NICT NEWS

National Institute of Information and Communications Technology

No.5
2019
Vol.477

FEATURE

Wireless Communication Technologies for the New Services Toward 5G and Beyond

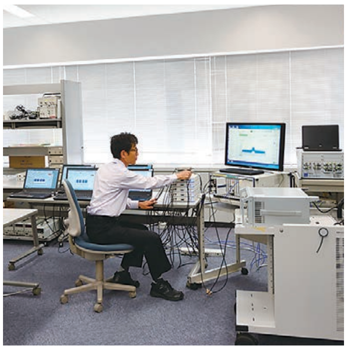
Interview

Evolving Forms of Wireless Communication Connect People and Devices

CONTENTS

National Institute of
Information and Communications Technology

NICT NEWS 2019 No.5 Vol.477



Cover photo:
A base station antenna being installed on the roof of the Yokosuka Research Park (YRP) No. 1 Building for field experiments. The Wireless Systems Laboratory has been researching and developing the STABLE wireless access technology, which is capable of simultaneously connecting numerous devices wirelessly and significantly reducing communication delays in anticipation of the widespread use of remotely controlled robots and drones.

Upper-left photo:
A laboratory in the YRP No. 1 Building. NICT researchers are developing a new wireless access technology using state-of-the-art measurement and analysis instruments.

FEATURE

Wireless Communication Technologies for the New Services Toward 5G and Beyond

Interview

TOPICS

Interview

Evolving Forms of Wireless Communication Connect People and Devices

Wireless Networks Research Center

Kiyoshi HAMAGUCHI (left)

Director General
Wireless Networks Research Center

After completing his graduate studies, HAMAGUCHI worked for a private company before joining the Ministry of Posts and Telecommunications' Communications Research Laboratory (since renamed NICT) in 1993. He assumed his current position in 2017. He has carried out R&D related to communications and radar and participated in ITU-R standardization. Ph.D. (Engineering).

Fumihide KOJIMA (right)

Director of the Wireless Systems Laboratory
Wireless Networks Research Center

KOJIMA joined the Ministry of Posts and Telecommunications' Communications Research Laboratory (since renamed NICT) in 1999 where he helped standardize and carry out R&D related to intelligent transport system (ITS), ad-hoc networks for disaster management and smart utility networks (SUNs), among other subjects. He assumed his current position in 2016. He has been working on R&D related to next-generation wireless communications (e.g., 5G/B5G) and the social implementation of these technologies. Ph.D. (Engineering).

Wireless communications have a long development history. Advances in digital and networking technologies are expected to push the evolution of wireless network systems forward.

Changes in wireless communications technology have been accelerating in recent years, driven by the popularization of portable communications devices, such as mobile phones, and the advent of fifth-generation cellular network technology (5G) and the internet of things (IoT). How are these changes shaping the visions, R&D policies and future direction of the Wireless Networks Research Center? We asked Kiyoshi HAMAGUCHI (Director General of the Wireless Networks Research Center) and Fumihide KOJIMA (Director of the Wireless Systems Laboratory); both of them are based at the Yokosuka Research Park (YRP).

■ Current status of wireless systems

——First of all, could you describe the Wireless Networks Research Center?

HAMAGUCHI: The mission of the Wireless Networks Research Center is to conduct research on advanced wireless communications technologies to increase the security and quality of public communications services. The Center consists of the Wireless Systems Laboratory—whose primary research focus is terrestrial wireless communications technologies—and the Space Communications Laboratory, which researches space-based communications technologies.

The Wireless Systems Laboratory is based at the YRP while the Space Communication Systems Laboratory operates at both NICT headquarters in Koganei, Tokyo and at the Kashima Space Technology Center in Kashima, Ibaraki Prefecture.

——NICT has been researching wireless communications technology for many years. Why are wireless systems attracting so much attention today?

HAMAGUCHI: It is difficult to find communications systems in our communities that operate by means other than radio waves. The penetration rate of radio wave communications systems is over 130% based on the number of mobile phone users, indicating widespread public use of diverse wireless communications technologies, such as Wi-Fi, RFID*1 and keyless entry systems. Demand for radio waves is expected to further increase as anticipated new technologies are deployed, such as 5G, IoT, and connected cars. The popularity of wireless systems is expected to undergo explosive growth.

When the Great Hanshin-Awaji Earthquake occurred in 1995, the mobile phone and PHS device penetration rate was less than 10%. This had increased significantly to more than 95% by the time of the Great East Japan Earthquake in 2011. These severe disasters reminded the public that mobile phones are a vital lifeline. It was also a big wake-up call for researchers: wireless communications technologies are indispensable not only for enjoying a higher quality of life but also in ensuring public safety.

A new issue has emerged, however, as the number of wireless communications users has increased: a looming radio frequency shortage. This issue necessitated the development of new technologies enabling larger-capacity, higher-speed communications using limited radio frequency resources. One approach is to use radio waves with very high frequencies, which allow transmission rates to increase in the millimeter wave band (30–300 GHz) and terahertz band (0.3–3 THz). The increasing number of wireless devices has also led to radio interference concerns. New technologies are needed to reduce or eliminate interference even when data traffic is high to ensure sound communications. The development of these technologies is expected to be further expedited by the introduction

Interview

Evolving Forms of Wireless Communication Connect People and Devices

of 5G and IoT.

Responses to 5G

——What is your approach to the development of 5G products?

KOJIMA: Generally speaking, communication systems are first subjected to international standardization. Stable products are then produced based on the established standards. Standardization organizations include IEEE 802*2 and 3GPP*3. We intend to actively participate in the activities of these organizations and apply their standards to NICT-developed products.

5G technology has outstanding potential, including ultrahigh speed transmission, significantly reduced communication delay and the ability to connect numerous devices simultaneously. However, these capabilities are not all simultaneously available. Different IT businesses are likely to gradually integrate specific 5G capabilities into their services. For example, according to one estimate, simultaneous device connections will reach the level of one million connected terminal devices per km^2. When 5G technology is introduced, this capability is predicted to be less important for many services than other capabilities. However, we have assumed that all 5G capabilities will be widely and effectively utilized and smoothly integrated into various services and have been actively engaged in 5G-related research to develop technologies that will enable the simultaneous connection of a huge number of devices. Last year, we conducted experiments in which we succeeded in simultaneously connecting 20,000 terminal devices to a single base station and released the results to the mass media. In addition, our lab developed a so-called STABLE technology to enable the simultaneous connection of numerous devices while minimizing communication delay. We confirmed that this technology was able to increase frequency utilization efficiency by 250%.

——Has progress been made in reducing high-frequency waves—such as millimeter waves—to practical use?

KOJIMA: 5G technology allows use of the 28 GHz band—close to the millimeter wave band—and even higher frequency bands in some countries. Because high-frequency radio waves have a strong tendency to travel in straight lines, like light, they attenuate greatly when obstacles interrupt their paths. To effectively leverage 5G capabilities, technologies that can stably handle high-frequency radio waves are needed. In addition, high-frequency radio waves can travel only limited distances. NICT has been studying a beamforming technology which allows a transmitter to direct a radio-wave beam to a moving terminal device and massive-element antenna systems (massive MIMO*4) to address this issue and enable this technology to function properly.

Coordination with mobile carriers

——How will NICT and the mobile carriers share roles?

KOJIMA: Because high-frequency radio waves, such as those in the millimeter wave band, may travel no more than several hundred meters, the effective service range of a base station will be very limited. This would necessitate the installation of a huge number of base stations for nationwide communication services. As this is financially impractical, a more practical approach would be to concentrate base stations in high-demand areas.

To put this strategy into practice, base stations with large and small service ranges will need to be coordinated. Technologies for achieving this coordination are therefore another key focus of our research. When 5G technology becomes available, its exploitation may not be limited to the major existing mobile network operators; new operators may also leverage it to start small cell network services. These new entrants may increase their user bases by attracting conventional LTE (4G) users. If this scenario comes to pass, short-range services will be available even if major operators do not take the initiative in installing short-range base stations across large areas.

We anticipate that 4G and 5G technologies will coexist for some time during the technological transition. We have therefore been investigating technologies capable of enhancing coordination between 4G and 5G base stations.

Extreme communication environments

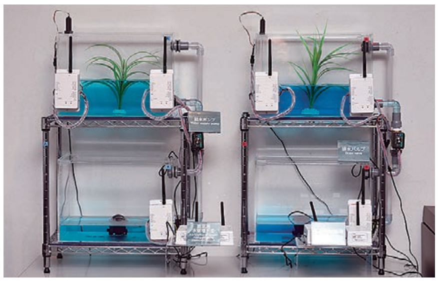
——What types of projects have been carried out at the Wireless Networks Research Center?

KOJIMA: We have three major R&D categories: "wireless network management technologies," which is an effort to develop advanced base station infrastructure, "wireless network customization technologies," whose objective is to enhance coordination between wireless terminal devices, and "wireless network technologies with enhanced reliability," which has the goal of expanding the range of applications for wireless systems and increasing their reliability.

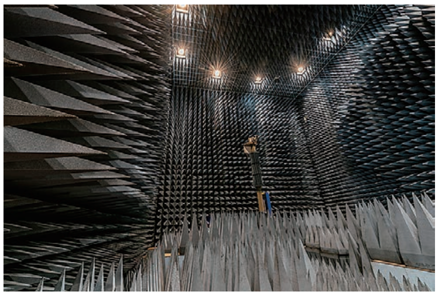
HAMAGUCHI: The management technologies are used to coordinate base station cells, minimize delay in 5G communications and enable the simultaneous connection of many devices. The customization technologies include wireless grid technologies that enable machine-to-machine and device-to-device communications and technologies that are being used to develop wireless communications environments in factories. Finally, the technologies with enhanced reliability include drones equipped with wireless repeaters that can be used in environments in which wireless communications infrastructure is unavailable (e.g., disaster-affected areas) and wireless technologies compatible with extreme environments considered unsuitable for radio wave use.

——In what scientific fields was it most challenging to apply radio waves?

Prototype of an autonomous micro-cell base station compatible with the millimeter wave band. Its ability to coordinate with and control a 5G system was evaluated.



Demonstration of SUN radio devices controlling water levels in tanks projected for use in agriculture. These energy-efficient devices are compatible with IoT technology.



Radio anechoic chamber at the YRP Center No. 1 Building. This chamber is isolated from external radio waves and prevents internal radio waves from escaping, thereby enabling unbiased radio wave transmission experiments.

KOJIMA: One example is the application of radio communications to drug delivery systems. The technology allows the precise location of a small drug capsule in the patient's body to be remotely detected after ingestion.

Some medical scientists are interested in accurately tracking the paths of ingested capsules in the body in order to find ways of delivering drugs to a precise target site. In this technology, a mechanism similar to an RFID device is incorporated into a drug capsule and its location in the body is determined using several external antennas. The electrical permittivity (a measurement of radio wave transmissivity) of different parts of the human body (e.g., skin, internal organs and bone) varies. For this reason, the development of this new technology has been very challenging, but the effort has been rewarding for me.

HAMAGUCHI: We are also carrying out undersea wireless communications research. Although the underwater marine environment is largely incompatible with radio wave transmission, close-range transmission is feasible. In collaboration with JAMSTEC (Japan Agency for Marine-Earth Science and Technology), we have achieved short-range transmission of radio waves in several MHz bands using modified antenna structures. This technology can be used to greatly increase the mobility of undersea exploration machinery (e.g., robots) by allowing it to be disconnected from a "lifeline" cable for more flexible operations within areas of up to several meters.

Strengths of the YRP and future prospects for 6G

——What unique research environments are offered at the YRP?

HAMAGUCHI: The YRP opened in October 1997 as a radio wave communications R&D center and NICT has since established its research base there. The YRP hosts many research facilities and laboratories established by companies and universities from all over Japan and overseas at which a wide variety of research, from basic to leading-edge, has been conducted.

NICT has been jointly carrying out research with these companies and universities. It also hosts the annual "Wireless Technology Park" (WTP) event around May—one of Japan's largest wireless communications technology events for professionals—in collaboration with the YRP R&D Promotion Committee and the YRP Academia Collaboration Network.

Moreover, NICT and the YRP R&D Promotion Committee cohost the annual International Symposium on Wireless Personal Multimedia Communications (WPMC) at various locations around the world to help promote the advancement of wireless communications technologies globally.

——What are the future prospects of wireless research?

KOJIMA: We carry out R&D projects based on medium- to long-term plans formulated by NICT every five years. The next five-year plan will be issued in 2021. Previous patterns predict that generational changes occur in communications technology every 10 years. Assuming that 6G technology enters service in 2030 based on this pattern, we plan to identify issues associated with 5G technology and discuss the conceivable demand for 6G technology during the implementation of the next medium-to-long-term plan.

As a national research institute, we have a responsibility to use our R&D results for the benefit of society and private companies. Accordingly, I hope to create technologies valuable to the Japanese people.

HAMAGUCHI: My ambition is to develop an ultimate wireless communications system capable of bringing new value to society by satisfying users' diverse needs, increasing energy efficiency, strengthening security, minimizing radio wave interference and raising the quality of wireless communications to that of wired communications regardless of time and location.

I believe that the YRP is Japan's premier hub for radio wave communications research. Because the next-generation 6G wireless communications technology is likely to emerge in 10 years, I would like to prepare for it by striving to develop world-leading, innovative wireless communications technologies.

---

*1 RFID (Radio Frequency IDentifier): mechanisms by which data is communicated via radio waves between radio tags containing ID information and radio tag readers. This technology has been in practical use in RF tags and non-contact IC cards.

*2 IEEE (Institute of Electrical and Electronics Engineers) 802 committee

*3 3GPP (3rd Generation Partnership Project): international standardization project to discuss and develop standards and specifications for mobile communications systems, such as mobile phones

*4 Massive MIMO (Massive Multiple Input Multiple Output)

A Roadside Infrastructure for the Future ITS…

Smart wireless traffic mirror

Changwoo PYO

Senior Researcher
Wireless System Laboratory
Wireless Networks Research Center

After graduate school, he entered NICT in 2005. He is engaged in research on media access control such as Wireless Communications and Networks, Millimeter Wave Communications, Cognitive Wireless Communications, and Broadband Wireless Communications in TV whitespace. Ph.D. (Engineering).

Intersections without traffic lights are often associated with high automobile accident risks. Intersections at which fences, buildings and stopped vehicles obstruct drivers' vision are particularly dangerous. To minimize these risks, we have developed a "smart wireless traffic mirror." When mounted on a roadside mirror pole at an intersection, this system is capable of collecting local traffic data (i.e., the movement of vehicles and pedestrians and the presence of obstacles in the vicinity of the intersection) using its sensors, wirelessly transmitting the data to a server where it is integrated into a database called a "dynamic map" and delivering local traffic information to nearby drivers and pedestrians, allowing them to view the movement of other vehicles and pedestrians on a map, thereby reducing traffic accident risks in the vicinity of intersections. In addition, this system may serve as vital roadside infrastructure capable of assisting in the operation of autonomous vehicles, a new technology anticipated to be put into practice in the near future.

Efforts to develop smart mobility technologies

The aging of the Japanese population is generating strong demand for smart mobility technologies, such as autonomous vehicles, as they may promote greater independence for elderly people and encourage them to more actively participate in social events. Remotely controlled vehicles—another smart mobility technology—are likewise being pursued in the hope of compensating for labor shortages as Japan's population shrinks.

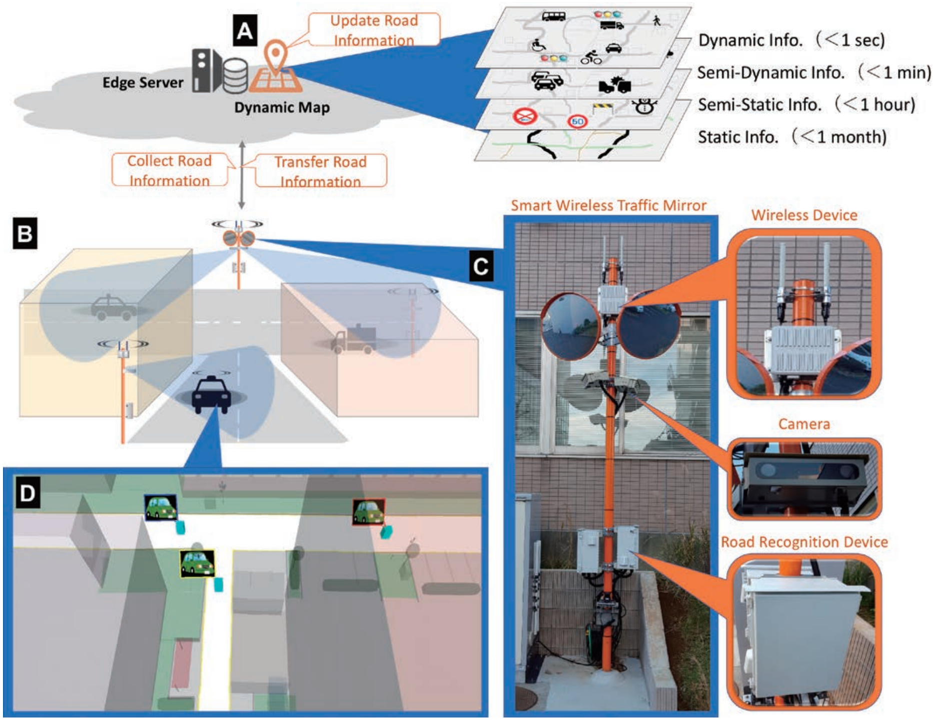


Figure 1 Mechanisms and composition of the smart wireless traffic mirror
A. Four-layer dynamic map (source: "Review of study group focused on the realization of a connected car society" released by the Ministry of Internal Affairs and Communications on August 4, 2017). B. Intersection with no traffic light and poor visibility which was used in our simulation studies. C. Smart wireless traffic mirror. D. Traffic information in the vicinity of the intersection displayed on a map.

R&D efforts are seeking to increase the reliability and precision of smart mobility technologies by effectively using information collected by a variety of sensors, including those installed in vehicles, and integrating information and communications technology (ICT).

To put the smart mobility concept into practice, new technologies need to be developed enabling the continuous collection and analysis of traffic data, integration of this data into a dynamic map and efficient delivery of the final traffic data to relevant users. A dynamic map—the integration of a variety of road-related information—is composed of four layers that are updated at different intervals (Figure 1A): a static layer updated daily containing information on road surfaces, traffic lanes and roadside structures, etc.; a semi-static layer updated hourly containing information on traffic restrictions and road construction, etc.; a semi-dynamic layer updated minute-by-minute containing information on traffic accidents and congestion, etc.; and a dynamic layer updated continuously containing information on the movement of vehicles and pedestrians and traffic light status, etc.

Most researchers have been focusing on ways of enabling individual autonomous vehicles to update traffic information on a dynamic map. In this method, a traveling vehicle collects traffic information (e.g., accidents, congestion and traffic restrictions) using onboard sensors and updates its dynamic map via wireless communications. However, these sensors may be ineffective when a vehicle approaches curves and intersections associated with frequent accidents due to poor visibility. Onboard sensors are also unable to detect traffic restrictions and obstacles that may exist beyond their range. These undetected events and objects cannot be incorporated into the dynamic map.

This problem may be effectively solved by using an alternative map updating method that involves roadside sensors, such as cameras and radar. In this article, I describe the smart wireless traffic mirror, a system capable of processing and transmitting traffic data collected by roadside sensor arrays.

Smart wireless traffic mirror visualizes events/objects beyond the range of a vehicle's onboard sensors

When deployed in low-to-zero visibility locations, such as the intersection shown in Figure 1B, a smart wireless traffic mirror is capable of detecting a variety of events (e.g., the presence and movement of vehicles and pedestrians, and road construction) and updating a vehicle's dynamic map with the information it collects. In addition, this system can wirelessly deliver local traffic information to nearby drivers in a timely manner, allowing them to foresee traffic situations beyond the range of their perceptions. Thus, this system is a vital element of roadside infrastructure that can make road traffic safer.

Figure 1C shows a smart wireless traffic mirror and its components:

- cameras capable of capturing images of all objects on the road;
- object detectors capable of identifying individual objects in captured images using machine learning; and
- a wireless communications device that transmits data on identified objects.

Data is sent to and compiled on an edge server. It is then subjected to integration processing and used to determine traffic conditions. The processed data is ultimately incorporated into an updated dynamic map. In simulation studies using a YRP testbed, we deployed three smart wireless traffic mirrors and allowed them to cover 40 meters of the three roads extending from a T-intersection (Figure 1D). These three systems successfully tracked vehicle movement in real time, captured images of it and determined its position.

Vehicles that received traffic information collected and transmitted by a smart wireless traffic mirror were able to display it on their monitors (Figure 2). These tests demonstrated that the system works effectively. Figure 2A shows an in-vehicle monitor indicating the presence of a vehicle beyond the right corner of the intersection which would ordinarily not be visible to the driver. In Figure 2B, a vehicle crossing the intersection from the right can be recognized both by the driver and by reference to the traffic information displayed on the monitor.

Future prospects

The deployment of smart wireless traffic mirrors may reduce the risks of traffic accidents in the vicinity of intersections by delivering local traffic information to nearby drivers and pedestrians. 5G mobile communications systems are expected to play a vital role in the operation of autonomous vehicles. By coordinating this technology with 5G systems, it may serve as an important element of roadside infrastructure capable of enhancing the reliability and precision of autonomous vehicle operations in the near future.

Figure 2 Real-time local traffic information sent from the smart wireless traffic mirror to a nearby vehicle

Promoting Industrial Collaboration to Achieve Stable Operation of Wireless Communications in Factories

Satoko ITAYA

Senior Researcher
Wireless System Laboratory
Wireless Networks Research Center

After receiving the Ph.D. degree in 2002, she joined Advanced Telecommunications Research Laboratory Institute International (ATR) from 2002 to 2007. She worked in NEC Central Research Laboratories from 2008 to 2013. Since 2014, she is a senior researcher at the Smart Wireless Laboratory of NICT. Her research interests include complex systems, networking, communications, data analytics, modeling, and applications. Ph.D. (Science).

Fumiko OHORI

Researcher
Wireless System Laboratory
Wireless Networks Research Center

After earning a master's degree in computer science, she joined the KOZO KEIKAKU ENGINEERING Inc. in 2010. Since October 2017, she is a researcher at the Smart Wireless Laboratory of NICT and aims to solve real problems for stable operation of wireless communications in the manufacturing sites.

The manufacturing sector has faced increasing demands to expedite its product development cycles in recent years. In response, manufacturers are becoming interested in introducing wireless communications at their factories. To address this subject, the National Institute of Information and Communications Technology (NICT) launched a Flexible Factory Project in 2015 with two objectives: coordinating the wide variety of wireless systems installed within factories and ensuring that they operate safely. During this project, we have been collaborating with many manufacturers across a variety of industries to survey the wireless environments found in actively operating factories. In this article, we describe a simulator—which we are developing based on survey results obtained during this project—capable of estimating the relationship between a factory's productivity and the quality of its wireless communications.

Background

Some factories need to make frequent changes to their production lines without compromising productivity, making flexible production line design important. Wireless communications play a vital role in achieving these objectives. When a factory's mobile equipment (e.g., automated guided vehicles (AGVs), lifting equipment and stacker cranes) uses wireless communications, the quality of these communications may impact productivity. Special care must therefore be exercised when introducing and operating wireless communications. An increasing number of manufacturers are showing interest in the development of visualization technologies and simulators, etc. that can be used to predict the performance of wireless communications in their facilities.

Scenarios for using wireless communications in factories

As part of the Flexible Factory Project, we have been surveying the wireless environments in factories, interviewing factory workers, carrying out academic research, preparing reports on the varied use of wireless communications in factories based on the information gathered and publishing these reports as white papers. The white papers describe the following four scenarios that represent typical usage of wireless communications.*1

(1) Metalworking factories

Various machine tools are arranged on a factory floor and materials and manufactured

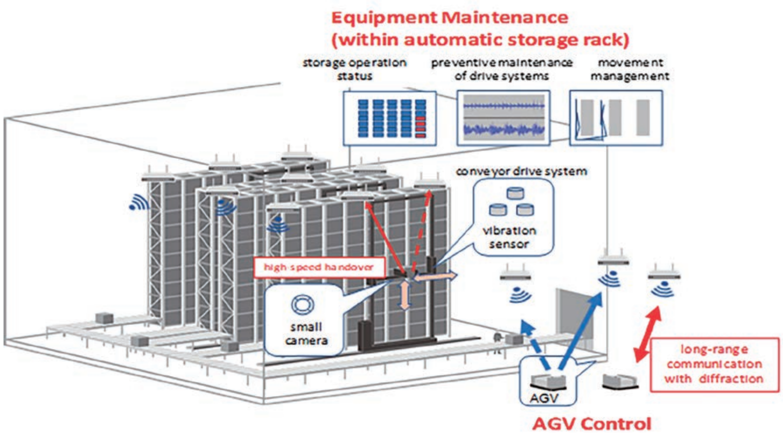


Figure 1 Conceptual image of wireless communications within a logistics warehouse

products are handled in specific parts of a facility. It is important to monitor machines when they are in operation, take accident prevention measures and maintain machine tools properly. Many machine tools we surveyed were old (i.e., 20 to 30 years old) and equipped with aftermarket sensors. Many factories expressed interest in introducing wireless communications to gather data from these sensors.

(2) Mechanical assembly factories

Many factories in this category have developed systems capable of monitoring assembly by collecting data on the quality of each process, analyzing it and providing feedback. Many of these factories expressed interest in using wireless communications to manage the operation of the AGVs they use to move components between different assembly processes.

(3) Elevated and high temperature work sites

Certain types of factories (e.g., chemical and steel plants) are associated with extremely hot and/or humid working environments and/or risks of collision and falling. It is important to monitor personnel working under these conditions using vital sensors, observation cameras and other tools. In addition, wireless communications-based data gathering is necessary to monitor workers who move between different locations.

(4) Logistics warehouses

Automated vertical storage and retrieval systems (e.g., stacker cranes) are commonly used in these facilities to increase space use efficiency. Large warehouses are often equipped with multiple orderly arrangements of racks, each 30 m in height and more than 100 m in width, separated by several-meter gaps. Operating stacker cranes in a large warehouse using wired communications requires adequate cables and properly installed wiring. Introducing wireless communications may lower warehouse operating costs by eliminating the need for cables and reducing maintenance costs (Figure 1).

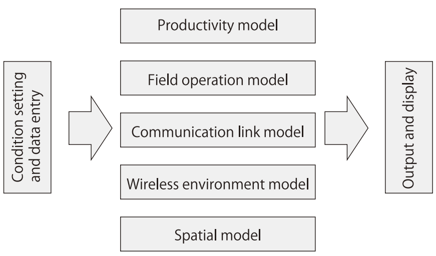
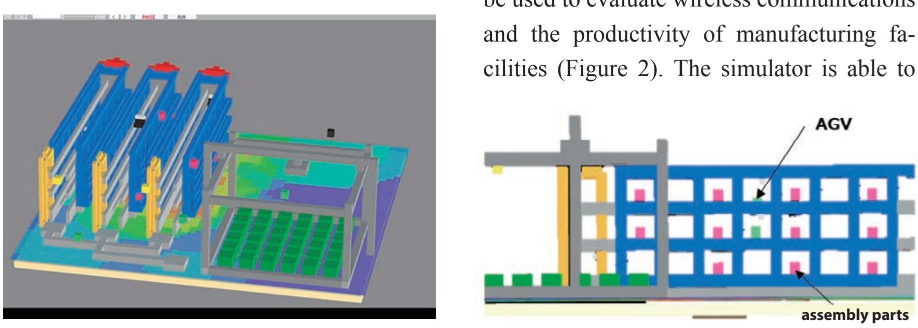


Figure 2　Five-layer model used to evaluate a manufacturing facility's wireless communications and productivity

Development of simulators suitable for on-site use

Wireless communications are expected to be useful in large automated storage systems. Three-dimensional simulators are an effective tool for simulating the vertical and horizontal movement of manufacturing equipment used in these facilities and determining optimum ways of maintaining high-quality communications with these pieces of moving equipment. Many of the existing wireless communications simulators, however, only perform radio propagation simulations and are difficult for manufacturing facility workers to use because these workers usually lack adequate knowledge on radio communications. In addition, three-dimensional simulations require significantly greater amounts of computing time than two-dimensional simulations. For these reasons, simulations of wireless system operations in manufacturing facilities had been difficult. Moreover, existing wireless communications simulators are ineffective in determining the relationship between facility productivity and wireless communications quality, and are therefore inadequate for identifying factors influencing productivity and proper ways of improving wireless environments. To address these issues, NICT has developed a simulator capable of generating a five-layer model that can be used to evaluate wireless communications and the productivity of manufacturing facilities (Figure 2). The simulator is able to perform computations at reasonably realistic speeds even when used at manufacturing facilities. We achieved this by allowing the simulator to describe the wireless environment in terms of a probability model. We are currently carrying out R&D to enable this simulator to perform mapping, computation and visualization in three dimensions by integrating positioning data collected for the Flexible Factory Project into the simulator (Figure 3). Our R&D is progressing with the help of feedback received from manufacturing facility workers.



(a) Overall view　　(b) Side view

Figure 3　Snapshots of a multi-level warehouse generated by the three-dimensional simulator under development by NICT

Future prospects

NICT has proposed the SRF Wireless Platform vision[*2] based on the concept of enabling coordination between a wide variety of wireless systems within the same facility to promote the stable and efficient operation of industrial systems. Two of the private companies participating in the Flexible Factory Project are particularly committed to this vision, and in July 2017 they established the Flexible Factory Partnership Alliance (FFPA), a non-profit organization, to put it into practice. On June 3, 2019, the FFPA received the "Info-Communications Promotion Month" award for the 2019 fiscal year from the Ministry of Internal Affairs and Communications (Figure 4) in recognition of the project and the steady collaboration between alliance members. This award encouraged us to work harder, and we hope to continue making progress on the development of a wireless platform that can be operated stably by manufacturing facility workers.

Figure 4　From left to right: FFPA Director Akihiro AMAGAI (Sanritz Automation Co, Ltd.), FFPA Director Masahiro IKUMO (OMRON Corporation), FFPA Vice-Chair Satoko ITAYA (NICT) and FFPA Secretary-General Hajime KOTO (NICT)

*1 http://www2.nict.go.jp/wireless/ffpj-wp.html

*2 SRF (Smart Resource Flow): A system engineering strategy for managing resources (e.g., human resources, facilities, equipment, materials, energy, and communications) using multilayer system analysis to achieve optimal performance

Wireless Systems Supporting the Safe Operation of Unmanned Aircraft Systems

Expanding UAS operations to fly further, higher, more often, and for a wider range of purposes

From the left: Lin SHAN, Fumie ONO, Toshinori KAGAWA

Fumie ONO

Senior Researcher
Wireless Systems Laboratory
Wireless Networks Research Center

She joined NICT in 2012. She is engaged in the research on wireless communication system using Unmanned Aircraft System(UAS), and wireless system for UAS. Ph.D. (Engineering).

Lin SHAN

Researcher
Wireless Systems Laboratory
Wireless Networks Research Center

He joined NICT in 2013. His research interests include D2D communication, multiuser-MIMO scheduling, cooperative relaying, and wireless system for Unmanned Aircraft System (UAS). He received the IEICE RCS Active Research Award and the IEEE VTS Japan Young Researcher's Encouragement Award in 2011, and the IEICE Best Paper Award in 2013, respectively. Ph.D. (Informatics).

Toshinori KAGAWA

Researcher
Wireless Systems Laboratory
Wireless Networks Research Center

He joined NICT in 2013. He is engaged in the research on indoor location system using IR-UWB, and wireless system for Unmanned Aircraft System (UAS). He is the member of the Institute of Electronics, Information and Communication Engineers (IEICE). Ph.D. (Engineering).

A great deal of interest exists in expanding the capabilities of unmanned aircraft systems (UASs), such as drones, to enable them to fly farther at higher altitudes with greater frequency and for a wider range of purposes. NICT has been researching and developing wireless communications systems that can be used to satisfy these demands and to allow communications between UASs. We hope that the practical value of these NICT R&D products leads them to become de facto standards.

Current radio systems used by drones and other aircraft

In recent years, drones have become widely available and are as popular a purchase as TVs and refrigerators at electronics retailers. Drones today are relatively easy to operate and are capable of carrying out a variety of tasks, such as aerial videography. However, drones have caused some problems: they are reported to have nearly come into contact with small helicopters (e.g., medivac helicopters) that take off and land in areas other than airports and the number of drone crashes is increasing. Safer drone operation will require the development of new technologies and improvement of the drone operating environment.

In general, UASs are remotely controlled by their operators (or pilots) by means of two-way wireless communications. UASs are able to transmit telemetry (measurements taken at remote locations) and image data, etc., to their operators, who send them commands. Although most UASs are operated manually, some recent UASs are capable of automatic (or autonomous) flight when an appropriate flight mode is selected.

While hobby drones normally operate within a visual range of several hundred meters, drones for commercial/industrial use are expected to fly from several to tens of kilometers over mountains and buildings beyond visual line of sight (BVLOS). The safe operation of commercial/industrial aerial drones will require ensuring that they do not collide with any ground-based structures (e.g., trees, power lines and buildings) or flying objects (e.g., birds and manned helicopters). Thus, new technologies are being sought that would enable operators to identify the flight positions and status of their

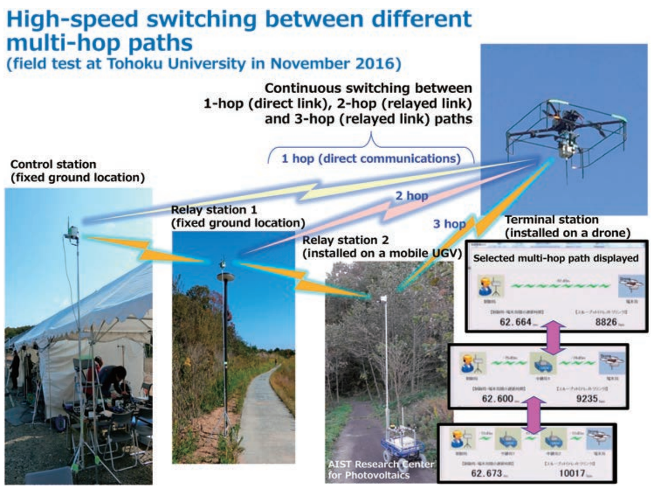


Figure 1 Multi-hop transmission field test by NICT and AIST

drones at any moment and to comprehend environmental conditions during takeoff and landing, whether the drone is autonomous or manually operated.

NICT has researched and developed technologies that enable operators to maneuver their drones BVLOS, technologies that allow drones flying in the same airspace to recognize each other's positions and technologies capable of estimating the operable coverage and the risk of co-channel interference in the vicinity of a flying drone.

Technologies enabling BVLOS drone operation

As the operating ranges of drones and other UASs expand, the chance that they will fly BVLOS of their operators or ground control stations increases. NICT has therefore been researching and developing technologies that enable direct communications between ground control stations and UASs and a relay transmission system (or multi-hop transmission system) called a "command hopper" that enables commands to be transmitted via radio repeaters. We carried out several field experiments and found that a single transmission hop (between two radio devices) can communicate commands at distances up to about 4 km (Figure 1). The use of multiple radio repeaters will therefore allow UAS operating ranges to expand in a variety of ways.

The command hopper system may also allow commands to be relayed to drones and other target devices via radio repeaters installed in other remotely controllable drones or ground-based unmanned robots. This application of the command hopper system may enable the development of autonomous command transmission systems.

Technologies enabling drones in the same airspace to recognize each other

NICT has also been researching "Drone mapper®" radio communications systems that enable different operators' drones operating in the same airspace to recognize each other's positions and avoid collision. This system is expected to assist drone pilots in identifying the locations of their drones relative to other drones even BVLOS environment and in maintaining a safe distance between drones. The current Drone mapper® uses specific, energy-efficient radio frequencies within the 920 MHz band, does not require a radio operator's license and is inexpensive and easy to use. Positional information communication systems have been available for manned helicopters and aircraft, but most are relatively expensive. No radio devices had been available that could be installed on small UASs, such as drones, enabling them to directly communicate with each other. We have confirmed that the developed Drone mapper® units installed on both small manned helicopters and drones enabled them to locate each other's positions within a range of about 9 km (Figure 2). In addition, we are building on the drone mapper's abilities by researching and developing an autonomous flight control system allowing two-way communication between drones. In field experiments, we succeeded for the first time in the world in causing two drones to recognize each other's positions and autonomously maintain a safe distance between themselves (Figure 3).

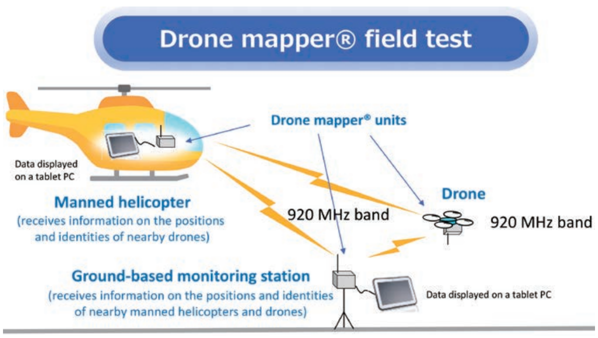


Figure 2 Drone mapper® field test (sharing of positional information between small manned helicopters and drones)

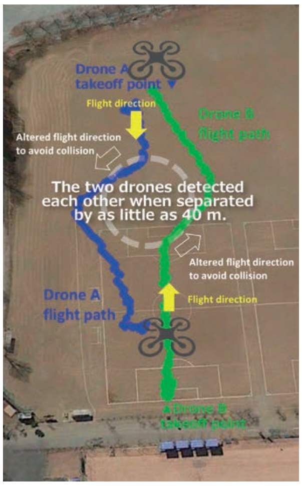


Figure 3 Autonomous flight control field test using two drones

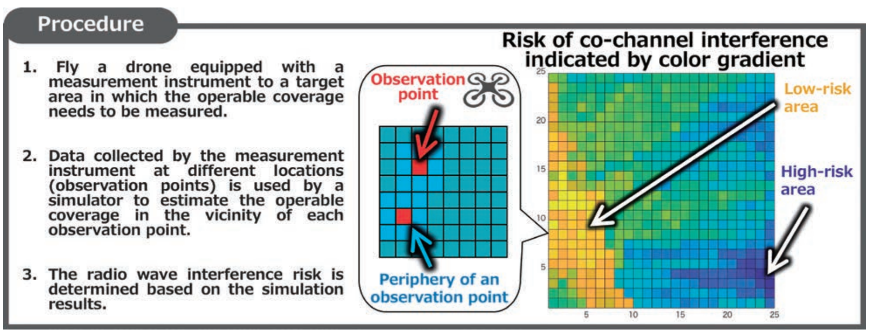


Figure 4 Technology capable of estimating the operable coverage in the vicinity of a flying drone

Technologies estimating the operable coverage and the risk of co-channel interference

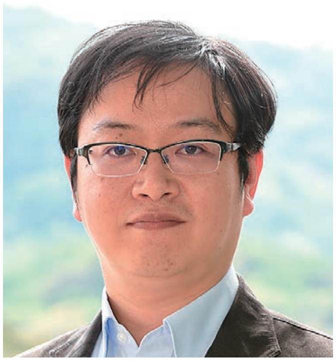
Expanding the areas in which drones are permitted to operate will bring more drones into densely populated urban areas where ground-based radio devices are already in widespread use. Many current drones use ISM bands, such as the 2.4 GHz and 5 GHz bands. Some ground-based radio devices use similar wave frequencies and may disrupt communications between drones and ground control stations, including the transmission of positional information and safety confirmation image data from a drone to a station.

NICT has been researching technologies capable of estimating the operable coverage in the vicinity of a flying drone using data collected by a measurement instrument installed on the drone (Figure 4). These technologies are intended to increase drone flight safety by predicting and informing drone operators of radio wave interference risks.

Future prospects

Studies have been conducted on drone use of radio devices that have previously only been used on the ground. The objective of these studies is to increase the safety of the simultaneous operation of many drones in the same airspace. We expect that ground-based radio devices will increasingly be integrated into UAS technology. NICT will continue its R&D efforts to achieve smart, aerial use of radio waves.

Challenges to Use RF Signals in Underwater to Open a New Field



Takashi MATSUDA

Senior Researcher
Wireless Systems Laboratory
Wireless Networks Research Center

After completing graduate school, joined NICT in 2010. He engaged in R&D in sheet medium communication and power supply, and underwater wireless communication using radio wave. Ph. D. (Engineering).

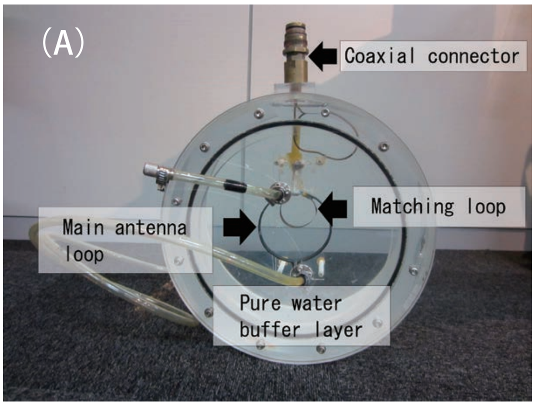
Ocean research and the exploitation of ocean resources have been progressing much more slowly than those of on land despite the fact that oceans cover approximately 70% of the Earth's surface. While this delay is undoubtedly due in large part to very limited human activity in the marine environment, the lack of underwater communications and sensor technology is also a probable cause. The development of new technologies enabling underwater radio wave utilization may facilitate advances in various marine technology fields, such as submarine resource exploration and excavation, marine ecological and geological surveys and the application of IoT technologies in fisheries.

Extreme oceanic environments significantly attenuate radio waves

Acoustic waves have been the primary means of underwater communications and detection. They also have disadvantages: because they are low frequency waves, they are unsuitable for use in higher-speed communications and cause significant propagation delay. For these reasons, other means of communication, including radio waves, have been studied. However, certain properties of seawater make underwater radio wave use. Seawater has electrical properties very different from air. Its relative permittivity of approximately 81 (compared to approx. 1 for air) and electrical conductivity of approximately 4 S/m* (compared to approx. 0 S/m for air) greatly attenuate radio waves. Lower frequency radio waves travel through seawater more easily. Some scientists have also been researching visible light communications underwater because certain wavelengths of blue light (which gives the ocean its blue appearance) is known to be more resistant to attenuation. Although the use of visible light enables high-speed communications, it is strongly directional and therefore requires careful emitter-receiver alignment. In addition, visible light may scatter in turbid water, preventing it from reaching a receiver. Radio wave-based underwater wireless technologies may therefore complement acoustic wave and visible light communications when conditions render them ineffective.

Prototype underwater antenna

Ground-based antennas are inadequate for underwater use without modification. As I explained above, the electrical properties of seawater are very different from those of air and greatly shorten radio wavelengths. To address this issue, I created a prototype



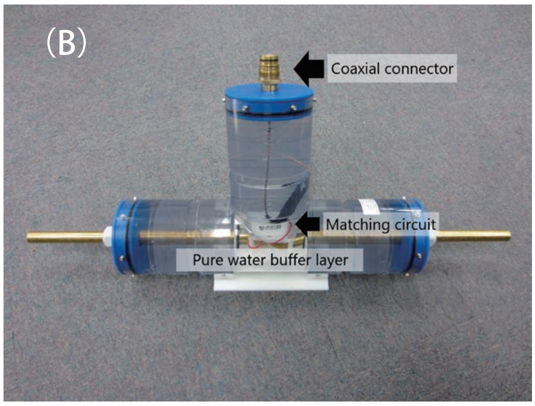


Figure 1 Prototype underwater antennas enclosed in a buffer layer of purified water. (A) Magnetic loop antenna (diameter: 310 mm, height: 200 mm, weight: approx. 50 kg). (B) Microdipole antenna (diameter: 100 mm, length: 800 mm, weight: approx. 20 kg).

antenna with its elements enclosed by a buffer layer of purified water with an electrical conductivity of 0 S/m (Figure 1A). The addition of this buffer layer isolates the antenna more securely from the changeable ambient environment. Although other mediums, such as air, could be used as a buffer layer, I chose purified water because it allows the external pressure applied to the antenna container to be equally distributed, increasing its overall structural strength when subjected to water pressure. The prototype underwater antenna is equipped with a magnetic loop. One of my objectives at the beginning of this research project was to accurately measure radio wave propagation characteristics. To achieve this, I set the center frequency of the antenna to 10 MHz to ensure adequate measurement of attenuation between antennas placed within the same measurement system.

I also created a prototype underwater microdipole antenna that will be evaluated to determine its properties in relation to different radio wave frequencies (Figure 1B). This antenna was designed to be lightweight and easy to construct since multiple antennas need to be produced and evaluated. Although the radiation efficiency of microdipole antennas is lower than that of magnetic loop antennas, they have a broader effective band, making impedance matching between matching circuits easier.

Development of underwater radio wave measurement systems

In another research project, I developed a portable vector network analyzer capable of measuring electrical properties in the range between 10 kHz and 10 MHz and an electromagnetic response measurement system that can be connected to an underwater cable for use in shallow seas. The system is equipped with interfaces to which a variety of sensors (e.g., cameras, CTD meters, tilt meters, and underwater altimeters) can be connected to record environmental conditions. I also constructed a frame (an underwater channel sounder (UCS)) onto which these measurement devices and sensors can be mounted that can be suspended in water for various experiments. The UCS is shown in Figure 2. You can see a transmitting antenna mounted on the far side of the UCS and three receiving antennas attached to the near side. The transmitting antenna was mounted on a movable stage and is able to move 900 mm in either direction from the central position in parallel with the array of receiving antennas. The receiving antenna array is also mounted on a movable table and can be moved within the frame, enabling the distance between it and the transmitting antenna to be adjusted. The control unit, mounted on the lower left corner of the UCS, controls antenna switching, communications with the network analyzer, various sensors, and other functions. A fiber optic cable connects this control unit with the terminal controller on the ship, enabling the ship to transmit control commands to and receive data from the UCS. The control unit, the network analyzer, and the battery are mounted in a row. These components are enclosed in pressure-resistant containers capable of withstanding water pressure up to about 100 m in depth. Using this measurement system, we were able to evaluate the propagation properties of 10 MHz radio waves while varying the inter-antennal distance from 60 cm to 140 cm.

I am also developing an underwater wireless measurement system with subseafloor sensing capabilities (Figure 3). This technology uses radio waves to detect buried objects invisible to acoustic waves and other sensory technology. The system is designed to detect objects buried under the seafloor by measuring radio wave propagation properties (amplitudes and phases) between antenna arrays directed at the seafloor. I have been using the system to measure various types of buried objects, such as metals, dielectrics and their composites (Figure 4). I am also examining methods of estimating the sizes and shapes of buried objects using the collected data.

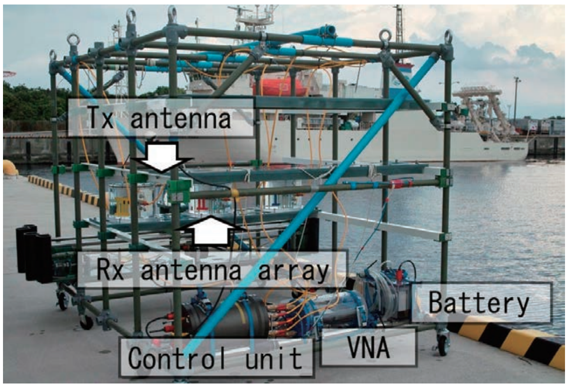


Figure 2 Underwater channel sounder capable of shifting the position of the transmitting antenna attached to it while operating underwater

Future prospects

The oceans are full of potential technological applications. However, the currently available technologies are still inadequate to achieve specific objectives. If an underwater wireless technology that employs radio waves is developed, it may enable wireless communications with unmanned underwater robots, subseafloor sensing and other new technologies, which could be used to enhance Japan's marine-related industries and natural resource development capabilities, further strengthening its prosperity as a major maritime nation. (Part of this research project was supported by the National Security Technology Research Promotion Fund provided by the Acquisition, Technology and Logistics Agency.)

* S/m (siemens per meter): a unit of electrical conductivity equal to the reciprocal of the corresponding electrical resistivity expressed in ohm meters (Ωm)


Figure 3 Sensing and measurement frame equipped with one transmitting antenna and four receiving antenna arrays

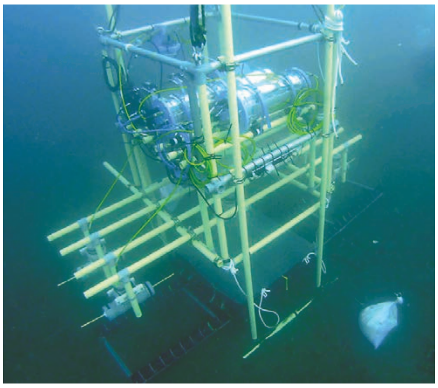


Figure 4 Sensing and measurement being conducted on the seafloor in Mitohama, Numazu City, Shizuoka Prefecture at a depth of 30 m

Creating a Wireless Network to Facilitate the Widespread Use of Robots

Toshinori KAGAWA

Researcher
Wireless Systems Laboratory
Wireless Networks Research Center
Ph.D. (Engineering).

Biography

1985 Born in Ishikawa Prefecture, Japan
2008 Graduated from Chubu University with a B.S. in Computer Science
2013 Graduated from the University of Electro-Communications with a Ph.D. and then joined NICT. Appointed to current position.

Awards, etc.

Won first prize in the 13th Electronics Contest sponsored by the University of Electro-Communications
Won first prize in the 2011 Human Media Lab Contest sponsored by the University of Electro-Communications

Tool rack Kagawa installed on the wall of his house

Q&As

Q How do you normally spend your holidays?

A I often go to home improvement retailers and 100-yen shops, buy some materials, and engage in DIY activities. I sometimes make racks for my tools and other items, but my wife complains about my creations; she says they look awkward and unfashionable.

Q What advice would you like to pass on to people aspiring to be researchers?

A I believe that creative thinkers have the potential to become researchers. I recommend that they develop the habit of keenly observing everything around them and thinking about its underlying causes and mechanisms.

Q What are you currently interested in outside of your research?

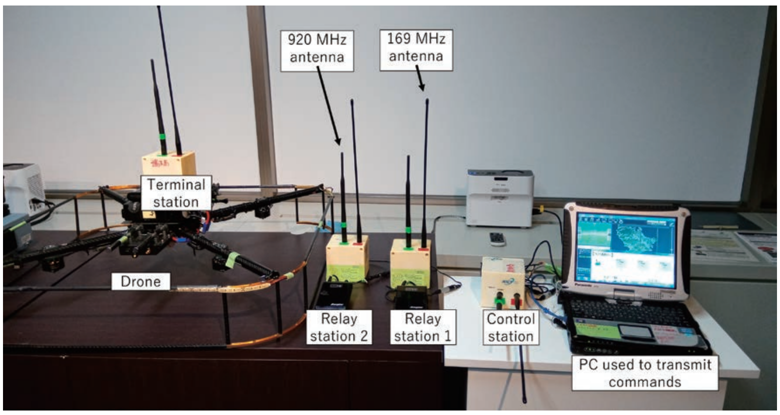
A I am currently hooked on Japanese-style luxury bathhouses. I alternate between a sauna and cold water to stimulate the sympathetic nervous system. This routine helps me to clear my mind and greatly increases my creativity and efficiency when performing intellectual tasks. Many sauna lovers are familiar with this acquired state of mind—mindfulness, so to speak.

Robots are expected to take on a greater role in supporting our everyday activities in the near future. They are capable of carrying out tasks in nearly inaccessible areas (e.g., areas affected by disasters, extreme ocean depths and remote mountainous areas). However, a new wireless system needs to be developed to enable communications with robots deployed in these areas, because currently available wireless systems are inadequate. The LTE network requires that a communications infrastructure be constructed in these areas and current Wi-Fi only allows devices to access the internet.

Our team has been researching wireless systems that can be used to communicate with robots and drones carrying out tasks in disaster-affected areas and remote mountainous areas. When communicating with robots, communications disruptions and transmission delays (the time it takes for a robot to receive a command after it is transmitted by the operator) should be minimized. We have developed a communications system to achieve these goals using time-division multiplexing and a combination of the 169 MHz band and the 920 MHz band. The system is also compatible with communications relays (multi-hop communications). Moreover, this system allows an operator to choose whether to prioritize transmission delay or communication speed and customize the balance between them depending on the nature of the mission a robot is tasked with.

Wireless technologies are already so ubiquitous that many people may take their existence and mechanisms for granted. Our mission is to leverage these well-established technologies efficiently and optimally to achieve specific goals.

Baien Miura, an Edo era Japanese philosopher, said, "The blooming of a living tree is even more amazing than the blooming of a dead one." In other words, ordinary technologies may enable more truly amazing innovations than revolutionary technologies do. I hope that we are able to create something amazing using these ubiquitous wireless technologies.



Prototype multi-hop communications system to control drones

The MEXT Minister Prizes are bestowed to scientists who have made significant achievements in science and technology R&D which have advanced understanding in their fields.

*The titles and organizations that the winners belong to are those at the time they won their awards.

FY2019 The Commendation for Science and Technology
by the Minister of Education, Culture, Sports, Science and Technology

Prizes for Science and Technology

Masugi INOUE

Director of the International Research Advancement Office, Global Alliance Department, Open Innovation Promotion Headquarters

Yasunori OWADA

Senior Researcher, ICT Testbed Coordination and Planning Office, ICT Testbed Research and Development Promotion Center, Social Innovation Unit, Open Innovation Promotion Headquarters

Kiyoshi HAMAGUCHI

Director General, Wireless Networks Research Center

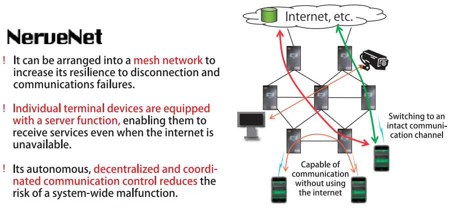
Overview ●Description: Development of resilient distributed autonomous cooperative communication system

●Date: April 17, 2019

Comments from the Recipients:

More than 10 years ago, we came up with a next-generation access network concept, more commonly known today as local IoT architecture. We then engaged in R&D focused on strengthening the network's natural disaster resilience and put NerveNet into practical use. NerveNet has been operating continuously in disaster-stricken Onagawa in Miyagi Prefecture and in municipalities preparing for an anticipated Nankai Trough earthquake, such as Shirahama in Wakayama Prefecture. In addition, the technology has been transferred to the private sector. We are very honored that our R&D efforts have been recognized for their practical and innovative value and for their significant contributions to the development of Japan.

From left to right: Kiyoshi HAMAGUCHI, Yasunori OWADA and Masugi INOUE



NerveNet overview

Kiyonori OHTAKE

Executive Researcher, Data-driven Intelligent System Research Center, Universal Communication Research Institute

Junta MIZUNO

Senior Researcher, Data-driven Intelligent System Research Center, Universal Communication Research Institute

Kentaro TORISAWA

Director General, Data-driven Intelligent System Research Center, Universal Communication Research Institute

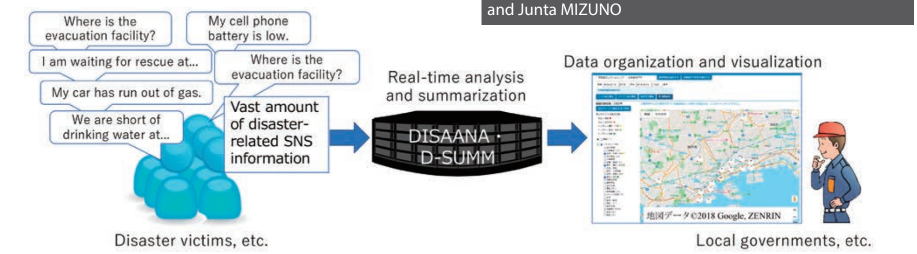
Overview ●Description: Research on Disaster Damage Analysis Technologies based on Deep Semantic Analysis of SNS Texts

●Date: April 17, 2019

Comments from the Recipients:

In response to the severe damage caused by the Great East Japan Earthquake, we developed DISAANA (a system capable of analyzing disaster-related SNS information) and D-SUMM (a system capable of summarizing disaster-related information). We appreciate the recognition our R&D efforts have received. We were able to put our R&D results into practical use at the local community level thanks to the advice and support of many collaborators, including governmental agencies—especially the Ministry of Internal Affairs and Communications—municipalities and private companies. These supporters have our deepest thanks.

From left to right: Kentaro TORISAWA, Kiyonori OHTAKE and Junta MIZUNO



DISAANA/D-SUMM overview

Chihiro TAO

Researcher (Tenure-Track), Space Environment Laboratory, Applied Electromagnetic Research Institute

Overview ●Description: Research on Generation, Emission, and Variation Processes of Aurora on Outer Planets

●Date: April 17, 2019

Comments from the Recipient:

Diverse planetary environments can be ideal research subjects for the purposes of testing the universality of knowledge developed through Earth-related research and expanding this knowledge. In addition, this type of research may advance our understanding of the impact of extreme space weather phenomena—such as massive solar storms—on Earth. I am delighted by the fact that a series of research projects I conducted related to auroras occurring on outer planets have been so well evaluated. I sincerely appreciate my coauthors and collaborators for their support.

NICT NEWS 2019 No.5 Vol.477
Published by **Public Relations Department, National Institute of Information and Communications Technology**
Issue date: July 2019 (bimonthly)

4-2-1 Nukui-Kitamachi, Koganei, Tokyo
184-8795, Japan
TEL: +81-42-327-5392 FAX: +81-42-327-7587

URL: https://www.nict.go.jp/
@NICT_Publicity
#NICT

Subscription applications accepted by
E-mail or on the Web site.

ISSN 2187-4050 (Online)