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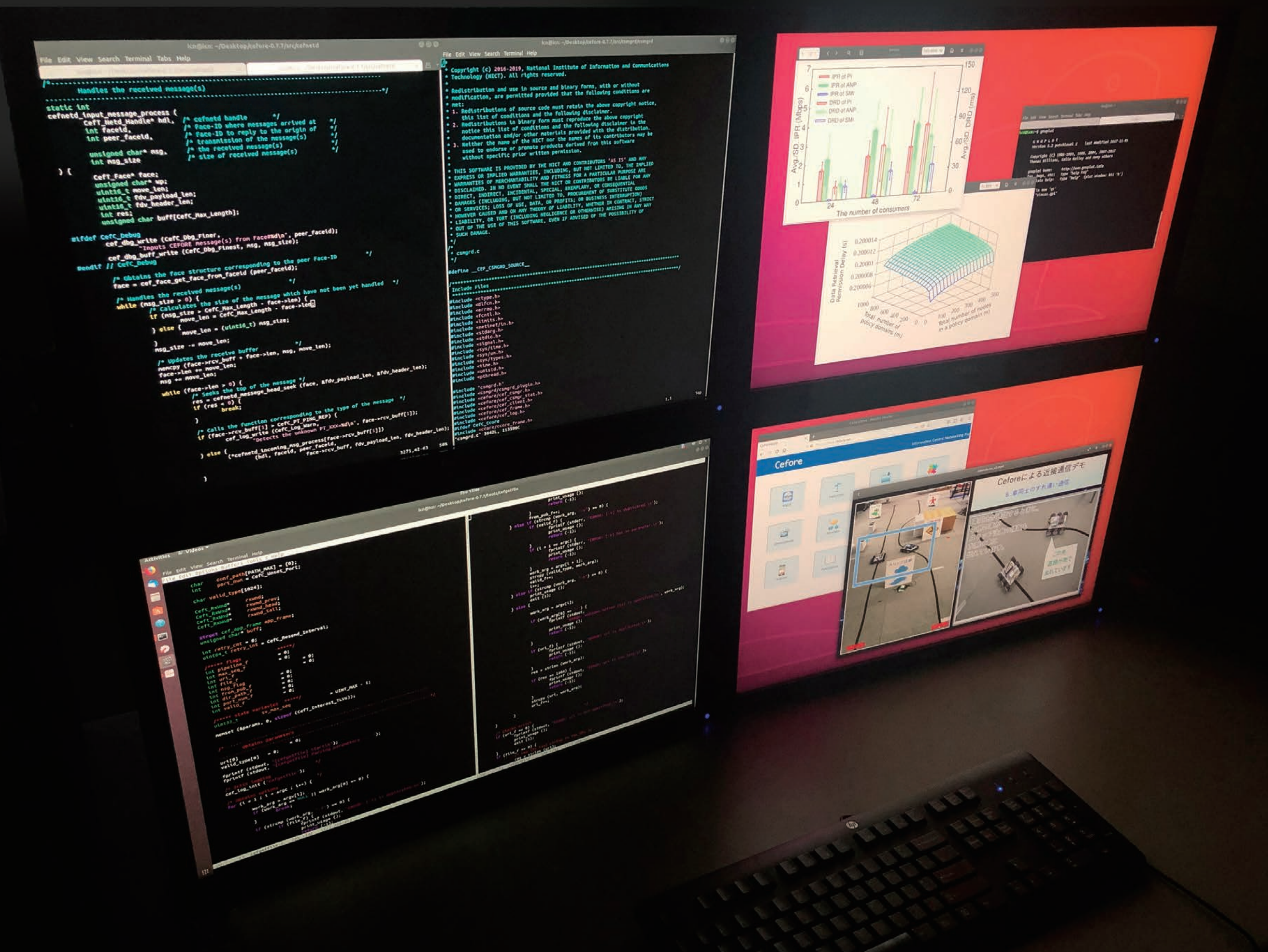
FEATURE

Innovative Networking Technologies to Support Future Society

Interview

Toward the Realization of More User-friendly Network Services



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FEATURE

Innovative Networking Technologies to Support Future Society

TOPICS

Cover photo:
The photo on the left (black screen) shows the Cefore source code. The photo on the right (red screen) shows the website of Cefore (open source) that realizes Content-Centric Networking and a demonstration video of near-field communications through mobile robots installed with Cefore, as well as the graphs given in the Cefore experiments.

Upper-left photo:
Server machines hosting Autonomic Resource Control Architecture (ARCA) system. ARCA exploits AI for the automation of network control functions that perform the elastic adaptation of resources in virtual network slices, enabling them to satisfy the requirements of dynamic network services effectively with a limited amount of resources.

Interview

Toward the Realization of More User-friendly Network Services

Network System Research Institute

Use of the Internet had previously been limited to education and research purposes, but about 30 years have passed since its commercial use became widely accepted. Now the Internet has become an indispensable part of our lives and work.

However, the core technology of the Internet has remained largely unchanged from before. It is basically a form of one-to-one communication carried out through Internet protocol (IP). Today, however, the communication environment surrounding information services has changed significantly from 30 years ago. In addition to the Internet of Things (IoT) that connects a vast number of objects through the Internet, the emergence of ultra-high-definition 4K video, 5G mobile communications that is fast, ultra-reliable, and with low latency, and other technologies have not only increased the volume of information to be delivered over networks, but also dramatically raised the level of communications quality demanded by users.

What we need in this era is a completely new and innovative network technology that goes beyond conventional concepts of one-to-one communication between two end devices. Below are the excepts from the interview with Research Executive Director Hiroaki Harai of Network System Research Institute and Executive Researcher Hitoshi Asaeda of the Network Science and Convergence Device Technology Laboratory about the latest trends in networking technology.

Hiroaki HARAI (left)

Research Executive Director

Network System Research Institute

He started his work carrier at NICT (formerly CRL) in April 1998 and is now also serving as Director General of ICT Testbed R&D Promotion Center. His current interests are R&D on automatic construction and control of virtual networks and promotion of social implementation of information and communication networking technologies. He holds Ph.D. in information and computer science.

Hitoshi ASAEDA (right)

Executive Researcher

Network Science and Convergence Device Technology Laboratory

Network System Research Institute

Prior to joining NICT, he was with IBM Japan, Ltd., a research engineer specialist at INRIA (France), and a project associate professor at the graduate school of Keio University. He joined NICT in 2012, and is engaged in the research and development of network protocols, as well as IETF standardization activities. He took up his present position in 2018. He holds a Ph.D. in media and governance.

——How has the technology required for the Internet changed over the years?

HARAI: For the Internet, IP addresses of computers, servers, or other communication devices are used to create the networks. The IP addresses assigned to servers and other communication devices in the Internet correspond to their locations.

However, the number of devices that connect to the Internet has increased rapidly, resulting in a vast volume of information and network traffic. In the future, the number of IoT devices that are connected to the Internet, as well as the types of services offered, will probably increase further at an accelerating pace.

For example, approximately 15 billion devices were connected to the Internet in 2015, and this is expected to double to 30 billion devices by 2020. On the other hand, Japan's population is on the decline due to its falling birthrates. The population of people aged 15 to 64 was about 75 million in 2015, and is predicted to fall to 67 million by 2030.

While the number of devices connected to the Internet and network traffic is growing, the pool of human resources is, conversely, shrinking significantly. In order to ensure that network services can be carried out smoothly with the limited resources, there is a need to explore new methods for using and controlling network and server resources efficiently and effectively. It is also vital to think of methods for automating resource control and management actions in the event of Internet traffic congestion or service outages.

In addition to conventional devices that are fixed in place, there will be an increasing number of devices that are designed with mobility in mind, such as smartphones and IoT devices. Information, too, will be generated not only from fixed locations, but will be generated and exchanged by mobile devices. Furthermore, the information itself will be utilized as big data. We are entering an era of mobile-centric network services.

That is why there is a need for new net-

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work design and network technology that can offer services at a quality that can satisfy users, while matching the trends of device mobility and the generation of a wide variety of contents. For example, if a 4K video starts breaking up and gets interrupted while the user is watching it, it would leave a bad impression on the user. To eliminate such problems, the method adopted to date has been to increase the bandwidth of the communication lines, or in short, to speed up the communications channel. Going forward, however, employing this method alone would not be sufficient; instead, it is becoming increasingly necessary to develop new technology that stores data in the network during the data forwarding process and automatically searches for an optimal and efficient route.

What is an innovative network?

——Is it not possible to support such developments with Internet protocol (IP)?

ASAEDA: The innovative network that we are aiming for seeks to bring about the realization of the high-quality, low-latency network services that we need now, as well as in the future, with greater efficiency and energy-saving, and with safety and stability (Figure 1). To achieve that, there is no need to be constrained by the restrictions of conventional communication methods.

Of course, IP is the starting point of the Internet, and replacing it with something new is not the purpose of the research. The aim of the innovative network is to develop network technology that can serve people in a more user-friendly and convenient way, regardless of how IP is used.

——What are the component technologies used for an innovative network?

ASAEDA: There are two main types of technology that we are currently conducting research on. These are, namely, technology to automate the configuration and control of networks, and information-centric or content-centric networking technology (ICN/CCN*1).

Apart from these two major pillars, we are also conducting research on related technologies, such as edge computing and optical network fusion technology.

Technology to automate the configuration and control of networks makes use of artificial intelligence (AI) to control networks. Such a system monitors the communications traffic and status of network resource usage, and when it detects specific services consuming a large amount of resources, automatically reroutes the service to a different route or carries out resource adjustment. In such situations, the AI decides on the optimal action to be taken in real-time while observing the traffic volume and resource usage patterns of communications services.

The second form of technology is ICN/CCN. To acquire information or content from the network, ICN/CCN uses the name of the content rather than the IP address as the communications identifier.

ICN/CCN makes use of the cache of information or contents that is saved in a decentralized manner, such as in a nearby router, to acquire contents. By doing so, it is able to carry out data transfer quickly not only from servers and clouds that may be located far away, but also from those caches that are located nearby. As a result, it is able to reduce communication latency and avoid the deterioration of service quality.

—— Apart from the original project, what are some of the other research and development initiatives that have been launched recently?

HARAI: The research and development project on innovative AI network integration platform technology, under the Ministry of Internal Affairs and Communications, is one such initiative. It involves the application of the automation of network management and control, which has been conducted jointly with KDDI Research, Inc. The research is carried out on the technology that makes it possible to configure a network very quickly by allocating the necessary amount of re-

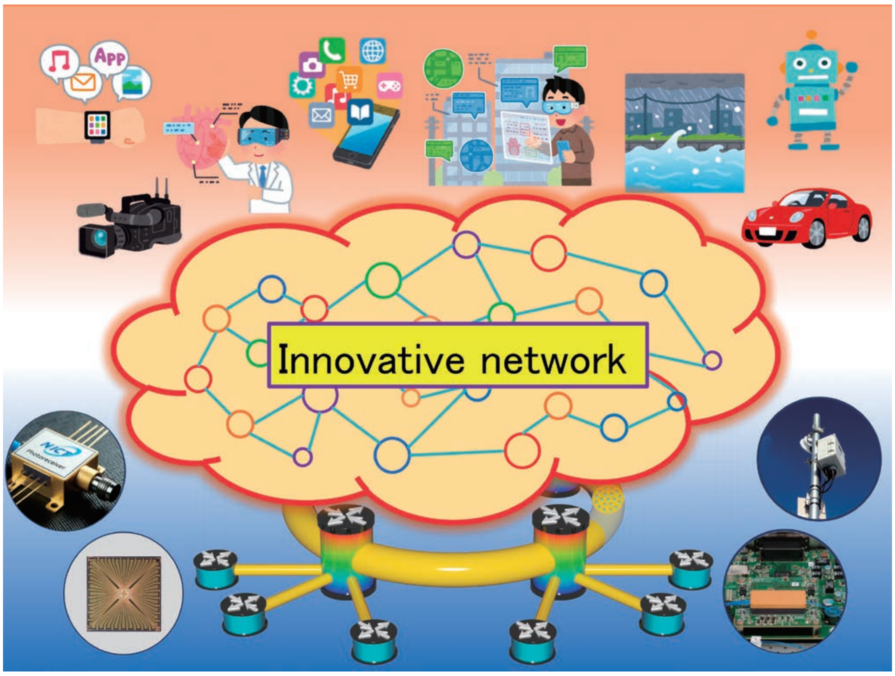

Figure 1 An innovative network is a network technology that connects various applications and services with the latest optical networks and devices to support the lives of people.

sources. Such technology is able to adjust the resources beforehand by predicting increase in traffic as a result of network congestion, movements of people carrying mobile devices, or occurrence of new events.

Research is also being carried out on a system that can arbitrate resource allocation without having an impact on the overall network (refer to Figure 2 on page 7).

For example, assume that a wide variety of data is flowing through a network, and some routers or servers become congested for some reason. As there is a threshold for users' dissatisfaction with a service, we aim to create a technology that can identify the related parameters before that threshold is reached, and determine within 10 seconds the amount of resources to be added by generating it from the available places.

Our research covers not only the adjustment of resources, but also covers service function chaining technology, which connects the functions of services in a chain. Our research aims at adapting such technologies successfully to achieve the appropriate diversion of resources.

Standardization and open-source initiatives

——How about initiatives in the area of standardization, the development of open-source, and approaches toward the social implementation of technologies?

ASAEDA: We are actively engaged in standardization activities through international standardization organizations such as IETF/IRTF*2 and ITU-T*3. Through industry-academia collaboration and joint research, we also plan to carry out activities such as validating the interoperability of specifications defined by the standardization organizations.

As for activities in the area of open-source, we have developed and released "Cefore," a communications software that realizes ICN/CCN. This was developed from scratch (newly developed) by our Laboratory, and can be freely downloaded and used by anyone not only in research institutes but also commercial companies (Figure 2).

We believe that such standardization activities and open-source development are important missions for us as a national research institute that emphasizes the social implementation of technologies.

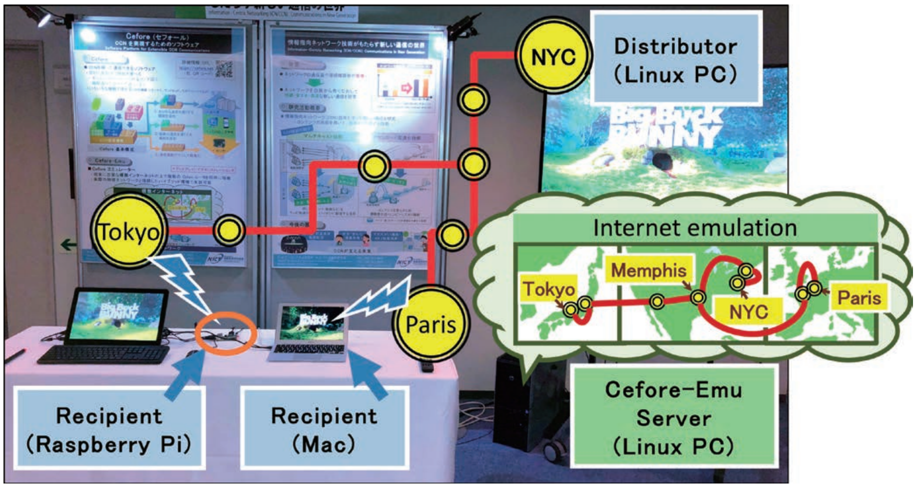

Figure 2 An experiment that involves building an emulation of the Internet on an emulator with Cefore incorporated (Cefore-Emu), and receiving live-streaming from New York by Cefore nodes in Paris and Tokyo via wireless access points.

Research direction

——What is the research direction of the Network Science and Convergence Device Technology Laboratory?

HARAI: We are currently conducting research on automation of network configuration and control functions, together with people from various organizations. We have also released Cefore as a CCN-based open-source software system, which is freely available to everyone for demonstration and validation purposes. In the next 10 years or so, we aim to establish fundamental technology for the realization of the complete automation of network configuration and control.

ASAEDA: Our research cannot progress beyond the transmission speed limits of devices, such as optical fibers and routers. Our mission is to develop technologies that can extract the maximum communications quality and speed within the physical limitations, and provide many users with a wide range of applications in a stress-free and dependable way.

When people are asked about "network technologies," they usually imagine physical devices or application services. Nevertheless, it would be great if the network protocols and software are also attracting a lot of attention as they are the center of the network technology to connect applications and devices effectively. All services that use networks cannot be viable without using the communication services provided by network protocols.

As the sole national research institute that specializes in the research of network architecture and protocols, we aim to engage in fundamental research from a long-term perspective, produce world-class research output, and contribute to society through international standardization and the implementation of prototypes.

*1 ICN: Information-Centric Networking / CCN：Content-Centric Networking

*2 IETF: Internet Engineering Task Force / IRTF：Internet Research Task Force

*3 ITU-T: International Telecommunication Union Telecommunication Standardization Sector

Development and Application of Information Centric Network Technology

Information dissemination technology without IP restrictions

Kazuhisa MATSUZONO

Researcher
Network Science and Convergence Device Technology Laboratory
Network System Research Institute

After completing the doctoral course at a graduate school, worked as a post-doctoral fellow at INRIA. Entered NICT in 2013. Engaged in R&D in information centric network technology. Ph.D.(Media and Governance).

In order to support the new communications services needed in the future, we are engaged in the research and development of a new network architecture known as "information/content-centric network" (ICN/CCN), which can realize high-speed, large-volume communications in an efficient manner as compared to conventional IP communications. This paper introduces the background and characteristics of ICN/CCN technology, the software platform "Cefore" that we are developing, and examples of its application.

ICN/CCN technology

Internet communications to date has involved the transmission of information using IP addresses that represent the locations of the party that one is communicating with (such as computer or network device). Examples of this includes file transfers and the sending of e-mails. However, in recent years, there have been dramatic and spectacular changes in communications services, including social media through which information sharing is carried out frequently, the transmission and reception of high-quality images and videos through smartphones, and the Internet of Things (IoT) that connects various sensors in devices ranging from home appliances to robots. Such new communications services make communications more efficient and faster by receiving the desired information directly through the nearest party holding the information, rather than constantly accessing servers in remote locations using IP addresses. The new form of communications known as information/content-centric network (ICN or CCN) technology enables communications not through IP addresses, but by using identifiers that represent the information itself (such as the name of the content) (Figure 1). ICN eliminates the restrictions imposed by IP communications to date, which made it necessary to find out the location of the server and access it. It can also reduce response time by acquiring information in distributed storage (cache) within the network, and further, enable one-to-many multicast communications that is achieved by aggregating requests for the same information within the network, as well as enable mobile communications using multiple routes within the network.

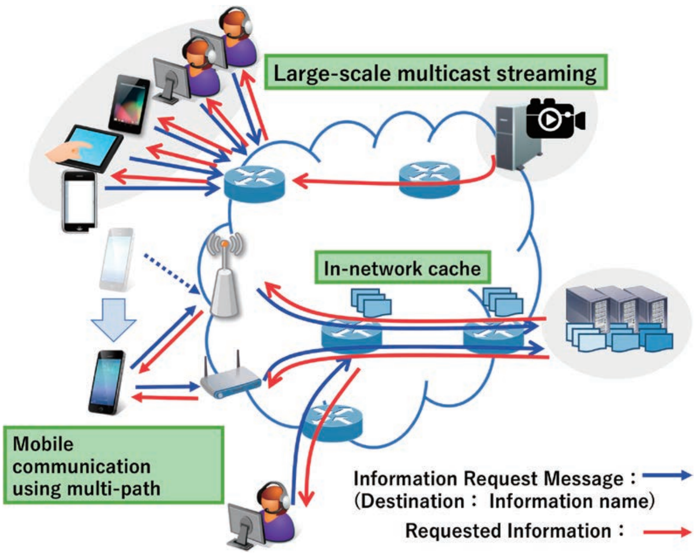

Figure 1 Conceptual diagram of information/content-centric network (ICN/CCN)

Cefore, an open-source software platform that realizes ICN communications

In anticipation of promoting the research of ICN and its development and implementation in society, we have developed a software platform called "Cefore" that realizes ICN communications (Figure 2) and published it as an open-source software. Cefore is characterized by the fact that the basic functions (cefnetd daemon that is responsible for the transfer of ICN messages) and extended functions (caching function, transport function for video distribution, mobile communication function, etc.) of ICN are packaged and installed separately, giving it superior versatility and functional extensibility. Developers of ICN communications technology and applications can implement the unique functions that they wish to incorporate as plugins, and incorporate these functions into Cefore without making any changes to cefnetd. Furthermore, the caching function, which carries a heavy processing load, can be moved to other computers. In environments that are lacking in computational resources such as sensors (for example, Raspberry Pi*1), ICN communications can be enabled by installing just the lightweight cefnetd.

Examples of applications that use Cefore

Using Cefore, we are working on demonstration experiments for various application case studies that harness the characteristics and merits of ICN communications. An example would be one-to-many large-volume, high-speed multicast communication. Figure 3 shows an overview of an experiment on general HTTP streaming and multicast distribution carried out through Cefore. The bandwidth for streaming one video was about 1 Mbps, while the bandwidth of a bottleneck link was 1.5 Mbps. As such, in cases where multicast communication is enabled, the environment will not cause any data loss. However, as multicast cannot be carried out in HTTP streaming, the total bandwidth for the video streaming exceeded the bandwidth of the bottleneck link, and the video stopped frequently. As a result, the video playback led to a latency of approximately 20 seconds in comparison with the actual playback time axis of the video content. On the other hand, as continuous multicast is possible in Cefore, video playback at the actual playback time axis was possible without data loss. Another example is its application in the field of proximity communications. At NICT Open House 2019, a demonstration was carried out on mobile robots equipped with Cefore, based on the assumption of connected cars*2 (Figure 4, right). The mobile robots and sensors that monitor roads and transmit the information are mounted with Raspberry Pi with Cefore installed. Mobile robots can quickly acquire information about one-way traffic and warnings about slippery roads, without communicating with a server, simply by sending a request message that specifies the name of the information as "ccn:/nearby information." In the example shown on the left side of Figure 4, the mobile robot in front is moving to the back. It receives information on slippery road warnings from the sensor, reduces speed and realizes safe driving. Furthermore, if information on slippery road warnings is transmitted when it passes the mobile robot at the back that is moving in the opposite direction, the mobile robot at the back acquires the information before communicating with the sensor, thereby enabling safe driving.

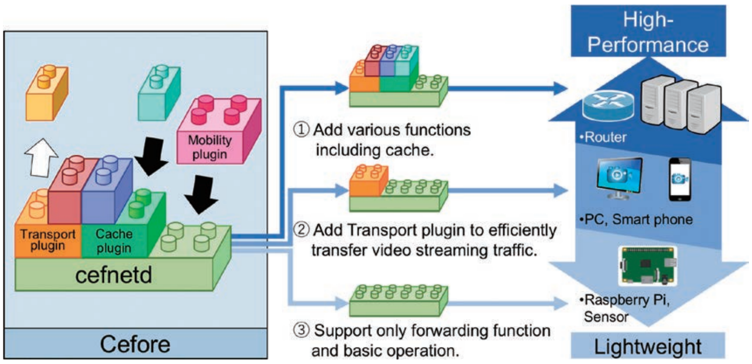

Figure 2 Conceptual diagram of Cefore software

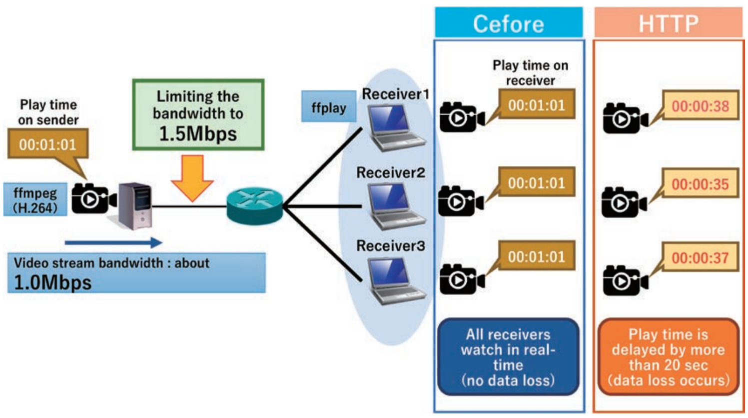

Figure 3 Comparison of HTTP streaming with Cefore streaming distribution

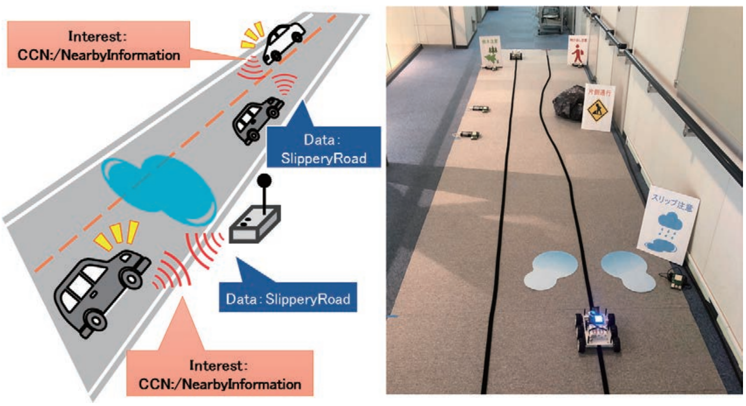

Figure 4 (Left) Example of proximity communication through Cefore. (Right) Scene of proximity communication demonstration using mobile robots at the NICT Open House 2019.

Future prospects

ICN/CCN communications can contribute to IoT services and large-volume, high-speed, and ultra-low latency communications, which are the core characteristic of 5G. We will continue to engage in research and development on the application of ICN technology, and advance activities with a view to demonstrating and spreading the superiority of the technology through the evolution of open source as well as the international standardization activities that are needed for the spread of the technology.

*1 Card-sized single board computer that is used widely as an IoT device. The standard OS RaspbianGNU/Linux supports desktop environments and various programming tools.

*2 Motor vehicle mounted with information communications system. Exchanges various information through road-to-vehicle communication in which a corresponding device installed on the road communicates with motor vehicles, and vehicle-to-vehicle communication in which motor vehicles communicate with one another.

Autonomic Resource Management System for Service Function Chaining

Applying the method used in natural language processing to virtual network management

Takahiro HIRAYAMA

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Network Science and Convergence Device Technology Laboratory
Network System Research Institute

After completing graduate school, he joined NICT in 2013. He engaged in optical packet switches, software defined networking (SDN), network function virtualization (NFV), and so on. Ph.D. (information science).

Network functions virtualization technology is developing at a dizzying speed, with a view to the building of network infrastructure that can respond flexibly to a wide range of service quality demands, including IoT services. On the other hand, infrastructure management is becoming increasingly complex in tandem with the diversification of services. In light of that, research and development are being carried out to enable the smooth provision of services with limited human resources through the autonomic control of network resources that utilize AI technology for infrastructure management.

Service Function Chaining (SFC*1) technology

Alongside with the introduction of 5G and growing popularity of IoT devices, there are greater expectations for the creation of a wide range of services. With services such as services that enable small-capacity communication between a massive number of devices such as environmental sensors, services that enable enhanced broadband communication for 4K/8K videos and VR/AR, and services that require ultra-reliability and low latency such as self-driving technology and remote medical services, for example, the demands of quality of services (QoS*2) vary widely, and there is a need for network infrastructure to respond flexibly to these QoS demands.

To meet the diverse QoS demands, research and development is ongoing in areas such as SDN*3 and NFV*4 technology. Our research group focuses on Service Function Chaining (SFC) technology, which involves the application of NFV technology (Figure 1). On the SFC platform, data is processed through the interlinking ("chaining") of multiple servers along the path from a terminal server to the user. By switching the servers that carry out data processing corresponding to the situation, it is possible to achieve the effective use of limited computational resources while realizing infrastructure that is equipped with a resource control mechanism to track changes in demand.

On the other hand, in maintaining QoS on the SFC platform, it is vital to continue allocating a suitable volume of resources (such as CPU) corresponding to the changes in the situation, such as type of service, time period, and demand. In this respect, this research and development aims to maintain QoS by making use of AI to control the SFC platform and reducing the time required for decision-making.

Autonomic resource management system for SFC

The SFC platform that we are developing carries out the following three phases of resource arbitration/network function migration (Figure 2) to maintain QoS. Here, we

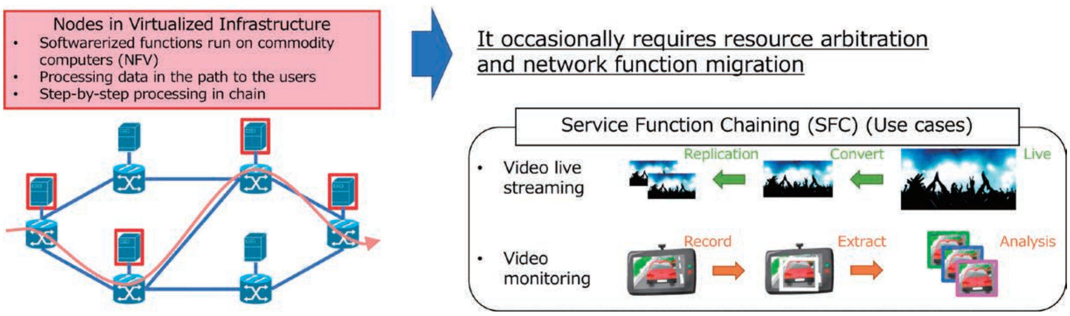

Figure 1 Service Function Chaining and its examples

*1 Service Function Chaining
*2 Quality of Service
*3 Software Defined Networking: Technology that can flexibly configure the transfer rules for network devices through software.
*4 Network Function Virtualization: Technology that enables flexible installation and modifications of the network functions as a result of virtualized infrastructure.

will introduce the use of AI to bring about the realization of (3) in particular.

(1) Resource arbitration in the server

In the event that the quantity of resources required by a certain service increases, this requirement is met by reducing the quantity of resources allocated to other services existing within the same server. Prompt response is possible since this involves only an adjustment of the quantity of allocated resources to network functions in the server. However, there is a limit to the range of adjustment for the quantity demanded that the system can support.

(2) Network function (NF*5) migration in the chain

In the event that the shortage of resources is not resolved through the above phase (1), network function (NF) is migrated to other servers that make up the same chain. This method carries out NF migration while maintaining the path, and narrows down the options to make it possible to reduce the amount of time spent on searching for a solution.

(3) Service Function Chain Reconstruction

It is not always the case that sufficient resources can be secured through methods (1) and (2). In such cases, servers are selected from the entire network, the path is changed, and the chain is reconstructed. However, the number of possible combinations is massive, and it takes time to find a solution. Furthermore, it is necessary to switch paths, so the time taken for reconstruction is longer in comparison with method (2).

In particular, in method (3) Service Function Chain Reconstruction, it is necessary to quickly make a decision on "when" and "where" to migrate NF from among an infinite number of options. For this reason, our research group is attempting to use AI in this process.

Chain reconstruction scheduling based on Encoder-Decoder RNN

Figure 3 shows the process of using AI to determine "when" and "where" to migrate NF. This AI decides on the servers for the deployment of each NF at time $t=t_1$, based on factors such as the status of usage of each server (quantity of resources) and forecasts of service demand at time $t=t_0$. If NF A-1 is migrated not to server SRV-2 but to SRV-3 at $t=t_1$, the migration frequency of A-1 will be reduced, as shown by the red lines in the figure. The aim is to use AI to decide on the destination and timing of migration by anticipating the need for NF migration several steps ahead, in order to maintain QoS and reduce migration frequency.

The learning model of AI uses an Encoder-Decoder Recurrent Neural Network (RNN*6) as shown in Figure 4, which was originally devised for use in the translation of languages. RNN is a mechanism that determines current output while referring to the memory of past input. It is effective in deciding on whether or not to carry out NF migration based on the time-series data for demand in the past, present, and future (prediction). Past input information is remembered through GRU*7 cells. A single piece of input data is read twice through the encoder and decoder, and the appropriate solution is produced as output.

In the problem in Figure 3, the optimal NF migration timing and destination are obtained through integer linear programming*8 for various combinations of demand fluctuation data and server capacity, and by educating as teacher data, it is possible to minimize resource shortage with a low frequency of migration as compared to cases of random configuration decisions or substitute DNN*9. This evaluation is targeted at small-scale networks with just a few units. Preparations are ongoing with a view to making improvements to enable the application to large-scale and complex networks with several dozen units, and to conduct validation tests on an actual large-scale IoT service testbed (JOSE) under NICT's Integrated Testbed.

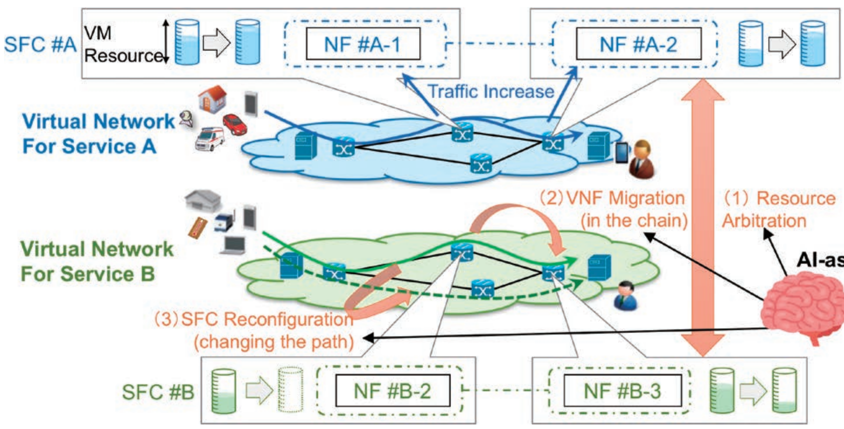

Figure 2 Autonomic resource control technology for Service Function Chain using AI

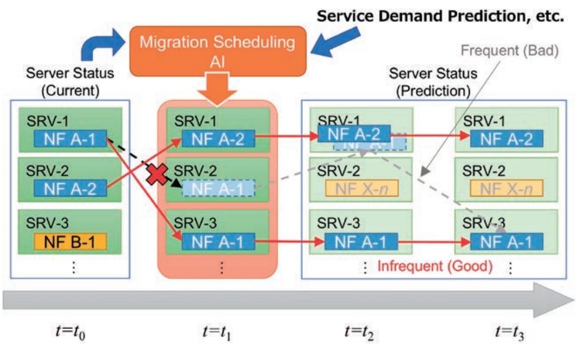

Figure 3 AI that automatically plans for the network function (NF) migration of services

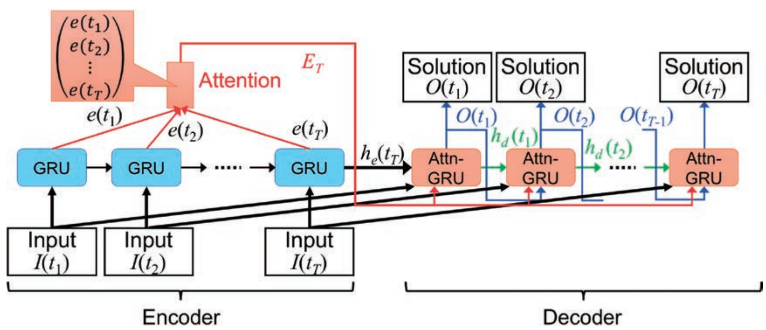

Figure 4 Encoder-Decoder RNN

*5 **N**etwork **F**unction
*6 **R**ecurrent **N**eural **N**etwork
*7 **G**ated **R**ecurrent **U**nit
*8 A method for obtaining combinations of each NF and the server that deploys the NF, by minimizing the objective functions (frequency of migrations, quantity of resource shortage) within a range that does not violate the constraint equations (such as server capacity and migration cost).
*9 **D**eep **N**eural **N**etwork

Towards Computing Infrastructures Supporting IoT Era

Realizing both high responsiveness and energy-efficiency

Hiroaki YAMANAKA

Researcher
Network Science and Convergence Device Technology Laboratory
Network System Research Institute

After receiving his Ph.D., Hiroaki YAMANAKA joined NICT in 2011 and has been engaged in research on network virtualization and edge computing technologies. Ph.D. (Information Science).

In the age of IoT, applications such as camera sensors, AR/VR, self-driving technology, which require massive communications traffic and low-latency response for servers, are expected to emerge. To bring about the realization of such applications, it is effective to employ edge computing, which utilizes servers set up in the vicinity of end-users, in addition to the use of large-scale, cloud-based data centers. The infrastructure system proposed in this study combines responsiveness with energy-saving performance, contributing to the enhancement of the economic efficiency of infrastructural resources.

Computing Infrastructure in the age of IoT

In the age of IoT, various things including many types of sensors (weather sensors, cameras, etc.) and actuators (robots, home appliances, motor vehicles, etc.) are connected to the Internet. As things have limited processing capability and battery capacity, many processes are executed on the server via the Internet. For this reason, much of the data is concentrated in data centers on the cloud, which causes the problems of a heavy load on the data centers and large bandwidth usage in the wide-area network that make up the Internet. Furthermore, communications with a cloud server that is located far from the end-user device requires round-trip time of about several tens to several hundreds of milliseconds. This round-trip time is too long for connected cars (cars equipped with an always-on connection), virtual reality (VR)/augmented reality (AR) and other technology that are expected to become key IoT applications.

In light of that, there are hopes for the realization of edge computing, which provides services using servers set up at the "edge" of a network (hereafter, "edge servers"), close to the end-user device (Figure 1).

Specifically, application services are realized through means such as the analysis of camera images and image rendering in AR/VR (generation of images based on data) on edge servers set up in the wireless base stations of mobile carrier networks or central offices within the city. Using an edge server enables communications with a round-trip time of several to several tens of milliseconds. Furthermore, as communications can mostly be completed with just the networks in the vicinity, it can reduce communications traffic going through data centers and wide-area networks.

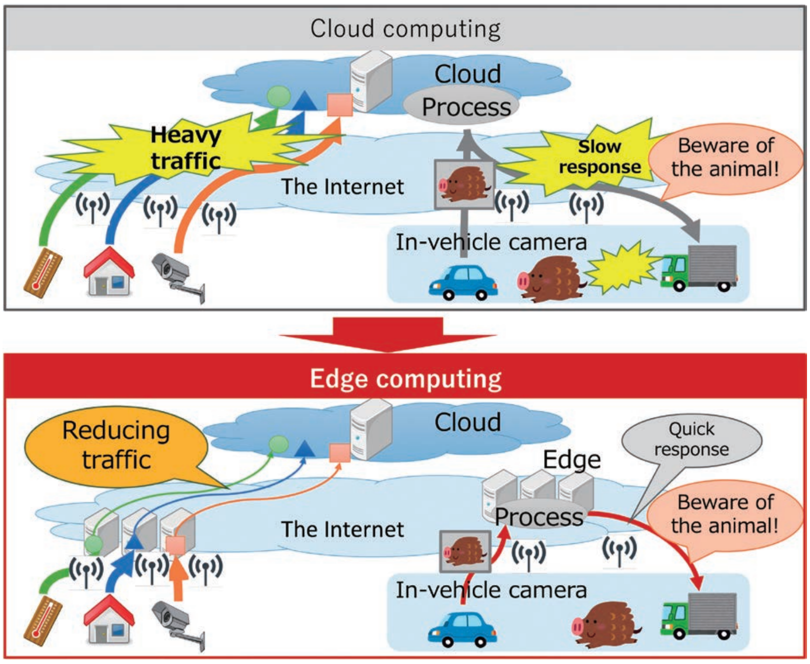

Figure 1 Overview of edge computing

Challenges and solutions toward the realization of edge computing

A challenge in edge computing is how to set up the edge server. While the installation of many edge servers can improve responsiveness, it would require enormous cost to develop the infrastructure and increase power consumption and in turn, increase operational costs.

Generally, in order to reduce infrastructure development costs, server virtualization technology is used to set up multiple virtual servers that are logically independent on one edge server. When doing so, it is possible to reduce the cost of infrastructure development by sharing sedge servers between multiple application service operators. Typically, in an infrastructure system that is intended for use in edge computing, a virtual server is set up on the edge server located closest to the end-user device. For this reason, for some application services that do not place much importance on responsiveness, the round-trip communications time between the virtual server and end-user device is reduced unnecessarily. Furthermore, as virtual servers are set up in the various locations that are nearest to a multiple number of end-user devices, there is an excess number of edge servers in operation, creating the problem of high power consumption (Figure 2).

In this study, in order to optimize communications time and reduce power consumption, power consumption by the entire infrastructure is reduced by using virtual servers that are positioned in locations other than those nearest to the device, but within a range that satisfies the acceptable response delay of the application service, and by consolidating the edge servers that are activated to reduce the number of servers in operation.

Resource allocation management based on virtual regions

This study proposes a model known as "virtual regions," which enables the consolidation of edge servers deployed in an edge computing environment where multiple wireless base stations can communicate with the same edge server within the acceptable response delay (Figure 3). A virtual region is defined as a group of wireless base stations created through clustering, which is a data analysis method. Specifically, when multiple wireless base stations that can communication with the same edge server are present within the range of acceptable response delay time for the application service, these wireless base stations are grouped together. Grouping is carried out such that as many wireless base stations as possible are assigned to a single group, which then determines the virtual region.

As a result, the total number of virtual regions is reduced. By including many wireless base stations in a single virtual region, it is possible to realize communications within the acceptable response delay from the same edge server to many end-user devices. For this reason, it is possible reduce the overall number of virtual servers as well as the number of edge servers that need to be started up, which in turn reduces power consumption.

In a simulation based on the assumption of edge computing infrastructure that uses this virtual region model, for a city with a population of 100,000, it was confirmed that this method produces up to 60% higher energy-saving performance than existing methods (Figure 4). In this situation, the virtual region satisfies all the low-latency responsiveness required by the application services.

Future prospects

Going forward, the aim is to implement resource management functions based on the virtual region model to enable support for various existing infrastructure, and to realize a practical infrastructure system that can effectively management a large number of edge server resources in many locations.

Figure 2 Set-up of virtual servers in existing research

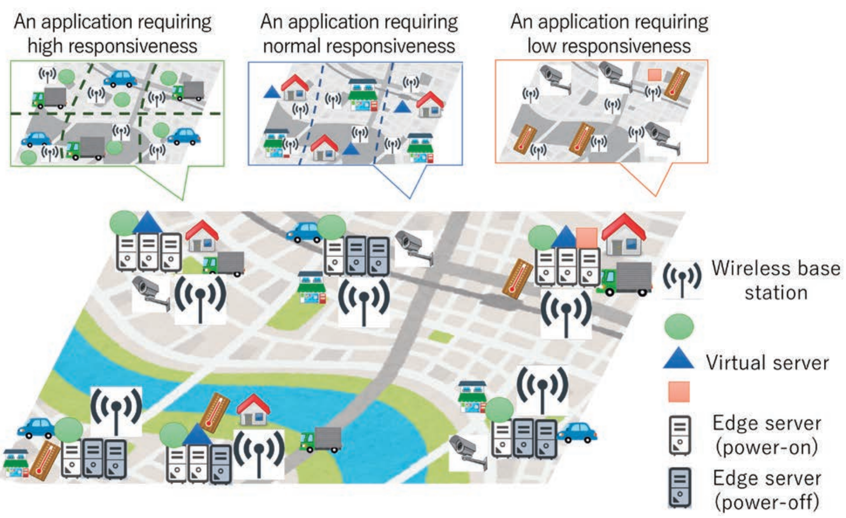

Figure 3 Set-up of virtual servers based on virtual regions

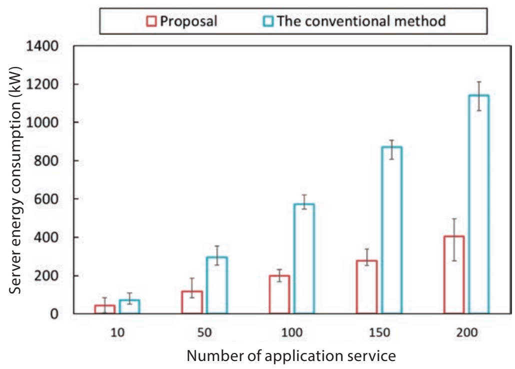

Figure 4 Evaluation of power consumption in a simulation

Spatial Division Multiplexing based Optical Networking Technologies

Toward realization of flexible and effective optical networks

Yusuke HIROTA

Senior Researcher
Network Science and Convergence Device Technology Laboratory
Network System Research Institute

After completing graduate school, Yusuke HIROTA became an assistant professor in Graduate School of Information Science and Technology, Osaka University, in 2008. Since 2017, he has been a senior researcher in NICT. His research interest includes all-optical networking. Ph.D. (Information Science).

Optical networks, which support communication services such as practical IoT applications and ultra-high definition video transmissions, have to fulfill various kinds of requirements e.g., increasing capacity, reliability, low cost, low power consumption, and low latency. This article introduces some of the optical networking technologies based on spatial division multiplexing technology*1 toward an optical network infrastructure of the future. Our research about the spatial division multiplexed optical networking technologies aims to connect network services with developing optical device technologies.

Optical fiber networks

The various buildings and structures that we see every day are all erected over strong and solid foundation works. It is also indispensable for communication networks to have a robust and high-performance network as the foundation to realize a wide variety of network services. However, it is difficult for the optical fiber networks that are currently used widely to meet rapid increase in demand for fixed and localized communications in various aspects, such as wavelength assignment, and we are gradually approaching its limitations in communications capability as well. In view of that, it is necessary to develop innovative optical networking technologies that satisfy the requirements of a wide variety of network services, alongside with the need to carry out various fundamental research and engage in the development of devices. We propose a spatial super-channel type of optical networking to meet the various requirements of flexibility, large capacity, low cost, and low power consumption. This type of optical networking is based on recently advanced spatial division multiplexing technology, which connects diverse network services with physical optical devices through the use of the spatial channels of optical fibers.

Spatial division multiplexing technology and pSSC

Much research is being carried out on spatial division multiplexing technology as one of the techniques for multiplexing multiple signals on a single optical fiber. Previous research had been carried out based on the assumption of individual wavelengths and spatial channels being used separately by the respective communications (optical paths, optical packets); at the switching nodes of the networks, the switching process has been carried out by separating the individual wavelengths and spatial channels each time, and multiplexed again before transmission. For that reason, it is necessary to have a large number of optical devices with the increase in the number of spatial and wavelength channel multiplexing. This switching process makes the node configuration large-scale and complex while also raising concerns over an increase in costs. To counter this problem, we study on time slot-based optical packet switching using spatial super-channels (pSSC*2) in order to realize larger capacity, lower latency, and lower costs for optical networks (Figure 1). A spatial super-channel is a format in which a single communication uses multiple spatial channels simultaneously. In the switching node, it is possible to switch multiple spatial channels jointly, and to simplify the switch configuration.

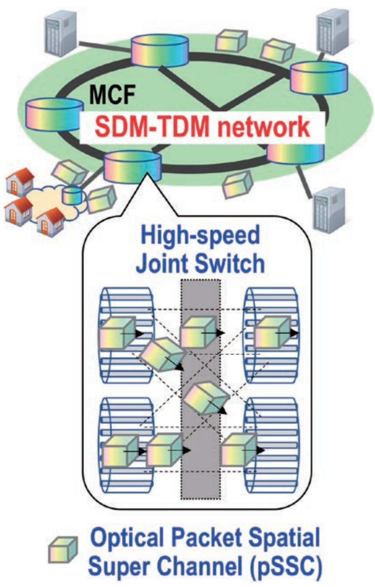

Figure 1 Spatial division multiplexing optical network

Joint switching process using spatial super-channels, and collision avoidance

In optical packet switching, it is important to avoid packet loss caused by collision of multiple packets. Hence, we developed a collision avoidance method within the fiber

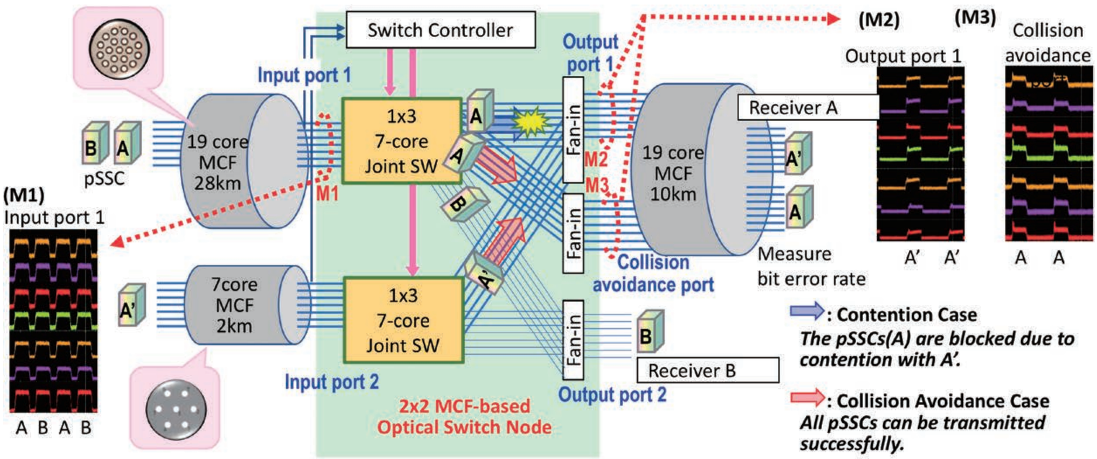

Figure 2 Experiment on collision avoidance function in spatial super-channels joint switch

64-wavelength multiplexing optical signals were generated at 50 GHz intervals, and transmitted at 80 nanoseconds of guard time between packets. Signals were measured at points M1, M2, and M3, and the operation of the collision avoidance function was confirmed.

using joint switch, and validated its functions (Figure 2).

For pSSC that is generated for experimental purposes, when input is made into input port 1 of the 2×2 optical switch node in the middle through the 19-core multi-core fiber, it conflicts with other signals from input port 2. If two signals are transmitted to the same channel, the signals would overlap and it would not be able to decrypt them correctly. Accordingly, we switched a different spatial channel of the same fiber as shown on the right side of Figure 2, thereby avoiding this conflict, and confirmed that there were no problems with signal quality*3. Through this function, it is possible to sustain communications without giving rise to latency through buffering or deflection routing.

When transmitting between small-scale nodes, there is the advantage of being able to keep the switching to a small scale through the joint switch of more spatial channels. On the other hand, the joint switch of a large number of spatial channels also has disadvantages such as the need for expensive switching devices that operate at ultra-high speed, since the pSSC packets that have many spatial channels become shorter. Furthermore, if we were to consider network scale from a more macro perspective, problems such as conflict between data transmitted from multiple ingress nodes, and latency and throughput deterioration as a result of deflection routing, can occur. Taking that into account, we propose spatial channel slicing (Figure 3), which enables the adjustment of the tradeoff between switching scale and collision avoidance performance, by transmitting large data such as videos and images using multiple spatial channels, and transmitting small sensor data through fine-grained channels. Figure 4 shows the results of the evaluation of this proposal. Depending on the slicing method used for the spatial channel, we confirmed a significant difference in the pSSC reject rate, and succeeded in calculating the optimal slicing method. In this way, by utilizing networking technology while considering the characteristics of the physical device, it is possible to strike a balance between increasing the capacity of spatial channels and reducing the scale of switching, and at the same time, enhance flexibility and efficiency across the network.

Toward a more flexible optical network

Various challenges remain in the goal to realize an optical network that can respond flexibly to changes in the environment. Of these, we could say that congestion and failure management are challenges that cannot be avoided for optical networks of the future. Future work includes research on networking technologies that are resilient against congestion and failures, while considering the unique physical properties of optical networks.

*1 It is possible to transmit multiple signals in parallel by using multiple modes of the optical fiber, or by using multi-core fibers with multiple cores in the optical fiber.
*2 Optical Packet Spatial Super Channel
*3 Bit error rate is significantly smaller than 10^{-3}, deemed error-free due to a forward error correction.

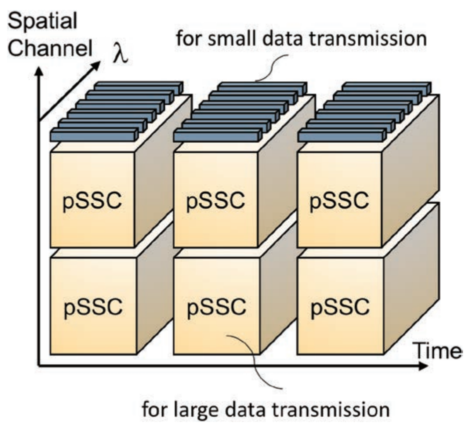

Figure 3 Image of pSSC

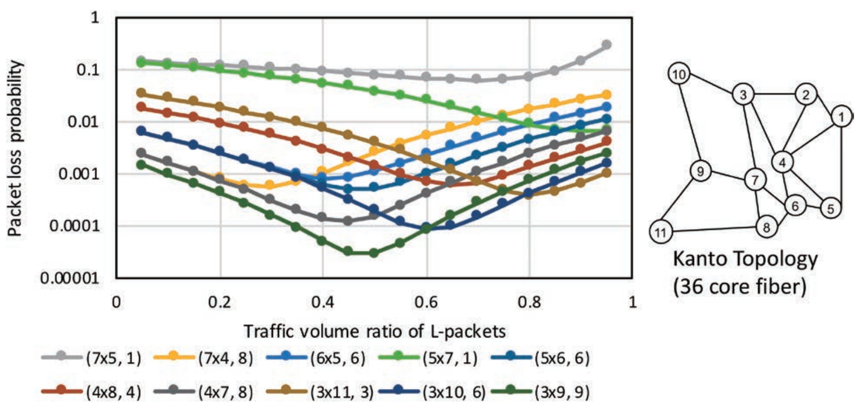

Figure 4 Results of network simulation for spatial channel slicing

The vertical axis shows the packet reject rate, while the horizontal axis shows the proportion of large-capacity data transmission, such as videos and images, as a percentage of all traffic. In the legend, (n1 ×n2, n3) shows the case when n1 core is treated as a super-channel, n2 slices are prepared, and the remaining n3 channels are subjected to exchange processing as individual spatial channels.

Holding of NICT New Technology Presentation Meeting

On July 18, an NICT New Technology Presentation Meeting was held jointly by NICT and JST at the Annex Hall, Tokyo Headquarters of the Japan Science and Technology Agency (JST). The New Technology Presentation Meetings are patent briefings where researchers make direct presentations to corporations with the aim of realizing the practical application of the research output produced by public research institutions. On this occasion, presentations were made on a total of nine new technologies (Table) from the fields of 3D display technology, drones and 5G related technologies, cryptographic techniques and AI, optical and quantum devices, and biotechnology. Unlike in regular academic presentations, the researchers, who are the inventors, provided comparisons of the new technologies with existing and competing technologies, and explained the characteristics of the new technologies as well as their anticipated applications. At the end of the presentations, they set out their expectations and appealed to the corporations for collaborative partners.

At this Presentation Meeting, some 380 participants mainly from large corporations and SMEs registered to attend, while the event also saw a good turnout of many visitors on the day itself. At the end of each presentation, corporate representatives who were interested in the respective presentations exchanged name cards with the researchers, and the number of interested corporations reached a total of 145 companies for the nine presentations.

Several of the new technologies received invitations to meetings even after the event, and viewings of the prototypes as well as meetings continued to be held. The individual technologies presented during this event were also picked up and featured by a number of leading media companies, including details such as the image of the realized product and plans toward the practical application of the technology. Going forward, this event is expected to contribute to the realization of collaboration with the industrial sector, in ways such as tying up the lectures delivered at this meeting with joint research, and creating opportunities for the social application of the research output.

Scene of a lecture delivered at the Presentation Meeting
(Annex Hall of JST's Tokyo Headquarters, Ichigaya)

<For inquiries about collaboration and licensing>
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TEL: +81-42-327-6950 FAX: +81-42-327-6659
Mail: ippo@ml.nict.go.jp

Table: List of New Technologies

	Presentation Title	Presenter
1	Fabrication Method of Hologram Screen for a Light Field Three-dimensional Display	Koki WAKUNAMI Senior Researcher, Electromagnetic Applications Laboratory, Applied Electromagnetic Research Institute
2	Glasses-free 3D Display Technology that can be seen from 360 Degrees of around a Table	Shunsuke YOSHIDA Senior Researcher, Information Services Platform Laboratory, Universal Communication Research Institute
3	Position Estimation Techniques using Drones or Moving Robots	Fumie ONO Senior Researcher, Wireless Systems Laboratory, Wireless Networks Research Center
4	Provision of Inexpensive Spot Services using 5G / LTE Technology	Kazuo IBUKA Researcher, Wireless Systems Laboratory, Wireless Networks Research Center
5	Secure Machine Learning via Cryptography and AI Integration	LE TRIEU PHONG Senior Researcher, Security Fundamentals Laboratory, Cybersecurity Research Institute
6	Secure Method for Adding, Deleting, and Searching for Files	Yohei WATANABE Researcher, Security Fundamentals Laboratory, Cybersecurity Research Institute
7	Optical Devices which can Operate Stably even in High Temperature Environments such as Cars	Atsushi MATSUMOTO Researcher, Network Science and Convergence Device Technology Laboratory, Network System Research Institute
8	Coupling Circuit between Quantum Bits for Quantum Computers	Fumiki YOSHIHARA Senior Researcher, Frontier Research Laboratory, Advanced ICT Research Institute
9	Functional Analysis of Specific Molecules in Living Cells - a Useful Tool for Drug Development	Shohei KOBAYASHI Research Manager, Frontier Research Laboratory, Advanced ICT Research Institute

Related links

- **JST archives** https://shingi.jst.go.jp/list/nict/2019_nict.html (in Japanese)

Toward the Real-world Application of Information-centric Networking Technology

Atsushi OOKA

Researcher
Network Science and Convergence Device Technology Laboratory
Network System Research Institute
Ph. D. (Information Science)

Biography

1990 Born in Hyogo Prefecture, Japan
2012 Graduated from Osaka University (early graduation)
2017 Graduated Graduate School of Osaka University with Ph.D.
Joined NICT
2018 Current position

Awards, etc.

Won first prize in NWGN sub-committee of JSPS 163rd Committee on Internet Technology

Q&As

Q What do you like the most about being a researcher?

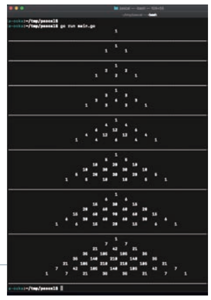
A The ability to carry out research with the broad perspective, connections, and practical perspective that I did not have as a student, and to engage in research that can actually serve society.

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

A I think it is important to be resolved to continue doing what you love. Put effort into doing that, draw in people with your positive attitude, and create a virtuous cycle.

Q What do you do on your days off?

A Read engineering books, try out new programming techniques, chat with friends online while playing games, etc.



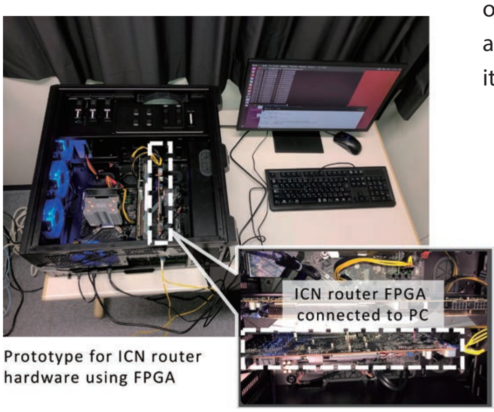
Pascal's triangle by go language

Information-centric and content-centric networking technology (ICN/CCN) is drawing attention as a new form of networking technology. Due to its high functionality, it is said to be difficult to strike a balance between realizing high performance and high speed, unlike conventional IP routers. When I was in graduate school, I carried out research with a view to finding a solution to this problem. In that process, I realized that NICT had focused on ICN technology from an early stage. In addition to disseminating its research results in that field around the world, it is also engaged in research activities that include the social application of the research, including the development and release of the ICN communications platform, Cefore. This approach attracted me, and I consequently joined NICT.

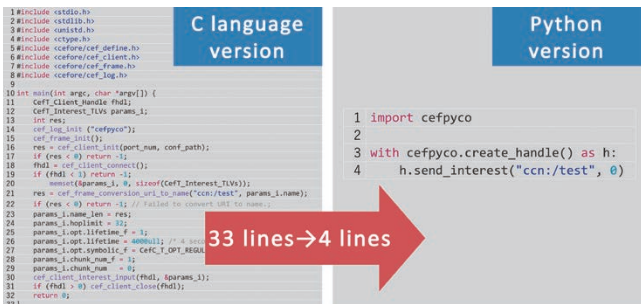
After joining NICT, I engaged in research on efficient pathway control systems when applying ICN to sensor networks, while also contributing to the development and release of Cefore. For example, using the programming language Python, I created a library “cefpyco” to simplify application development using Cefore. I released this while serving as a lecturer at a hands-on session of the Technical Committee on ICN of the Institute of Electronics, Information and Communication Engineers (IEICE), and it was very well received.

In view of the need for high-speed hardware routers, I am currently working on the research and development of a router that can realize high communications speed to enable the use of Ultra-High Definition (UHD) video distribution services and other applications in the real world. Even when hardware is high-speed, it is difficult to add or extend functions. Hence, I am working on the research of technology that strikes a balance between high speed and function extensibility while mounting a router using Field Programmable Gate Array (FPGA).

In addition to supporting the development of ICN applications, I also aim to carry out research and development on high-speed communications and technological infrastructure that can be applied to real-world services, in order to bring about the realization of better networks.



Prototype for ICN router hardware using FPGA



Comparison of simple packet transfer codes
(Left: Original code. Right: Using cefpyco)

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