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# NII Today

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FEATURED **TOPIC**

## Next-Generation Wireless Network



**INTERVIEW** WITH

# Yusheng Ji

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# Towards Faster, More Reliable Wireless Networking Available Anywhere

**Suppose for a moment that wireless networking technology has not advanced to its stage today. You'd then realize how much our lives have benefited in such a short time from its development. Mobile phones and the Internet come to mind as prime examples of the use of wireless networking. But, in fact, another major consequence of this technology is growth of Big Data – for example, the gathering of information by persisting sensors without human presence. Professor Yusheng Ji, who brims with visionary ideas even as she tackles a host of technological challenges, describes the current state and future of wireless networking.**

**Yamamoto** Communication networks have become an intimate part of our lives. But there are still many aspects about them that most of us don't understand, due in part of their countless technical terms. Please tell us first how wireless communication differs from wired communication.

**Ji** There are all sorts of electromagnetic waves traveling through space, such as infrared radiation, visible light waves, and X-rays. Of these waves, those with long wavelengths are frequently used to send information, such as radio and TV broadcasts and mobile phone signals. Because data is sent through space by radio waves without the use of wires, it's called wireless communication. With wireless communication, because your device is not connected to a cable, you're not tied to a certain spot. You have the freedom to move around with your device. This makes wireless communication very appealing. But because radio waves spread out as they propagate through space, they fade out, resulting in weakened signal strength. A wave can also be disturbed by another wave, a phenomenon called interference. Another major challenge for wireless communication is that radio waves, by their very nature, have limited bandwidth. Wired communication, in contrast, has advantages where wireless has disadvantages, and disadvantages where wireless has advantages. You can't move around freely with a device connected to a cable. On the other hand, the quality of communication is usually excellent. And, by making cables thicker, you can send a vast amount of information. For example, SINET, the Science Information Network in Japan, has nodes – network connection points – connected by optical fiber cables. Users can have high-speed network service by connecting to SINET with wireline when they are in labs. But when they're outside, they use wireless connections with their mobile devices. Similarly, wireless LANs (local area networks), which have become popular in homes, are playing a greater role in giving users access to the Internet.

**Yamamoto** Mobile phones were once only used for phone calls. I never expected that in such a short time, they would be used to surf the Web and watch video.

**Ji** This has become possible due to the dramatic growth of bandwidth – that is, the amount of information that can be transmitted per unit time. Still, wireless network's capacity is very low compared with that of a wired network. A major challenge is to speed up wireless communication. In my research, I tackle the problem of resource management – how to make efficient use of limited resources such as radio frequencies and the power available at a facility. What prioritization leads to overall efficiency? We also need to keep in mind fairness for all users. We apply mathematical techniques to the problem of optimization. A critical keyword is multiplexing. This means, for example, how to split the


use of different frequencies effectively and how to switch between users in an extremely short period of time, like a millisecond. A technology called MIMO (Multiple-Input Multiple-Output) expands communication capacity by attaching multiple antennas to a device like a mobile phone. It essentially multiplexes space - in other words, reuses space. Mobile devices operate on batteries, so we always need to think about how to improve power efficiency.

**Yamamoto** Until quite recently, calls on a mobile phone were quickly dropped in a moving train. Technology has come quite a long way in dealing with a problem like this.

**Ji** Radio waves are reflected if they hit obstacles. They also become weaker the farther they travel. These phenomena will cause problems during wireless communication. To cover the distance that wireless signals travel over, mobile network operators install base stations. Each station covers a space that is several hundred meters to several kilometers in diameter. We call this space a cell. Cells join up with one another. You can picture a honeycomb structure to visualize the cells' connections to one another in every direction. Now, when the caller in a certain cell makes a mobile phone call, he's connected to the base station at the center of that cell. His partner is connected to the base station of another cell far away. When you make a mobile phone call in a moving train or car, your call is maintained by one cell's switching signals to the neighboring cell as you travel through them. Research is being done on having different sizes of cells and coordination among neighboring cells to keep up with changes in network traffic and environments. And, because base stations consume a lot of electrical power, studies are also considering ways to conserve their use of energy. Ideas include powering down stations during idle periods and having neighboring base stations help out when needed. There are also concepts to build small cells to improve the communication capacity in these cells while carefully avoiding interference.

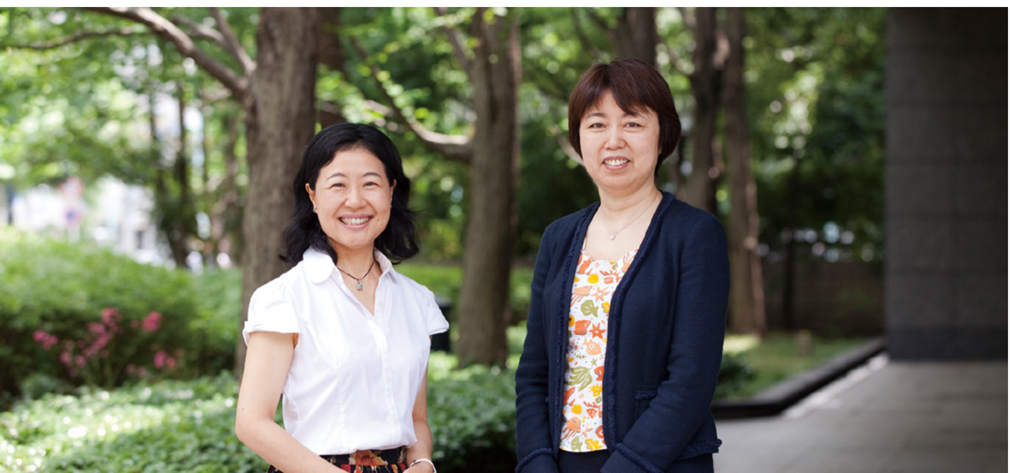
**Yamamoto** There are still plenty of problems that need to be solved. Yet, at the same time, there are many approaches to solving them, aren't there?

**Ji** IEEE is the world's largest technical society. At its international conferences on communication, about 70 to 80 percent of papers presented are on wireless networking. The evolution in mobile telecommunication technology is indicated by "G" (which stands for "Generation"). Right now, we're at 3G and LTE (equivalent to 3.9G), and it's expected that we'll reach 5G by 2020. We will keep sending more and more information with less and less energy, all the while improving quality and reliability.

**Yamamoto** What are some other areas of development in wireless technology besides mobile phones?

**Ji** I'd like to touch on "ad hoc networking." This technology creates wireless connections only when needed without any infrastructure. It's gaining attention as a system that can activate on its own when required, for example during a disaster. It's also expected to make contributions to Big Data, which is the collection of massive amounts of data on a variety of phenomena in society. For example, to monitor the environment, we can drop a bunch of coin-sized sensors from an airplane over a forest. These randomly distributed sensors then take measurements and transmit the results wirelessly, which are then collected and assimilated. To reduce battery consumption, we can design transmission protocols that keep the sensors asleep the majority of the time, and then wake them up periodically to take measurements. To me, superior communication technology means technology that keeps people unaware of the existence of the network. When users are aware, most of the time it's because there are problems. An unobtrusive, transparent presence brings comfort to users. Now, because radio waves traveling through space can be accessed by anyone in principle, allowing users to connect anywhere is not the only issue. Safety and privacy have also become major concerns. At NII, we are tackling these challenges, and working to remove obstacles that we encounter in our information society.

> Superior communication technology means technology that keeps people unaware of the existence of the network.



### A Word from the Interviewer

"Ubiquitous computing," once a popular keyword, means the ability to use computers anywhere. Suddenly, its scenarios have become reality, and I can't help but feel some fear toward this technological development. No matter what area of science or technology, we must be positive as we face a future that takes advantage of these advancements. At the same time, we need to be afraid to some extent. Wireless networking technology, which has become an integral part of our lives, invokes both wonder and fear in us at different times.


## Kayoko Yamamoto

**Editorial Writer and Senior Staff Writer**
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Graduated from the Faculty of Science, Ochanomizu University, and completed a master's degree at the Tokyo Institute of Technology. Joined The Nikkan Kogyo Shimbun in 1990, covering science and technology, business, and university-industry partnerships. She completed a doctorate at the Tokyo University of Agriculture and Technology in 2011, focusing on communication in academic-industrial-government collaborations. Received an award from the Japan Society for Intellectual Production for her achievements the same year. She works as a part-time lecturer at three universities, including the Tokyo Institute of Technology. Ad hoc member of the Ministry of Education, Culture, Sports, Science and Technology's advisory panel on science and technology and academics. Author of "How to Use Communication Media to Increase Research Funding" (in Japanese) (Maruzen Publishing Co.).

# Leveraging Existing PCs and Smartphones
## To Set up Wireless Networks for Swift Recovery from Disasters

**The focus of Professor Shigeki Yamada's research is Resilient Access Networking. This wireless network technology assumes that when a major disaster occurs, existing communication infrastructure fails. Professor Yamada shares the background and current state of his concept. Even in a disaster area where means of communication are severed, the wireless LAN capability of existing PCs and smartphones can be used to restore communication networks by connecting the devices together wirelessly – like beads on a string. Professor Yamada's efforts are heading into field trials, with the goal of practical use in two years.**

### During a disaster, what we need are **prompt restoration of network services and ease of use**

At disaster-stricken areas, the communication infrastructure may be massively damaged. Base stations may lose power, network facilities may be crippled, and networks may become congested. When a major disaster hits, networks are needed the most: to confirm the safety of loved ones, and to exchange information about rescue and aid. Yet, they cannot be used – even though people in disaster areas need them more than anybody else. We need technological developments to relieve us of this dilemma as quickly as possible.

At NII, Professor Yamada is conducting research on wireless networks that can quickly recover when existing communication infrastructure fails during a major disaster. His research is one of the projects launched by the Japan Society for the Promotion of Science (JSPS)'s "Construction of Resilient Social and Life Spaces" program. Following the damages caused by the Great East Japan Earthquake on March 11, 2011, this effort seeks to apply solutions from academic research to major disasters.

Professor Yamada explains the content of his research:

"I have two major goals. The first is to create networks that can swiftly recover even when the communication infrastructure is damaged during a disaster. The second is to create networks that users can use in communication environments they're accustomed to, even during emergency conditions. We call networks achieving these two goals 'resilient networks' – they have the ability to bounce back."

### Connecting existing PCs and smartphones **wirelessly like beads on a string**

If we compare the types of networks to roads, we can say that backbone networks are analogous to major thoroughfares and highways, whereas access networks are equivalent to general roads. The goal of Professor Yamada's project is to quickly establish access networks during a disaster.

Professor Yamada's approach seeks to create networks that function during a disaster by exploiting the wireless LAN capability built into commercial PCs and smartphones. The distance covered by an ordinary single hop wireless LAN is limited to approximately one hundred meters. However, by linking wireless LAN in PCs and smartphones owned by many people confined in disaster areas – like beads on a string – much larger distances and areas can be covered. This technology is called "multi-hop connection."

Resilient Access Network technology is constructed by using wireless LAN functions embedded in everyday PCs and smartphones as the foundation and creating multi-hop connection over them. In disaster-stricken areas where communication lines are severed, connecting many PCs and smartphones in multi-hops makes it possible to restore networks to access to the Internet through

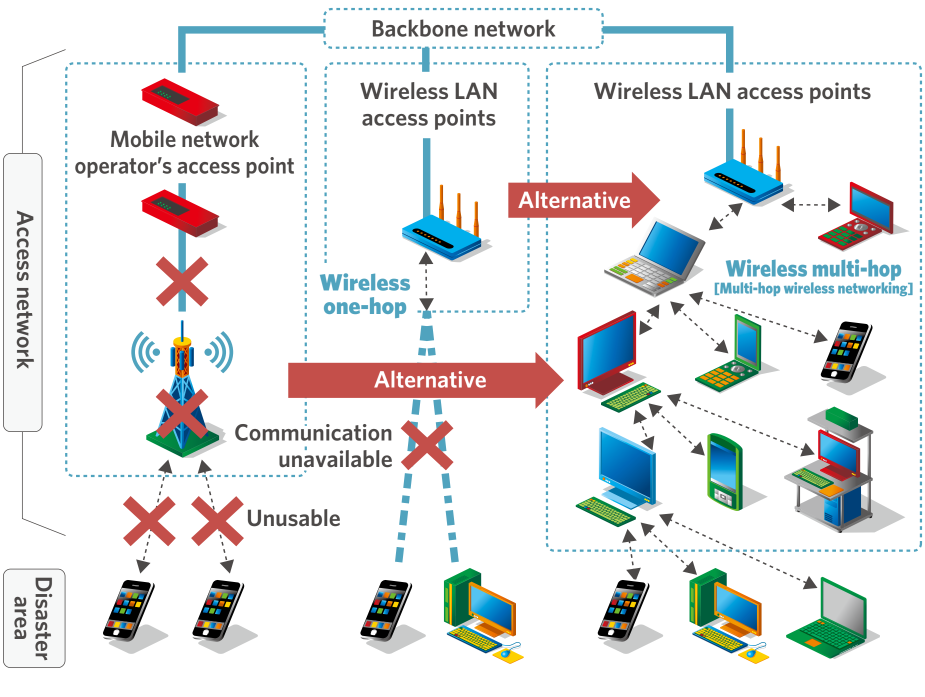


Figure: Basic concept of resilient access network: Wireless + Multi-hop + Virtualization an Internet gateway that "comes alive." The gateway connects users to the backbone network.

There has been ongoing research of ad-hoc wireless networks that connect PCs together without infrastructure. However, the weaknesses of ad-hoc networks include the inability to use wireless LAN functions embedded in commercial PCs and smartphones and the need for special protocols (communication procedures). These drawbacks make it difficult to use these technologies to restore networks during a disaster. Resilient Access Network technology resolves these issues by simply installing software that implements multi-hop connectivity in many existing PCs and smartphones in use today.

Resilient Access Network technology builds up wireless networks with "tree-structured" multi-hop connections (as shown in the figure). Furthermore, this system makes it possible to use existing wireless LAN in PC and smartphone terminals in almost the same way as in the ordinary wireless LAN environment. With such a method, wireless networks to restore communication can be established quickly. This technology seeks to be truly useful - immediately - to people in major disaster areas.

## The challenge is **optimal design of the tree-structured network**

Resilient Access Networks face several challenges. One is how to design and form the network. Performance deteriorates as the number of hops - that is, the number of times beads are connected on the string - increase. Meanwhile, when the physical distance between a terminal (a PC or a smartphone) and another terminal becomes larger, the transmission speed usually drops. Performance also varies depending on how many or how few terminals are connected at each level of the tree structure. Many parameters must be adjusted to design an optimal network. A challenge that researchers must tackle is how the optimal network design can be automated.

Resilient Access Network technology must also deal with circumstances particular to wireless LAN. It must consider the possibility that a smartphone or PC may drop out of the network due to movement by its owner, or because its battery ran out. Adding new terminals must also be taken into account. Resilient Access Networks technology must be able to handle such dynamic reconfiguration of the network.

What's more, in a tree-structured network, network traffic is concentrated near the "root" of the tree structure, resulting in a performance bottleneck. This brings up another issue of this technology: the need to avoid any malfunctioning when introducing a multiple tree structure. And, because an electrical outage during a major disaster may occur just at the time when people really need to use Resilient Access Networks, another major challenge is to keep providing power to PCs and smartphones to keep the network running.

Professor Yamada and his team are evaluating the performance of Resilience Access Networks under a variety of assumed conditions. In July 2013, they used the campus of Iwate Prefectural University to conduct a field trial involving fifteen PCs. Going forward, they will work on making Resilient Access Network technology available for practical use while continuing field testing.

Professor Yamada is studying the feasibility of releasing the open-source software for Resilient Access Networks to the public so that it can be widely deployed by people who need it.

"My goal is to create and release the open software within two years so the general public can use it," Professor Yamada says. He continues:

"I want to help nurture disaster-resilient information and communications infrastructure as a new industry. I hope to deploy systems that benefit the reconstruction of Japan into our society. This philosophy lies behind the reason I began research on Resilient Networks."

Resilient Access Networks, made of PCs and smartphones we already own, will soon be available to us, providing us with a communication infrastructure during emergencies.

(Written by Akio Hoshi)

**Shigeki Yamada**
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# Sharing Wireless Sensor Networks
## A New Approach

**We have just now begun to enjoy services that use sensors to understand conditions of the real world, analyze the massive amounts of data gathered, and provide us with feedback. The infrastructure of these life-easing services includes wireless sensor networks that can be dispersed over a variety of places. Two NII researchers at the forefront of this research discuss their research of this technology.**

### Sharing wireless sensor networks

Wireless Sensor Networks (WSNs) are networks made up of small computers (sensor nodes) that transmit data wirelessly. We can understand phenomena in the real world by dispersing a large number of these sensors over an actual space. Besides measuring such physical phenomena as temperature, humidity, sound, brightness, and vibration, each sensor node also comes with computation and wireless communication functions. A WSN system forms a network with its nodes and transmits gathered information to an administrative server, where it is stored.

Because a WSN is easy to install, it is used especially to monitor wide outdoor areas. For example, it can monitor the integrity of public structures such as bridges and tunnels, observe natural phenomena like volcanic activities and changes in the earth's crust, and track the growth of crops and moisture content of soil in farms.

The XAC Project*1, begun at NII in 2006, seeks to build open WSNs, which can be shared for multiple purposes as an open platform. Assistant Professor Kenji Tei, who spearheads the XAC Project, explains the concept as follows:

"The innovation of the project is its ability to share WSNs. With previous WSNs, you had to install a dedicated WSN for each separate purpose. This made installation costly. So we thought about reducing the cost of developing individual monitoring systems by making it possible to share one sensor network for multiple applications. The vision of the XAC Project is that we'll be able to use a single WSN for multiple purposes as a shared platform for collecting diverse information."

**Fuyuki Ishikawa**
Associate Professor
Digital Content and Media Sciences Research Division, NII

### Distributing limited resources for sensor nodes

According to Assistant Professor Tei, an issue that arises when using a single WSN to observe different physical phenomena is deciding how to allocate resources, such as memory processes, communication capacity, and battery power:

"When we install a WSN in a room and share its use for different purposes - for example, to manage the room temperature and lighting and to prevent crime - we must decide which sensors will be used for what purpose. We also need to make adjustments to the method of allocating resources while the network is actually running. For example, we assign sensors in an area of a certain scope to crime surveillance. But once a suspicious phenomenon is observed, we bring sensors in the vicinity to bear to observe it in greater detail. In a case like this, we need to create a system that flexibly redistributes and optimizes resources, for example, by reassigning sensor nodes for managing room temperature or lighting - a low-priority task - to the task of crime surveillance." In other words, the WSN optimizes its battery resource and monitoring precision by redeploying sensor task groups to a different purpose.

We also cannot neglect the fact that wireless communication, the technology underlying WSN, has its own inherent issues, such fast consumption of battery power and the tendency to drop data due to unstable transmission. To handle these problems, besides improving the capabilities of wireless communication itself, Assistant Professor Tei and his team are also designing software that automatically adapts to changes in the environment. It determines the optimal timing and path of data transmission on its own so that the sensor nodes can gather data stably and provide highly reliable information.

Assistant Professor Tei says, "The operations of WSN

**Kenji Tei**
Assistant Professor
Information Systems Architecture Science Research Division, NII

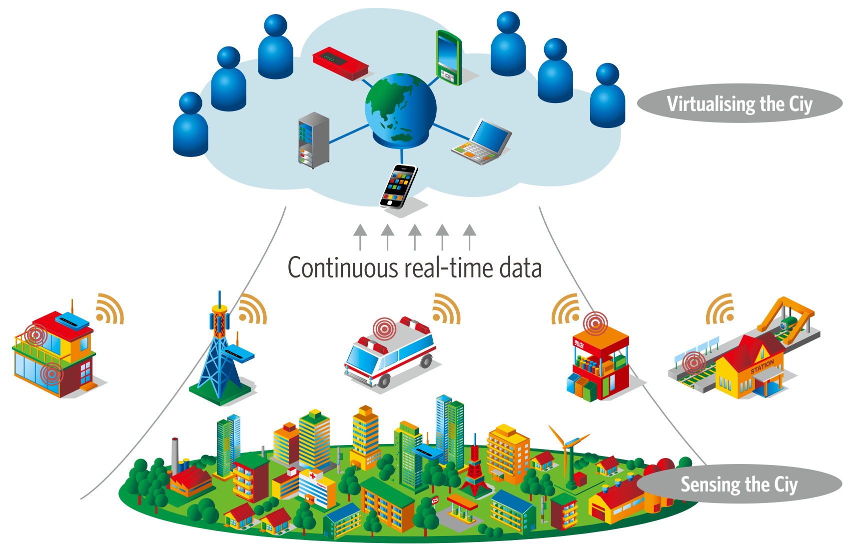


Figure: Overview of the project. The goal is to make it easier for individuals to easily obtain the information they want as a result of research that turns WSN into a shared resource to provide information that can be converted and linked.

applications are distributed across the wireless network, so the programs naturally become complex. They're extremely difficult to write." To address this problem, he has developed middleware for application programmers. Middleware is a set of software services that connect the operating system, which controls a computer's basic functions, with applications. This allows programmers to focus on developing programs that are essential to WSN processes, such as measuring and collecting data.

## Freely connecting, transforming, and utilizing all information

The XAC Project has already completed its development of basic technologies. The next step is to produce actual applications. This effort has begun. The "ClouT Project"[*2] is handling field testing of the applications.

The ClouT Project, begun this fiscal year, seeks to provide new network services to residents living in cities by integrating the physical network and the cloud. This project is being implemented under FP7[*3], a program that manages Europe's largest competitive grants. An organization of nine European and Japanese research institutes, universities, and companies, and four cities (Santander, Spain; Genoa, Italy; and Mitaka City and Fujisawa City in Japan) are participating in this project. Large-scale trials are being conducted in each city. Associate Professor Fuyuki Ishikawa, who leads this project NII together with Assistant Professor Tei, explains:

"The ClouT Project's name comes from the idea of a 'cloud of things.' It is a network where all sorts of things are connected. In other words, the name expresses the project's purpose of gathering and utilizing information from the real world. The word 'clout' also means the ability to influence. So the project's name includes the hope that the project will strengthen the influence of citizens and make their lives richer and more convenient. For example, let's imagine a train station. In that place, there's a lot of information, like data from wireless sensors measuring the station's congestion, announcements from the railway company, and Twitter messages from commuters. What's more, the sources and formats of the information are all different."

Associate Professor Ishikawa continues: "These sources of information are captured by every sensor. The data from the sources can be assimilated and homogenized to provide a service - say, a service[*4] to find out about the station's congestion. Each information source can also be used in different ways to provide different services. If information can be used as a software component, it can be used to create different applications. These could be apps for dealing with the daily rush hour or everyday congestion or congestion due to special events, or for responding to disasters."

In other words, applications that benefit each individual can be created by processing myriad amounts of information as described above, combining them, and utilizing them in the real world through a variety of media, such as electronic billboards and informational e-mail.

Actually, even before the ClouT Project began, the city of Santander, Spain, had been conducting field tests. Currently, there are about 20,000 sensors placed in the streets. The information from the physical sensors can be used like information from the Web. One research project being conducted use the different information as components that software can freely connect and use in different ways.

"Going forward, I want to make life more convenient for people by connecting real-world information to the Internet so residents can understand the conditions of their city," says Assistant Professor Tei.

He continues, "What's more, we're seeking to create technologies that will allow people in their cities to freely and easily build applications that gather the information they want. The results of the field trials being conducted now will be applied to other cities around the world in the future."

Sensor technologies developed in the XAC Project are being introduced into the field in the ClouT Project. When wireless sensor networks are incorporated into cities, allowing movements of things and people to be visualized and information to be freely used, our lives will undoubtedly become richer.

(Written by Akihiko Hoya)

***1: XAC Project**
Abbreviation of "X-Aware Computing." It means technology that is aware of diverse information X, including users' conditions, and processes the information based on this awareness.

***2: ClouT Project**
Its formal name is "Cloud of Things for empowering the citizen clout in smart cities."
Project website: http://clout-project.eu/

***3: FP7**
The Seventh Framework Programme for research and technological development seeks to improve Europe's overall international competitiveness and technological capabilities. It is an important part of the European Commission's policy for funding research activities in the continent.

***4: Service**
Here, "service" is used as a technical term to indicate "component(s) used by software." A program that provides information from one sensor is a service, as is a program that combines different "services" together, and looks just like software used by general users.

# Immersive inter-personal visual communication

Video and voice communication between distant locations – video conference, to take an everyday example – is now commonplace. However, while one party can see the other's face clearly on a display monitor, they cannot converse eye-to-eye (gaze mis-match), resulting in an unnatural communication experience. Can communication between distant locations be realized with a realistic sense of your partner's presence, as if he is sitting right in front of you? A collaborative effort between researchers in multimedia information processing and networking technology, including wireless communication technology, is seeking to answer this question.

## Non-verbal elements make up more than 60 percent of communication

Maintaining eye contact while one is talking to another person is a basic manner during a conversation. Further, when we communicate with another person, we perceive much more than what is spoken. Specifically, we also perceive non-verbal elements, such as eye contact, subtle changes in facial expression, the tilt of our head, and body and hand gestures.

According to Associate Professor Gene Cheung, a researcher in interactive multimedia communication at NII, "more than sixty percent of communication between tw people takes place with non-verbal elements."

He elaborates: "When you desire mutual understanding in a conversation or a meeting, it's best to communicate face-to-face with your partner. However, to reduce monetary cost and the carbon footprint, it is essential to have means of communicating remotely, like video conference systems. So my team is conducting research into building multimedia telecommunication systems that achieve almost the same immersive experience as directly meeting a person, even when you can't. In other words, we're integrating multimedia and telecommunication technologies to create interpersonal communication systems that bring you and your partner's presence into the room when you communicate."

## Visual Immersion: "in the same room" experience even when participants are physically far apart

The sense of presence being considered by Associate Professor Cheung means the ability to have the same ultra-realistic visual experience as if your partner is sitting across the same room as you. This includes making eye contact during conversation, and being able to see the background behind your partner when you tilt your head – a visual effect commonly known as motion parallax. He considers the ideal to be the ability to perceive your partner and his surroundings as 3D objects, just as in real life, and to feel that he is really sitting across the desk in the same conference room as you.

Speaking of 3D images, we are now familiar with them, thanks to 3D movies now common in theatres. However, because 3D movies are really filmed with two fixed cameras – one to produce images for the left eye and one to produce images for the right eye – if one shifts his head in an attempt to induce a different viewing perspective of the scene, it is not possible because the same two captured images are still presented to one's eyes.

What Associate Professor Cheung is pursuing is completely different. His system changes perspective of the rendered images in real time corresponding to the observer's movements. It detects the line of sight and features like the head portion of the person looking at the images. Based on these

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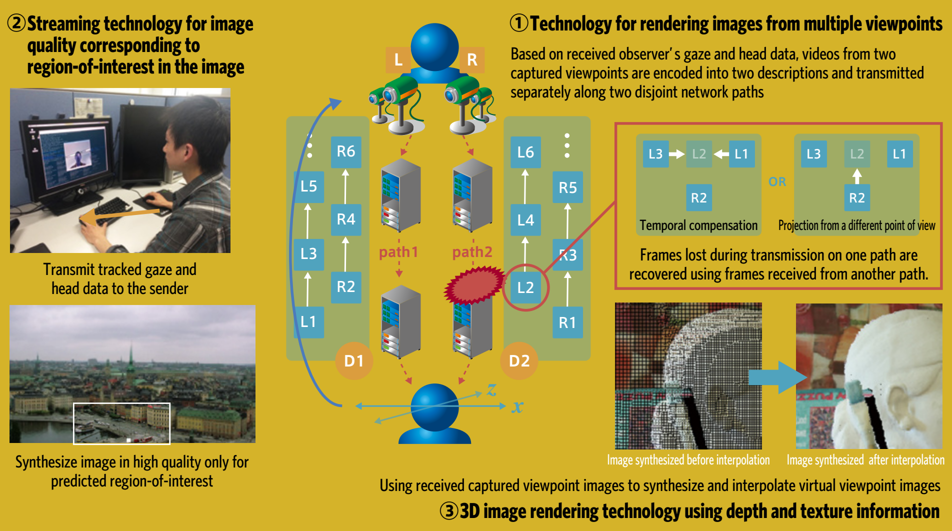



The three technologies being developed by three students at the Graduate University for Advanced Studies, with their comments.

① The challenge is to implement the system for rendering high resolution images only for the area of interest within the limits of wireless bandwidth. (Mr. Liu)

② Even if you can track and predict a single person's gaze location, it becomes difficult when there are several conference participants. I'm working on this challenge right now. (Mr. Feng)

③ I'm dealing with how to render transmittable images that don't feel unnatural from reality given the limits in the data volume that can be sent. (Mr. Mao)


conditions, the technology instantly constructs more realistic 3D images, so that the viewpoints from which the images are rendered change, and you can see the background behind your partner becoming visible as you move your head. To achieve these features, what are needed are two-way interactivity and processing at speeds to the extent that you don't feel any sense of unnaturalness compared with face-to-face conversations.

The bottleneck to realizing such a system is the large amount of data that must be transmitted on the network. Professor Yusheng Ji, who is conducting research on networking technology, observes, "We are usually exposed to insufficient network bandwidth for transmitting multimedia data, including 3D information. It's even tougher with wireless networks."

She continues, "In communication networks, especially wireless communication, you always have delay and packet loss - time lag and the loss of data. To enable communications with a high level of presence under such restrictions, what we need are efficient data compression/reduction technologies, and multimedia streaming technologies that can produce realistic 3D images even if there is little bandwidth available or a portion of the data is lost."

## Three advanced imaging technologies for communication with presence

Specifically, Associate Professor Cheung and his team are working on the following three advanced imaging technologies:

**① Technology for rendering images from multiple viewpoints**

If separate network path experiences packet losses or delay, using multiple paths will alleviate the adverse effects. Given that multiple cameras are required to capture a 3D scene of interest from different viewpoints for rendering of any intermediate virtual view, one can choose to encode multiple viewpoint videos into multiple descriptions and transmit them on different network paths, so that if packet losses corrupt one description in one path, delivered video frames in the other description in the alternate path can be used for loss recovery.

**② Technology for bitrate reduction based on region-of-interest (ROI) video encoding**

It is known that humans' ability to discern details in a spatial area of an image deteriorates precipitously as the distance between one's point of visual focus and the area increases. Thus, one can reduce overall video bitrate without any drop in perceived visual quality by encoding only the spatial area containing the observer's point of visual focus (called region-of-interest (ROI)) in high quality and all other areas in low quality to save coding bits. However, performing ROI video encoding means the encoder must know the gaze location of the observer in real-time, which is not possible in a network streaming scenario where tracked gaze data at observer is transmitted to the video streaming server over a data network, incurring one round-trip-time (RTT) delay. To overcome this RTT delay, gaze location of the observer one RTT into the future is predicted for ROI video encoding. Because this technology can transmit images by lowering the encoding rate of spatial regions outside the ROI, it makes more efficient use of precious network bandwidth. These techniques make it possible to reduce the bit rate by 30 to 40 percent.

**③ Technology for rendering viewpoint 3D images using depth data and texture information**

Multiple cameras must be set up to capture images from a variety of viewpoints. However, the volume of data becomes too large if the images are compressed as-is. Therefore, Associate Professor Cheung and his team are considering techniques to send images carrying only color and depth data, taken by a relatively fewer number of cameras. If appropriate images can be formed by detecting the angle of the receiver's line of sight and interpolating from the received data, then natural 3D images can be created even with a small amount of data. For example, when the observer moves his head closer to the 3D scene, or shifts his head slightly left or right, the technology does not request image data in response to these changes. Instead, it interpolates the missing pixels using the data available on the receiver's side.

Associate Professor Cheung says, "Immersive communication technology means that you feel as if your partner on the other side of the screen is right there in front of you. It's promising not just for developing video conferencing systems. For example, if an autistic child gets nervous facing a counselor on a video display, he may open up to a computer-generated anime character appearing in front of him instead. I also anticipate such technology being applied to telemedicine. It will change the way we communicate as humans."

Start dreaming big about immersive communication technology, which makes interpersonal communication that transcends distance a reality.

(Written by Masahiro Doi)

# Next-Generation Wireless Networks
# Accelerating Research Thanks to International Exchange

**As mobile communication devices such as smartphones and tablets proliferate, wireless communication networks continue to evolve. Currently, the marketplace is seeing the expansion of LTE, a shift towards 4th generation technology (4G). Research and development of the next-generation wireless cellular network (5G) is speeding up internationally. Professor Fuqiang Liu of Tongji University in China (NII visiting professor) and NII's Professor Yusheng Ji discuss the state of international R&D and trends in international exchange and collaborative research.**

## Unresolved issues still remain as **3G yields to 4G**

Until just several years ago, most users connected to the Internet from their PCs with a fixed cable. The past few years, however, have seen a vast increase in the demand for mobile Internet connectivity as mobile communication devices like smartphones and tablets jump in popularity. As a result, more advanced functions and higher quality are being expected of wireless communication networks. They include the ability to connect any devices anywhere, anytime, and the ability to use services and applications with ease on the network.

In Japan, LTE continues to spread after the adoption of 3rd Generation (3G) technologies. LTE - technically 3.9G - plays a "stopgap" role until 4G networks are completed. LTE networks have a downstream (from base stations to mobile terminals) transmission rate greater than 100 Mbps, and an upstream (from terminals to base stations) rate greater than 50 Mbps.

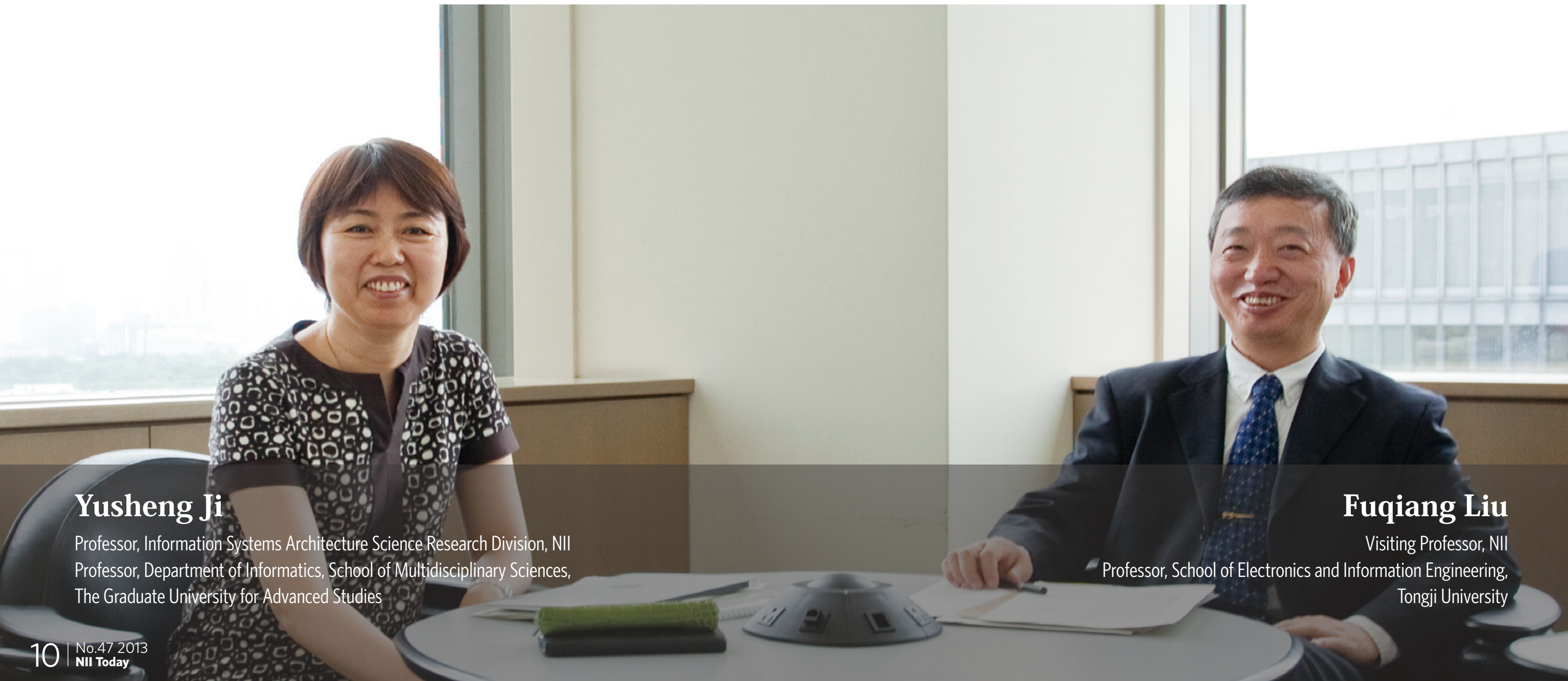
What is the state of wireless communication networks in different countries around the world? Professor Liu comments on the state of affairs concerning 4G:

"4G is at the stage of being widely adopted, including in Japan and China. Still, not all of 4G's issues have been completely resolved at this point. There are still issues concerning relay technology and MIMO (Multiple-Input Multiple-Output) technology, which increases the communication capacity by using multiple antennas in the transmitter and receiver. In addition, work has just begun on D2D (Device to Device) technology, which allows devices to communicate directly with one another without transmission by base stations."

R&D efforts on 4G began about 15 years ago. International standards were determined by the International Telecommunication Union (ITU) in 2010, and the spread of 4G began around last year. It has indeed been a long journey for the commercialization of a single technology. Research and development has begun on the next-generation wireless cellular network,* called 5G, in countries around the world.

## **Countries around the world** are starting 5G R&D projects in rapid succession

Although deliberations to establish international standards



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Professor, School of Electronics and Information Engineering, Tongji University


**Mr. Pedro Chaparro**
**(Universitat Politècnica de València, Spain)**

"My research is on relay node selection in cooperative communication. I'm very thankful to be given the opportunity to come into contact with different cultures and learn cutting-edge, world-class research."

**Ms. Tachporn Sanguanpuak**
**(Asian Institute of Technology, Thailand)**

"I'm developing algorithms for optimizing resources in cooperative communication. This program is highly significant for me. I'm having a great experience thanks to the cooperative research spirit in this group and guidance from wonderful professors."

**Mr. Wei Luo**
**(Tongji University, China)**

"I'm working on cooperation between cells to effectively build heterogeneous networks. I'm very happy to have many chances to come into contact with ways of thinking different from my own, for example through NII professors' guidance and listening to lectures by world-class researchers."

**Comments from interns in Professor Ji's lab at NII**

for 5G have not yet begun, we can say that the targets are an approximate 1000x increase over 4G's capacity and energy efficiency. We are entering the era of the gigabit, where transmission rates enter the range of several 10 Gbps. In the past year or two, acceleration of 5G R&D has begun in different countries around the world.

Professor Liu says: "In the EU, major telecommunication companies like Ericsson have turned their attention to research. In addition, in just the fourth quarter of the last fiscal year, more than twenty EU-supported partnerships have been formed inside and outside the union. This shows just how far international cooperation is advancing. In the U.S., Qualcomm and Intel have partnered to conduct basic research on 5G. This alliance shows the future of the further integration of communication and PC."

In Japan, this past February NTT DOCOMO and the Tokyo Institute of Technology conducted experiments toward realizing ultra-high speed mobile communication. They succeeded in transmitting upstream packets with a maximum speed of 10 Gbps, a world first. In China, Professor Liu has started a 5G project at Tongji University in which communication is applied to reduce traffic accidents and congestion.

As the Tongji University project - which focuses on applying 5G to vehicle traffic - shows, 5G's strength in applications is one of its features. Professor Liu says that there is another critical element to building application services:

"In the field of communication networks, the emphasis until now has been on QoS - quality of service - in other words, on performance issues like transmission speed and packet loss. Going forward, we'll not just pay attention to QoS, we'll also start paying attention to QoE - the quality of users' experience. There's an emerging need to quantify users' subjective evaluation, such as a network's usability and convenience when using its applications and services, and to incorporate this data in the design of networks."

In addition, when switching from 4G to 5G, it is more important than ever to build heterogeneous networks. This means networks with a variety of different communication formats, including wireless standards (e.g. mobile communication standards and Wi-Fi) and wired and machine-to-machine communication, such as sensor transmissions. A critical point going forward will be the integration of these diverse networks and using them to provide user-friendly services to people.

## International cooperation to establish 5G standards is brewing

For the research and development of next-generation communication networks, even as countries and regions compete, many international exchanges and joint research efforts are also taking place. What is the significance of international cooperation? Professor Ji explains:

"Communications arise as a result of human beings' working with each other. Therefore, international information exchange is essential to producing even greater results. It is especially difficult to accomplish standardization of technology without cooperative relationships between many countries."

Initially, wireless communication network standards differed by country. However, with 3G, four international standards were approved, and 4G received approval for two international standards. With 5G, a unified international standard might be expected. In this process, it is critical that countries create cooperative research frameworks not only with neighboring countries, but also with different countries around the world.

Still, nailing down the specifics of 5G will take several years. It is expected that standardization will be completed around 2020. Commercialization will be then be finalized several years after that.

Professor Ji says: "The development of technology takes time. Technological development does not take place simply by extending an existing technology to a certain level. Sometimes, there is a breakthrough that gives rise to completely new technologies. I anticipate that 5G R&D will bring about such a technological revolution. For example, researchers in the field of communication simply can't achieve 5G's goals of energy efficiency by themselves. If we expand the application of 5G, then developers of smart cities can become involved. Technological innovations that create more comfortable communication environments come from exchanges with specialists in diverse fields, including the basic sciences, which produce new fundamental theories."

To advance international exchange with overseas universities and research institutes, NII has signed memorandums of understanding (MOU) with 78 institutes in 24 countries. Twice a year, interns are accepted for internship programs lasting two to six months. These programs take in more than 120 foreign researchers per year. NII also has a system called "MOU Grants," which extends invitations to overseas faculty. Since 2005, NII has been engaged in vigorous personnel exchange with Tongji University.

Professor Liu says: "Until now, professors from Tongi University have been sent to NII a total of fifteen times, along with twenty-nine interns. Meanwhile, Tongji University has welcomed NII professors nine times and has taken in two NII interns. Wonderful achievements were produced each time. We wish to engage in exchange with more countries in the future so we can realize major technological innovations."

Having an international outlook and coming up with ideas from multiple perspectives are now essential for researchers. Precisely because we have diverse methods of communication, we will be able to realize a new era of networks where anyone will be able to use mobile devices with comfort and ease, anytime, anywhere.

(Written by Yuko Sakurai)

***: Wireless cellular network**
Wireless communication system in which base stations are each placed in divided areas called "cells" to transmit communication signals.

NII Essay

# New Collaboration between Ubiquitous Computing and Big Data

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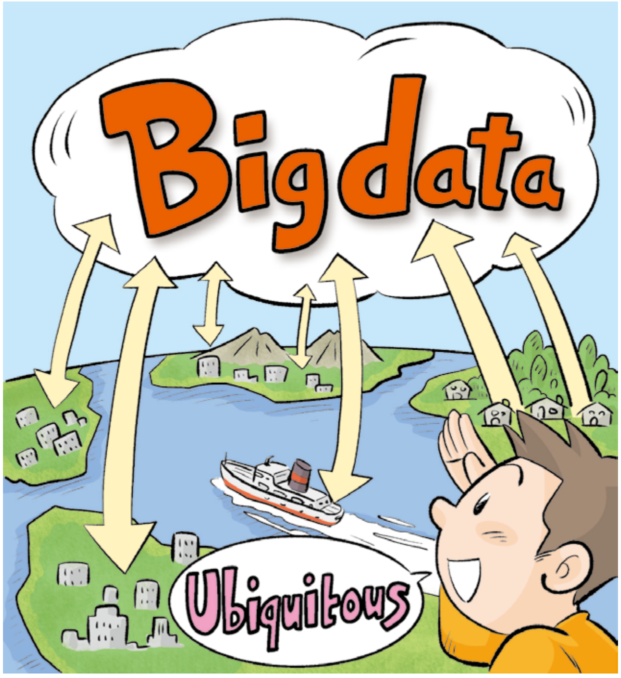


About ten years ago, the word "ubiquitous" was in vogue in Japan's ICT world. It represented the concept of creating ubiquitous connections that link not just people, but all things in the real world. The goal was to provide optimal services anytime, anywhere, in response to real-world conditions, including those of people, objects, and the surrounding environment. At the time, Japan led the world in mobile Internet services, as exemplified by 3G mobile phones and DOCOMO's i-mode service. It sought to lead the world as a trailblazing, advanced mobile technology country.

Research and field trials were conducted with enthusiasm. However, there were still not enough devices that could be connected to real-world objects, and the wireless environment could not bear the weight of demands placed on it. Computational infrastructure that could carry out processes economically was not in place. As a result, services could not get a viable commercial foothold. Technologies labeled "ubiquitous" and policy discussions about ubiquitous computing became things of the past.

Meanwhile, when we look at the rest of the world, we see that changes in information technology during the past ten years have been dramatic. The U.S., which leads the IT field, has made great strides in the area of mobile devices. U.S. companies are making use of computing clouds to economically process massive amounts of data. Silicon Valley entrepreneurs are launching context-aware mobile services, based on the understanding of people and conditions (time and place), one after another. Lightweight, energy-efficient communication systems that connect devices in the real world, called the "Internet of Things" and "M2M (machine-to-machine)," are closing the distance between the information space and the real world. The creation of value in the real world, imagined a decade ago by researchers and engineers in Japan under the rubric of "ubiquitous," is actually now being demonstrated.

While Japan had been preoccupied with building devices and networks as "limbs" and "nerves," the rest of the world took the approach of processing the real world's big data, which represent the "brain," and claimed one success after another. Japan has outstanding wireless and device technologies that support ubiquitous computing. We also have experience in understanding diverse technological and commercialization challenges. The word "ubiquitous" is no longer trendy. However, the now-or-never chance to reclaim Japan's innovative power has come, even though we have been late. We will do this by offering new value through the total linkage of devices and networks. We must actively advance open research activities by joining forces with industry and by involving users.

Weaving Information into Knowledge

NII

**Cover Illustration**

The frequencies of radio waves are likened to undulating ribbon tapes. The ends held by the angels depict the frequencies assigned to wireless communication. The angels swoop in flight to bring the assigned frequencies to places needed by wireless communication. The radio waves support the advanced wireless technologies that make anywhere, anytime connectivity possible.

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