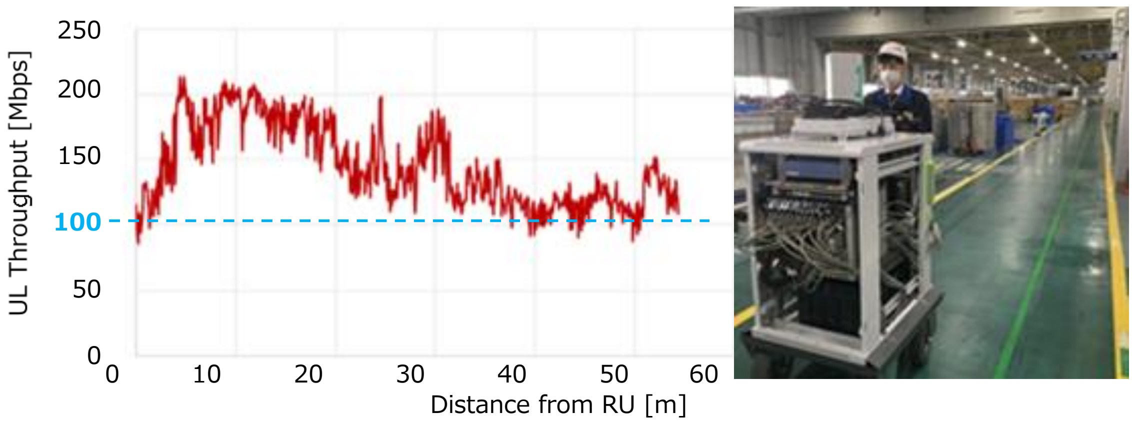


Fig. 3.3.3-4 Measured result and measurement scene

<u>Application of 5G to robot control</u>

The system configuration for trial is shown in Fig. 3.3.3-5. 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 100 MB can be sent from the 3D scanner, which will realize flexible layout change in a factory.

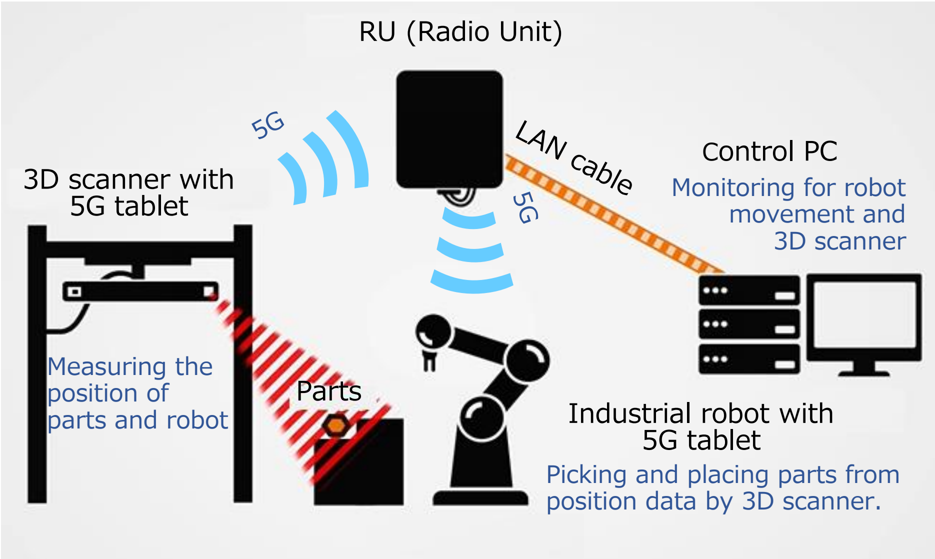


Fig. 3.3.3-5 System diagram in the factory

Figure 3.3.3-6 shows the visualized image using the measurement results of 3D scanner and the uplink throughput from the 3D scanner.

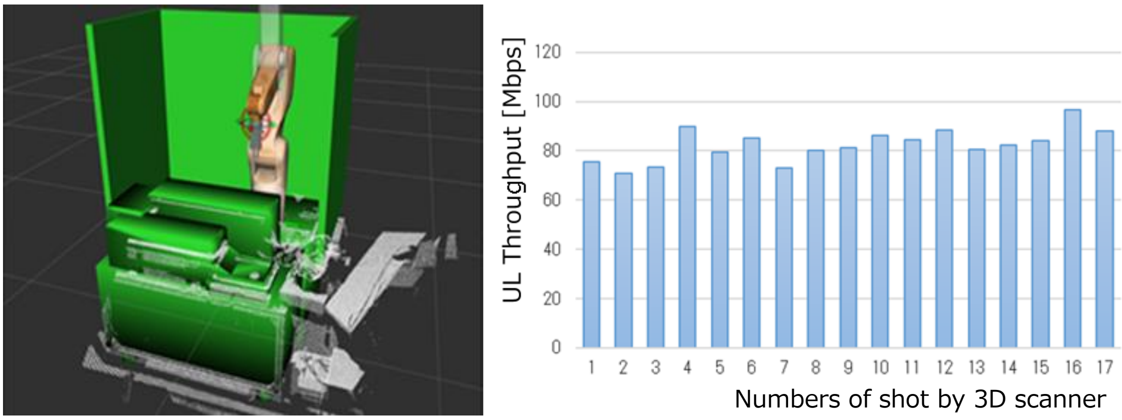


Fig. 3.3.3-6 Visualized image based on measurement result of 3D scanner and uplink throughput from the 3D scanner

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. 3.3.3-7 Before and after relocating the industrial robot

These trials have been conducted by the team of ATR, KDDI Corporation, Kyushu Institute of Technology, and DENSO Corporation.

3.3.3.4 FY2017 Field Trials by NICT and Partners

(1) Smart Office

In the future, it will be expected that all the devices in an office are connected to one network. This network paradigm shift will bring a smart concept to the office that is more harmonized with human sensations and feelings than those of today. These offices will be able to hold high presence teleconferences where a sense of distance won't exist, allowing people to be able to feel as if all the participants of the meeting are in the same room and be able to understand accordingly atmosphere. In addition, news and information related to what is being discussed in the meeting will automatically be displayed if desired. And if progress in a particular meeting slows down, a robot will start to join the meeting and lighten any tension through some timely words of encouragement or soften a place by a friendly joke. Through innovations such as these the efficiency of the office is expected to increase.

One method to achieve massive multiple connections that this trial will demonstrate is creating a closed proximity communications area through a sheet that is placed on table, through which only devices in the area can be connected to a high speed, secure network. Since the communication area is limited near the table, the same frequency can reuse for the communication around the table. Thus the frequency reuse efficiency will be improved. As one of application, electronic white boards using 5G with its low latency capabilities enable a smooth and less delay teleconference being held over long distances. Simultaneous writing on white boards from multiple conference sites will be demonstrated. Chairs will also have sensors in them that will receive and analyze a variety of information about the participants, which will allow for the creating of a feedback system to help create a positive meeting atmosphere, even in teleconferences.

With the items described above, a smart office environment was developed to validate its scenario as shown in Fig. 3.3.3-8. The Smart chair is operated using the Bluetooth Low Energy technology assuming to be replaced with 5G mMTC system. The smart table supports 3.7 GHz as well as 2.4/5 GHz of wireless LAN systems. Two sets of the whiteboards were deployed in two NICT branches in Sendai city and Nomi city to test the function with conventional TV conference system. Figure 3.3.3-9 gives closeup shots of the smart office environment.

Fig. 3.3.3-8 A Smart Office environment assuming to use 5G features

Fig. 3.3.3-9 Components of the Smart Office environment assuming to use 5G features

3.3.3.5 FY2018 Field Trials by Wireless City Planning and Partners

(1) Field Trials of Massive Simultaneous Connections using 5G for Smart Office

<u>Realizing IoT with 5G</u>

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. Figure 3.3.3-10 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. Figure 3.3.3-11 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. 3.3.3-10 5G mMTC wireless transceiver

Specifications

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

Fig. 3.3.3-11 Ad-hoc 5G System

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. 3.3.3-12.

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.

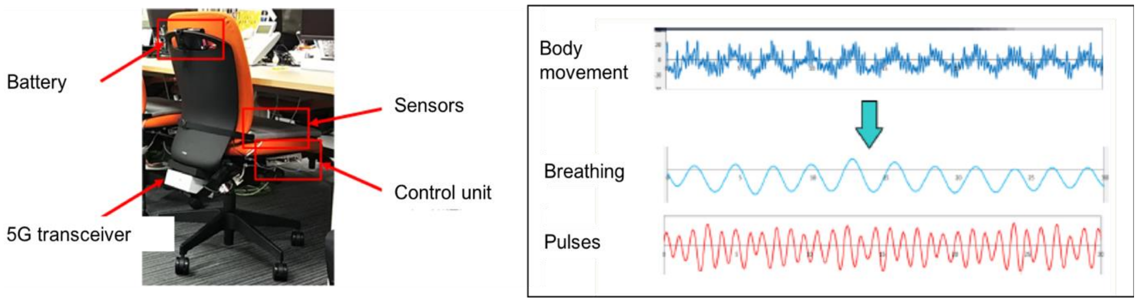


Fig. 3.3.3-12 The Smart Office Trial

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.

3.3.4 Use Case 4: Medical Application

3.3.4.1 FY2019 Field Trials by NTT DOCOMO and Partners

- **Responsible organization:** NTT DOCOMO, INC.

(1) Field Trial Utilizing 5G for Highly Efficient Telemedicine

- **Partners:** Wakayama Prefecture, Wakayama Medical University, Tokyo Women's Medical University

This field trial was held in Hidakagawa Town, Wakayama Prefecture in January 2020. This field trial continued those that were held beginning in 2018 with the aim of mitigating the problem of the unequal level of medical care in metropolitan and regional areas through advanced telemedicine consultations. In the trials held in 2018 utilizing 28 GHz frequency band and 2019 utilizing 4.5 GHz frequency band 5G radio device was used to transmit video from HD cameras (Details of FY2017-2018 are described in Section 3.3.4.2 (1)). At 2020, utilizing 4.5 GHz frequency band 5G radio device was used to transmit viewings of highly medical equipment installed in "hyper doctor car", in which high level medical consultations and treatment could be conducted. It was confirmed that consultations could be held when specialists were able to connect with mobile clinic vehicles or clinics at a remote location via HD video on a 5G network, consultations that felt as if the university hospital physician was sitting right in front of the patient through said HD video transmitted via 5G, with participants commenting that these consultations provided a much higher level of quality than those they had previously. This trial confirmed that an even higher quality of consultation could be performed using a mobile clinic vehicle, which is expected to raise the level of medical consultations that can be provided in locations such those located in remote mountainous regions

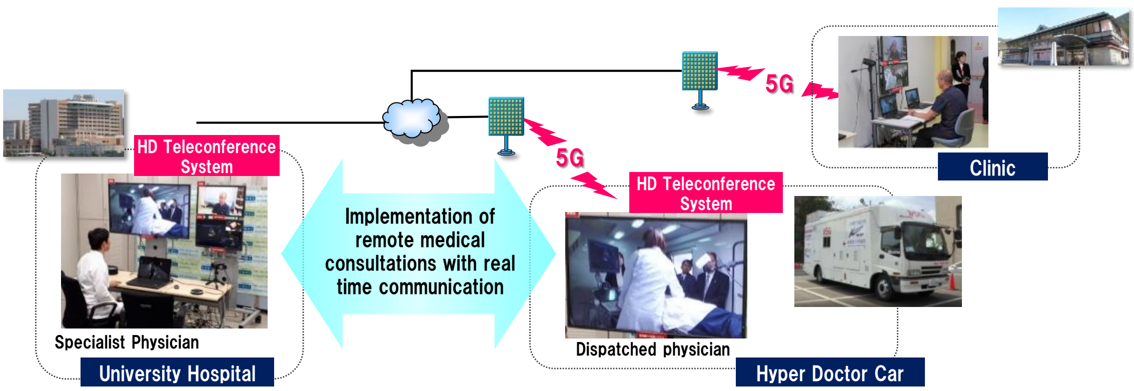


Fig. 3.3.4-1 Field Trial utilizing 5G for highly efficient telemedicine

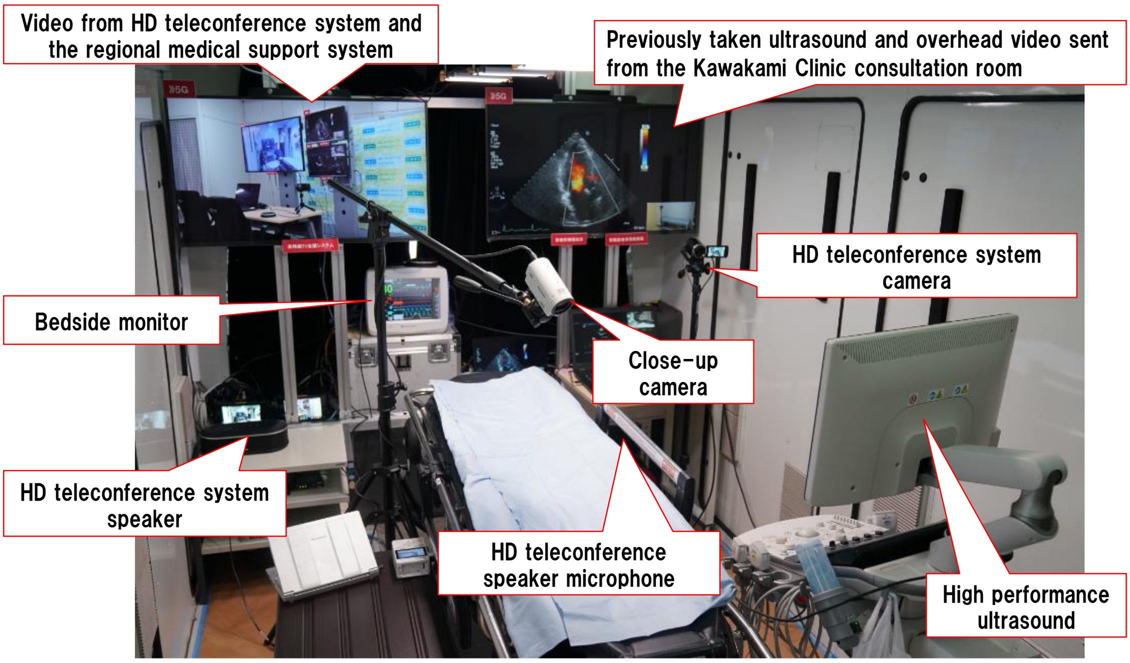


Fig. 3.3.4-2 Medical equipment and bed inside the "hyper doctor car"

(2) Field Trial Utilizing 5G for Efficient Emergency Ambulatory Care

- **Partners:** Maebashi City, Maebashi Fire Department, Maebashi Red Cross Hospital, The Organization for the Promotion of ICT Community Development and Common Platform, Maebashi Institute of Technology, Maebashi Medical Association

This field trial utilizing 5G for emergency ambulatory care was held in October 2019, a continuation of trials held in 2018. This year's trial utilized a 5G radio apparatus at the 28GHz frequency band to send information from several different high definition video cameras and vital sign data tracking devices from an ambulance with a 5G mobile station to a "hyper doctor car" with a 5G device as well as the local designated emergency hospital and the patient's personal physician in order to shorten the time necessary to conduct the initial check up and diagnose the patient's condition as well as time needed to check the patient into the hospital. Communications by video were made possible with the realization of upload and download speeds of 15 Mbps as well the simultaneous transmission of viewings of high definition ultrasonic and bedside monitor, which was thought to be difficult to achieve with 4G networks. In addition, the ability to quickly ascertain the condition of the patient and provide the appropriate medical treatment was confirmed with the ability to use 5G to transmit HD video along with the simultaneous transmission of data while the patient was being transported in the ambulance. New prospects in emergency ambulatory care are now expected with more advanced plans for equipment for medical personnel as well as for ambulances and "hyper doctor cars".

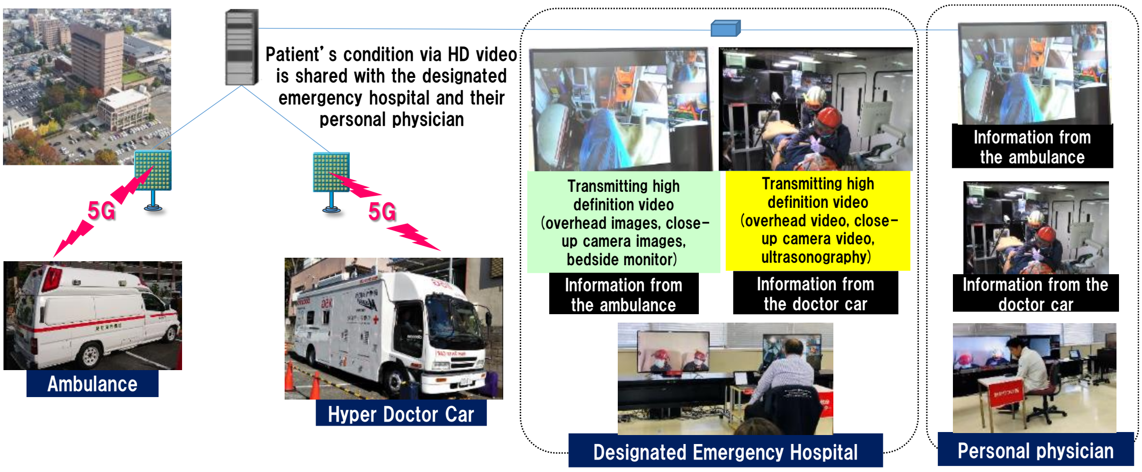


Fig. 3.3.4-3 Field trial for utilizing 5G for efficient emergency ambulatory care

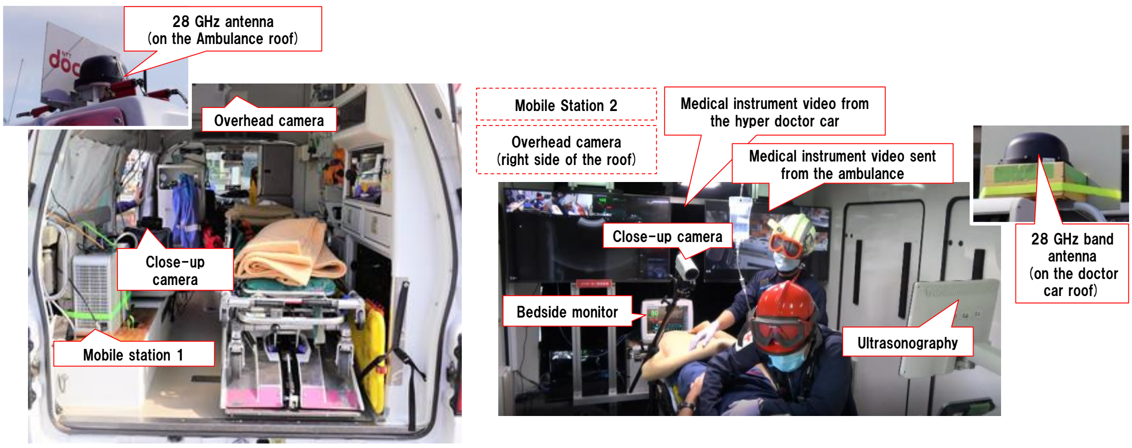


Fig. 3.3.4-4 The interior environments of the ambulance (mobile station 1) and hyper doctor car (mobile station 2)

(3) Field Trial Utilizing 5G for High Definition Facial Recognition and Use of Sensors in Monitoring and Care Services

- **Partners:** SOMPO Holdings, Inc., NEC Corporation

One problem facing society today is the lack of nurses able to staff elder care facilities due to the declining birthrate and aging population. One possible way to solve this issue is to reduce the need nurses while improving operation efficency through the use of cameras at mealtimes to realize services such as: “identify residents with facial recoginition”, “automatically manage caloric intake with before and after meal photos”, and “improve accuracy of dietery restriction checks via an alert system”. A field trial to test the use of a 5G network to monitor and care for elder care facitility residents though a meal management service was conducted in February 2020 in Hiroshima city, Hiroshima prefecture, where a 5G radio device operating on the 4.5 GHz frequency band was installed inside such a facility. Through the 5G network, it was verified that images could be transmited so that facial recognition anaylsis could be used for dietary restriction alerts as well as helping to manage the issue of leftover meals. As these services once handeld by staff members could now be taken over by the network, expectations that the introduction of 5G could lead to the ability to reduce staff requirments at elderly care homes was confirmed.

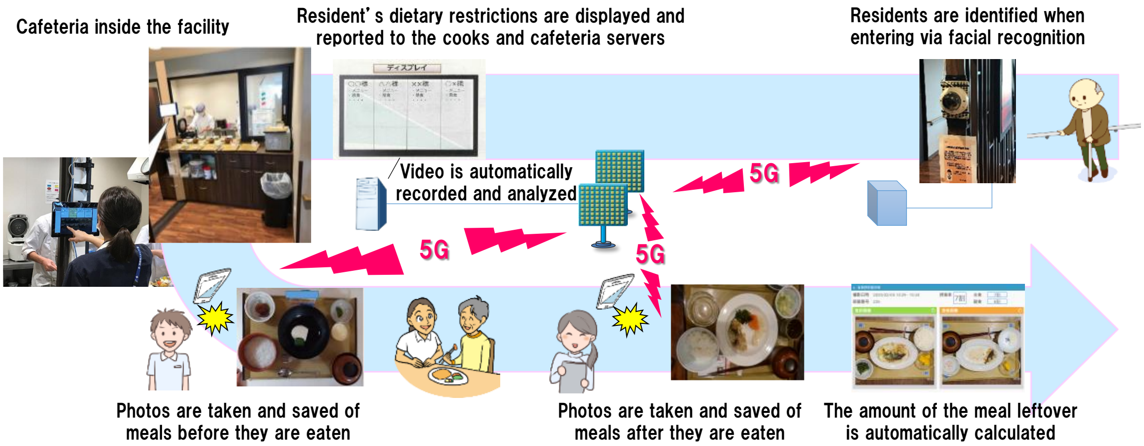


Fig. 3.3.4-5 Field Trial Utilizing 5G for Monitoring and Care Services

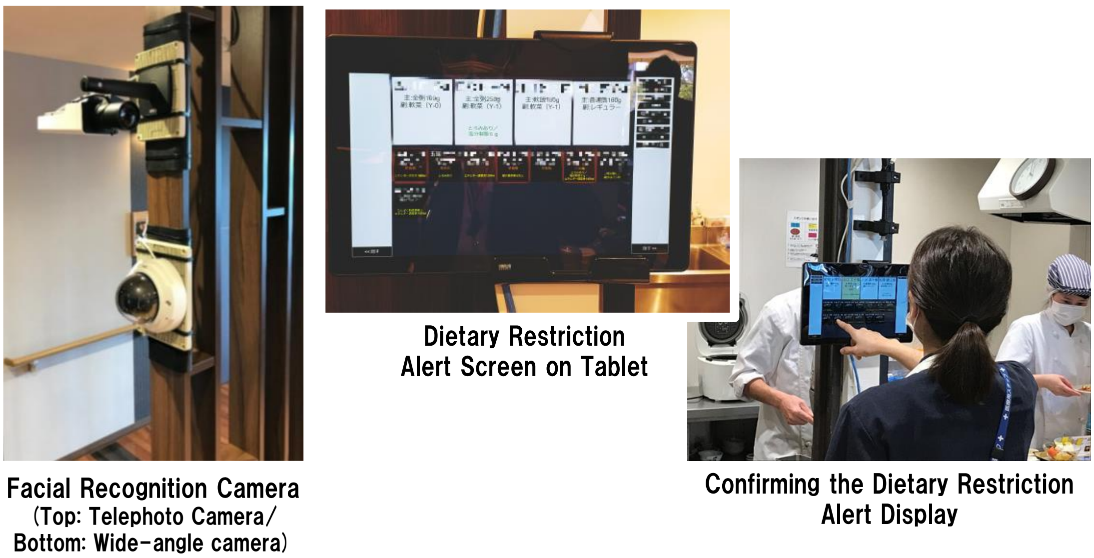


Fig. 3.3.4-6 Facial Recognition Camera and Dietary Restriction Alert

3.3.4.2 FY2017-2018 Field Trials by NTT DOCOMO and Partners

(1) Advanced Remote Diagnostics Using 5G

Trials in FY2017

Figure 3.3.4-7 shows an overview of 5G system performance evaluations for proposed services in the fields of telemedicine. Wakayama Medical University and local medical clinic in Wakayama Prefecture were joined to host this trial as an example of a general hospital with advanced medical care and welfare services that could support telemedicine activities. These facilities were connected via 5G networks including wired network and 5G trial equipment. Doctors carried out remote real time diagnostics by exploiting 4K high definition teleconference (video communications), 4K high definition close-up camera, and full HD video taken by tablet-type ultrasonic image diagnosis (echography) as shown in Fig. 3.3.4-8. Several comments from doctors after actual medical diagnosis for patients were obtained in department of dermatology, cardiovascular internal medicine, orthopedic surgery, and it includes that "improving the quality of the telemedicine services by applying 5G is very useful and it is possible to do medical treatment without feeling that it is a remote location."

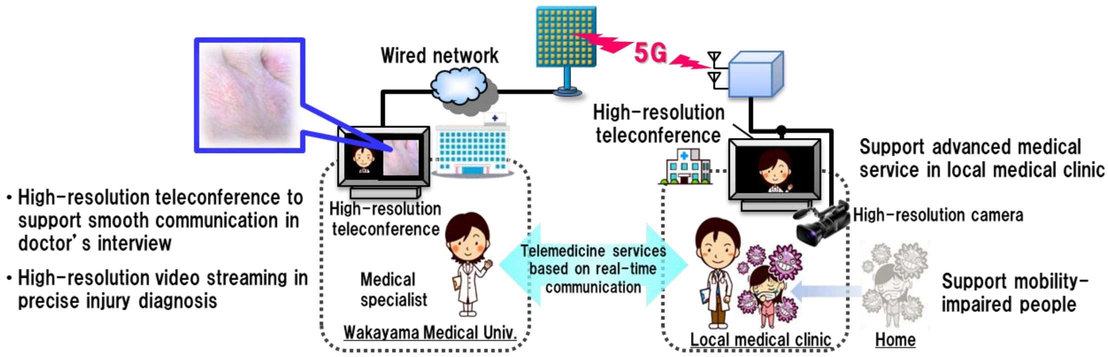


Fig. 3.3.4-7 5G system performance evaluations for Telemedicine

Fig. 3.3.4-8 Telemedicine services exploiting 5G

Trials in FY2018

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, Inc., 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.

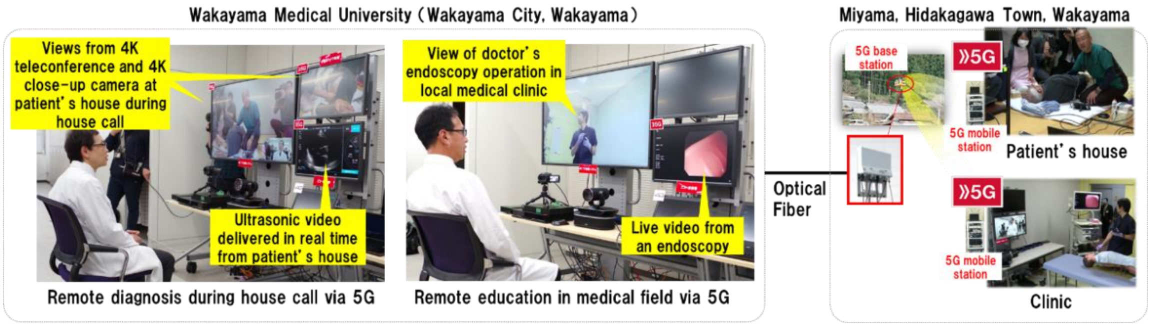


Fig. 3.3.4-9 Realization of house calls as well as remote education of doctors in local medical clinic using 5G

(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 NTT 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 enroute 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.

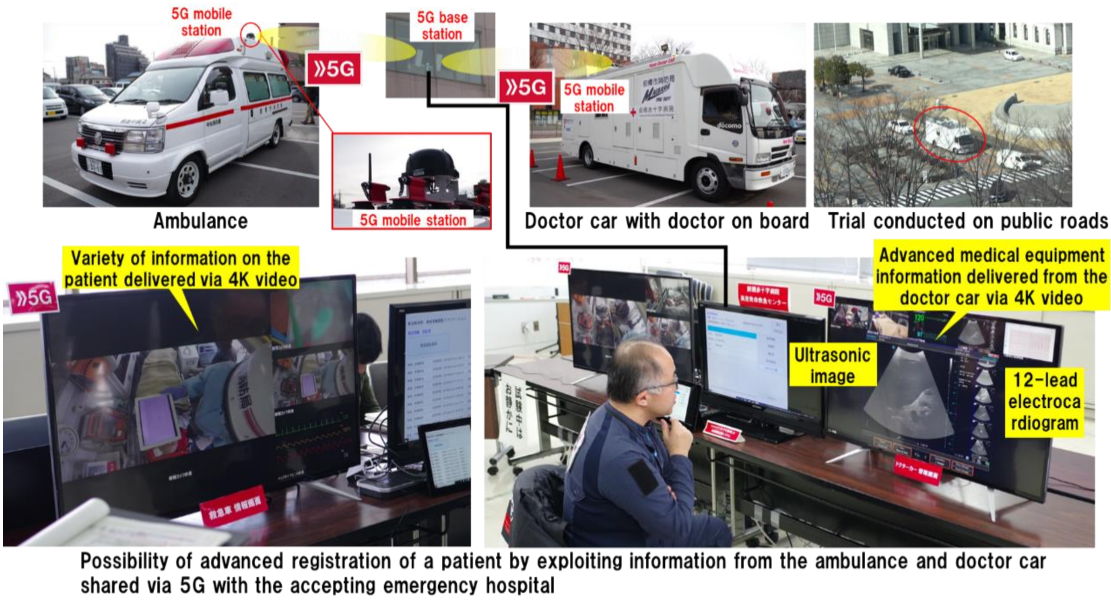


Fig. 3.3.4-10 Realization of efficient emergency patient transport using 5G

3.3.5 Use Case 5: Smart House/Life Application

3.3.5.1 FY2019 Field Trials by NTT DOCOMO and Partners

- **Responsible organization:** NTT DOCOMO, INC.

(1) Field Trial Utilizing 5G to Support the Transmission of Traditional Arts

- **Partners:** CBC Creation Co., Ltd., Chubu-Nippon Broadcasting Co., Ltd., CBC Television Co., Ltd.

This 5G field trial was held in Nakatsugawa City, Gifu prefecture in October 2019. The trial demonstrated how 5G could support theater training by connecting a Kabuki master instructor with student-actors in several different Kabuki classrooms via a 5G radio device utilizing the 28 GHz frequency band. Four separate streams of 4K live video were simultaneously transmitted between the student-actors in their respective classrooms and the room where the master instructor was. It was verified that the master instructor's presence could be felt as he was able to instructe his students even on very specific details, such as the movement of one's eyes in Kabuki. Distance learning conducted simultaneously to several different locations can be expected to efficiently provide training without regards to the location of students or instructors. As an increasingly aging society and an overall declining population is leading to a decrease in possible successors to whom traditional culture can be transmitted, the utilization of TV broadcasts and other similar means will increase the opportunities available to connect more people to Kabuki, resulting not only in an increase in interest in Kabuki itself but also to the economic revitalization of the tourism industry.

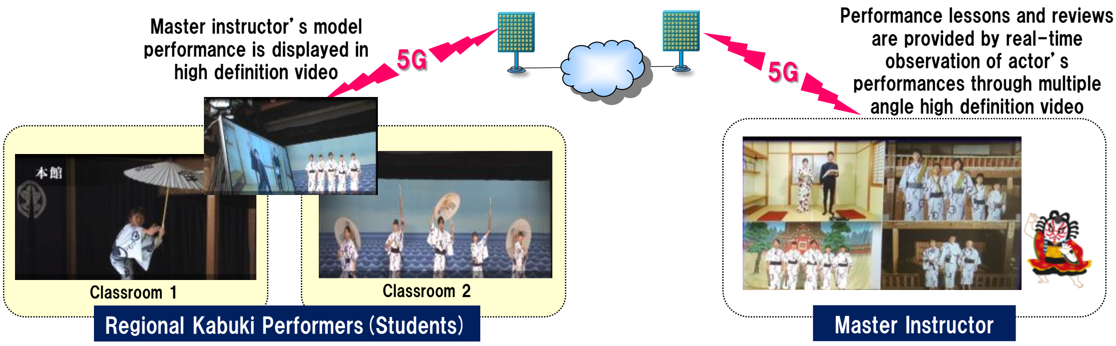


Fig. 3.3.5-1 Field trial for distance education using 5G

Fig. 3.3.5-2 Views of performance lessons via two-way communication using 4K video

3.3.5.2 FY2017-208 Field Trials by ATR and Partners

(1) Field Trials in School

Trials in FY2017

One desired use case at schools for 5G is to give schools the ability to access large data files simultaneously using multiple ICT devices in order to improve a learning environment.

Fig. 3.3.5-3 Proposed Trial for Schools

<u>Basic evaluation using 4G system</u>

In 2017, we evaluated a performance of simultaneous access of large size contents using 4G as a preliminary study and evaluation in cooperation with Maehara Elementary School and KDDI Corporation. 71 elementary school students participated in the experiment.

The evaluation results are shown below. The left diagram shows the distribution of time spent to upload the videos (size 37 MB to 400 MB) created by students. The right diagram shows 4G uplink throughput (upload rate).

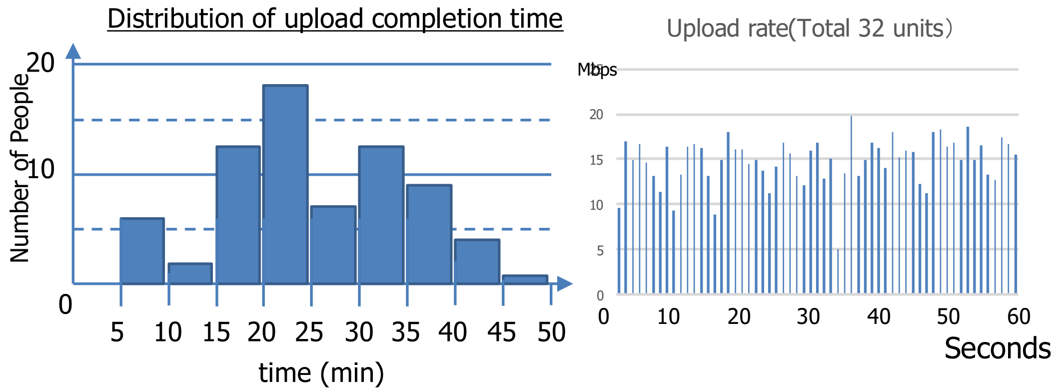


Fig. 3.3.5-4 Evaluation results

We found the following from the evaluation.

・Uploading is not completed during class due to uplink speed limit (10-20 Mbps).
・In the class, upload is required in about 1 minute (questionnaire to the teachers).
・High speed (1 Gbps) is required for uplink. 5G ultra high speed is expected.

Trials in FY2018

<u>**The transmission characteristics evaluation**</u>

Indoor test environment in 28 GHz was constructed in a gymnasium in Maehara elementary school in Tokyo and the radio performance was confirmed with KDDI Corporation. The total downlink throughput was over 2 Gbps/800 MHz *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 800 MHz, as specified in the technology target.

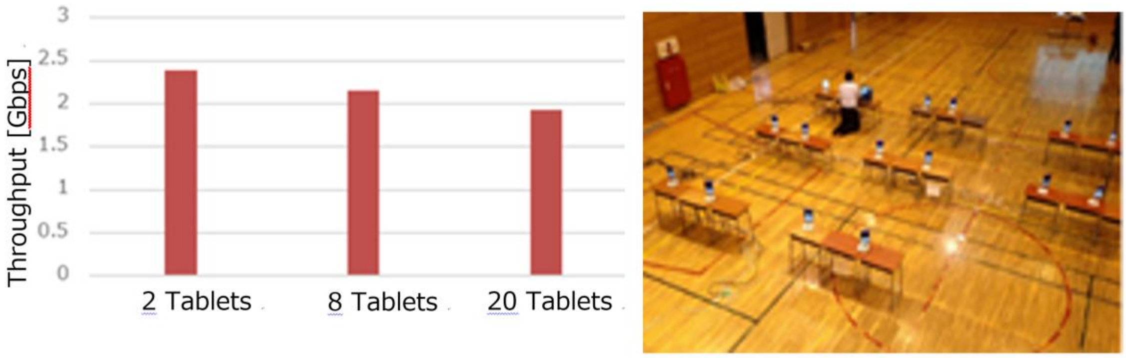


Fig. 3.3.5-5 Measured results and tablet placement *2

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

<u>**Comparison between 5G and Wi-Fi**</u>

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.

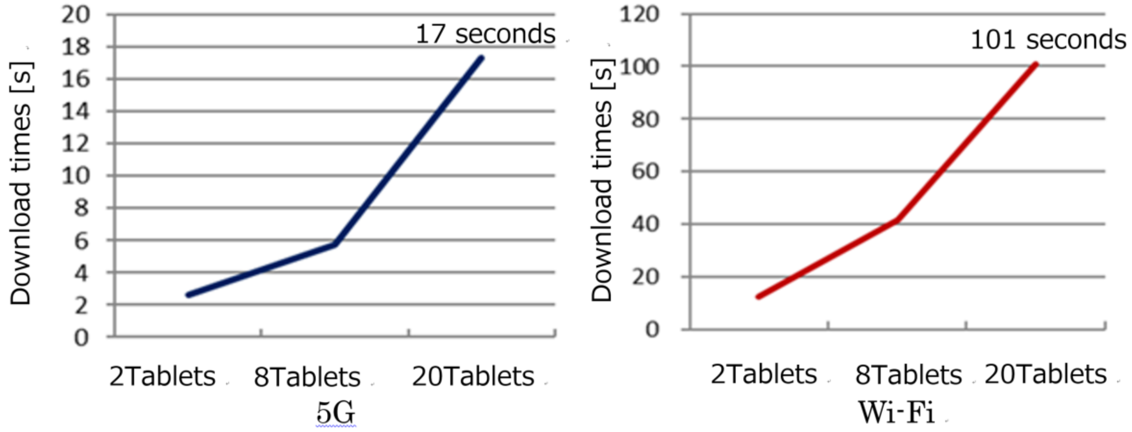


Fig. 3.3.5-6 Results of download time

Fig. 3.3.5-7 Scene of evaluation in School and Screen example used in evaluation

3.3.7 Use Case 7: Agriculture/Forestry/Fisheries Application

3.3.7.1 FY2019 Field Trials by ATR and Partners

- **Responsible organization:** Advanced Telecommunications Research Institute International (ATR)

(1) Streamline of Dairy Industry

- **Partners:** KDDI Corporation, Tokachi Murakami Farm, Kamishihoro Town, University of Miyazaki, Waseda University

This trial was held in November 2019 at Tokachi Murakami Farm in Kamishihoro town, Hokkaido. Two applications are tested, with an objective to enhance the efficiency of dairy industry.

The first application aimed to reduce time required to identify the location of cows in the cowshed. The 4K video of cows were taken while they were fixed to the stanchion in the cowshed during feeding. The video streams were transmitted by 5G to sever, which recognized ID numbers on ear tags to locate of the cows and the identified locations were displayed on the farmer's tablet.

The second application was remote monitoring of cows in the stable. Real time or stored 4K video of the cows in the stable was shown on the screen in the office. The cow was specified by ID number, utilizing the mechanism in the first application. Figure 3.3.7-1 shows overview of the trial of streamline of dairy industry.

Fig. 3.3.7-1 Overview of the trial of streamline of dairy industry

The vice president of the farm offering the test environment to the trial, Mr. Murakami expressed, "In the daily work, we have to spend a time to find the cows for screening, treatment and breeding, since the ranch is large. It will be very convenient if the system can locate exact location by using 5G technologies, since we can go directly to the site to see the cows. I hope that in the near future we can watch the condition and size of the cow without going to the site."

In the future, robot with 4K camera will be running in cowshed, and image analysis will detect symptom of disease and decrease of feed. Figure 3.3.7-2 shows the image of future smart cowshed.

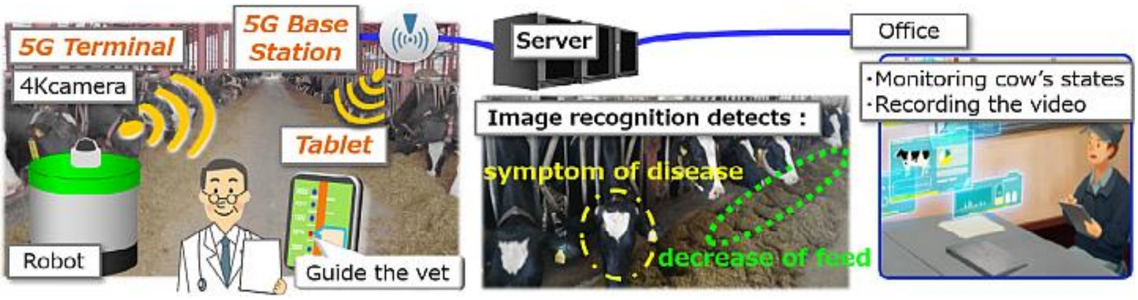


Fig. 3.3.7-2 Image of future smart cowshed

(2) Support of Racehorse Breeding

- **Partners:** KDDI Corporation, Sharp Corporation, The University of Tokyo, Niikappu Town, Hidaka Racehorse Cooperative Upbringing Center

Hidaka Racehorse Cooperative Upbringing Center trains foals entrusted from producers or owners, and raises them to be racehorses. Owners wish to see their horses walking, gloss of horses' hair in real time, in order to observe their horses growing. However, currently, they must visit the stable to do so. Also, it is difficult for vets to examine horses in emergency, since vets are few and live far from the Racehorse Center in many cases. Three applications were verified in the trial held in November 2019 to demonstrate 8K video delivery by 5G can solve these issues.

The first application assumed remote observation of horses by vets and employees. An 8K video consisting of four multi-angle 4K video taken from four sides of the horse stall was transmitted to the office 8K monitor by 5G.

In the second application, 8K video of walking horse taken in corridor of stable was transmitted to the office, to enable the owners and/or producers to confirm gloss of horse's hair.

In the third application, delivery of 8K video of running horse on training course taken from the drone was verified, using 5G. The third applications also supposed delivery of video to owners and/or producers.

Figure 3.3.7-3 shows Overview of the trial of Support of Racehorse Breeding.

(a) 4Kx4 multi angle video (b) 8K video of walking horse (c) 8K video from drone

Fig. 3.3.7-3 Overview of the trial of support of racehorse breeding

The director of the Racehorse Center expressed, "Production ranches, trainers, and owners are wishing to see the condition and training status of their horses with high definition live video, in particular, the gloss of the horse's hair. The combination of 8K + 5G + drone proved to be effective in achieving this goal."

3.3.8 Use Case 8: Smart City/Area Application

3.3.8.1 FY2019 Field Trials by NTT Communications and Partners

- **Responsible organization:** NTT Communications Corporation

(1) Field Trial Utilizing 5G to Support Safety and Security in Underground Train Corridors (disaster prevention)

- **Partners:** Hanshin Electric Railway Co., Ltd., ITOCHU Techno-Solutions Corporation, FUJITSU BROAD SOLUTION & CONSULTING Inc., NTT DOCOMO, INC.

This 5G field trial was held at Hanshin Electric Railway's Fukushima Station in Osaka city, Osaka prefecture in January 2020. This trial demonstrated the realization of a service that ensures safety and security at a train station with the automatic notification of abnormal behavior or entry into a prohibited areas (onto the train tracks, for example) by utilizing artificial intelligence to analyze video that is recorded and sent to a server from inside a train as well as from the station platform. The trial utilized the 28 GHz band, a mobile station located inside the train could connect to a base station from around 300 meters at the non-line of sight. It was confirmed that video can be transmitted while the train is still moving until it stops at the station platform in order to alert station staff about possible abnormal activities. With the support of a 5G network, the trial demonstrated that the station employees could be notified of such abnormal activities that was detected without the need for a human presence. In addition to detecting abnormal behavior, these services could also be used to ensure a safe environment in other situations, such as when the station employees are rushing to board trains, as well.

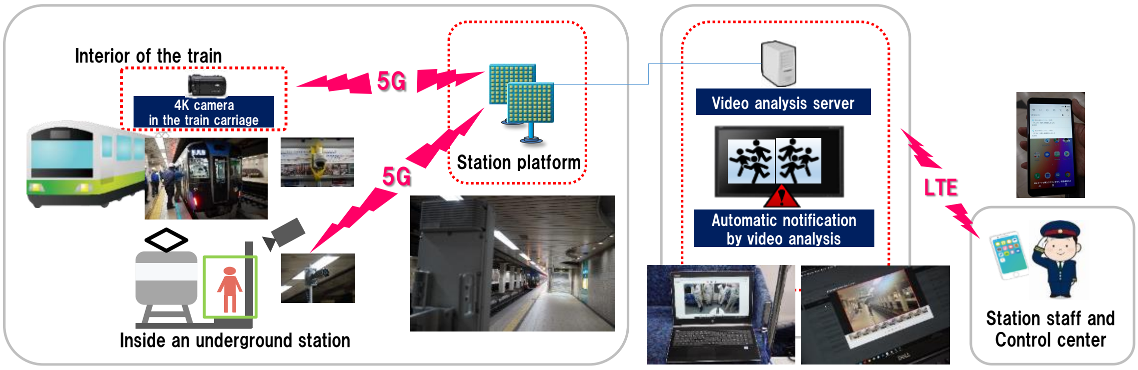


Fig. 3.3.8-1 Field trial on utilizing 5G to support safety and security in underground train corridors

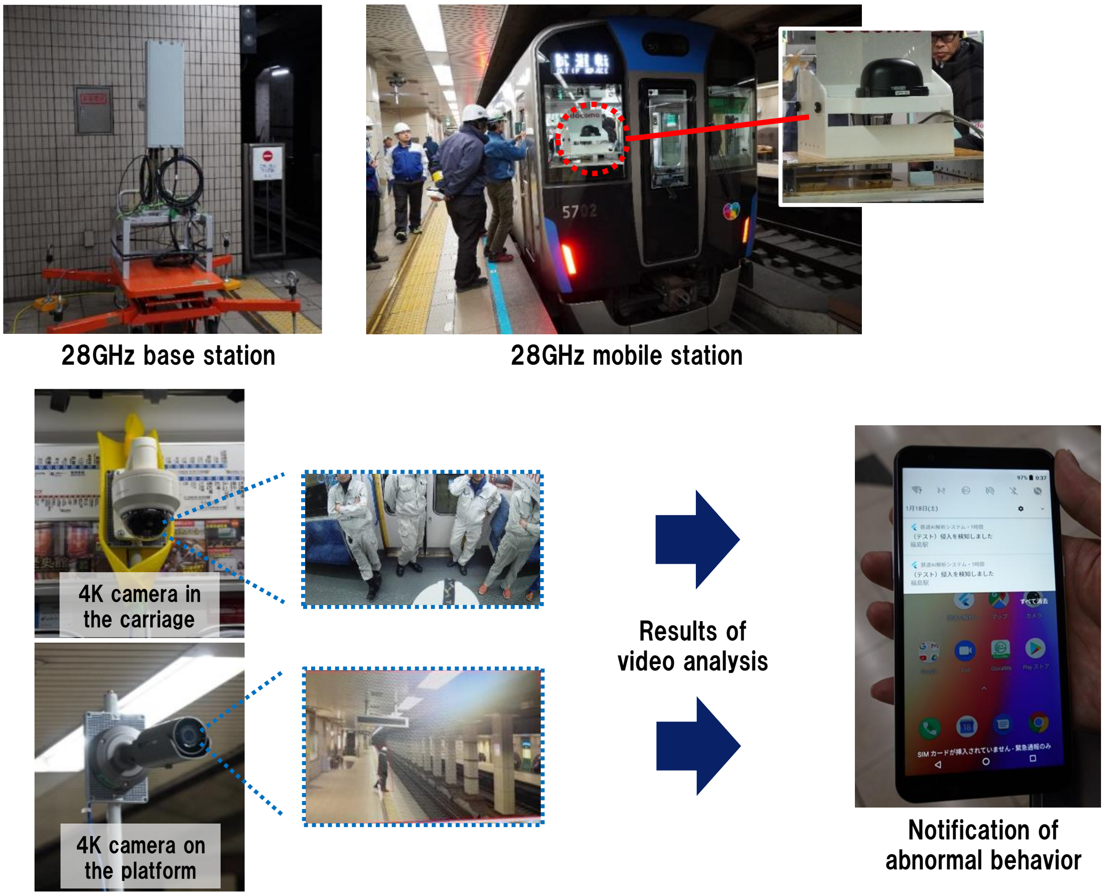


Fig. 3.3.8-2 View field trial on utilizing 5G to support safety and security in underground train corridors

(2) Filed Trial Utilizing 5G for Snow Clearing Operations - Efficient Snow Removal - (government services)

- **Partners:** Eiheji Town, Panasonic Corporation, zibil co., Ltd., NTT DOCOMO. INC.

This field trial was held in the areas surrounding the Shikinomori Bunkakan, Eiheiji, Fukui Prefecture in January 2020. This trial verified the ability to transmit high-definition video to a control center from snowplows and patrol vehicles. It was verified that information could be rapidly shared with the control center and residents by transmitting the video of areas where snow had accumulated or been removed taken by 4K 360° camera from the running snowplow via 5G. As the location of the snowplow as well as the state of accumulated and cleared snow could be confirmed it became possible to provide exact instructions on where to proceed with snow clearing activities as well as provide a higher level of service to residents. Additionally, as snowplow operators could receive support remotely, it was expected that operator skill would improve and snow clearing operations could be carried out more safely.

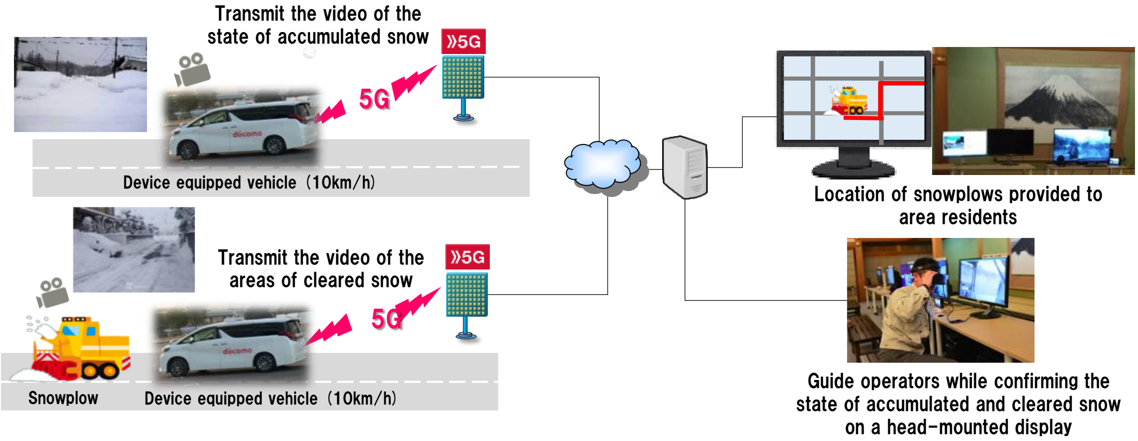


Fig. 3.3.8-3 Field Trial utilizing 5G for Snow Clearing Operations (Efficient Snow Removal)

Fig. 3.3.8-4 Views of the Snow Clearing Operations Trial

3.3.8.2 FY2019 Field Trials by KDDI Corporation and Partners

- **Responsible organization:** KDDI Corporation.

(1) Integrated Management System of Construction Work

- **Partners:** Obayashi Corporation, NEC Corporation

MIC (Ministry of Internal Affairs and Communications) started 5G Comprehensive Demonstration test (5G field trials) in FY 2017 and application of 5G to remote control of construction machinery were carried out in three fiscal years. In FY2017, basic operation of one machine via 5G was verified. In FY2018, remote control of two machines working jointly in the recovery from landslide disaster was verified, expecting to realize safe environment for operators as well as prompt recovery from disasters. Details of FY2017-2018 trials are described in Section 3.3.8.5 (1).

In FY2019, the trial scope was further extended to include integrated management system, targeting the improvement of efficiency of standard road construction work, based on the specified design. The system consisted of (i) machine guidance system which informs operators of the locations of machinery and the status of spreading and rolling compaction work in comparison with the design, (ii) 3D laser scanners to scan over the construction area, in addition to (iii) remote control system of construction machinery.

The trial was carried out at the construction site of Kawakami Dam in Mie prefecture in Feb. 2020. In the trial, three machines (a backhoe, a crawler dump, and a bulldozer) were controlled remotely using 5G, while a rolling roller was autonomously driven, as shown in Fig. 3.3.8-5.

In this trial, work progress management is executed remotely and in real time. In particular, precise shape, which is important for standard construction, and stiffness, which is most important for road construction were monitored remotely in real time. The machine guidance system displays the status of rolling compaction work, by showing how many times machine rolled the road, and the measurement result of unevenness of the road construction using 3D laser scanners, as shown in Fig. 3.3.8-6 and 3.3.8-7.

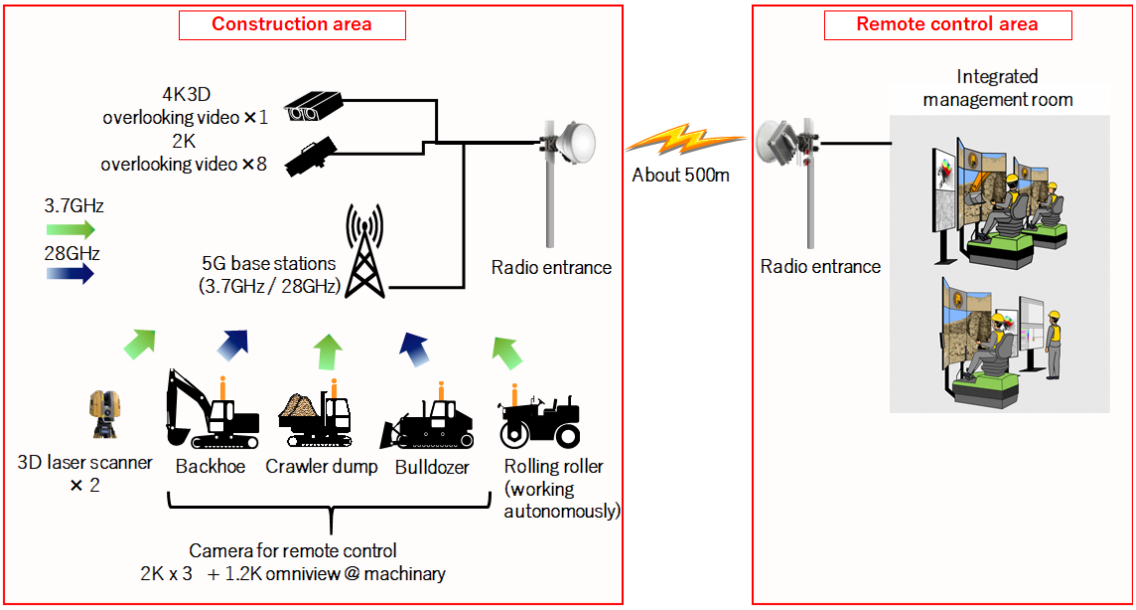


Fig. 3.3.8-5 Trial configuration.

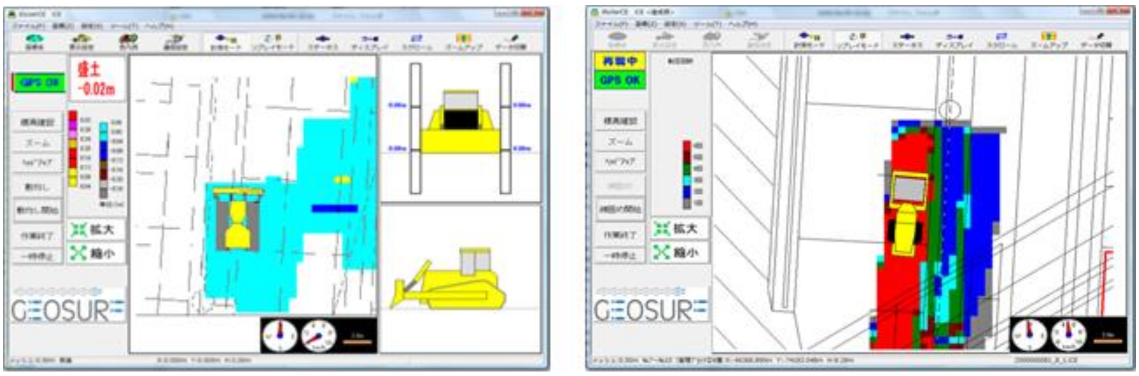


Fig. 3.3.8-6 Display view of machine guidance system.
(Difference between spread compacted surface and the planned height(left), estimated stiffness of the constructed road(right))

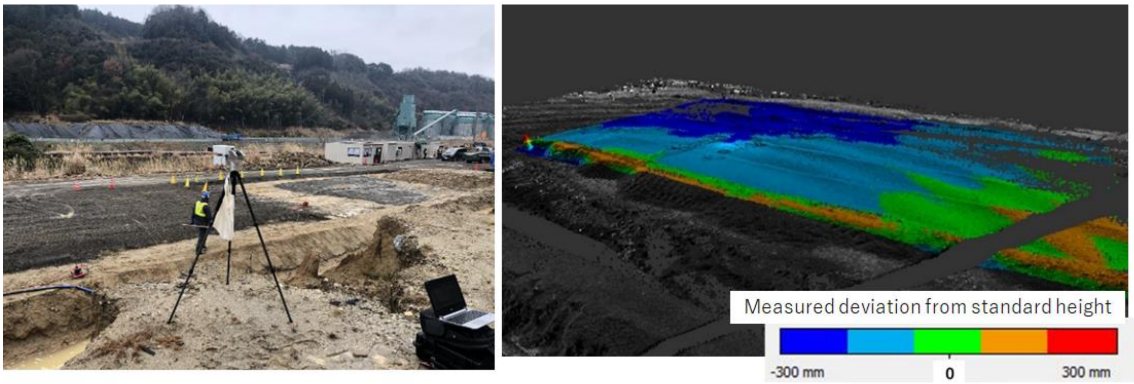


Fig. 3.3.8-7 3D laser scanner (left), measured deviation from the designed height (right)

The whole trial area was covered by two 5G base stations using 3.7 GHz and 28 GHz respectively based on the 3GPP compliant Non-Standalone Architecture.

For each remotely controlled construction machine, three 2K cameras were installed on the front and 1.2K omni-view camera was installed on the roof top to provide operators with sufficient video images for remote control operation, as shown in Fig. 3.3.8-8. Video streams were encoded, transferred to integrated management room via 5G. And they were displayed in front of operators in the room.

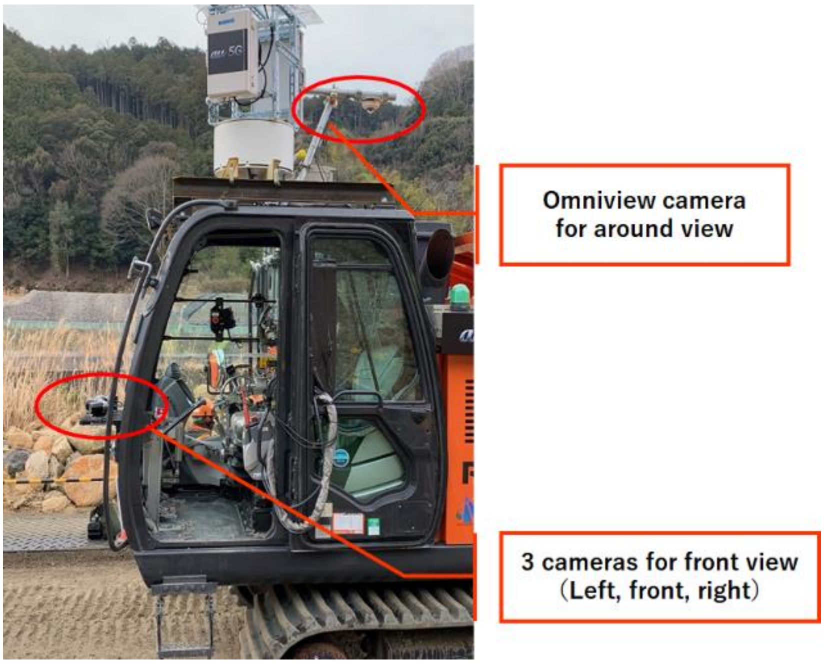


Fig. 3.3.8-8 Camera positions on machinery

As a result of the trial, it was confirmed that the required IP throughput for each video stream was between 10-16 Mbps and the aggregate throughput for each machine of 40-65 Mbps were achieved.

It was also confirmed that the distribution of the latency of video transmission ranged from 140 to 220 msec. In the testing with backhoe and bulldozer, latency was below 200 msec which was the target value to prevent discomfort of machine operators. Although the latency in the crawler dump testing was 220 msec, the operator of the crawler dump expressed that there was no problem in remote operation. The reason why the latency for crawler dump was longer than others was due to longer encoding/decoding time associated with the lower encoding rate for the crawler dump.

In the trial, the time required to perform a series of road construction work, including excavation & transportation of sediment, spreading, rolling and compacting was measured and compared with the standard unit price of the Ministry of Land, Infrastructure, Transport and Tourism of Japan. As a result of the trial, the required time was 1.4 times as long as the standard time. Since the typical time required in remote operation is 1.5-2.0 times, the result of the trial was proved to be more efficient. Following are the assumed reasons for this:

- Operators were able to utilize high definition video and supplementary information including 3D laser scanners comprehensively.
- Operators of construction machines working jointly were able to communicate directly each other, since they were seated next each other in the management room.

The operators engaged in the trial expressed that they did not feel any discomfort in remote operation and that the integrated management room facilitated comfortable circumstance for remote control operation.

As for the work progress and the quality control capability of this system, it turned out that there was room for improvement. The soft and argillaceous soil of the construction site made it difficult to complete the work to flatten the uneven plane by the remotely controlled bulldozer. In the trial this time, it was difficult to control the blade of bulldozer manually by remote control. If automatic bulldozer blade control system is adopted, which has been already available, more precise operation will be made possible and operators can concentrate on driving bulldozer.

In conclusion, this trial verified the feasibility of the integrated management system for road construction by utilizing remote control technology by 5G and proved the feasibility of applying this technology to typical construction work. It is expected that the remote control technology will open up the possibility to concentrate part of construction works to one place. The technology will also contribute to control the quality more efficiently, and to reform the work styles.

(2) Discovery of a Potential Distress and Sharing Information in the Mountain Climbers Observation System

- **Partners:** Shinshu University, Komagane city, Chuo Alps Kanko Co., Ltd.

In recent years, as the number of accidents of mountain climbers increases, the workload of rescue team is becoming more and more serious. To solve this problem, a mountain climber observation system was developed. In this system, a mountain climber carries an LPWA terminal which transmits the location information recognized by GPS embedded in the terminal. In the event of an accident, the alpine rescue headquarter identifies the location of the mountain climber, based on the information provided by the system.

In this trial, the high-speed uplink data transmission feature of 5G was utilized to grasp the condition of mountain climbers of the potential accident, which complements LPWA in terms of coverage and data rate.

In the trial area, two 28 GHz 5G base stations were installed, as shown in Fig. 3.3.2-5. A drone equipped with a 4K camera, a loudspeaker, and a 5G terminal was prepared to shoot images from high air. In response to the inquiry through the loudspeaker, the reaction of the mountain climber was featured by the 4K high-definition video. Then, the 4K video was sent to the monitor of the alpine rescue headquarter as well as to the tablet of the rescue personnel in real time. The system assists the rescue personnel to reach the injured climber safely and promptly. The physical condition of the climber can be grasped using the medical equipment brought by the rescue team and the appropriate medical treatment may be instructed by the doctor of the alpine rescue headquarter using 4K video delivered by 5G.

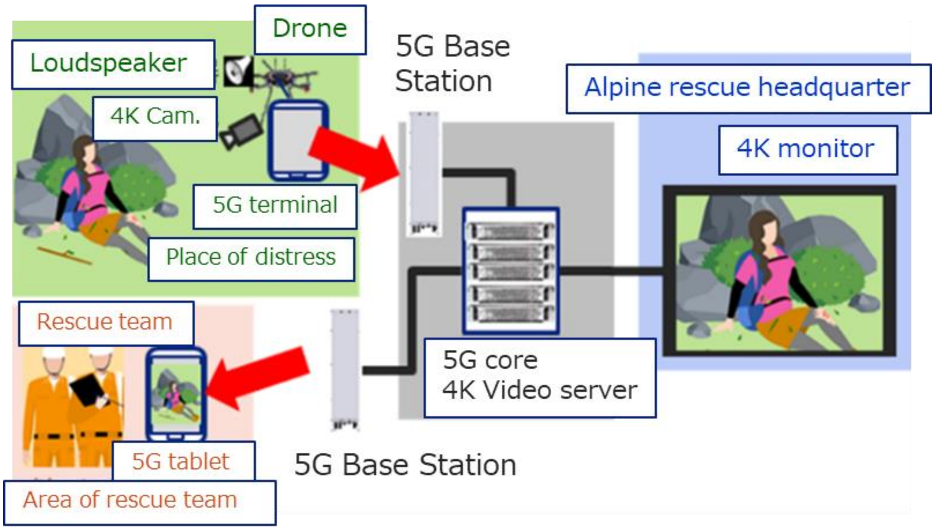
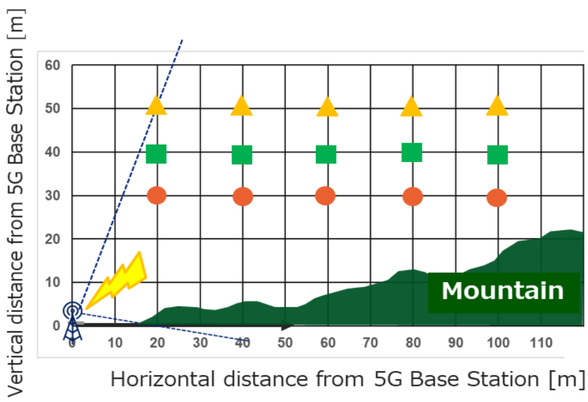


Fig. 3.3.2-5 Mountain Climbers Observation System

In order to prove the feasibility of this system, the field trial was conducted in October, 2019, near the Hotel-Senjoujiki of Nagano Pref. which is located in the real mountain area.

In the trial, the uplink throughput from the 5G terminal on board the drone to the base station was measured first with respect to the distance at 15 points in



the sky, as shown in Figs. 3.3.2-6 and 3.3.2-7. The result shows that the uplink throughput of 30 Mbps required for 4K video transmission was secured within 200 m distance from the 5G base station, as shown in Fig. 3.3.2-8.

Fig. 3.3.2-6 Flying Drone with a 4K camera and 5G terminal

Fig. 3.3.2-7 Points of measurement

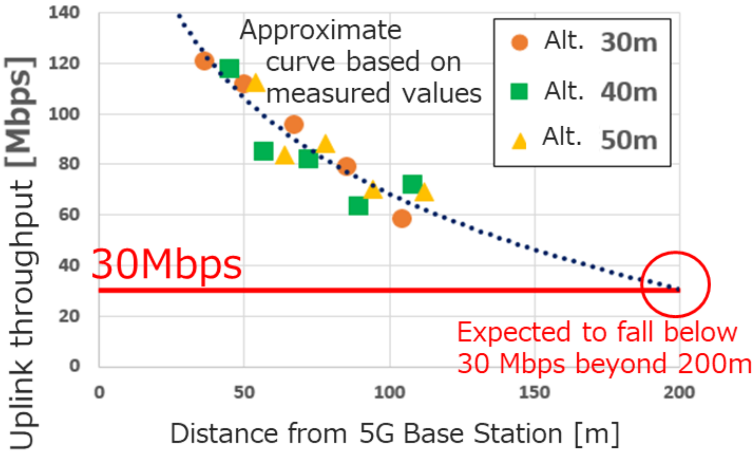


Fig. 3.3.2-8 Measured results

The trial was then conducted to verify the feasibility of the application in the trial area constructed in the actual mountain site as shown in Fig. 3.3.2-5. The trial demonstrated that the system enabled to transmit high-definition 4K video from the drone to the monitor of the alpine rescue headquarter and to the 5G tablet of rescue personnel using 5G, and to utilize the video to enhance the quality and the efficiency of observing system of mountain climbers. The rescue workers who participated in the demonstration expressed their expectation that “the situation of a mountain climber can be grasped more accurately by employing this system", as shown in Fig. 3.3.2-9.

Fig. 3.3.2-9 Rescue member monitors climber’s situation with a 5G tablet

3.3.8.3 FY2019 Field Trials by WCP and Partners

- **Responsible organization:** Wireless City Planning Inc.

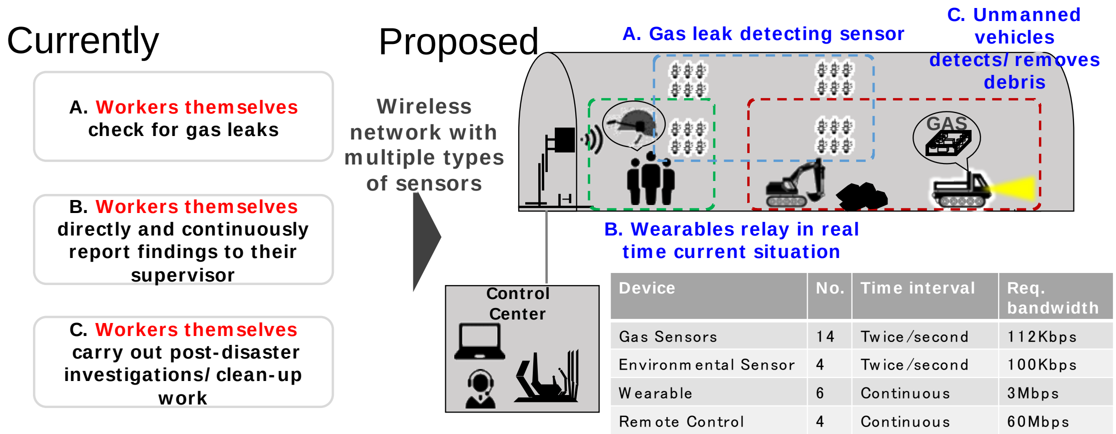
(1) 5G for i-Construction

- **Partners:** Taisei Corporation, SoftBank Corp.

This trial, held in the Yoichi District of Hokkaido at the Hokkaido Shinkansen Shiribeshi tunnel in December 2019, utilized the Fifth Generation Mobile Communication System (5G) was able to demonstrate the concept of *i-Construction*, a process which aims to improve worker safety while working at tunnel construction sites.

As the working population in Japan decreases, increases in productivity in a variety of industries has been brought about through the use of data to reduce unnecessary movements and the number of workers overall as well as the greater use of information and communication technologies (ICT) generally. Additionally, Japan's vast mountain ranges include many tunnels that are a key part of the societal infrastructure. These bring many risks of disaster, including falling debris, landslides, oxygen deficiency, and fires, which necessitate the need for a safe and secure working environment.

This trial was conducted to test the ability to detect dangers in a tunnel via sensors that can detect temperature and carbon dioxide, indicators in the work environment of highly dangerous toxic or flammable gases. These sensors were installed in the tunnel and data was collected from them via 5G. In addition, tests were run on the ability recognize the signs of a safe environment inside a tunnel while detecting the first signs of a disaster through the use of unmanned, remote controlled construction vehicles.



Device	No.	Time interval	Req. bandwidth
Gas Sensors	14	Twice/second	112Kbps
Environmental Sensor	4	Twice/second	100Kbps
Wearable	6	Continuous	3Mbps
Remote Control Camera	4	Continuous	60Mbps
Remote Control LiDAR	1	Continuous	70Mbps

Fig. 3.3.8-9 Problems and Trial Contents related to Tunnel Work

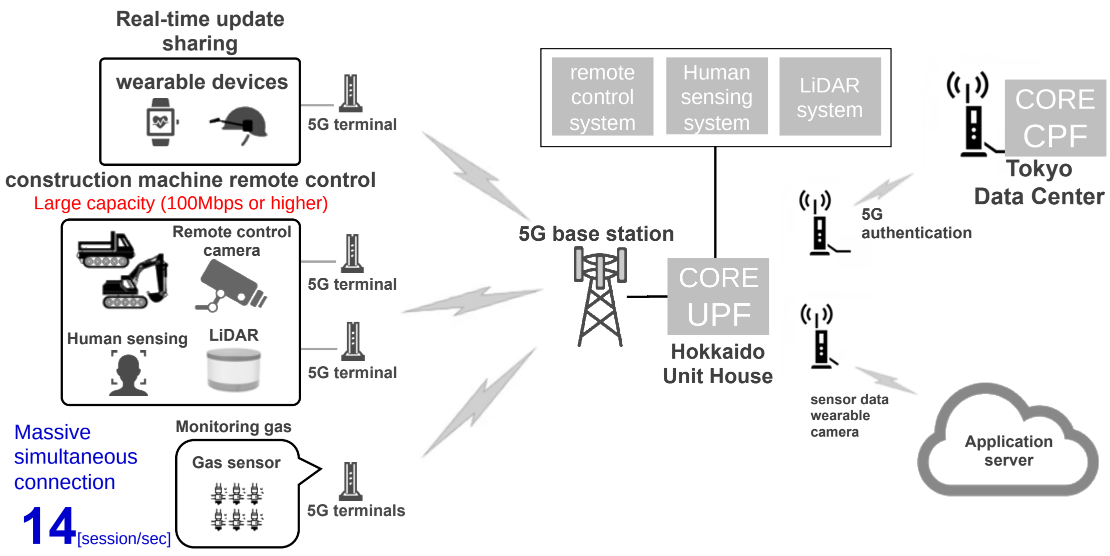


Fig. 3.3.8-10 System Architecture

<u>Use of gas and environmental sensors as well as wearable sensors as well as utilizing remote controlled construction equipment at a tunnel site for quick and early confirmation of tunnel safety and stability during a disaster</u>

This trial confirmed a process to monitor safety at a tunnel construction site by utilizing of gas and environmental sensors as well as wearable sensors to collect data on highly dangerous toxic and flammable gases, leaks of which often occur at tunnel construction sites. Alerts could be sent immediately to operators of a work site if dangerous levels of temperature and carbon dioxide, which were monitored in real time, were detected.

At the tunnel construction site, a remotely controlled hydraulic excavator and crawler dump truck were also equipped with 5G devices. In order to operate this equipment remotely a control center was constructed outside the tunnel. The trial confirmed that by utilizing 5G's high transmission capacity using a MEC server, the vehicles could be controlled up to 1400 m away from the control center while 4 full HD video cameras installed on the construction vehicles streamed video back to the control center, all without any transmission issues occurring. Additionally, these construction vehicles have gas sensors installed on them so that they could also be used to confirm the environment inside the tunnel.

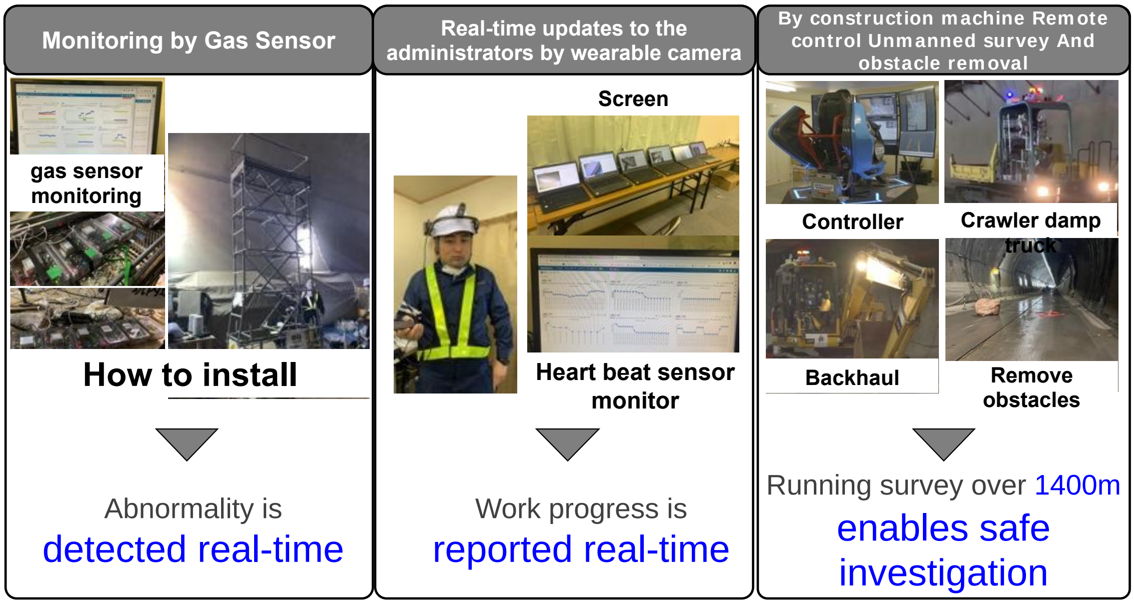


Fig. 3.3.8-11 Result of trials

<u>Confirmation use of slicing functionality to integrate various communication requirements</u>

Remote controlled construction vehicles operating inside the tunnel construction worksite with a variety of sensors installed, such as those to detect gas and report on the surrounding environment, require a large amount of transmission capacity to confirm a safe environment inside the tunnel when an incident occurs. This trial confirmed that during such times, when it was predicted that wireless transmission capacity would be under stress, slicing can be used to prioritize control functions. Using slicing's functionality, it was possible to ensure the priority usage of certain bandwidth during times when transmission capacity was strained. This trial gave the highest priority to gas sensors, in order to protect the life of workers involved. The next highest priority was given to transmissions necessary to remotely control construction vehicles. It was confirmed that in this way data collected from gas sensors was not incomplete while still ensuring latency low enough to control the construction vehicles remotely as well as ensuring the streaming of video from the machinery.

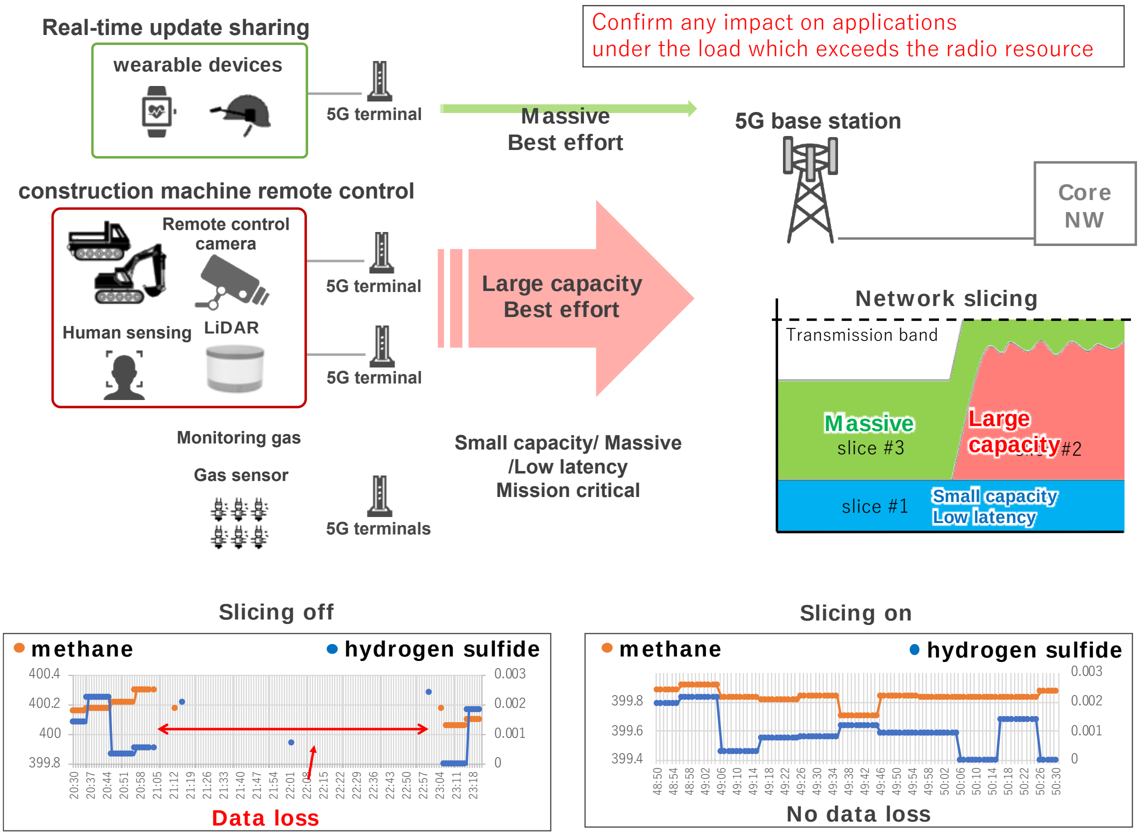


Fig. 3.3.8-12 Further Usage of Network Slicing

References

[1] MIC, "Start of FY2019 5G Comprehensive Demonstration Test (Updated)", https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/2019_9_6_04.html, Sep 6, 2019.

[2] Wireless City Planning, "Conducting a field trial towards the realization of utilizing 5G in i-Construction", https://www.wirelesscity.jp/info/press/2020/01/5g_i-construction.html, Jan 28, 2020.

3.3.8.4 FY2017-2018 Field Trials by NTT DOCOMO and Partners

(1) Remote Monitoring by High-Resolution Video for City Security

Figure 3.3.8-13 shows an overview of 5G system performance evaluations for proposed services in the fields of smart city. Security services in the field of smart city were evaluated. This includes placing security cameras and security personnel with wearable cameras in the dense urban areas such as stadiums at the Tokyo Olympics and Paralympics. These cameras deliver high definition video via 5G networks provided by 5G trial equipment to a security center to be analyzed to cover wide areas to be observed. In FY2017 trials with the cooperation of SOHGO SECURITY SERVICES CO.,LTD. (ALSOK), evaluations of high definition video delivered to security guards by the 4.5 GHz band 5G trial equipment were carried out in the dense urban areas of Shinjuku-

Ward, Tokyo as shown in Fig. 3.3.8-14.

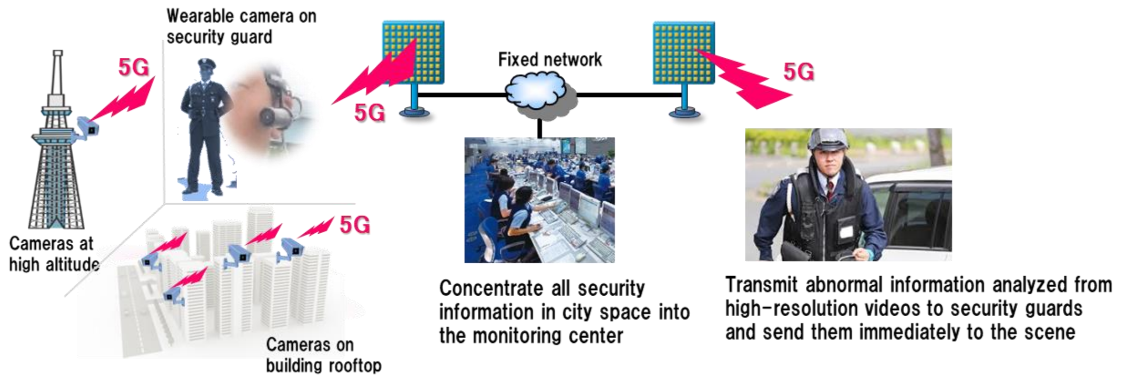


Fig. 3.3.8-13 5G system performance evaluations for Smart City / Smart Area

Fig. 3.3.8-14 Remote monitoring by high-resolution video for security

(2) Car Security with 5G

Security applications utilizing 5G were demonstrated, with the cooperation of SOHGO SECURITY SERVICES CO.,LTD. (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 enroute to an incident or providing information to relevant organizations in such a situation.

Fig. 3.3.8-15 Realization of car security via flying view using 5G

(3) Community Security Services Using 5G

Community security services were demonstrated, with the cooperation of Aizu Wakamatsu City, with the cooperation of SOHGO SECURITY SERVICES CO.,LTD. (ALSOK), and NEC Corporation, 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.

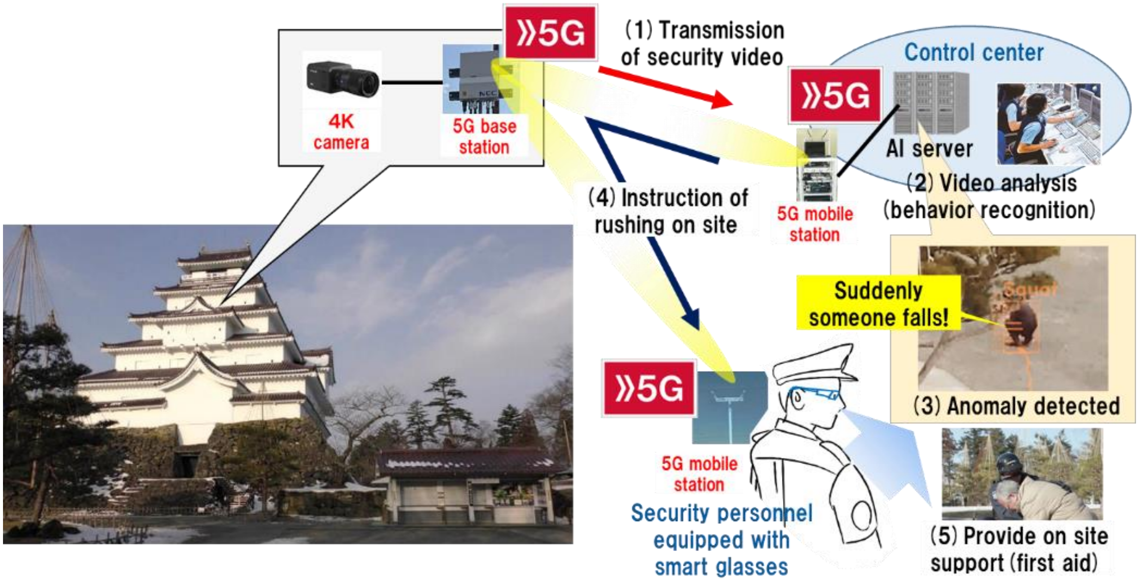


Fig. 3.3.8-16 Realizing community security services using 5G

3.3.8.5 FY2017-2018 Field Trials by KDDI and Partners

(1) Remote Control of Construction Machinery

Trials in FY2017

In this trial, HD and 4K/3D video streams taken by multiple cameras installed at the construction machinery are transmitted to a remote site via 5G, where an operator controls construction machinery remotely by watching the video streams. The efficiency of remote control is expected to increase by utilizing high resolution video, however, it is not feasible for 4G networks to support high resolution video due to the limitation of data speeds, capacity as well as latency. In the trial in FY2017, the advantage of 5G over Wi-Fi is verified quantitatively with Obayashi Corporation and NEC Corporation.

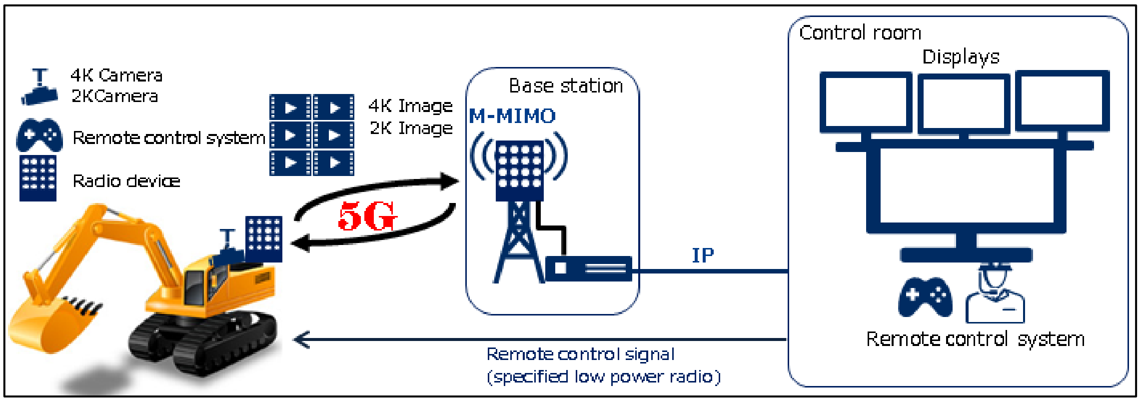


Fig. 3.3.8-17 Proposed trial for the ICT Construction

Quick relief and recovery of social infrastructure are of imminent importance in case of natural disasters in Japan. In some cases, operation of construction machinery is required in inaccessible environment. Working population is on the decrease in Japan, in particular, shortage of specially skilled workers is prominent.

Remote operation of construction machinery is one of the solutions in order to cope with the issues above and is already in use in some cases. However, current remote operation system using Wi-Fi bear following restrictions;

- Capacity is not sufficient. Video quality and the number of machinery controllable at the same time in one place is restricted.
- Radio quality may not be stable, affected by radio interference.

As a result, efficiency of remote operation using Wi-Fi is reduced by about 50-60 % in general, as compared with manned operation. The capability of 5G is expected to improve efficiency in remote operation.

In the testing illustrated in Fig. 3.3.8-18, time required for stacking three blocks by construction machinery (i.e. backhoe) was evaluated as a quantitative measure of efficiency.

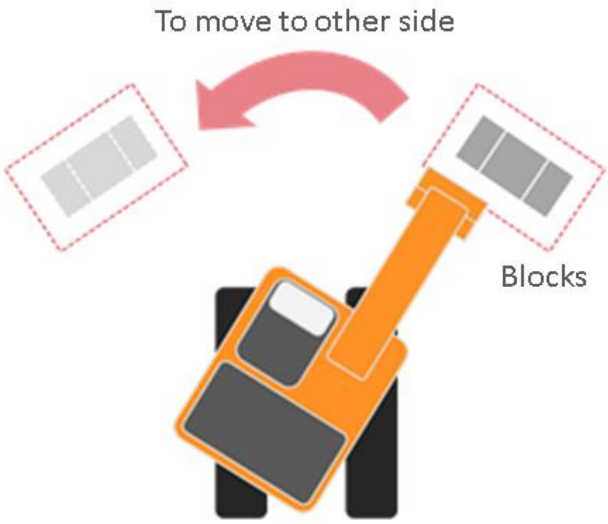


Fig. 3.3.8-18 Image of experiment

Figure 3.3.8-19 shows the test results: remote operation using 5G improved construction efficiency by 35 % as compared with Wi-Fi, mainly due to improved information quality and reduction of burden on an operator by three-dimensional 4K high definition video. Total system delay (E2E) is about 600 ms, comprising processing delay of codec, 4K video equipment, 3D monitor etc.

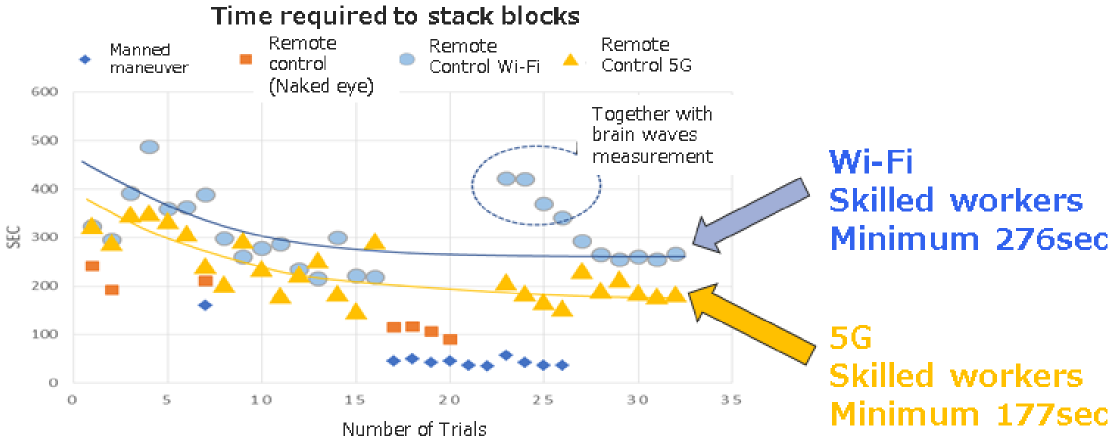


Fig. 3.3.8-19 Experimental result of ICT construction

Trials in FY2018

In the trial, the application of 5G to remote control of construction machinery in recovery from landslide disaster is verified with Obayashi Corporation and NEC Corporation, which is expected to realize safe environment for operators as well as prompt recovery from disasters. The trial configuration is shown in Fig. 3.3.8-20.

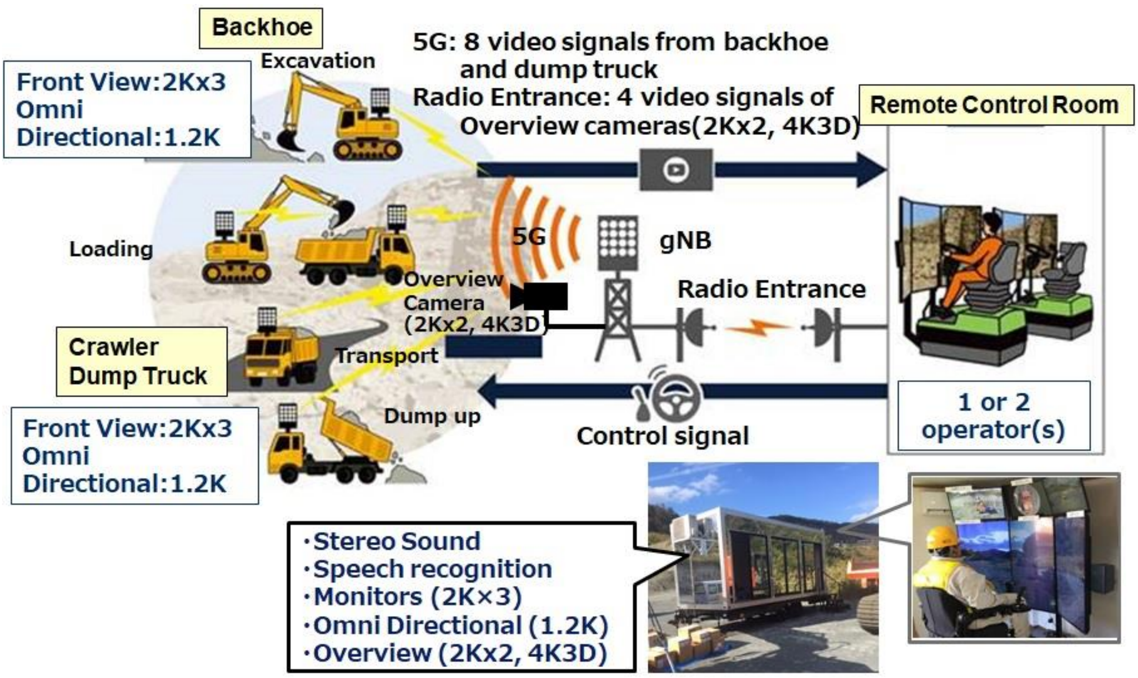


Fig. 3.3.8-20 Trial configuration for remote control of construction machinery

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.

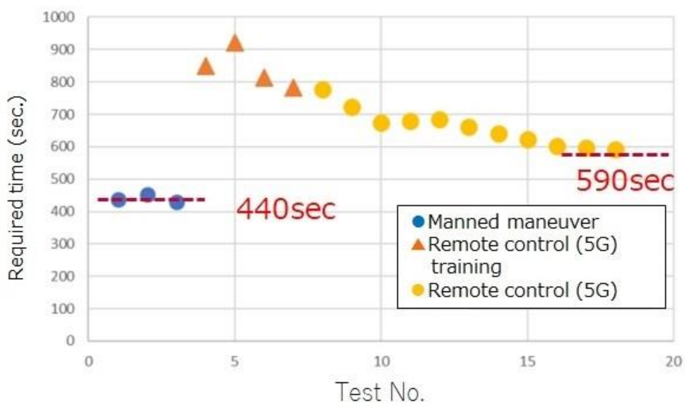
Reduction of E2E latency is essential from the viewpoint of improving operation efficiency. In the trial, considering the tradeoff between video quality and processing time required for coding/decoding, 2K video was adopted instead of three dimensional 4K video used in the trial last year. As a result, E2E latency of 80 ms 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. 3.3.8-21.

1. Excavation by backhoe → Loading to crawler dump truck → Transport → Dump up.
2. Three bucketful of earth and sand (about 2 ㎥) 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. 3.3.8-21 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.

(2) 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 with Hakuba village, Ritsumeikan University, and Kanaidoryoukou 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.

In FY2018 trials, 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. 3.3.8-22. 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.

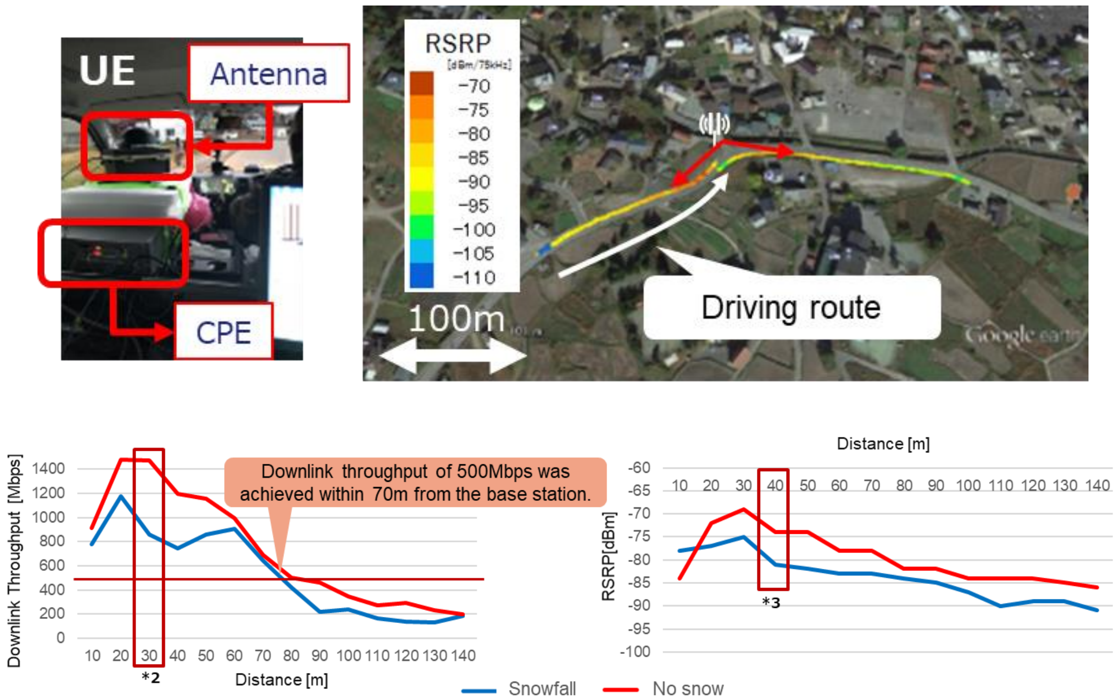


Fig. 3.3.8-22 Experimental results using 28 GHz

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.

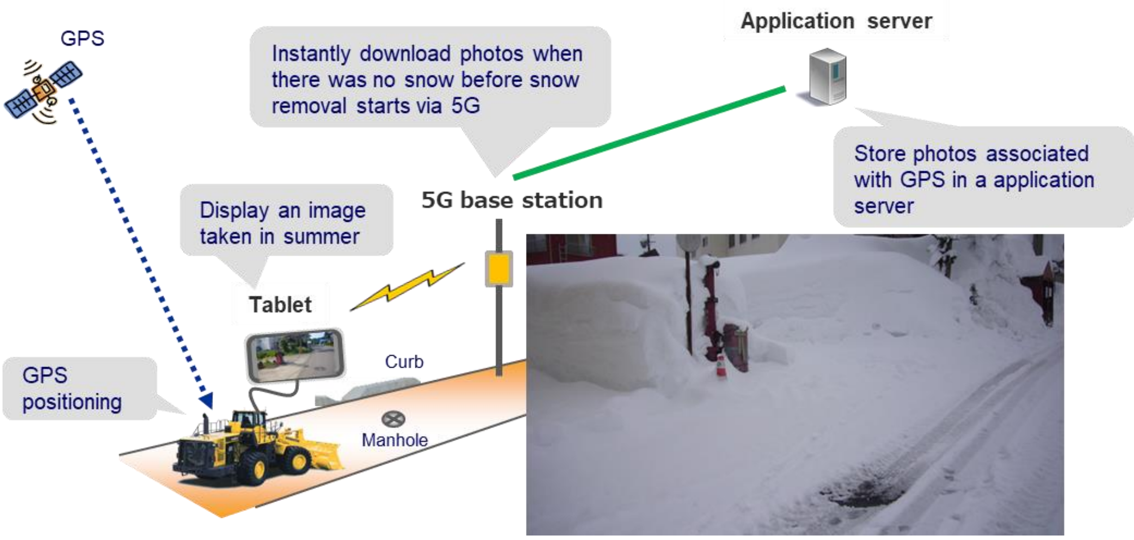


Fig. 3.3.8-23 Operation assistance system

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. 3.3.8-24, the uplink throughput of 23 Mbps required for 4K video transmission was achieved, and 4K video was successfully displayed in real time.

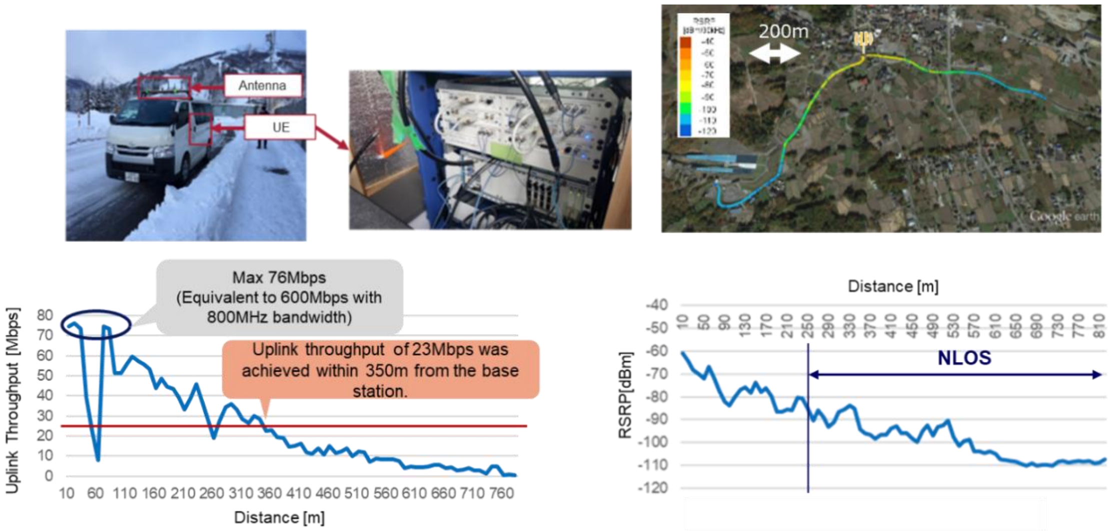


Fig. 3.3.8-24 Radio performance in 3.7 GHz

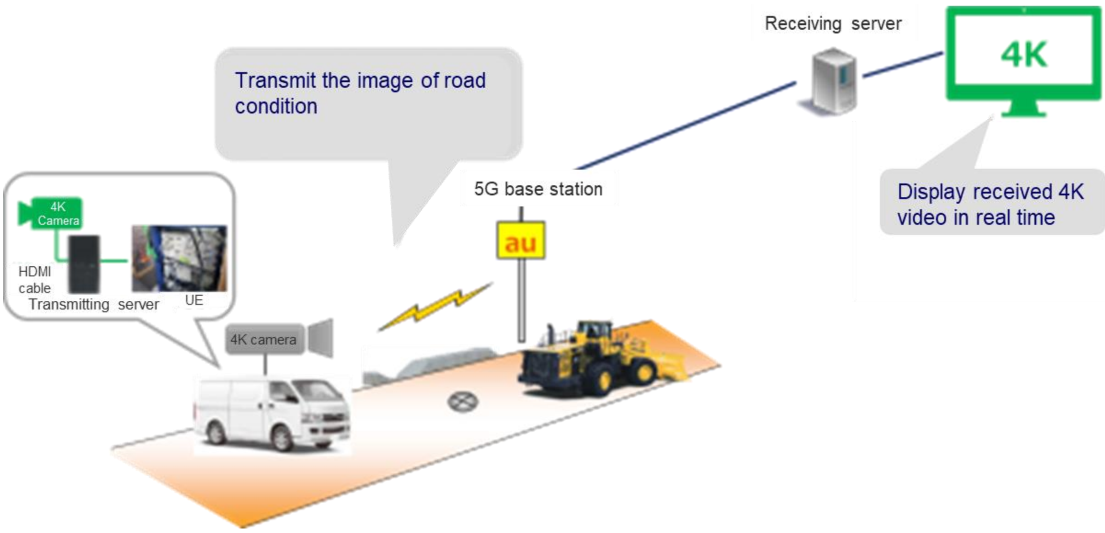


Fig. 3.3.8-25 4K video upload system

3.3.8.6 FY2017 Field Trials by NICT and Partners

(1) Demonstration Experiment Utilizing 5G Massive Simultaneous Connectivity - Disaster Shelter Application -

The ability to handle massive multiple connections is one of the special characteristics of the fifth-generation mobile communication system (5G). Other characteristics of 5G, including ultra-high-speed communications and ultra-low latency, they will affect the communication quality of individual devices, but the ability to handle massive multiple connections will affect communication capabilities over a coverage area. With the current demand for massive Machine Type Communication (mMTC), this unique characteristic of 5G is expected to change how mobile communication systems are used by society.

The authors of this section built a demonstration system focusing two usage scenarios of accessing emergency relief warehouse supplies and smart offices. These usage models need the ability of a mobile communications system to handle massive multiple connections. The effectiveness of 5G ability in these situations will be demonstrated by comparing the use of 4G in the same situations. This section discusses these usage scenarios and the built system to demonstrate their potential.

Massive multiple connection communications are defined as one million devices connected within a 1 km^2 area. In this specific trial, especially, aims to demonstrate that one base station can be connected to 20,000 devices simultaneously.

<u>Usage scenarios of Massive Connections at Emergency Relief Warehouse</u>

Once a disaster strikes, it is necessary to control the movement of a large number of goods and to support people in extreme, emergency conditions. This means knowing where goods are stored and where they need to be delivered, what types of goods are available or needed, and what their expiration dates are. For supporting people, knowledge of where doctors and volunteers are, as well as knowing the victim's location in the disaster area, as well as their conditions, such as biometric data from people with heart conditions and other medical issues. This data can be collected and distributed over a wide area by a base station of 5G system that is managed by authorities of city or at a disaster relief center. This scenario, which is illustrated in Fig. 3.3.8-26, shows how delivery of goods will be able to be managed efficiently to and from locations such as relief supply warehouses in areas not affected by the disaster or evacuation centers.

5G will be able to adopt a grant free access for machine type communications that makes the overhead of the communication process smaller and more efficient. Figure 3.3.8-27 shows the evaluation system to compare the performance of the 5G system with the grant free method to that of the 4G system. In this system, 20000 connections from 5G system are emulated in 4.6 GHz over the air and 100 real devices of 4G LTE are operated in 2.6 GHz with RF cables. Regarding 5G, the system was configured so that packets are transmitted every 5 second and it was confirmed that all the data from 20,000 devices has been received in 70 second. It was revealed that, depending on applications and configurations, an optimal transmission interval exists to receive the maximum number of packets. In case of 4G, simultaneous attempts of 100 or less connections sometimes make the network system unstable

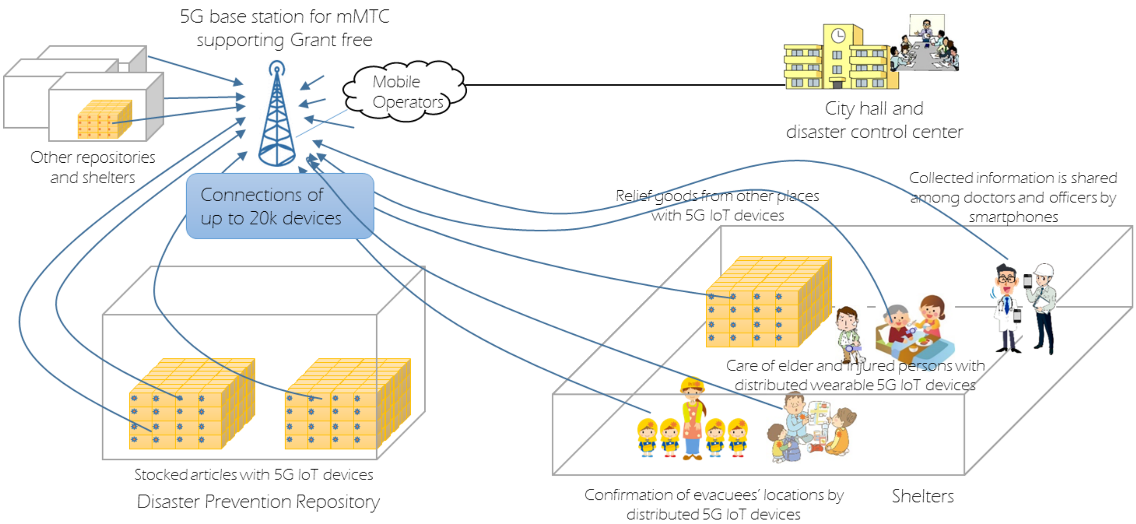


Fig. 3.3.8-26 A Disaster Relief Warehouse Use Scenario

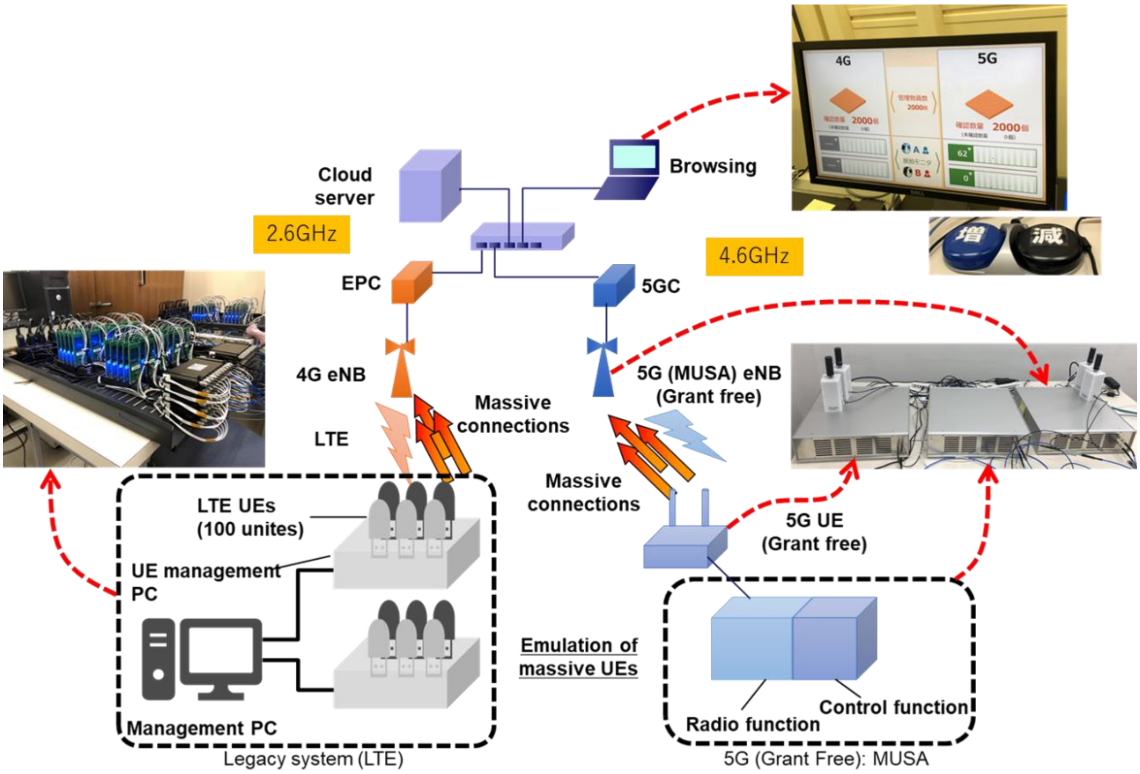


Fig. 3.3.8-27 Evaluation system to compare the mMTC performance of 5G and LTE

3.3.8.7 FY2018 Field Trials by WCP and Partners

(1) 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. 3.3.8-28. 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. 3.3.3-10 at Section 3.3.3.5, 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. 3.3.8-29. 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. 3.3.8-30. 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. 3.3.8-30. 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.

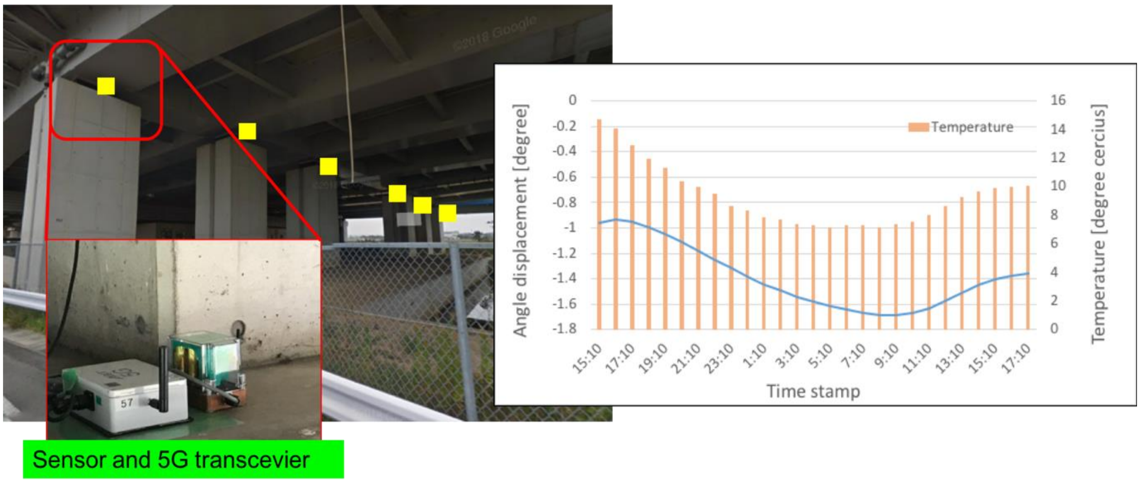


Fig. 3.3.8-28 Health monitoring of highway bridge.

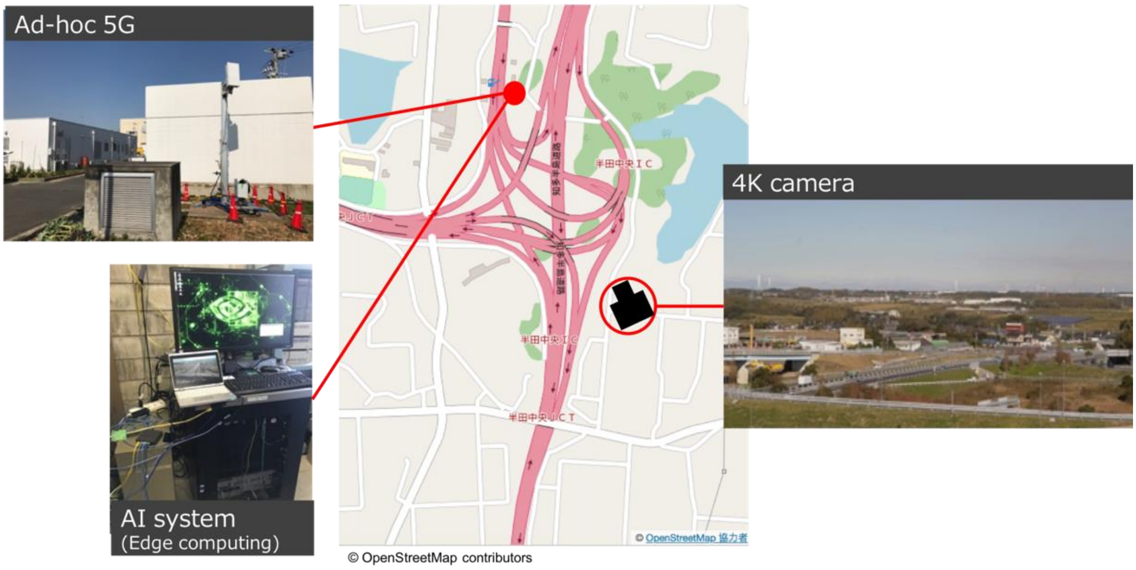


Fig. 3.3.8-29 Road monitoring at highway intersection.

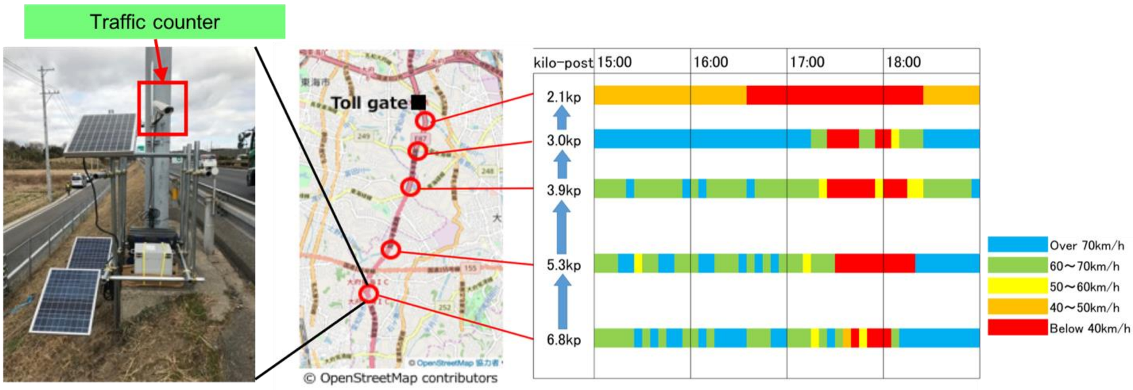


Fig. 3.3.8-30 Traffic jam Monitoring using traffic counters.

3.3.9 Use Case 9: Transportation Application

3.3.9.1 FY2019 Field Trials by NTT DOCOMO and Partners

- **Responsible organization:** NTT DOCOMO, INC.

(1) Filed Trial Utilizing 5G for Sound Visualization for Lifestyle Support (mobility)

- **Partners:** SUNCORPORATION

This field test took place in Nakatsugawa city, Gifu prefecture in October 2019. This trial utilized a radio device operating on the 28 GHz frequency band to provide a new lifestyle support service to those who are hearing impaired by detecting dangerous sounds in surrounding areas and providing visual information about the sound. Sounds were detected and analyzed, and that information was sent to smart glasses where that information was displayed visually to provide warnings to the hearing-impaired wearer of the glasses. It was confirmed that video and 3D models could be played on the smart glasses display within 1 second in order to notify the wearer of a dangerous situation. In addition to the use of this mechanism to react to sounds and display content for lifestyle support, it is expected many uses in the field of entertainment will be found, as well.

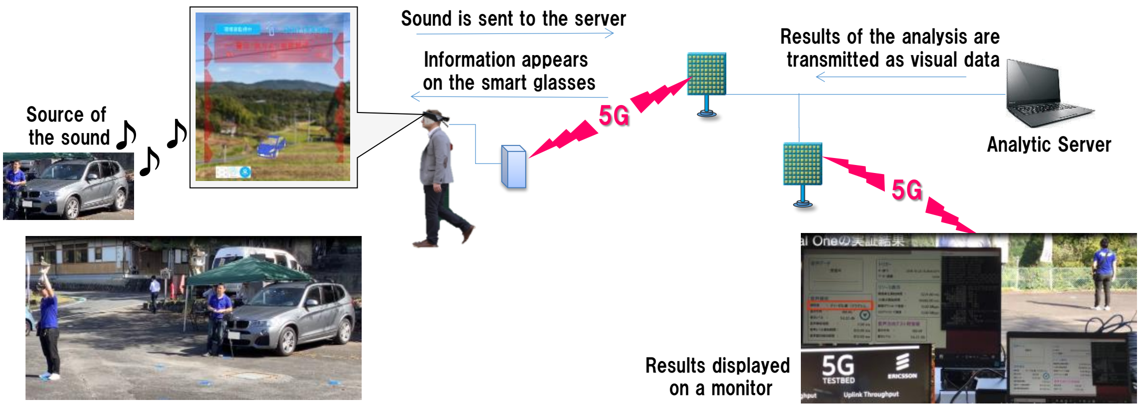


Fig. 3.3.9-1 Field test utilizing 5G for sound visualization for lifestyle support

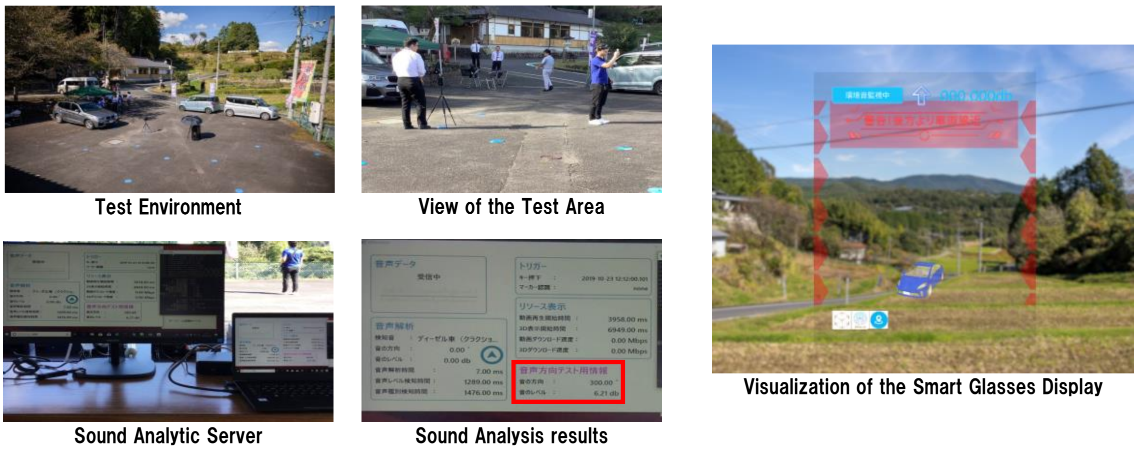


Fig. 3.3.9-2 Heads-up Display and Analysis of Surrounding Sounds

3.3.9.2 FY2019 Field Trials by NTT Communications and Partners

- **Responsible organization:** NTT Communications Corporation

(1) Filed Trial Utilization of 5G for Driving Assistance in Heavy Fog (mobility)

- **Partners:** Oita Prefecture, Autobacs Seven Co., Ltd., Response Council for Fog-Related Issues on Expressways in Oita Prefecture, T PLAN Inc., NTT DOCOMO, INC.

This field trial was held on an expressway in Oita prefecture as well as the Showa Denko Dome Oita in February 2020. This trial was the first study in Japan of the possibility of a driving support system utilizing 5G to provide drivers in heavy fog to see objects in car lanes around them as well as in front of them through the use of 4K and thermal cameras. This trial was conducted in an artificially fogged environment. Via 5G's special characteristics of high speeds, massive capacity, and ultra-low latency, The image taken by thermal camera and 4K camera mounted on the car were transmitted to the image analysis AI on the cloud, and the analysis results were displayed on the car's head-up display. It was confirmed that the support to driving safely could be achieved with this system as the driver of a moving vehicle could be notified with this auxiliary information on difficult to see obstacles through AI analysis.

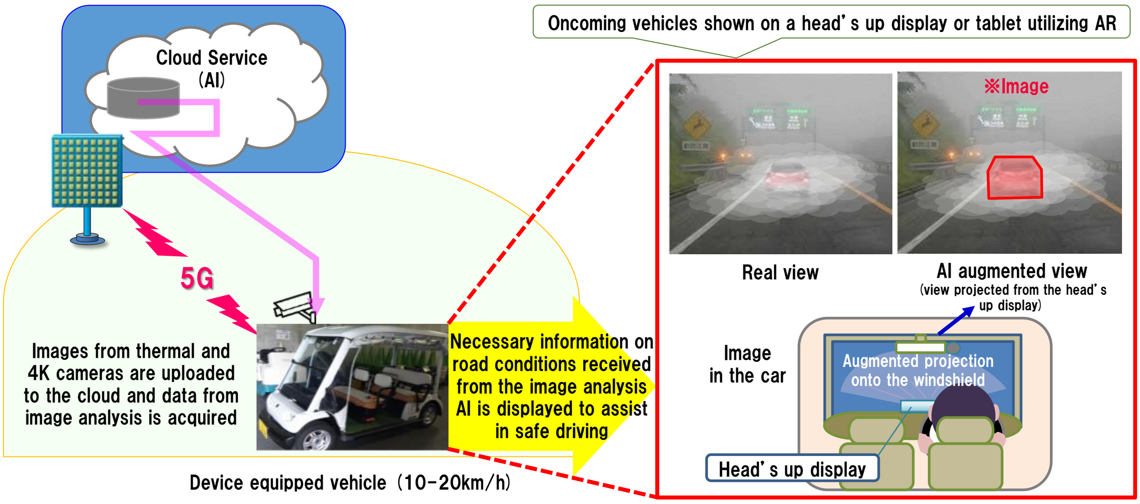


Fig. 3.3.9-3 Field trial on utilizing 5G to assist driving in heavy fog

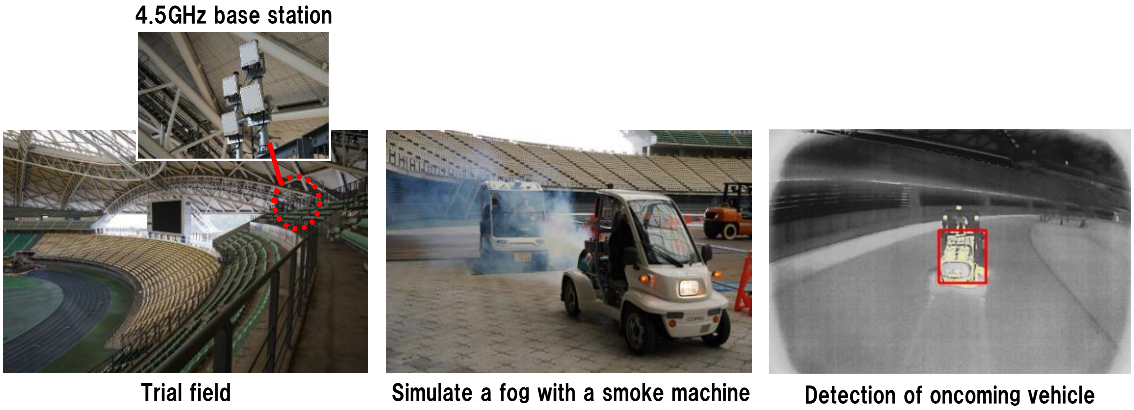


Fig. 3.3.9-4 Views of the driving assistance trial in heavy fog

3.3.9.3 FY2019 Field Trials by SoftBank, Wireless City Planning and Partners

- **Responsible organization:** SoftBank Corp., Wireless City Planning Inc.

(1) Truck Platooning

- **Partners:** Advanced Smart Mobility Co.Ltd.

The trial aims to assess 5G URLLC capability in Truck platooning. The trial was performed several times from February, 2019 to February, 2020, on Shin-Tomei Highway, which literally means New Tokyo-Nagoya Highway, in cooperation with Advanced Smart Mobility, Co. Ltd (Details of FY2018 trials are describes in Section 3.3.9.5). 5G communication systems both via Base Station (Up- and Down-link) and direct vehicle-to-vehicle communication (Sidelink) were demonstrated in application of 5G URLLC to truck platooning. Both 4.5 GHz and 28 GHz bands were used in the trial.

Truck platooning involves multiple trucks driving together in a convoy. Each truck in a platoon is controlled to form a convoy by keeping inter-vehicle distance constant between trucks. Truck platooning becomes more stable by exchanging information of vehicle speeds and/or geographical positions over inter-vehicle radio communication. Development to implement truck platooning is currently underway in several countries around the world.

Several social issues can be resolved through use of truck platooning. Platooning can enable trucks to drive closer together to reduce wind resistance, which can reduce fuel consumption. It has been shown that a platoon of three trucks travelling 4 m apart at 80 km/h consume 15% less fuel. If the distance between trucks is reduced to 2 m, the fuel consumption would be reduced by 25 %. Reducing the distance between vehicles can also increase the traffic capacity of roads, mitigating congestion. In Japan, an aging driver population and driver overwork are also social issues, so truck platooning can reduce the burden on drivers and increase safety. 5G URLLC would greatly contribute to the truck platooning.

5G URLLC enables stable operation with less fluctuation in following distance (hunting or vibration) due to less control delay. Fuel consumption can be further reduced and traffic capacity of roads, i.e. number of vehicles per km, can also be increased while maintaining safety by further reducing the following distance and increasing the number of platooned trucks, if 5G URLLC would be applied to the radio communication between the vehicles, which realizes low latency and high reliability. 5G URLLC is very promising in this field.

Fig. 3.3.9-5 5G Truck Platooning trial on a highway,
on Shin-Tomei highway in Shizuoka, Japan (Bird view)

Fig. 3.3.9-6 5G Truck Platooning on a highway,
Shin-Tomei highway in Shizuoka, Japan (Rear view)

Fig. 3.3.9-7 5G BS and its antenna, co-located in 4G LTE commercial BS,
along Shin-Tomei Highway

References

[1] Ministry of Internal Affairs and Communications, "5G System Trial Begin," Press Release, http://www.soumu.go.jp/menu_news/s-news/01kiban14_02000297.html, May 2017.

[2] H. Yoshino, "5G Undergoes Overall System Tests in Truck Platooning", TECH

FOCUS, Asia Electronics Industry (AEI) , pp.21-24, Volume 24, Serial No.277, October 2019, Dempa Publications Inc. https://www.dempa.co.jp/en/pdfs/contents_october19.pdf
[3] M. Mikami and H. Yoshino , "Field Trial on 5G Low Latency Radio Communication System towards Application to Truck Platooning," IEICE Trans. Commun, vol.E-102, No.8, Aug. 2019.

(2) Remote Control of Abandoned Cars in Case of Disaster

- **Partners:** FEV Japan

The trial was demonstrated in Kita-Kyushu Science and Research Park in February 2020, with support of Kita-Kyushu municipal government and Kita-Kyushu Foundation for the Advancement of Industry, Science and Technology (FAIS). The trial was performed under the assumption of disaster relief, where a river in the city overflowed and was flooding the street and then people needed to evacuate to the safer area by car. In the evacuation process, some people abandoned their cars on the rescue road. The local government needed to remove the cars to other parking place to keep the road clean for its rescue operation. The removal of the cars can be done from remote area, e.g. 100 km apart from the disaster place, by using the nature of wide area coverage of the cellular systems, including 5G, and the capability of 5G ultra-reliable and low-latency. So the trial use case can be regarded as a wide-area low-latency remotely-controlled valet parking technology.

The trial used a 5G prototype in 3.9 GHz band and MEC (Mobile Edge Computer) server for remote operation.

Fig. 3.3.9-8 Remote operation of a vehicle test area in Kita-Kyushu Science and Research Park

Fig. 3.3.9-9 Vehicle remote operation from a remote site

Fig. 3.3.9-10 Remotely-controlled vehicle

(3) Smart Intersection for Collision Avoidance of Cars

- **Partners:** Nippon Signal, FEV Japan

The trial was demonstrated in Kita-Kyushu Science and Research Park in February 2020, with support of Kita-Kyushu municipal government and Kita-Kyushu Foundation for the Advancement of Industry, Science and Technology (FAIS). The trial was performed under the assumption of disaster relief, where a river in the city overflowed and was flooding the street and then people needed to evacuate to the safer area by car. In the evacuation process, some cars would crash each other due to the reckless driving. The traffic accidents would further cause the delay of evacuation. In 5G smart intersection, surveillance camera is set at every intersection, collecting status information through 4K video streaming. AI at MEC server analyses and detect danger status which lead to vehicle or pedestrian collisions and suddenly sends "warning" to the cars and finally sends "stop" command so that the cars approaching to the intersection can be arbitraged to avoid collision.

The trial used a 5G prototype in 3.9 GHz band and MEC (Mobile Edge Computer) server for remote monitoring at intersections and remote operation of cars.

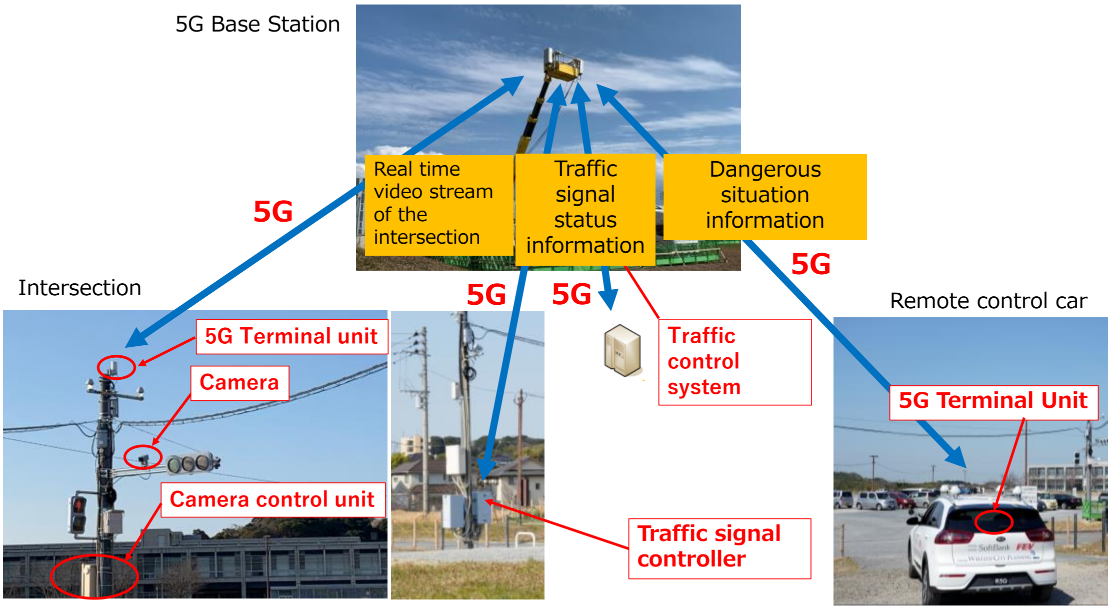


Fig. 3.3.9-11 Smart intersection configuration by using 5G terminals

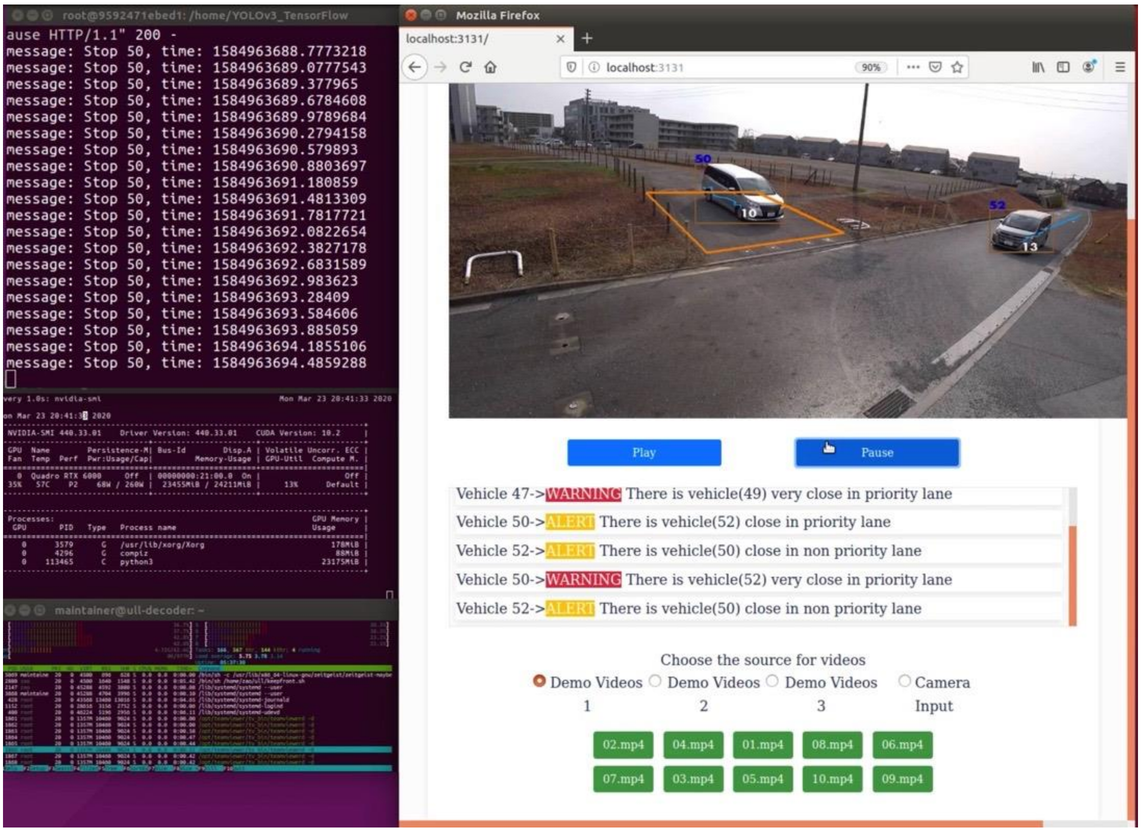


Fig. 3.3.9-12 Intersection traffic arbitration by 5G and AI

3.3.9.4 FY2019 Field Trials by WCP and Partners

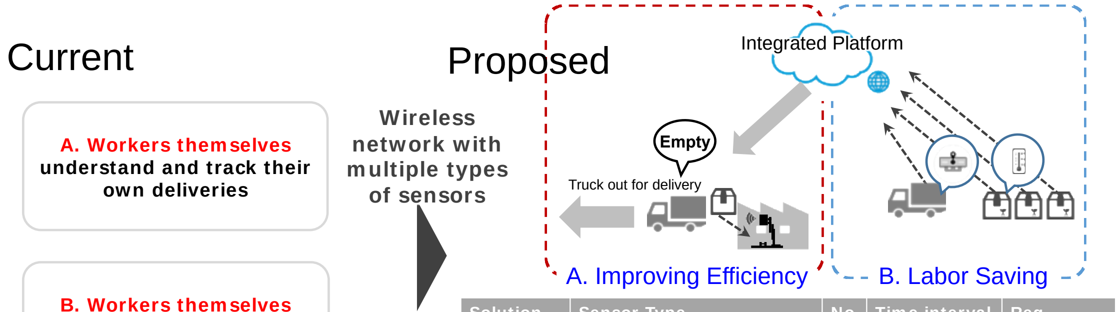
- **Responsible organization:** Wireless City Planning Inc.

(1) Smart Logistics

- **Partners:** NIPPON EXPRESS CO., LTD.

This field trial demonstrated the use of “smart logistics”, utilizing the 5th Generation Mobile Communications System (5G) to realize greater efficiencies in logistics processes. It was held at the Nippon Express Ekoda Distribution center from the end of January until the end of February in 2020. It is hoped that implementing a more efficient cargo pickup system will help the logistics industry as it faces major challenges such as a shortage of truck drivers and work-style reforms. The need for visualizing load capacity data is also increasing with the development of Mobility as a Service (MaaS) along with the proposed use of a variety of combined and joint freight and passenger operations

WCP and Nippon Express conducted this field trial to demonstrate the ability of utilizing a 5G network to determine the number and size of packages loaded on trucks and remaining load capacity through the use of accelerometers and other similar sensors as well as technologies such as LiDAR. The trial also demonstrated the ability to verify cargo capacity as well the state of the cargo's temperature utilizing technologies such as Cat. M1 devices.



Solution	Sensor Type	No.	Time interval	Req. bandwidth
A. Improving efficiency	Acceleration	3	40 times/sec	40Kbps
	GPS・Temperature Type A	3	2 times/sec	100Kbps
	LiDAR	1	Continuous	22Mbps
B. Labor Saving	Capacity	24	1 time/minute	A few Kbps
	GPS・Temperature Type B	25	1 time/minute	A few kbps

This trial utilized LTE
Smart logistics will see further improvement with the use of 5G

Fig. 3.3.9-13 Issues related to the logistics of picking up cargo and the field trial overview

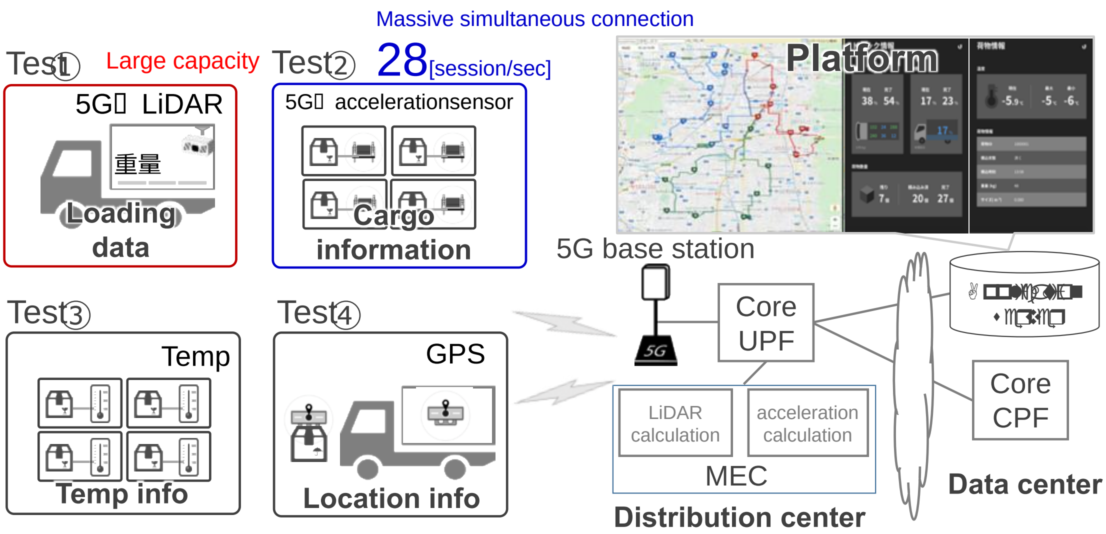


Fig. 3.3.9-14 System Architecture

<u>Understanding and visualizing the state of used and available cargo space on a truck through the utilization of 5G and MEC servers.</u>

In order to visualize the available space in a truck's cargo compartment, a 5G device is used to collect cargo point group data with LiDAR. The collected data is sent to operators at a remote location. Using 5G's large capacity and an MEC server, the cargo point group data is sent and analyzed in real time and the cargo capacity can be visualized and displayed on the operator's screens at the control center. In addition, the trial demonstrated that sensors attached to cargo can rapidly send acceleration and location data to be used to determine how much cargo is loaded into a cargo space. In the future, it will be possible to visualize and understand the amount of available space trucks with a low loading rate can be expected to fill with cargo. This is expected to contribute to decrease the amount of extra labor needed to be done by delivery drivers to confirm the capacity of their trucks.

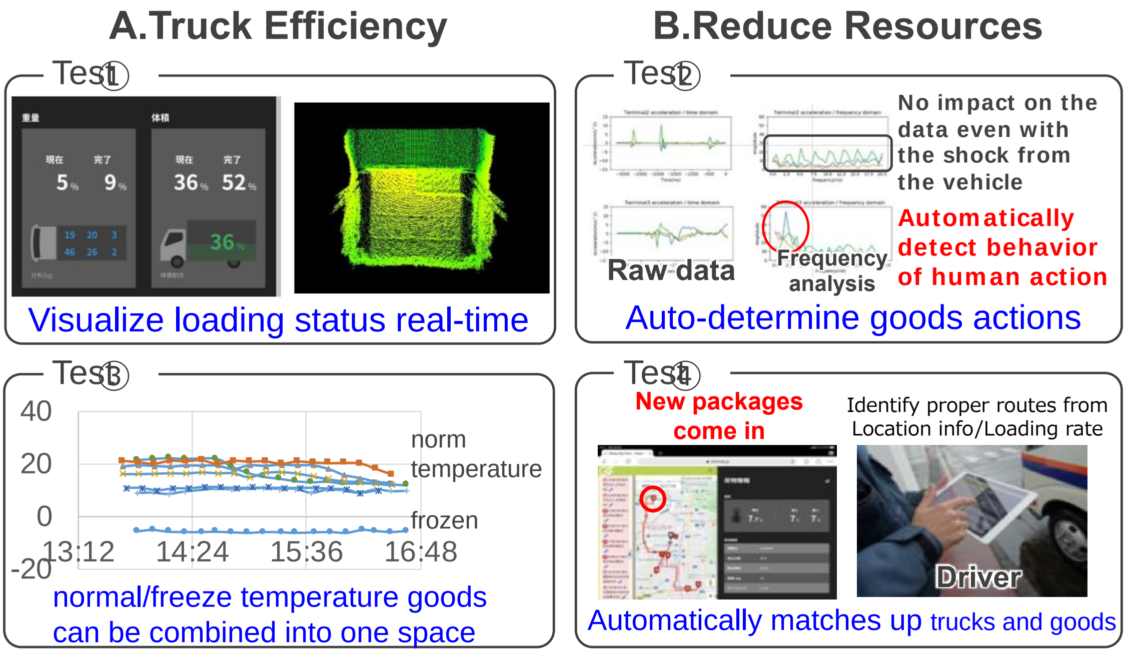


Fig. 3.3.9-15 Result of trials

References

[1] MIC, "Start of FY2019 5G Comprehensive Demonstration Test (Updated)", https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/2019_9_6_04.html, Sep 6, 2019.

[2] Wireless City Planning, "Conducting a field trial towards the realization of utilizing 5G in smart logistics" https://www.wirelesscity.jp/info/press/2020/02/5g_smart_logistics.html, Feb 19, 2020.

3.3.9.5 FY2018 Field Trials by NTT Communications and Partners

(1) Railway Infrastructure Monitoring for Safe Railway Management

In the trials with the cooperation of West Japan Railway Company and NTT DOCOMO, INC., 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

Figure 3.3.9-16 shows Overview of the demonstration experiment.

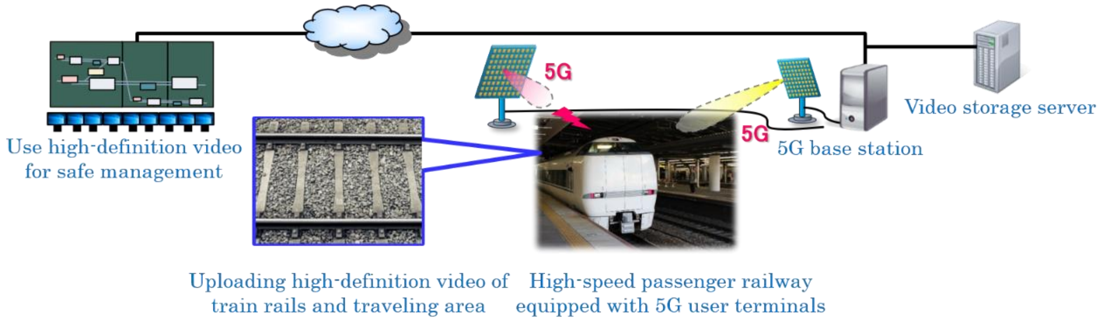


Fig. 3.3.9-16 Overview of high-definition video uploading in JR Kyoto Line

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". Figure 3.3.9-17 shows the arrangement of base stations.

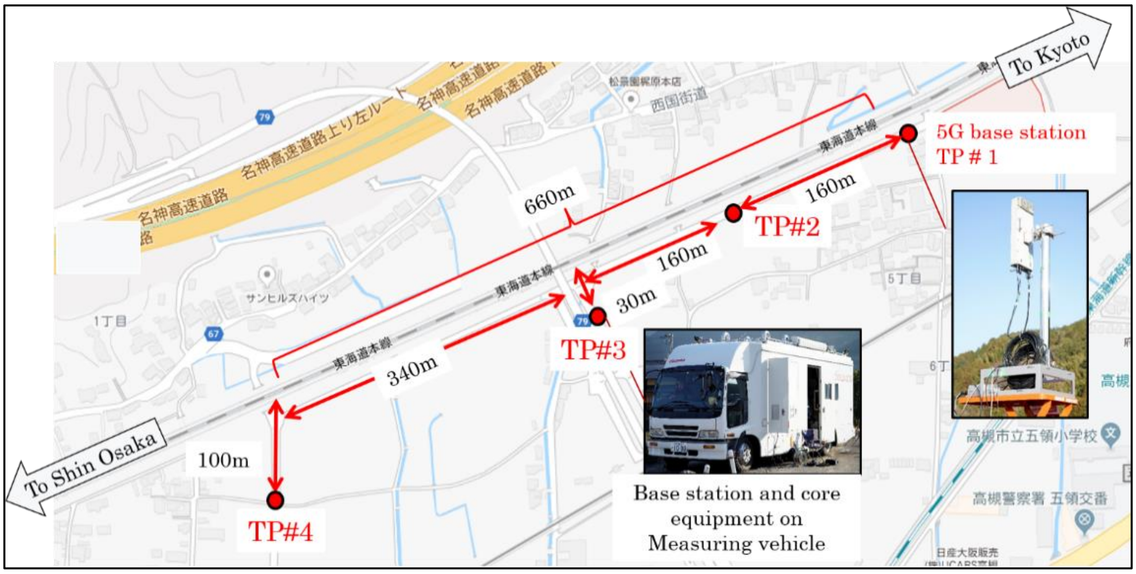


Fig. 3.3.9-17 Arrangement of base stations at the experimental site of JR Kyoto line

Figure 3.3.9-18 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.

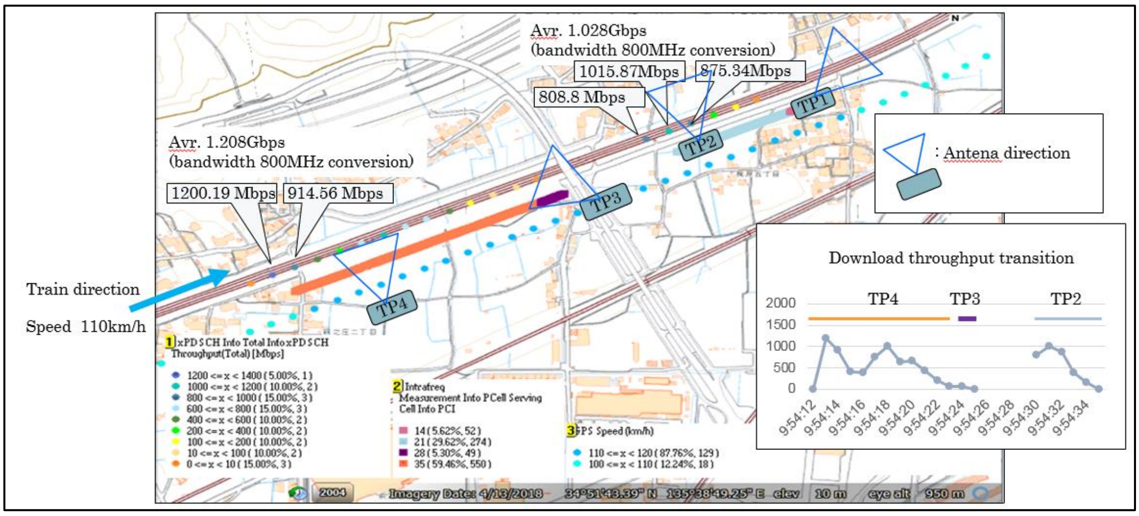


Fig. 3.3.9-18 Download throughput distribution

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.

Figure 3.3.9-19 shows demonstration results of these two use cases for safe railway management.

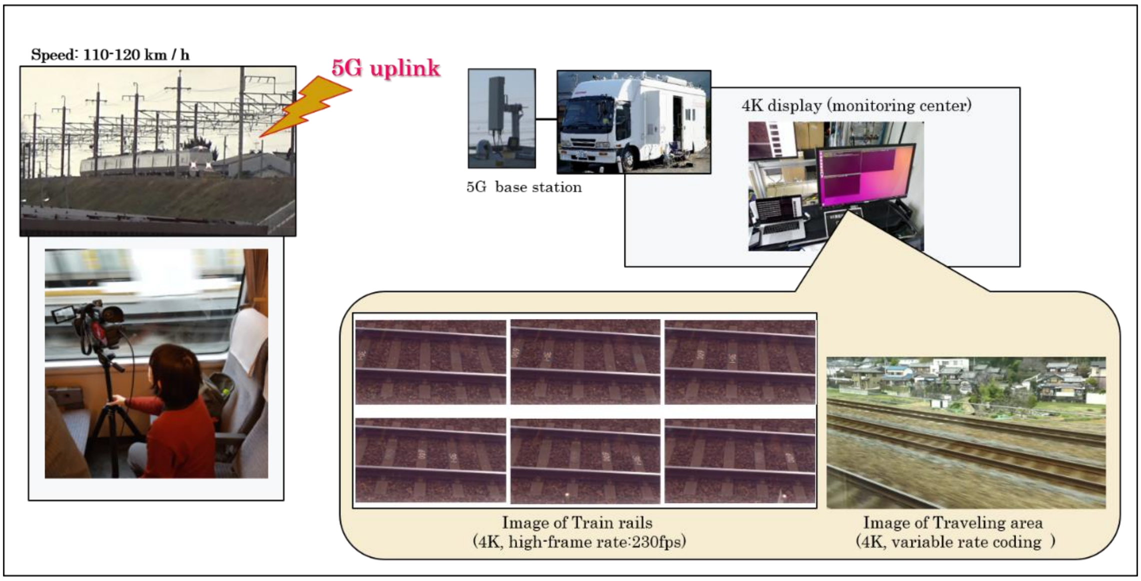


Fig. 3.3.9-19 Two use cases for safe railway management

3.3.9.6 FY2018 Field Trials by KDDI and Partners

(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 with TOYOTA InfoTechnology Center. The transmission of 4K video from a moving automobile in real time is made possible by using 5G and cannot be realized by 4G.

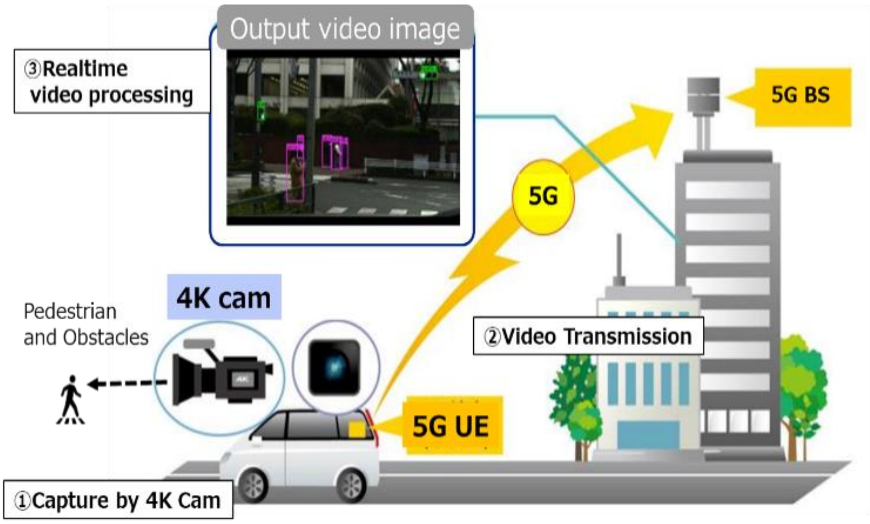


Fig. 3.3.9-20 Overview of trial for automobile services

In FY 2018, 5G radio performances were measured for this trial in Shinjuku, Tokyo. Fig. 3.3.9-21 shows the area of the field trial and the driving routes. Figure 3.3.9-28 illustrates the seasonal fluctuation of UL SINR (Signal to Interference Noise Ratio) measured in 4.5 GHz and 28 GHz.

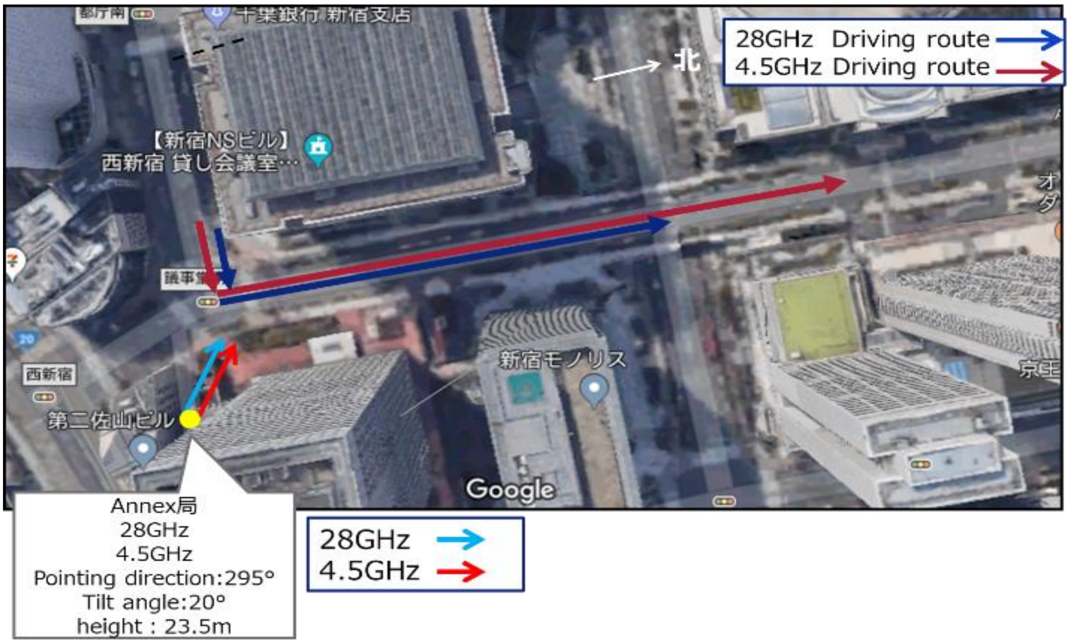


Fig. 3.3.9-21 Field trial area and driving route

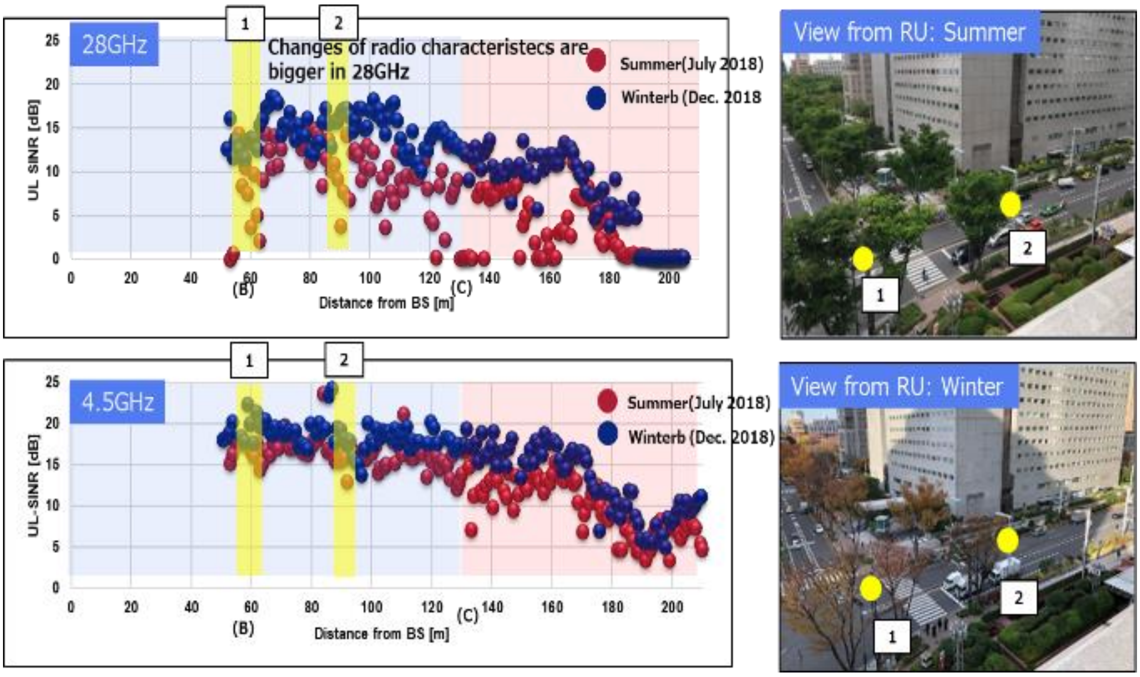


Fig. 3.3.9-22 Measured UL SINR's in 28 GHz and 4.5 GHz

UL SINR varies depending on frequency bands and seasons. The results are summarized in Table 3.3.9-1.

Table 3.3.9-1 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 3.3.9-1 are medians in the areas in yellow in Fig. 3.3.9-22, 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.

Figure 3.3.9-23 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.

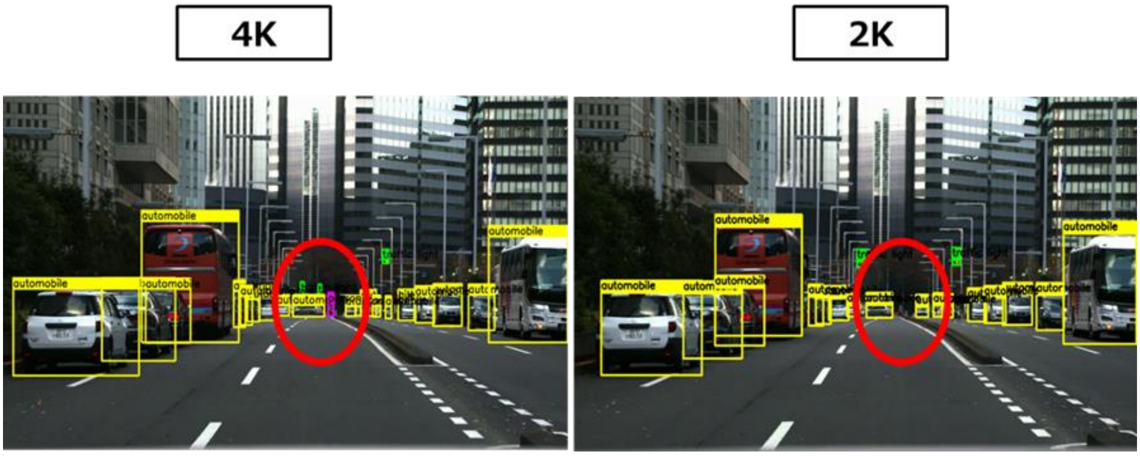


Fig. 3.3.9-23 Comparison between 4K and 2K

3.3.9.7 FY2017-2018 Field Trials by ATR and Partners

(1) Field trials in Station

Trials in FY2017

We have a plan to evaluate applications that analyze high definition video via 5G to autonomously detect dangerous items and suspicious situations in order to provide a safe station environment for passengers and staff in a railway station.

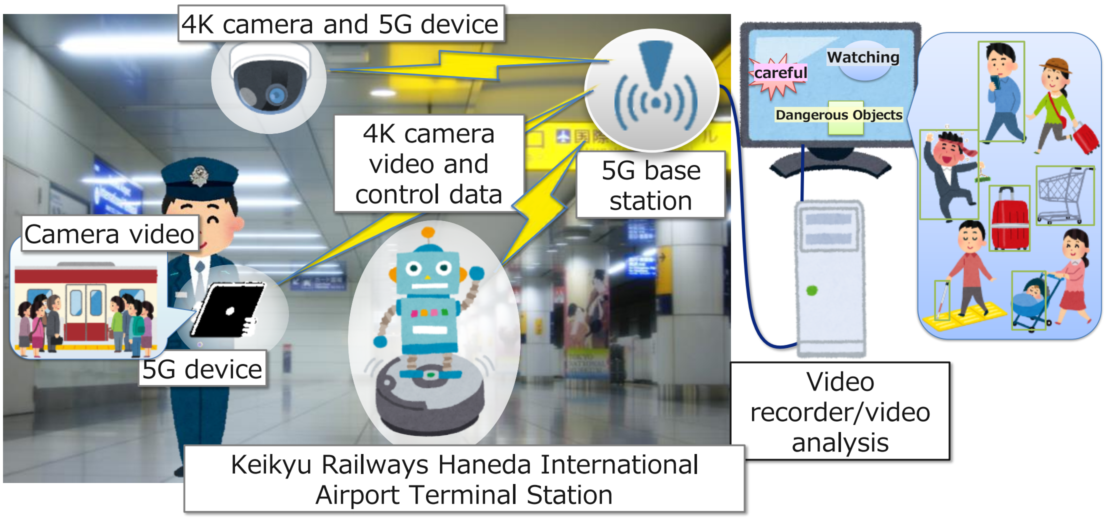


Fig. 3.3.9-24 Proposed Trial for Station

<u>Basic evaluation of image analysis application of High-Definition image</u>

We conducted a basic evaluation of high definition image analysis application using 4K video as a preliminary study and evaluation in 2017.

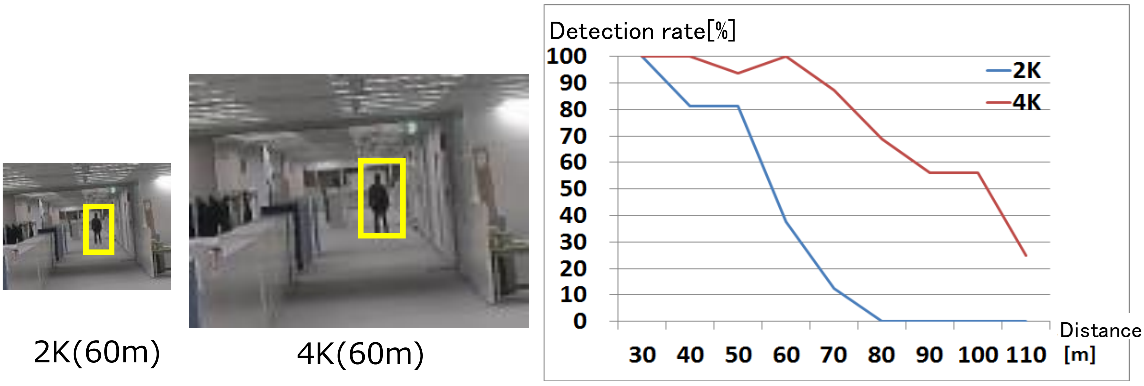


Fig. 3.3.9-25 Comparison of human detection ranges

In human detection using image analysis, it was confirmed that human detection range of 4K image was almost twice as much as of 2K image.

Trials in FY2018

<u>The transmission characteristics evaluation</u>

The radio performance in 28 GHz 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 Fig. 3.3.9-26 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.

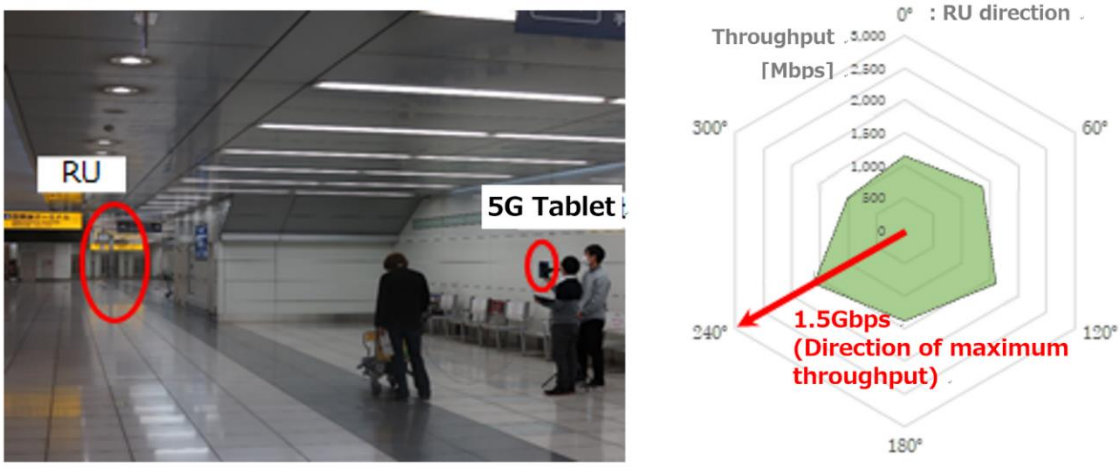


Fig. 3.3.9-26 Example of measurement point and result of throughput

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. 3.3.9-27 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. Figure 3.3.9-28 shows a robot used in the trial and the coding rate of the adaptive-rate-control video encoder employed in the trial.

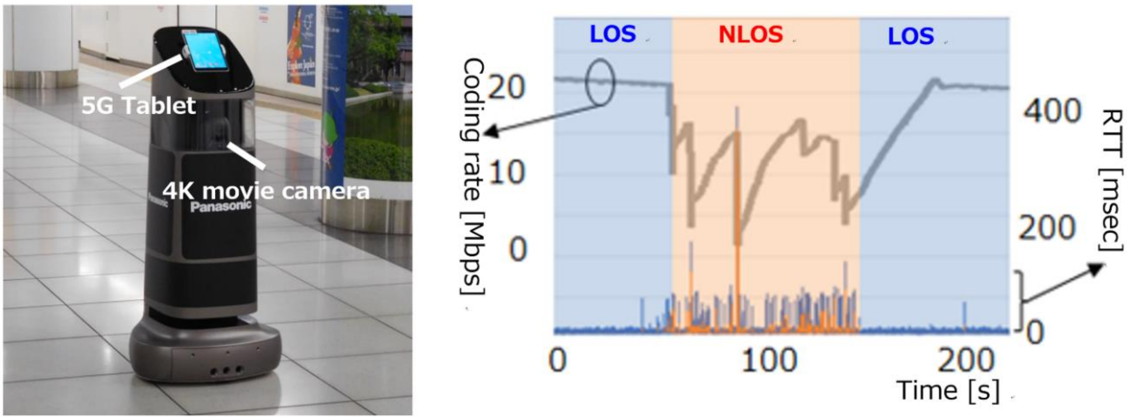


Fig. 3.3.9-28 Moving robot with 4K video camera and video coding rate control verification result

These two-year trials have been conducted by the team of ATR, KDDI Corporation, Panasonic Corporation, Keikyu Corporation, and Waseda University.

3.3.9.8 FY2018 Field Trials by SoftBank and Partners

(1) Demonstration Experiment on 5G Ultra Low Latency Communication for Assisting Autonomous Driving - Truck Platooning Applications –

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.

<u>Use Cases in Truck Platooning</u>

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 Figs. 3.3.9-29 and 3.3.9-30.

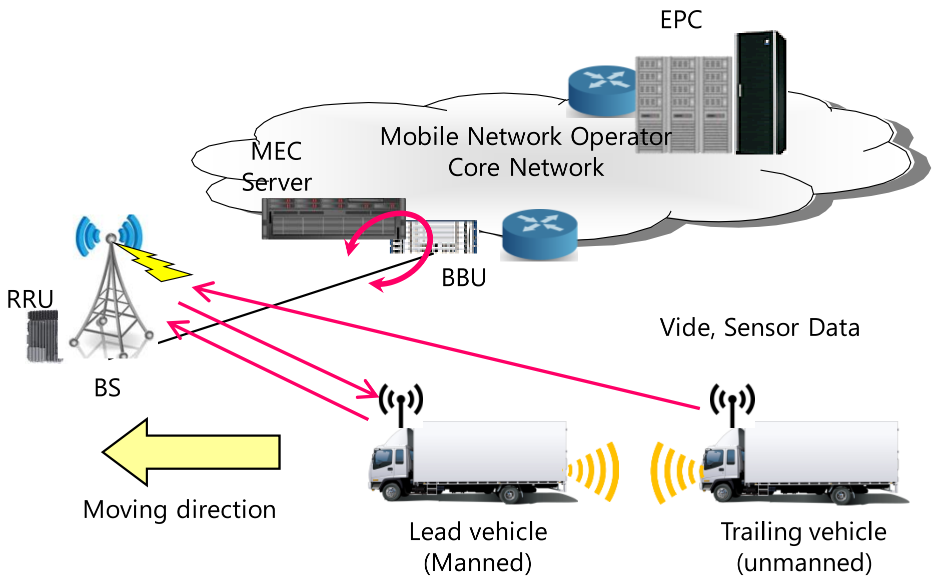


Fig. 3.3.9-29 Use Case 1: Communications between vehicles in Truck platooning

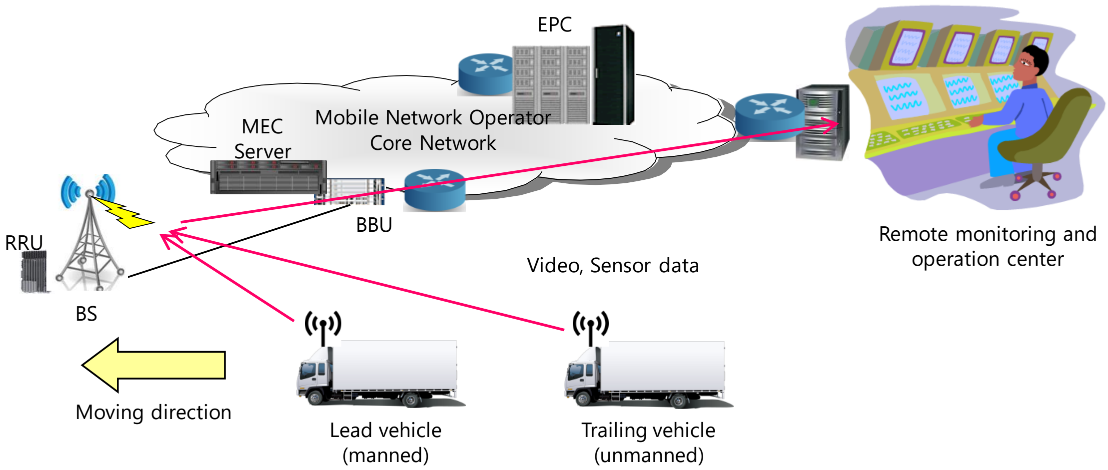


Fig. 3.3.9-30 Use Case 2: Remote monitoring / control for truck platooning

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.

Figure 3.3.9-31 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.

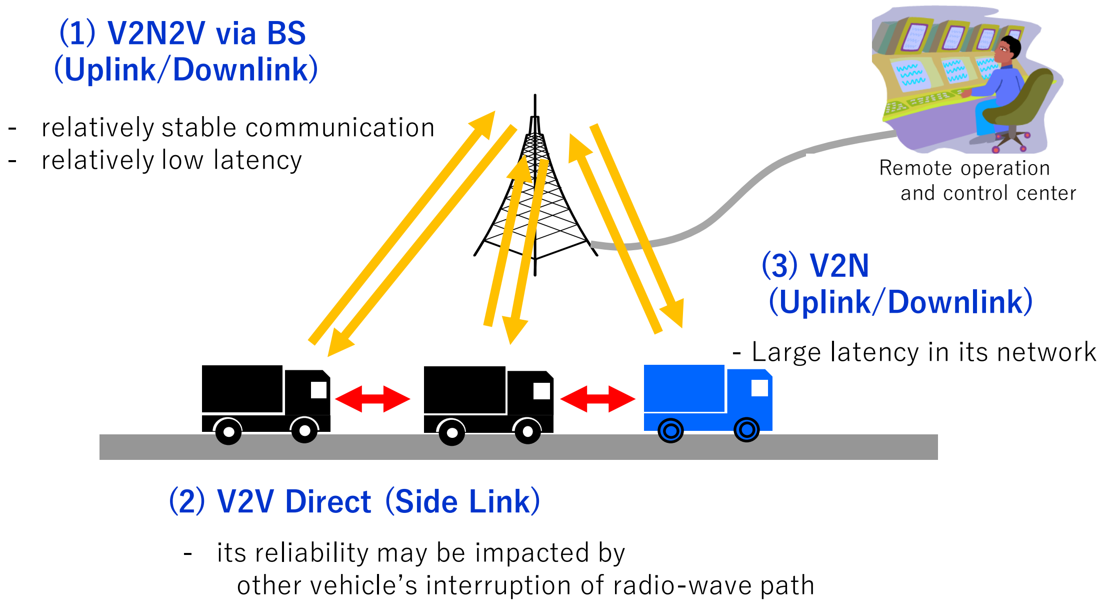


Fig. 3.3.9-31 Types of communication in platooning

<u>5G System Performance Evaluations in Truck Platooning Application</u>

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. (Figure 3.3.9-32)

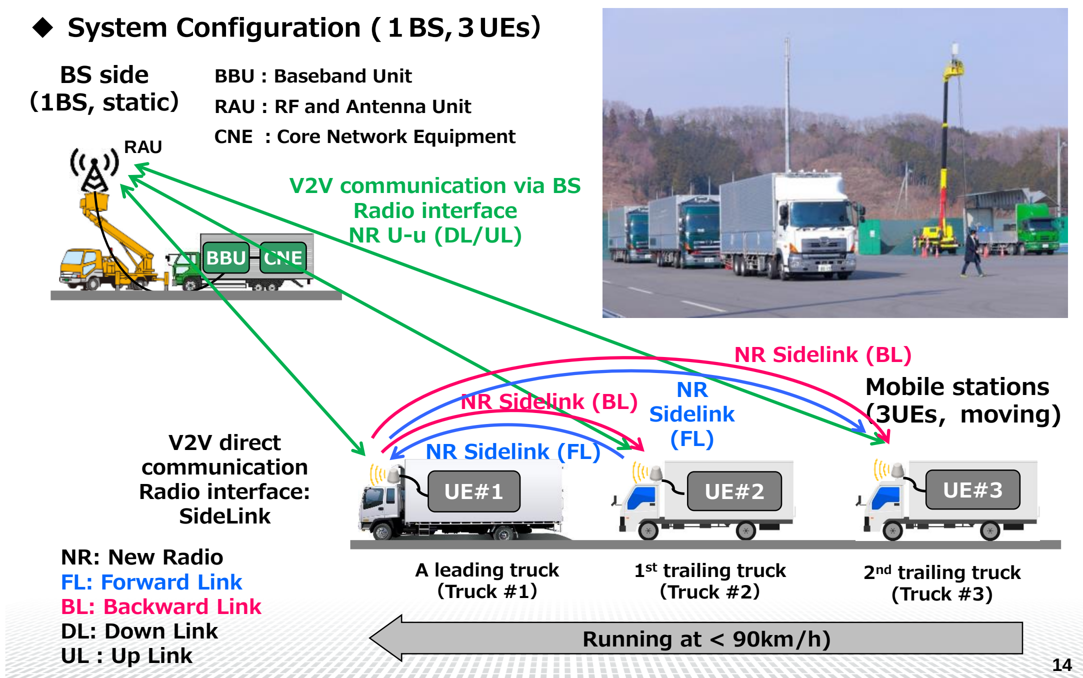


Fig. 3.3.9-32 Field trial test environment for V2N communications

Figures 3.3.9-33 and 3.3.9-34 show 5G-NR based BS prototype and 5G-NR based UE (User Equipment) prototype, including side link function.

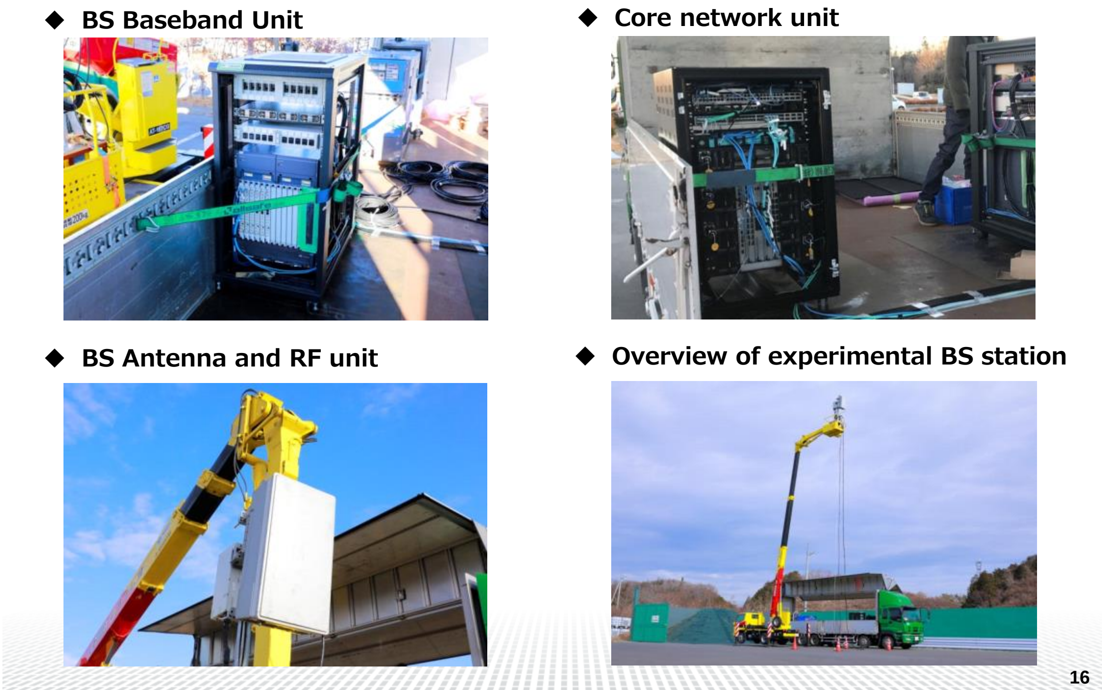


Fig. 3.3.9-33 5G-NR based BS prototype

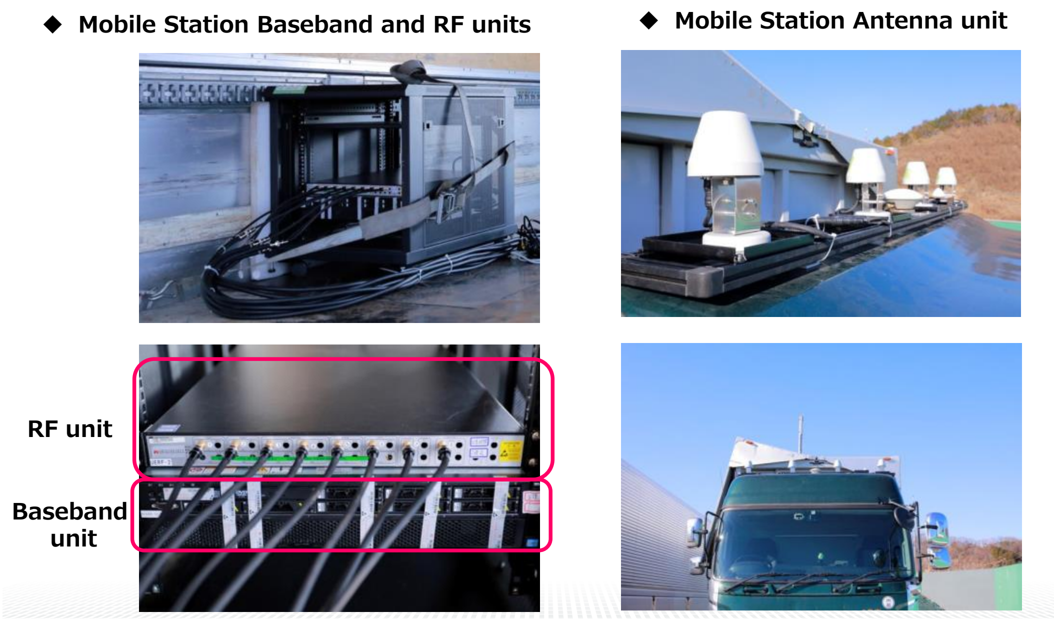


Fig. 3.3.9-34 5G-NR based UE prototype

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

Figure 3.3.9-35 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 1 ms (round-trip is less than 2 ms).

Fig. 3.3.9-35 transmission latency of Up- and Down-link

Transmission latency performance of 5G-NR sidelink

Figure 3.3.9-36 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 1 ms. It also shows that IP-layer latency is less than 2 ms (round-trip is less than 4 ms).

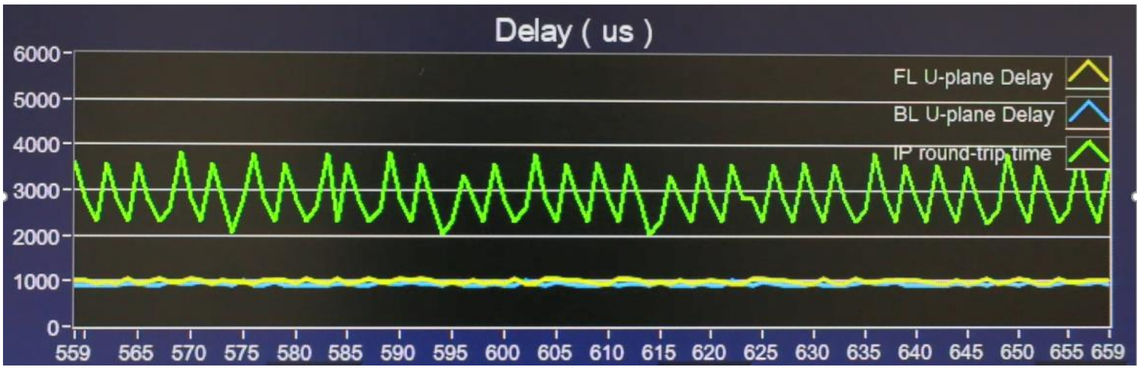


Fig. 3.3.9-36 transmission latency of sidelink

Vehicle control message transmission over 5G sidelink

System configuration

Figure 3.3.9-37 shows system configuration of vehicle-control message transmission trial. The vehicle-control messages, including acceleration, braking and position messages, are transmitted over 5G sildelink.

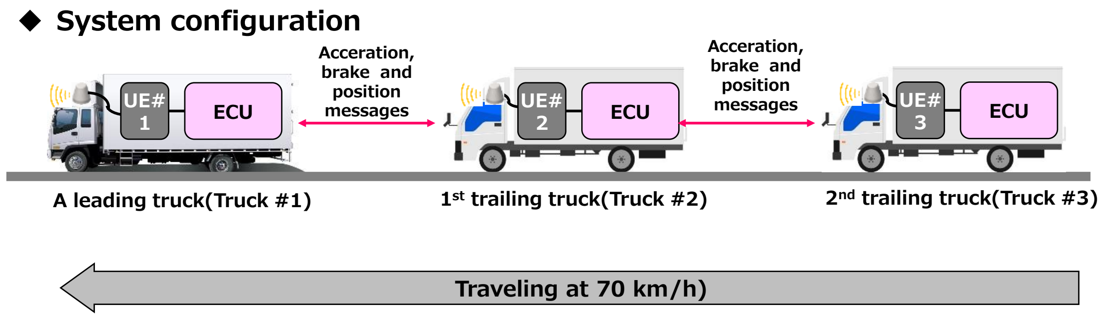


Fig. 3.3.9-37 System configuration of vehicle-control message transmission trial

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 3.3.9-38 depicted the trials on the highway.

Fig. 3.3.9-38 Vehicle-control message transmission trial over 5G on Shin-Tomei express highway

Fig. 3.3.9-39 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.

Figure 3.3.9-40 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.

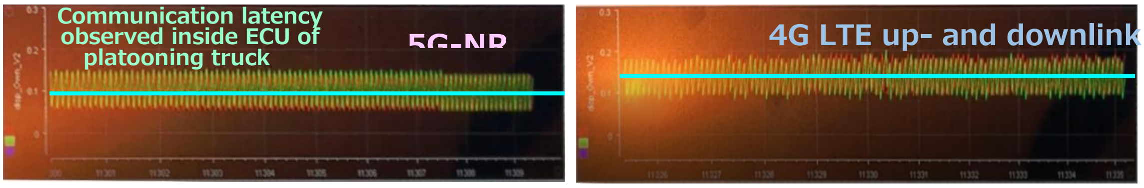


Fig. 3.3.9-40 Communication latency observed inside ECU (5G-NR left and 4G-LTE right)

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.

3.4 Summary

3.4.1 Summary of Field Trials by NTT DOCOMO and Partners

The 5G Field Trials that began in 2017 have been conducted in the locations noted on the map below to extract problems and evaluate in real time issues related to 5G video quality and throughput, focusing on video transmissions applications from the perspective of high speeds and high capacity.

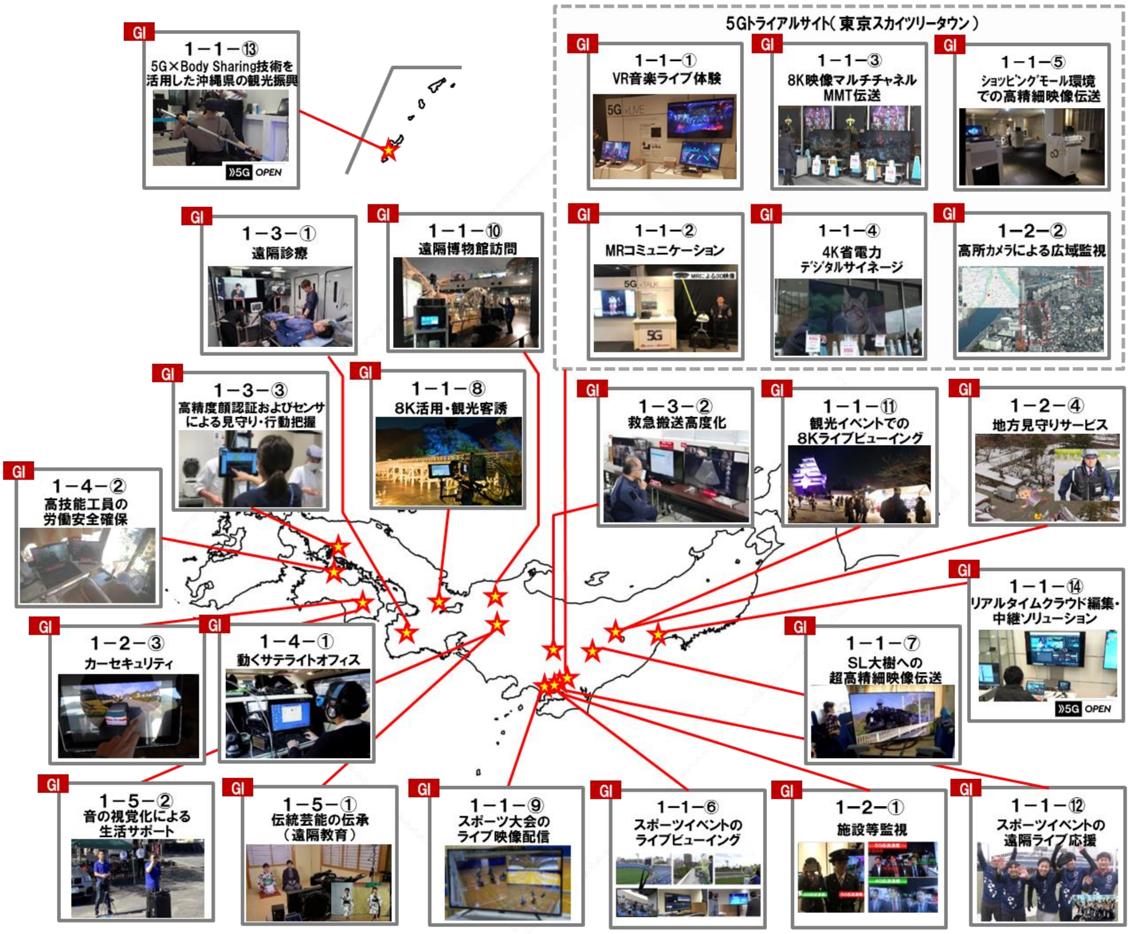


Fig. 3.4.1-1 Locations where field trials have been conducted

It has been shown that, in terms of high transmission speeds, it is possible to provide wireless downlink speeds of up to 10 Gbps through a base station utilizing the 28 GHz frequency band with signal bandwidth of 800 MHz with two connected user devices. It has also been shown that it is possible to offer downlink speeds of up to 2.4 Gbps with four user devices connected to a base station utilizing the 4.5 GHz frequency band with a signal bandwidth of 100 MHz

In regard to service area configuration, in addition to effective downlink throughput having been shown when using 5G test equipment as well as an increase in uplink demand in terms of throughput and transmission latency from TDD ratio allocation. Use of the 4.5 GHz band in a 5G pre-service environment in a non-standalone (NSA) configuration was also evaluated for use in 5G commercial environments.

These field trials were held with the cooperation of many different partners and the services providers who conducted trials that did not only utilize 5G's maximum, ultra-fast transmission speeds, but rather overall average throughput speeds and areas, as well as the wireless optimization and areas with the optimal parameters necessary to provide services and offer applications as well. However, it is still thought that more tests are needed for coordination and operations related to business deployments of 5G.

From the prospective of proposed services, the trials conducted in 2017 focused on ultra-high speed downlink transmissions. However, after the 5G Ideathon and listening to the opinions of partners of the trials, there was an increased focus on uplink as well as two-way communications, with the appropriate allocation of transmission capacity and the corresponding possibility of a diverse range of services and the ability to transmit high definition video. Trials were therefore conducted for services that could provide a higher level of quality than what is possible with 4G, such as image presence and improved ability to use video analysis for the purpose of identification.

Transmission capacity could be ensured 100% of the time allowing for the transmission of high definition video, but due to issues related to latency in regard to video coding and the increase in the quality of image recognition systems, application side issues that were not clear with 4G were made apparent.

In terms of high definition video, resolution and framerates for use in a variety of situatoinsand issues related to buffering need to be made more efficient, and further studies are needed on how to handle wireless quality changes from one moment to the next. It is currently thought that more efficient and optimized parameters are necessary.

In the development of 5G, at first limits were expected due to non-standalone (NSA) configurations and limited area developments. More studies are needed due to consideration of area developments of stand-alone configurations and changes in performance, including operational workarounds, for desirable services where consumers do not feel these limitations or changes in performance.

3.4.2 Summary of Field Trials by NTT Communications and Partners

The 5G Field Trials that began in 2017 have been conducted in the locations noted on the map below to extract problems and evaluate in real time issues related to 5G video quality and throughput, focusing on video transmissions applications from the perspective of high speeds and high capacity.

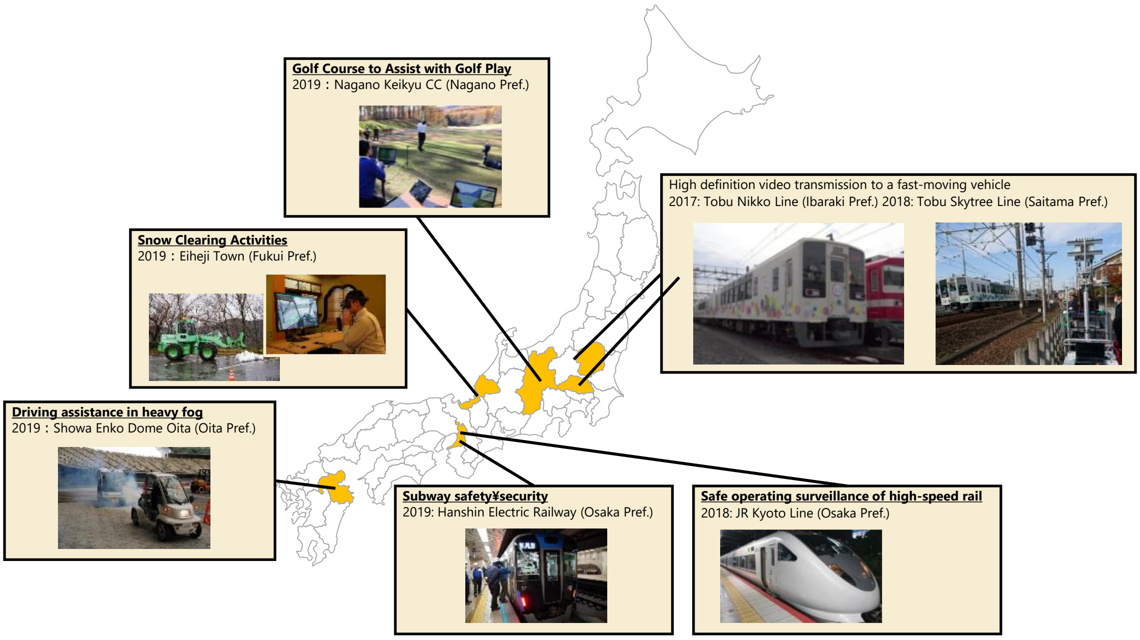


Fig. 3.4.2-1　Locations where field trials have been conducted

It has been shown that, in terms of high transmission speeds in regards to mobile communications, utilizing the 28 GHz frequency band with signal bandwidth of 800 MHz, it is possible to offer downlink maximum speeds of 2 Gbps in a mobile environment of 90 km/h and an average of 1 Gbps in a mobile environment of 60-120 km/h. Utilizing the 4.5 GHz frequency band with signal bandwidth of 1000 MHz, it is possible to offer average wireless downlink speeds of 240 Mbps in a mobile environment of mobile environment of 60-120 km/h

In order to maximize the area of stable transmission quality while moving at high speeds, handover studies were conducted using a maximum of 4 base stations utilizing the 28 GHz frequency band. Uplink and downlink throughput were evaluated, and issues came to light related to wireless parameters, adopted algorithms, and the optimized area configuration. As there are several issues related to realizing 5G's high transmission speeds when moving in excess of 120 km/h, more studies are necessary on high speed mobile environments.

The performance of 5G commercial apparatuses in non-stand alone (NSA) configurations in 5G preservice areas was also evaluated. However, tests have yet to occur on handovers between multiple base stations while moving at high speeds and it is thought that more studies are needed to realize high transmission speeds while moving at high speeds.

From the prospective of proposed services, in the trials conducted in 2017 the focus was on ultra-high speed downlink transmissions, however after the 5G Ideathon and listening to the opinions of the trial partners, there was an increased focus on uplink as well as two-way transmissions, with the appropriate allocation of transmission capacity and the corresponding possibility of a diverse range of services and the ability to transmit high definition video. It was demonstrated that 5G services could provide a higher level of quality than what is possible with 4G, such as the realization of the transmission of high definition video while moving.

However, the field trials for 5G transmission areas in mobile environments were limited, and as the initial connection took time, there are major limitations related to studies of services in this area. Because of this, it will be necessary to re-evaluate these studies as service areas increase as commercialization grows.

Additionally, momentary interruptions have been occurring with the current test equipment during handovers between multiple base stations, so services need to be configured and parameters need to be adjusted accordingly to handle this situation. Wireless quality while moving also fluctuates at high speeds and it is necessary for video transmission technology to track these changes, for example in regard to the variability and optimality of resolutions, framerate, buffer size, etc., as appropriate to transmit high definition video

5G communications are possibly limited due to the area and connectivity speeds in non-stand alone (NSA) environments, so it is thought that the equivalent performance during the field trials is not be sufficient and that more studies related to operational methods are necessary. Currently service providers need to not only understand the performance of 5G communications but also what are the optimal parameters for services and applications. Therefore, more fine tuning in regard to these issues are needed to go along with progress in commercial systems in order to promote business creation in the age of 5G.

3.4.3 Summary of Field Trials by KDDI and Partners

The 5G Field Trials by KDDI and partners were conducted at the locations shown in the map below in FY 2017-2019.

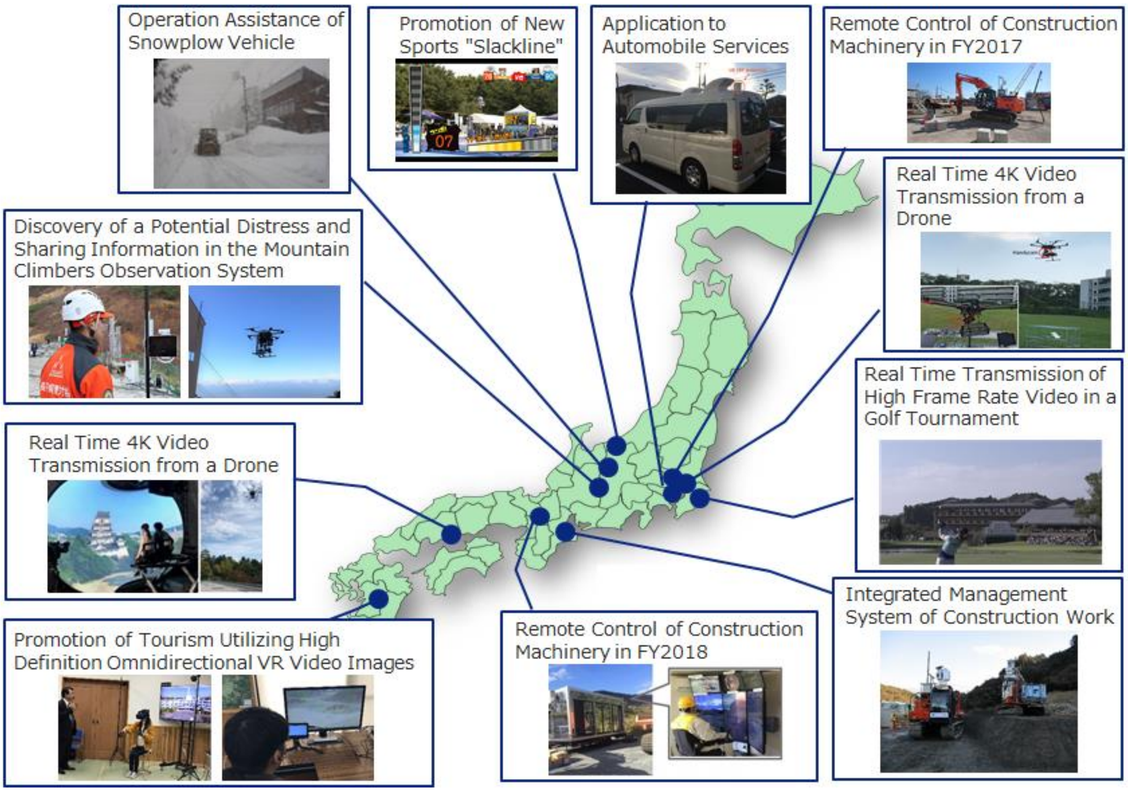


Fig. 3.4.3-1 Locations where field trials have been conducted

During three years, radio propagation characteristics and fundamental performance of 5G were verified, a variety of use cases were demonstrated, and the issues were identified associated with network implementation comprising multiple base stations/terminals.

The trials were carried out focused on the 5G characteristics of low latency and enhanced mobile broadband capabilities (eMBB) for upstream data transmission. In the first place, radio wave propagation characteristics were verified in the 4.5GHz band and 28GHz bands respectively. Then, various use cases taking advantages of low latency and upstream eMBB capabilities were demonstrated, including video transmission from drones, remote control of construction machinery and so on, along with evaluation of 5G wireless performance such as end-to-end latency and upstream data throughput.

In FY2017, radio wave propagation characteristics were evaluated in urban environment surrounded by buildings and outdoor environment with construction materials and structures. The measurement result was compared with the ITU-R scenarios (InH, UMi, UMa, RMa) and it turned out that in urban environment, the propagation loss, delay spread, and angle spread were in good match with ITU-R UMi scenario. Fundamental performance of the 5G system, including low latency characteristics and upstream data transmission capacity were evaluated and it was verified that the 5G has the upstream data transmission capacity required for 4K video transmission. A use case of remote control of construction machinery, in which three dimensional 4K video was transmitted via 5G for remote control purpose, was successfully demonstrated.

In FY2018, the use cases relevant to upstream of high definition video including 4K via 5G were demonstrated and it was verified that 5G satisfies the upstream requirement of applications in various environments, such as city roads, snowfall area, dam construction sites, in the sky, and golf courses. In the demonstration of remote control of construction machinery, multiple 2K video streams were transmitted in less than 100 msec, which satisfied the target of 200 msec, not to cause a feeling of discomfort of an operator and to improve operation efficiency.

The radio performance between 28GHz and 4.5GHz was compared in urban environment and it was confirmed that in 4.5GHz, the performance was less affected by roadside tree leaves than in 28GHz.

In the field trials in FY2019, the trial network was scaled up assuming more practical use scenes. The wireless performances relevant to scale up were confirmed, including handover between multiple base stations and simultaneous communication of multiple terminals.

As for use case demonstration, the simulation of road construction by three construction machines controlled remotely by 5G was conducted, and the time required for whole construction was 1.4 times as long as standard onboard working time, while it is 1.5 to 2 times in conventional remote control using Wi-Fi.

Other use case demonstration scenarios were developed based on the ideas proposed in the 5G utilization idea contest. The use of 5G in the mountain climber observing system to send 4K video from a drone in potential distress was also verified, and workers involved in actual rescue activity expressed expectations to the realization of this system. Use cases which were aimed to provide user with new exciting experiences were also demonstrated, such as promoting the tourism industry by high-definition 360-degree VR images from drones and promoting new sports “Slackline”, etc.

3.4.4 Summary of Field Trials by ATR and Partners

The 5G Field Trials that began in 2017 have been conducted in the locations noted on the map below to evaluate the high speed and high capacity of 5G.

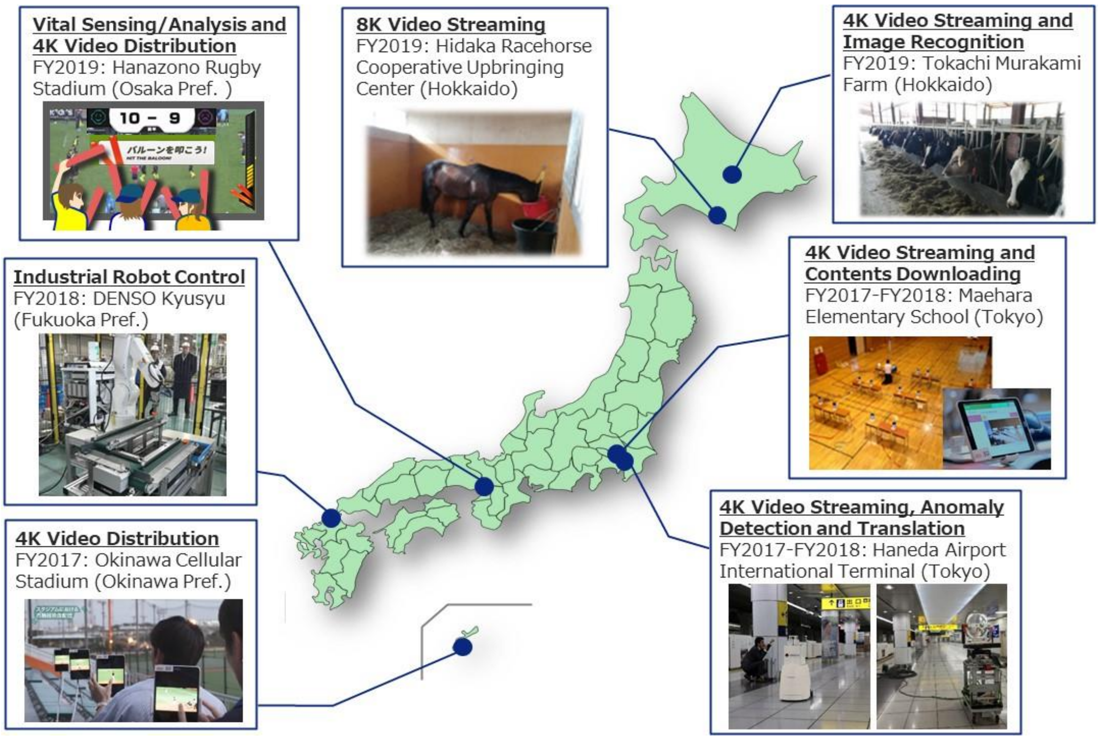


Fig. 3.4.4-1　Locations where field trials have been conducted

(1) FY2017 Field Trials

Fundamental measurements and evaluations of radio wave propagation was conducted in Okinawa Cellular Stadium and Haneda Airport International Terminal using 28 GHz frequency band for indoor environment. Based on the measurement results, the maximum downlink throughput was estimated over 5 Gbps by the simulations considering the characteristics of transmittance and reflectance of materials used for the buildings such as glasses and woods. In the field trials, actual downlink throughput reached 2.2 Gbps, and 4K video streaming was successfully distributed to the fifty terminals in the stadium at the same time. The channel models in the stadium and the station were fitted to the ITU-R UMi model and InH model, respectively. It was found that the radio communication channels become unstable due to the shielding by columns, walls, and human bodies.

(2) FY2018 Field Trials

Field trials was conducted to provide solutions for the three focus areas, education, tourism, and labor force, using the 5G ultra-high-speed downlink communication capabilities. In Maehara Elementary School, students enjoyed 4K video streaming and rich contents download in the 5G trial area built in the gymnasium. The average downlink throughput was over 2 Gbps, and the replay quality and download time were much better than 4G/LTE and Wi-Fi. In Haneda Airport International Terminal, remote monitoring by robots and translation of tourist information were demonstrated. It was found that shaded areas like behind pillars can be covered by the reflections from walls. In order to extend the coverage to the non-line-of-sight area, a repeater was developed and its effectiveness was verified in the station. In a factory of DENSO Kyusyu, 5G is used for industrial robot control system, consisting of an industrial robot, a three-dimensional measurement sensor, and a robot controller. It was confirmed that the lead-time required to relocate industrial robots could be greatly reduced by replacing wired communication lines with 5G systems.

(3) FY2019 Field Trials

Field trials are designed to realize three excellent concepts proposed in the 5G utilization idea contest by the use of 5G ultra-high-speed uplink capabilities. In Hanazono Rugby Stadium, the data of players' vital sensor was transmitted to the server via 5G, and superimposed on the 4K live video on the main screen and 5G terminals in the stadium. A sense of unity is enhanced between players and spectators and/or among spectators by sharing the information about players' activities and spectators' cheering levels. In Tokachi Murakami Farm, the solutions of remote monitoring and automatic positioning using 4K video streams via 5G are demonstrated. The channel model in the cowshed was found to be the ITU-R InF model. In Hidaka Racehorse Cooperative Upbringing Center, four multi-angle 4K video streams are merged into one 8K video stream and transmitted to the remote office via 5G. The world's first trial of real-time 8K video transmission from a flying drone succeeded by using over 120 Mbps uplink throughput per video stream via 5G.

3.4.5 Summary of Field Trials by SoftBank/WCP and Partners

5G provides capabilities in the new domains of Ultra Reliable and Low Latency Communication (URLLC) and massive Machine Type Communication (m-MTC), and is highly anticipated as social infrastructure for our advanced information society. URLLC and m-MTC in particular have potential for developing new markets, and establishing concrete 5G applications for these is an urgent matter.

SoftBank and Wireless City Plaonning (WCP) of SoftBank Group undertook 5G system trials of MIC of Japan as Group V (GV) of the MIC of Japan, focusing on 5G URLLC in FYs of 2017, 2018 and 2019. These trials aimed at evaluating of 5G URLLC capability, ultra-reliable and low transmission delay time, taking into account possible use cases relating to mobility and traffic arena, together with vertical sectors, including Advanced Smart Mobility Co.Ltd, FEV Japan, the City of Kita-Kyushu and Nippon Signal Co., Ltd. The trials used both sub-6GHz and 28GHz bands, which are to commercially deployed in 2020.

Figure 3.4.5-1 shows the use cases and technical items considered during the 3-years field trials. In Fiscal Year 2018 and 2019, having considered 8 social issues pertaining to ICT infrastructure, which were identified by MIC of Japan, we decided to take the use case of truck platooning. The use case is a good application area of 5G URLLC, which provides high reliability and low transmission latency. In FY 2018, we focused on developing a 5G URLLC prototype and examined its transmission performance both in laboratory test bed and field. In application of 5G to truck platooning, we considered both 5G via Base Station, which is a typical cellular links, and Vehicular-to-Vehicular direct communication. Their basic performance was checked and confirmed in Fiscal Years 2018 and 2019. We was able to confirm that our prototype satisfied 5G requirements. In FY 2020, we further took other use cases, which were also mission critical cases; remote control of vehicules and smart intersection, under the circumstance of disaster relief, together with local government in Kyushu. In all use cases that we considered, we confirmed that 5G URLLC was able to provide its capability that satisfied mission critical applications.

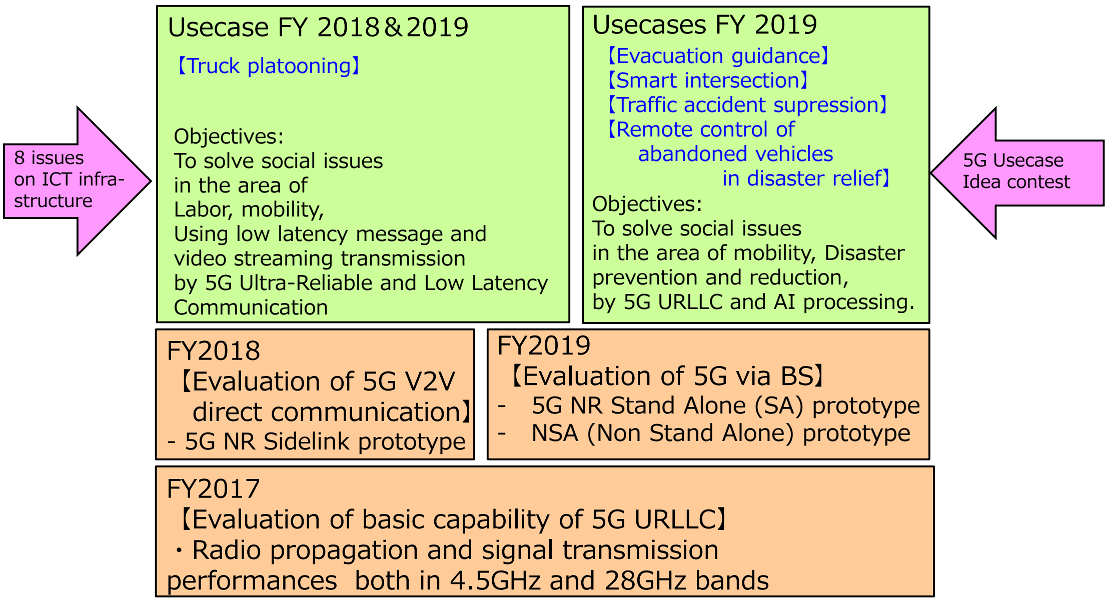


Fig. 3.4.5-1 Summary of 5G trials in 3 years

Table 3.4.5-1 summaries field trial items and their corresponding outcomes.

Table 3.4.5-1 Table of field trial item and their outcomes

FY	Field trial items	Findings
2017	【Evaluation of 5G performance】 a. Radio Propagation on a highways b. Performance evaluation of 5G Base station and User Equipment c. Over-the-air transmission delay evaluation d. Adaptive beam forming and control test applied to V2V direct communications e. Video stream transmission test in automotive test course	a. Identified that two-path ground reflection model can mainly be applied with regard to the propagation model of V2V direct communication on highways b. Clarified 5G radio transmission performance, e.g. throughput c. Confirmed less than 1ms transmission delay over the air with our prototype d. Comment was received from trial partner that on-board adaptive beam forming solution might not be appropriate due to its equipment cost efficiency and its power consumption when deployment. e. V2V direct video streaming transmission was demonstrated in JARI test course in Ibaraki prefecture
2018	【Evaluation of 5G V2V direct communication】 a. End-to-End transmission delay performance evaluation (target: less than 10ms) b. 5G New Radio (NR) sidelink prototype performance evaluation c. Study on antenna configuration for 5G V2V direct communicartion	a. Confirmed End-to-End transmission delay of less than 10ms, b. Succeed the development of 5G New Radio sidelink prototype, and achieved over-the-air delay of less than 1ms, and End-to-End delay of less than 10ms, c. Succeed in development of Null-fill antenna prototype and evaluate it, so that the developed antenna meets to the requirement commended by our partner, item d) of FY2017 Findings
2019	【Evaluation of 5G V2V direct communication】 a. Reliability evaluation b. Radio propagation and transmission performance in tunnels on a highway c. Field trials on V2V communication for vehicle control messages 【Evaluation of 5G communication via BS station】 d. Establish field trial system using multiple BSs e. Evaluation 5G system for the use case of remote operation of driving f. Evaluation of 5G sytem for the usecase of wide-area coverage: the usecase of disaster evacuation guidance in Kita-Kyushu city	a. Confirm the performance of over-the-air delay of 1ms when allowing 2 HARQ retransmissions, and Packet reception rate of more than 99.9% b. Found the radio propagation which boosted signal strength up in a highway tunnel in 4.5GHz band signal transmission tests c. Successful demonstration of Coordinated Adaptive Cruise Control (CAACC) using 5G URLLC message transmission for vehiclular control on Shin-Tomei Express way d. Successfully established multi-BS trial site both for V2N2V/V2N(Vehicular-to-Network-toVehicular/Vehicular-to-Network) communication, as well as the communication via BS(Badr Station) e. Confirmed the feasibility of 5G URLLC by truck platooning demonstration on a highway f. Confirmed the feasibility of possible 5G URLLC wide-area network by the demonstrations of remote control of abandoned vehicles in case of disaster, as well as rapid and safe evacuation from disaster point.

Future issues

- Coverage issue: initial 5G system uses higher frequency ranges, e.g. 3.9 GHz and/or 29 GHz. The main radio link assumes Line-of-Sight communication. It is, therefore, very difficult to support enough coverage.
- Cellular systems employ retransmission scheme, such as Hybrid ARQ. It is very useful to achieve high reliability. There is, however, a trade-off between the number of retransmissions and low-latency.
- It would be much useful to use sidelink, i.e. Vehicular-to-Vehicular direct communication for the use cases, which are applications for traffic infractructure, such as truck platooning.

3.4.6 Summary of Field Trials by NICT/WCP and Partners

Figure 3.4.6-1 outlines the field trial's three years, while below is a summary of trials, with a short overview of the results of each of the three years.

(1) Year 1 Overview

In a step towards realizing massive multiple simultaneous connections in 5G, grant free access prototypes (for both base stations and devices), studies of which were conducted to see if it could be introduced into 5G, were developed and an emulated 20,000 device simultaneous connection trial was implemented. This trial was able to confirm that all the emulated devices could complete data transmission within designated parameters, such as a specified period of time. However, latency and insufficient capacity issues were also recognized to occur due to data congestion (interference) issues related to the grant free access.

(2) Year 2 Overview

In order to solve the issues related to insufficient capacity that occurred in the previous year, grant free access was combined with power capacity related non-orthogonal multiple access (NOMA), the results of which indicated that it was possible for 5G to realize massive multiple simultaneous connections in a highly dense concentration of one million devices within one square kilometer. In addition, in order to deploy 5G to support IoT in rural areas, ad-hoc 5G (*odekake 5G*) configurations were also shown to be effective. 5G performance tests during the field trials also confirmed the ability to deploy within a narrow area consisting of a radius of only 100 meters, either indoors or outdoors, an IoT data communication service utilizing the 4.5 GHz band that can provide massive multiple simultaneous connections, ultra-fast transmission speeds, access edge computing, etc. Trials also showed that it was possible for a heterogenous configuration that combined 4G and wireless LAN with 5G to be maintained as an efficient network.

Among the use cases to be demonstrated within the 8 issues of ICT infrastructure, two fields, "work force" and "disaster prevention and relief", were given attention in such projects as "smart offices" and "smart highways", as 5G will be able to provide very effective solutions to problems in these fields that were difficult to solve with current technologies.

(3) Year 3 Overview

Looking ahead towards the beginning of commercial 5G services in 2020, calculations were made on the number of devices necessary for different use cases. It was determined from the results of the possible level of traffic from these use cases that environments with grant free access as well as NOMA, which was studied in the first and second years of the trial, would not be needed. Therefore, looking from the perspective of the early period of 5G's introduction into the marketplace, trials in the third year were based on the necessary number of multiple devices that could be connected simultaneously, as required by the use case being demonstrated.

Assuming that multiple devices would particularly increase transmission frequency, studies on initial connection loads found no problems with current specifications. Evaluations from the perspective of CPU loads as related to base stations were also held, which confirmed no problems, as well.

Use case trials were held with the aim of solving regional issues, relating to solutions such as "labor saving" and "work from anywhere". Two trials were held which related to these concepts: i-Construction, a use case which came out of the 5G utilization idea contest and smart logistics. These two use cases were studied under the assumption that the amount of traffic would exceed ITU specifications, however they both were realized with no problems having come to light. However, 5G's ultra-fast speeds and massive multiple connections will be necessary to realize these two use cases, which was shown to be achievable with a single base station.

	Area of Assessment	Use Cases Tests	Technology Evaluated
Year 1	Technical verification for 5G use fields	Disaster Relief Warehouse; Smart Office	・Simulation to study on the effects of multiple connections on congestion during data transmission ・Concerns appeared on occurrence of high transmission latency and insufficient transmission capacity (interference?)
Year 2	8 Issues of ICT Infrastructure	Smart Office; Disasters on the expressway	・Studies were held on the effects of NOMA and PreScheduling to solve issues on the lack of transmission capacity which occurred in trials the previous year. ・Realization of heterogeneous infrastructure for use cases that need multiple connections and large capacity
Year 3	Solving regional issues	"Labor Saving" and "Work from Anywhere" Idea Contest proposals i-Construction Tunnel Workplace Safety Smart Logistics Improved delivery efficiency	・Evaluating use case effectiveness ・Trials of transmission capacity and initial connection load in related use cases ・Realization of a single base station that can handle multiple simultaneous connections and high capacity transmissions

Fig. 3.4.6-1 Activities during the Three Years of the G6 Field Trials

Chapter 4 Conclusion

The latest progress of the 5G field trials being conducted by each trial group has been reported so far at many domestic and international conferences and other events as shown in the Table 4-1. The 5G-TPG has been supporting each trial group with their presentations and exhibits as well as coordinating and summarizing each group's results. The goal of these activities is to inform people from a wide range of industries and businesses, not limited to telecommunications, of the details of the trials and to provide an opportunity to feedback their comments and opinions to the trial members. At the Global 5G Events, held twice yearly by 5G promotion organizations in various countries and regions, the 5G-TPG introduced the latest trial results from each trial group, spreading the development and testing of 5G use cases in Japan across various regions, and promoting the use of 5G to find solutions to various societal issues faced, not only by Japan, but by countries around the world.

Table 4-1 Domestic and International Presentations and Exhibits

Date	Title	Sponsor	Type	Format
Oct. 2016	5th Generation Mobile Communication Systems (5G) Workshop 2016 @CEATEC2016 "5G System Trials for Realizing 5G Systems"	MIC, 5GMF	Domestic event	Presentation (5G-TPG Sub-leader)
Oct. 2016	5G Technology Workshop "5G Key Concept and System Trial in Japan"	TAICS	International event	Presentation (5G-TPG Sub-leader)
May 2017	The 3rd Global 5G Event in Tokyo, Japan Session 3: "Overview of 5G System Trial Concept & Plan in Japan"	5GMF	International event	Presentation (5G-TPG Leader)
Oct. 2017	5th Generation Mobile Communication Systems(5G) Workshop 2017 @ CEATEC2017 "Activity Status of 5G Trial Promotion Group in 5GMF"/"Overview of 5G System Trials Project Execution"	MIC, 5GMF	Domestic event	Presentation (5G-TPG Leader/Test Groups)
Nov. 2017	The 4th Global 5G Event in Seoul, Korea "Recent Activities on 5G System Trials in 5GMF"	5G Forum	International event	Presentation (5G-TPG Leader)
Nov. 2017	MWE2017 Microwave Workshop/Microwave Exhibition "5th Generation Mobile Communication Systems System Trials for Realizing 5G"	IEICE APMC Japan Committee	Domestic conference	Presentation/Exhibit (Test groups)
Mar. 2018	5G International Symposium 2018 Part 1: What can we do with 5G? — Results from the 5G System Trials —	MIC, 5GMF, ARIB	Domestic event	Presentation/Exhibit (Test Groups)
Mar. 2018	2018 General Conference BP-1 "System Trials for Realizing 5G and Future Expectations"	IEICE	Domestic conference	Presentation (Test Groups)
May 2018	The 5th Global 5G Event in Austin, USA "5G System Trials in Japan -Activities of 5G Trial Promotion Group (5G-TPG) in 5GMF-"	5G Americas	International event	Presentation (5G-TPG Leader)
Nov. 2018	APMC2018 Workshop "5G System Trials in Japan"	IEICE	International meeting	Presentation (5G-TPG Leader)
Nov. 2018	The 6th Global 5G Event in Rio de Janeiro, Brazil Panel 7: "5G System Trials in Japan"	5G Brazil	International event	Presentation (5G-TPG Leader)

Nov. 2018	MWE2018 Microwave Workshop/Microwave Exhibition “5th Generation Mobile Communication Systems System Trials for Realizing 5G II”	IEICE APMC Japan Committee	Domestic conference	Presentation/Exhibit (Test Groups)
Jan. 2019	5G International Symposium 2019 Part 2: 5G System Trial Results Presentation	MIC, 5GMF, ARIB	Domestic event	Presentation/Exhibit (Test Groups)
Mar. 2019	2019 General Conference BI-4 “[5G Day] Part II, 5G System Trial Results and Development for the Future”	IEICE	Domestic conference	Presentation (Test Groups)
June 2019	The 7th Global 5G Event in Valencia, Spain Session 2: “5G System Trials in Japan”	5G-IA	International event	Presentation (5G-TPG Leader)
Aug. 2019	2019 Next-Generation Mobile Communication Technology and Application Workshop “R&D Activities and Field Trials toward 5G Actualization in Japan”	FuTURE Forum	International meeting	Presentation (5G-TPG Leader)
Sept. 2019	IEEE VTC2019-Fall WS-TPoC5GE2019 “Outcomes of Korea - Japan Joint 5G Collaboration -5G Field Trials in Japan-”	IEEE VTS	International meeting	Presentation (5G-TPG Leader)
Oct. 2019	5G International Seminar 2019 @CEATEC2019 “5G System Trials in Japan”	MIC, 5GMF, ARIB	Domestic event	Presentation (5G-TPG Leader)
Nov. 2019	MWE2019 Microwave Workshop/Microwave Exhibition “5th Generation Mobile Communication Systems System Trials for Realizing 5G III”	IEICE APMC Japan Committee	Domestic conference	Presentation/Exhibit (Test Groups)
Dec. 2019	Shimane Prefecture 5G Utilization Workshop “5G Overview and Use Cases – Overview of 5G System Trials–”	Shimane Prefecture	Domestic event	Presentation (5GMF Office)
Jan.-Feb. 2020	IoT/ICT Implementation Seminar	MIC Bureau of Telecommunications at 11 locations throughout Japan	Domestic event	Presentation (5GMF Office)
Feb. 2020	5G International Symposium 2020 Part 1: 5G System Trial Results	MIC, 5GMF, ARIB	Domestic event	Presentation/Exhibit (Test Groups)
Mar. 2020	2020 General Conference TK-5 “5G System Trial Results and Future Expectations”	IEICE	Domestic conference	Presentation (Test Groups)
Jun. 2020	CSA Japan Summit 2020 “Trends in Testing New 5G Services in Japan —MIC 5G System Trial Results for Starting 5G Commercial Services—”	CSA Japan	Domestic event	Presentation (5G-TPG Leader)
July 2020	Yamaguchi Prefecture 5G Research Conference and Lectures “5G/Local 5G Utilization— 5G System Trial Results (3 years) —”	Yamaguchi Prefecture	Domestic event	Lecture (5GMF Office)
Oct. 2020	CEATEC 2020 ONLINE “5G Special Day II/ 5G Workshop” Session 1 “5G System Trials Review”	ARIB, 5GMF, CIAJ	Domestic event	Presentation (5G-TPG Leader)
Dec. 2020	Technical Committee on Radio Communication Systems (RCS) “[Invited Talk] General Report of 5G Field Trials -- History of Activities Related to Trials in Various Use Cases from FY2017 to FY2019 -- ”	IEICE	Domestic conference	Presentation (5G-TPG Leader)
Mar. 2021	Tokyo 5G Boosters Project DEMODAY 2021 “Introduction of 5G Technology Overview and Application Examples in Various Fields”	Tokyo Metropolitan Government	Domestic event	Presentation (5G-TPG Leader)

General Report on 5G System Trials in Japan from 2017 to 2020

March, 2021