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Special Feature

Demonstration and Experimental Evaluation Environments of Communication Equipment Interoperability

Open Innovation and Demonstrations of Communication Equipment Interoperability

Interoperability Testing Using Actual Equipment at a Network Technology Event

iPOP2024 Interoperability Experiments for Verification of Advanced Optical Network Orchestration

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C O N T E N T S

About ITU-AJ

The ITU Association of Japan (ITU-AJ) was founded on September 1, 1971, to coordinate Japanese activities in the telecommunication and broadcasting sectors with international activities. Today, the principle activities of the ITU-AJ are to cooperate in various activities of international organizations such as the ITU and to disseminate information about them. The Association also aims to help developing countries by supporting technical assistance, as well as by taking part in general international cooperation, mainly through the Asia-Pacific Telecommunity (APT), so as to contribute to the advance of the telecommunications and broadcasting throughout the world.

Open Innovation and Demonstrations of Communication Equipment Interoperability

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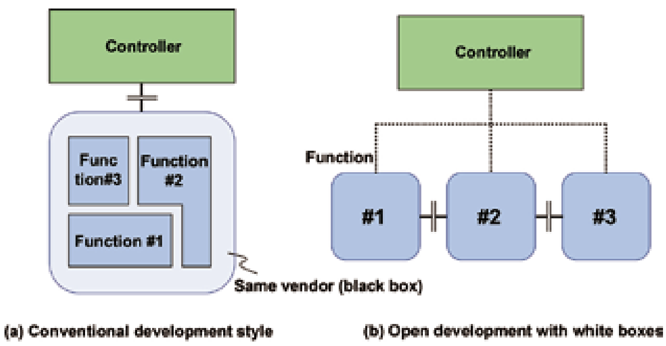
1. Introduction

Why is the importance of demonstrating interoperability between communication equipment increasing? The background to this question lies in white box development that provides specialized technology in the form of building blocks to speed up development as system and network functions become increasingly advanced and complex. Since this involves deciding on and developing interfaces, interoperability must be ensured, so it can be said that the interoperability of such interfaces is more important than the specifications written on paper. "Interoperability" means checking specifications, showing their feasibility, and establishing an overall concept, and going further, having communication carriers gather together communication equipment vendors and conducting demonstration experiments targeting actual operation. Here, it would be difficult if vendors were to independently gather together to verify interoperability since know-how leaks could occur, so historically speaking, the approach has been to establish consortiums centered about universities or other institutions with the aim of securing demonstration sites. In Japan too, as presented in this special issue, ShowNet of Interop Tokyo is a typical communication-equipment interoperability demonstration experiment, and the Keihanna Info-Communication Open Laboratory of the National Institute of Information and Communications Technology (NICT), which promotes interoperability focusing on optical technology, is steadily exchanging know-how. This article describes open innovation and interoperability demonstrations and reports on future network and system development styles.

2. What is open development?

Change in the style of developing communication equipment is shown in Figure 1. As shown in Figure 1(a), the conventional style was to accumulate extensive know-how within a single vendor and develop all functions likewise by a single vendor, which meant that internal details and interfaces would be developed in a black-box manner. This method simplified and accelerated fault isolation and recovery at the time of a network problem. It also clarified responsibility in terms of quality guarantees and made operation easy by essentially leaving it up to a single vendor. Under this method, communication carriers configured "vendor islands" that form communication networks with single-vendor equipment and promoted interoperability demonstrations along with the standardization of the physical and control interfaces between those vendor islands. In the Automatically Switched Optical Network (ITU-T ASON) era of about 20 years ago, the Optical Internetworking Forum (OIF) and the Keihanna Info-Communication Open Laboratory conducted interoperability demonstrations on a global scale as Generalized Multi-Protocol Label Switching (GMPLS). However, with a system becoming ever larger in scale and increasingly complex, all development by a single vendor meant that specialized and non-specialized functions would be mixed, which would prevent the adoption of any superior functions even if another vendor had already developed them. In response to this drawback, the development style has been changing to one that modularizes the interior of the black box in a function-by-function manner, precisely determines inter-module interfaces, and promotes the free development of each module as a white box in an open environment as shown in Figure 1(b). This evolution permits partial entry into the market and encourages competition and collaboration. However, the conventional black box made it easy to optimize performance, and it was thought that the white-box format would make it difficult to optimize the entire system even if individual functions could be optimized. In particular, it was considered that a system in which physical performance easily affects the performance of the entire system would have many problems with the white-box format making it difficult to adopt such a development style. In recent years, though, the Open Radio Access Network (O-RAN) of the 5G radio base station system and the Open Reconfigurable Optical Add-Drop Multiplexer (Open ROADM) of the optical transmission network system, for example, have been changing to open development even for

Figure 1: Change in communication-equipment development style



super-advanced technology for which physical performance is important. At the same time, increasing the flexibility of each function through software has been evolving and the possibility of extracting optimal combinations of functions has been verified through interoperability tests.

For vendors, this flow toward open development means a reduction in competitive costs while also making it easy to enter the market with only some function modules, to enter a market composed of several carriers, or to even enter a global market. In the case of RAN, for example, Radio Unit (RU) equipment is a strong point of Japanese companies, and in the case of optical networks, many companies around the world are adopting high-speed transporters increasing the possibility that they will come into practical use.

3. Consortium-based activities

As described above, standardization is, of course, essential to dealing with open development, and equally important are early discussions and demonstrations with other vendors and carriers centered about diverse consortiums. We, as well, have cooperated with ISOCORE (sponsored by George Mason University) based in Washington D.C. in the United States for more than 20 years and have mainly conducted demonstrations of standard interfaces for Multi-Protocol Label Switching-Transport Profile (MPLS/MPLS-TP) and GMPLS at the Internet Engineering Task Force (IETF). These activities provided us with excellent opportunities to understand specifications not shown in standardization documents and to grasp real development trends and strategies around the world including those of other companies.

This special issue introduces the results of the Interop Tokyo ShowNet demonstration that has been extremely effective over many years and the results of the iPOP2024 international conference that mainly performs public experiments on the interoperability of optical technologies (including the Innovative Optical and Wireless Network (IOWN)). The Keihanna Info-Communication Open Laboratory, Photonic Internet Lab, etc. are the mother bodies of these iPOP consortium activities.

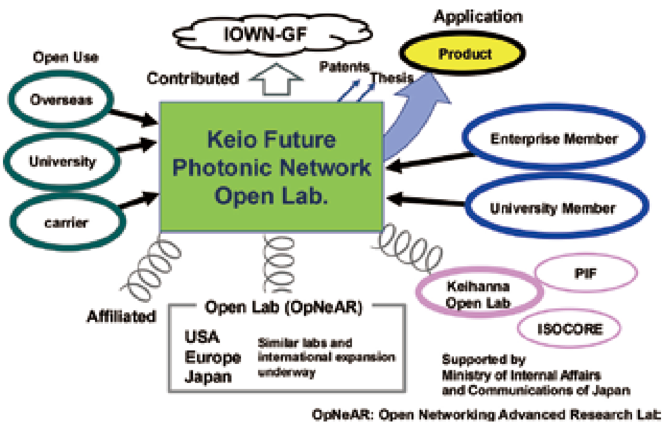
4. Keio Future Photonic Network Open Lab

Before conducting interoperability demonstrations, it is important to construct an environment in which multiple communication-equipment vendors, communication carriers, and academia can exchange technologies, global technology trends can be grasped, and experiments and discussions can be held in an open format. At Keio University, with the support of the "Research and Development of Advanced Optical Transmission Technology for Green Society (JPMI00316)" project of the Ministry of Internal Affairs and Communications, the Keio Future Photonic Network Open Lab opened in April 2023 to accelerate such open innovation (Figure 2). It was on the campus of the Open Lab that hollow-core fiber (in which the optical core consists of air) was laid for the first time in the world. Making free use of this fiber, the research of breakthrough technologies is being conducted through the collaboration and cooperation of communication carriers, equipment vendors, and academia.

Examples of research topics at Keio Future Photonic Network Open Lab are given below.

(1) Research of Power over Fiber (PWoF): Hollow-core fiber, whose damage resistance is 1,000 times higher than existing optical fiber (since the core consists of air), can transmit energy simultaneously while maintaining the communication broadband performance of optical fiber.
(2) Research of analog Radio over Fiber (RoF): Due to an air core, linearity is high and signal distortion due to nonlinear effects is nearly nonexistent. As a result, studies are being performed on future beam extension of millimeter waves, etc. combined with PWoF and on the wraparound of radio signals by optical fiber instead of metasurfaces.
(3) Research of super-multi-wavelength, low-latency communications: In an era of one wavelength per person, there will be no need for multiplexing the signal along the time axis (a single wavelength bandwidth for high-speed use will be occupied even at low speeds). It will be possible to change the wavelength bandwidth as desired and to achieve a network with no multiplexing delay. Also being researched are networks using the large amount of energy entering optical fiber and networks using new functional fiber that is expected to ease the bandwidth limitation of light.

■ Figure 2: Structure of the Keio Future Photonic Network Open Lab



5. Conclusion

This article described the importance of interoperability accompanied by open innovation and network open development, research collaboration based on consortiums, and means of cooperation. Looking to the future, consortium-based research involving mutual collaboration and cooperation in contrast to single-company research will become increasingly important as will activities that provide viewpoints from third parties such as academia, NICT, and the WIDE Project.

Interoperability Testing Using Actual Equipment at a Network Technology Event

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1. Introduction

The procedures for network construction and operation are becoming increasingly complex as networks and related technologies evolve and new systems emerge. Testing using actual equipment is an effective approach to ensure seamless interoperability in such intricate network environments.

This article introduces ShowNet, the network built for Interop Tokyo, a major network technology event, as an example of large-scale interoperability testing using actual network equipment.

2. Interop

Interop is a global event dedicated to network technologies. It originated in 1986 as the TCP/IP Vendors Workshop in Monterey, California, and was later renamed Interop, expanding to multiple countries worldwide. The name "Interop" is derived from "interoperability," reflecting the event's core purpose—building a network within the venue to serve as a testing environment for interoperability. In Japan, Interop Tokyo was first held in 1994 and has since become an annual large-scale event in June at Makuhari Messe. The network built for this event is known as ShowNet.

3. ShowNet

ShowNet is a concept network designed as an innovative model for the next 5 to 10 years, incorporating the latest technologies and cutting-edge equipment provided by exhibitors. It provides internet connectivity for exhibitor booths and visitor Wi-Fi. Attendees can see and experience firsthand how these state-of-the-art technologies and equipment operate with ensured interoperability, helping them make informed decisions for future technology and equipment selection. This chapter outlines ShowNet, its construction, history, distinctive operations, and significance.

3.1 ShowNet Organization

ShowNet is organized by Network Operation Center (NOC) team members (assigned by Interop Tokyo organizers), contributors (companies and organizations providing equipment and services), and ShowNet Team Members (STM; volunteer members recruited from the public). In 2024, ShowNet featured 95 contributor companies and 650 engineers (including NOC members, STMs, and contributors). Over 2,300 devices and services were provided, making it one of the world's largest interoperability testing events.

3.2 ShowNet Design

NOC team members are invited around September of the previous year and begin discussions on the ShowNet concept in October. In December, exhibitors who are willing to join ShowNet (will participate as contributors) are gathered and briefed on the concept for the following year. Contributors then propose the equipment they plan to provide for ShowNet. NOC team members design the network based on the proposed equipment to align with the concept. From January to May, monthly meetings are held to refine the parameters, culminating in specific IP address allocations and interface connections by May.

3.3 ShowNet Construction

ShowNet is built over 12 days, starting from the Friday two weeks before Interop Tokyo. The first 8 days are known as the HotStage, where ShowNet is built while conducting interoperability tests to ensure the network functions as designed. Since ShowNet incorporates many world-first products and newly implemented technologies, interoperability testing during the HotStage is crucial in ensuring the network is built as designed. At the same time, multiple health checks are conducted on the ShowNet backbone to ensure that the constructed network remains stable and operational. These tests are repeated continuously until the backbone is fully stabilized, right up until the exhibition. Since HotStage takes place at the location where the ShowNet booth is set up, it also serves as an opportunity to begin building ShowNet in advance. Once HotStage concludes, ShowNet enters the Deploy phase. During this phase, after the exhibition hall for Interop Tokyo becomes available, ShowNet is deployed across the entire venue. In the deployment process, the integrity of each exhibitor's network is verified from both logical and physical perspectives. Through this approach, ShowNet establishes a network as illustrated in the diagram. ShowNet integrates emerging technologies and builds networks reflecting the most relevant industry trends of the time. Key areas include network models for telecom carriers, ISPs, enterprises, and campuses, as well as concepts for wireless and broadcasting industries. As a result, the volume of equipment used in ShowNet continues to grow each year, and the technology involved is becoming increasingly complex. Consequently, the workload required for ShowNet's construction has also increased.

To achieve efficient construction, ShowNet hosts Pre-HotStage events for each domain, providing increased opportunities for interoperability testing and pre-configuration. Additionally, ShowNet aims for efficient and rapid network construction through detailed pre-event discussions and the use of a proprietary trouble ticket database (TTDB), among other strategies. TTDB not only provides conventional trouble ticket functionality but also consolidates information on equipment and connections used in ShowNet. In an environment involving many participants, accurate data collection and swift information sharing are crucial for troubleshooting. These efforts enable ShowNet to achieve efficient network construction within a short time frame.

3.4 ShowNet History and Achievements

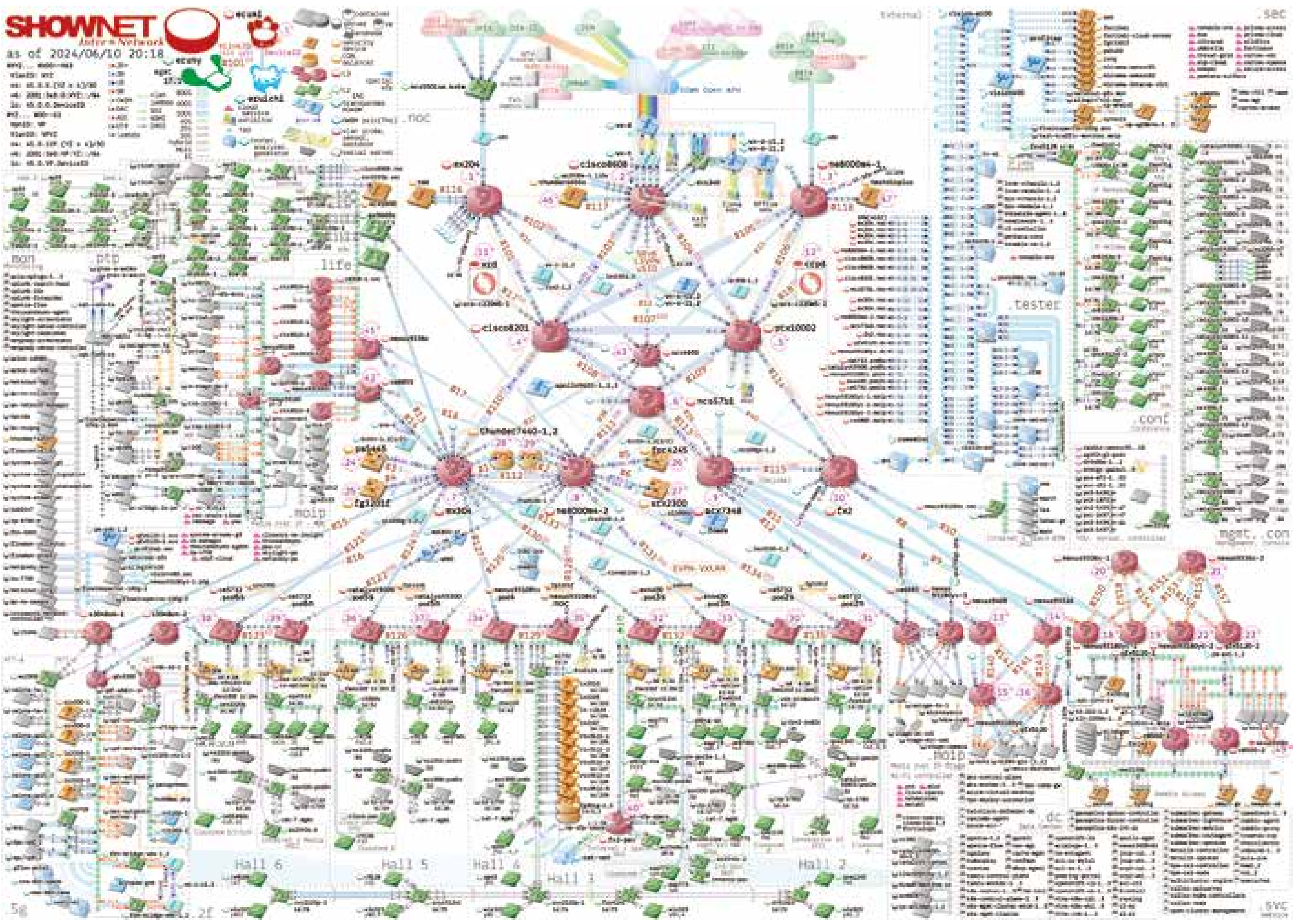
ShowNet has been an ongoing project since the inaugural Interop Tokyo in 1994. Staying true to its core concept of implementing networks that reflect the state of the industry two to three years ahead, ShowNet has continuously integrated pioneering technologies ahead of commercial deployment (see table).

These initiatives have provided feedback for product development by contributors and even led to proposals for standardization activities by NOC members. Notable examples include the Internet-Drafts, such as *draft-upa-srv6-service-chaining-exp* in 2019 (a document summarizing insights gained from the real-world operation of SRv6-based service chaining in ShowNet) and *draft-eden-srv6-tagging-proxy* (a proposal introducing the END.AT method as a new approach for SRv6 Proxy, designed to support large-scale, multi-chain configurations like those used in ShowNet's service chaining).

3.5 ShowNet Operations and Publicity

At ShowNet, it is common for contributors to bring in products equipped with pre-release components or development-stage firmware. Furthermore, as a testing environment for new technologies, not all interoperability connection testing is guaranteed to succeed. Due to this experimental nature, sensitive information—such as details on unreleased products,

Figure: ShowNet Topology



■ Table: Pioneering technologies introduced by ShowNet

Era	ShowNet initiatives	Commercial service trends
1990s	ATM Metro Ethernet	ATM Mega Link Wide-area Ethernet services
2000s	ADSL Carrier-grade NAT SOC	DSL services CGN SOC services
2010s	100GbE SDN Service chaining	100GbE services SDN/NFV Network slicing
2020s	Segment routing SASE Zero Trust Wi-Fi 6E, Wi-Fi 7 Media over IP	

the success or failure of new technology trials, and network design parameters—is strictly managed as confidential among participants. To ensure this, all participants are required to sign a non-disclosure agreement. This safeguard allows companies to confidently contribute their latest products and actively engage in interoperability testing. At the same time, ShowNet serves as a platform for exhibitors to promote their products and showcase their adoption of emerging technologies to a large audience. Therefore, effectively communicating the results of interoperability tests is crucial. Managing the balance between confidentiality and publicity remains an ongoing challenge each year. This information control is primarily handled through coordination between the NOC team and the Interop Tokyo operations office. In particular, various outreach activities are conducted during the event, including ShowNet walking tours led by NOC team members and presentations on the ShowNet Stage. After the event, NOC team members compile the results and host shownet.conf_, a conference dedicated to sharing key findings with the broader community.

Operating a large-scale testbed like ShowNet requires significant investment. Nevertheless, the interoperability results demonstrated at ShowNet provide valuable insights for attendees, helping them evaluate and adopt new equipment and services. This, in turn, increases the likelihood that ShowNet contributors' products will be selected for deployment. Additionally, participation in ShowNet fosters industry collaboration, as members engage in discussions, exchange feedback, and work together on interoperability challenges. As a result, many contributors return as exhibitors at the following year's Interop Tokyo, allowing the exhibition to evolve. In this way, ShowNet has established itself as a business ecosystem for conducting interoperability testing with concepts that resonate with attendees, making sustainable activities possible—one of its key features.

3.6 The Significance of ShowNet

ShowNet serves not only as a network providing internet connectivity during the event but also as a platform where engineers and companies from industry and academia come together to share the latest technologies. This project goes beyond theoretical designs and product specifications—it demonstrates, in a short period, the whole process of interconnecting devices, running services, and operating the network. This enables attendees to see firsthand how a particular device or technology can be used and will function in their next project. Under the pioneering concepts proposed by the NOC team members, contributors bring a wide range of devices to simultaneously conduct large-scale interoperability testing, while promoting their technologies to the next market. The most significant aspect of ShowNet is testing and validating cutting-edge network technologies in a real-world environment.

Additionally, for STM members—volunteers recruited through an open call—ShowNet provides a rare opportunity to gain hands-on experience with the latest technologies and build large-scale networks in a short time frame. Many of the NOC team members who lead ShowNet's design and construction are former STMs, highlighting how the STM program not only fosters the growth of engineers but also provides them with visibility in the industry. This, too, is a key part of ShowNet's significance.

3.7 How to Participate in ShowNet

To participate in ShowNet as a contributor providing equipment or services, the primary requirement is to be an exhibitor at Interop Tokyo. Since there are various ways to participate, contacting the Interop Tokyo operations office for details is recommended. Typically, the first round of exhibitor applications for the following year closes at the end of November. By December, an announcement is made to exhibitors regarding the recruitment of ShowNet contributors. There is no specific participation fee for ShowNet. However, companies must cover expenses such as shipping costs for some equipment and travel costs for engineers. Once a company expresses its intent to participate, it can join the project. Participating companies are categorized into different sponsorship tiers based on their level of contribution, with various marketing benefits provided according to their rank. For further details, please contact the Interop Tokyo operations office.

Additionally, individuals can participate through the STM program, an open-call volunteer initiative. Recruitment for STMs is typically announced around December via Interop Tokyo's official website and ShowNet's social media accounts. Since the number of available positions is limited and selection is competitive, not everyone can participate. However, those who are enthusiastic about networking technology are encouraged to apply.

4. Conclusion

This paper has introduced the initiatives of Interop Tokyo ShowNet as a large-scale interoperability testing environment. Network architectures vary widely, as do their roles, but ShowNet facilitates the continuous evolution of the know-how in network design, construction, and operation to match these characteristics. By doing so, it enables the broader sharing of valuable insights and results within the industry. We hope that more companies, organizations, and individuals will join this initiative in the future. At the same time, we remain committed to sustaining this important effort in the networking industry going forward.

Cover Art

Cherry Blossoms on the Sumida Bank (Tokyo Sumidadote no sakura) from A Hundred Views of Musashi Province

Woodblock prints depict famous landmarks in Tokyo.

Kobayashi Kiyochika (1847-1915)

Source: National Diet Library, NDL Image Bank (https://rnavi.ndl.go.jp/imagebank/)

iPOP2024 Interoperability Experiments for Verification of Advanced Optical Network Orchestration

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1. Introduction

Increase in traffic is driving not only an increase in network communication capacity but also new communication demands such as Ultra Reliable Low Latency Communications (uRLLC) toward the Beyond 5G/6G era. From the viewpoint of large capacity and low power consumption, there are high hopes for a mechanism that can give programmability to a network such as the All-Photonics Network (APN) in IOWN (Innovative Optical and Wireless Network) and optimize and control the entire network consisting of virtualized network slices, optical equipment on the physical layer, etc. by an orchestrator. At the same time, network services used by users generally consist of multiple interconnected networks and data centers. It is therefore important to conduct not only functional tests in a single network configured with equipment from a single vendor but also tests in an interconnected communication environment configured with various types of equipment.

This article provides a brief introduction to International Conference on IP/IoT & Processing + Optical Network (iPOP) 2024[1], a key event providing an interoperability verification environment. It also introduces the purpose and details of Showcase interoperability experiments, a major feature of this conference. These interoperability experiments are conducted through the collaboration of the Research Promotion Council of Keihanna Info-Communication Open Laboratory, Interoperability Working Group, and various other institutions. For iPOP 2024, these experiments were conducted by the iPOP showcase members in an environment that connected a variety of devices and equipment installed mainly at the National Institute of Information and Communications Technology (NICT) in Koganei City and the Yagami Campus of Keio University in Japan via the JGN*, which is a network testbed for research and development provided by NICT[2].

2. What is iPOP?

The iPOP conference is an international gathering on next-generation networks integrating optical and IP technologies. The iPOP2024[1] conference was held from June 27th to 28th, 2024 in Harmony Goryokaku, Hakodate-shi, Hokkaido, Japan. It consisted of technical presentations and exhibitions as well as Showcase interoperability experiments that are a major feature of iPOP conferences. The iPOP international conference began in 2005 as “IP + Optical Network” but became “IP/IoT & Processing + Optical Network,” the current name, after adding the fields of IoT and computing in 2021. Recently, moreover, given the rapid progress in AI technology, iPOP has also come to mean “Intelligent and Processing over Optical networks.” In this sense, it has also become a place for discussing all-optical/photonic networks and AI platforms targeted by IOWN and 6G.

Although iPOP is usually held in the Tokyo area, it has sometimes been held in other areas such as Okinawa Prefecture in 2015 owing to deepening collaboration with Okinawa Open Laboratory (OOL). This time, on the occasion of the 20th anniversary of the iPOP conference, it was held in Harmony Goryokaku, Hakodate-shi, Hokkaido, Japan. Sponsored and managed by Photonic Internet Lab. (PIL) and ISOCORE, there was no participation fee for iPOP2024. This conference featured 3 keynote speeches, 9 technical lectures, 17 exhibitions, 2 sponsor sessions, a special panel discussion session on multicore fiber transmission and other topics under the theme of “Innovation in Optical Technology,” and a Showcase exhibition and presentation.

3. Showcase interoperability experiments at iPOP2024

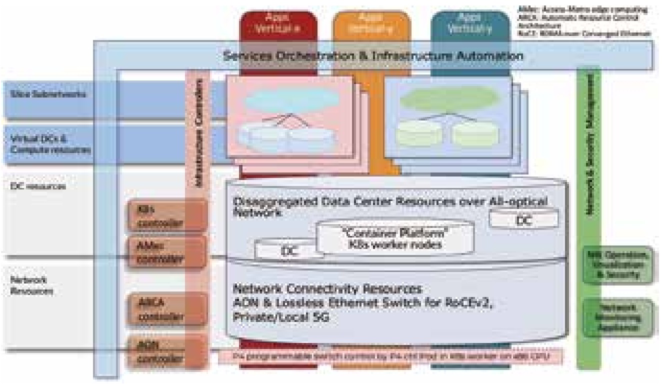
The Showcase was conducted in collaboration with Showcase committee members as valuable opportunities for experiments/demonstrations that would be difficult for a single organization (in particular, a single research and development group) to perform could be held. Here, a variety of companies bring technologies they would like to promote and content they would like to demonstrate in an interoperability environment while providing each other with facilities and technologies.

At this year’s iPOP2024, Showcase committee members and others studied technology themes and other matters and recruited institutions for participation under the Showcase title of “Integration of the Heterogeneous All Optical Network and End-to-End Automation in Hybrid Cloud Era.” Figure 1 shows a conceptual diagram of all optical/photonic networks of the hybrid cloud era and end-to-end autonomous control and service provisioning that have been taken up since 2021. Main technology themes are listed below. Items 9 and 10 represent newly added technology trends for iPOP2024 Showcase.

* Supported by JGN (TB-A24002)

1. Open/disaggregated packet and optical network systems
2. All-optical/photonic networks
3. Remote control/orchestration
4. Machine learning-based networking
5. Lifecycle management in cloud and edge computing
6. In-network computing for network service application
7. Enhanced technology of network security
8. Monitoring/streaming telemetry
9. Technologies for robust networks
10. Technologies for network digital twin

Figure 1: iPOP Showcase target



3.1 Showcase Configuration

This Showcase was conducted over a one-month period in June 2024 by nine institutions (NICT, ALAXALA Networks, OA Laboratory, OKI Electric Industry, Keio University, TOYO Corporation, Furukawa Electric, Mitsubishi Electric, and UBiqube) in cooperation with three companies (Fujitsu, Spirent, and Calnex) providing equipment.

Figure 2 shows detailed configuration diagrams of equipment connections for the above institutions. The equipment corresponding to APN-T, APN-G, and FXC was configured as the core optical network and networks, applications, and the control plane were constructed on the edge side.

In addition, this configuration installed 1Finity transponders, 16 x 16 optical switches, traffic testers, servers for machine learning, etc. (provided by NICT), Open ROADM-compliant Degree/SRG (Mitsubishi Electric), OLTs and ONUs (OKI Electric Industry and Furukawa Electric), XR-Optics (Furukawa Electric), and Open ROADM-compliant transponders (Fujitsu) at NICT (Koganei City) (Figure 3) and connected the above equipment via JGN to the experimental equipment installed at Keio University (Figure 4). It also connected a computer server group (Keio University) for applications using the constructed network. This system also installed a Spirent Network Emulator (SNE) (Spirent and Calnex) and an AX-Sensor (ALAXALA) at the Yagami Campus of Keio University and connected this equipment to a computer server group at the Shin-Kawasaki Campus of Keio University via an inter-campus network. An MSActivator orchestrator (UBiqube) running on a server in Grenoble, France controlled part of the above. During iPOP2024,

Figure 3: Experimental setup at NICT (Koganei City)

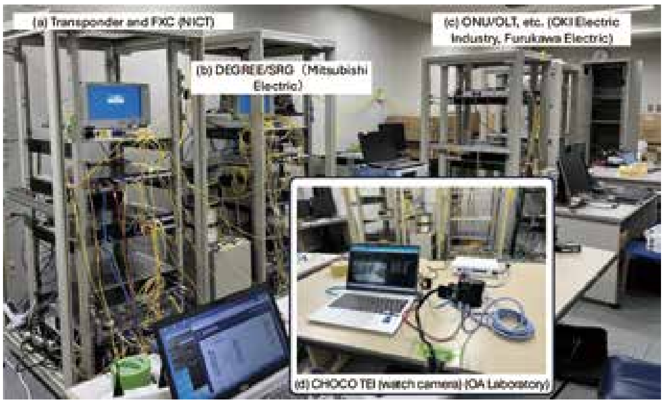
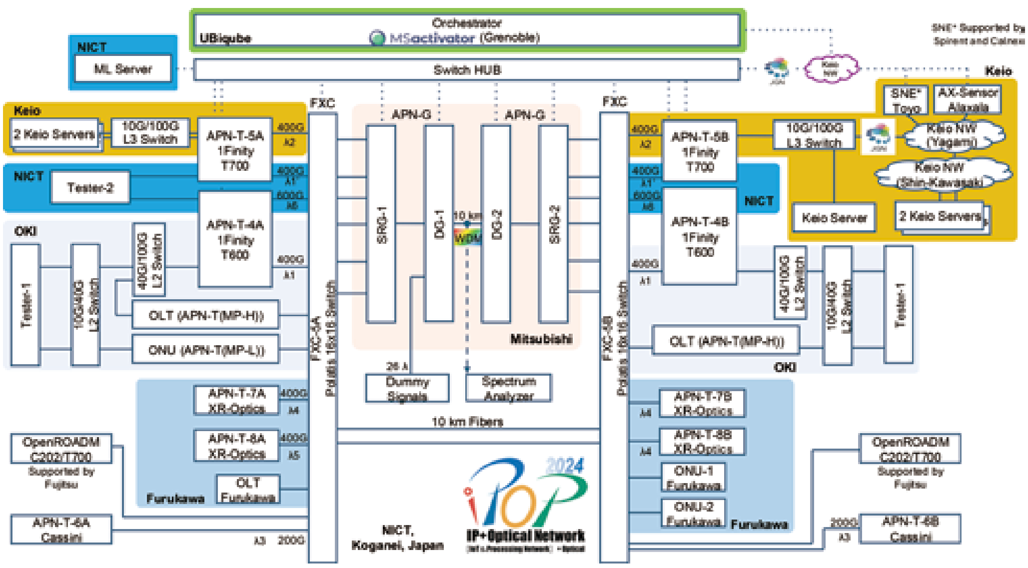
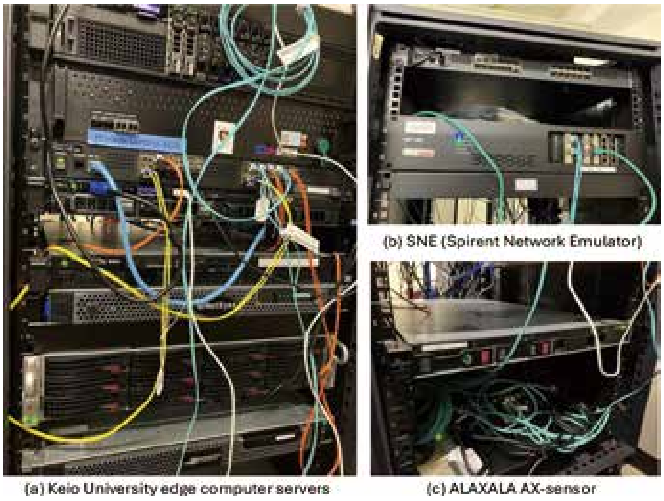


Figure 2: Showcase experimental system



■ **Figure 4: Experimental equipment installed at Keio University**



a connection was made between the iPOP hall and NICT (Koganei City) to provide a real-time dynamic exhibition of "CHOCO TEI (watch camera)" (OA Laboratory), a live demonstration of APN equipment control by the orchestrator and security sensor, etc.

3.2 Interoperability Experiment 1

Interoperability experiment 1, titled "APN control and performance experiments with OpenROADM and PON system Plus Applications on the APN," provided an example of cloud-native orchestration control. It featured a demonstration of lightpath setting/release conforming to OpenROADM, demonstration of P2P (point to point) and P2MP (point to multi-point) transmission functions and latency characteristics in a PON domain, etc.

For this experiment, we first used Scenario A, titled "Multi vendor APN control including ROADM (APN-G) using NETCONF/OpenROADM interface." Here, assuming an environment in which APN-G configured with a disaggregated-type Degree/SRG conforming to Open ROADM MSA accommodates multiple lightpaths for different transponders, an experimental system was constructed connecting a total of 32 lightpaths including 6 transponders. This experimental system was used to verify equipment management functions (lightpath setting/release) by NETCONF protocol from the orchestrator.

Next, in Scenario B titled "APN-T (MP-H/L (XGS-PON)) with low latency DBA and APN," P2P and P2MP connections were verified using ONUs and OLTs configured with XGS-PON as APN-T (Figure 5). In addition, transmission delay, jitter, etc. were measured when connecting two FXC units by a lightpath and a fiber path.

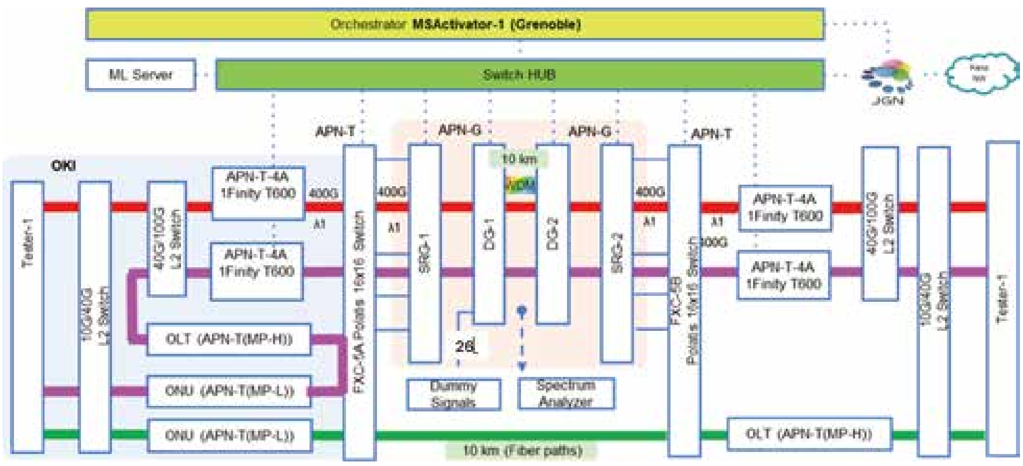
In Scenario C titled "XR Optics, EPON and APN," P2P and P2MP connections were verified using XR-Optics as APN-T and EPON transmission quality was measured on a fiber path. Additionally, we verified a simulation of automatic operation and control using two disaggregated edge servers connected via APN. This evaluation also included DDoS attack detection and damage mitigation using in-network computing, as well as real-time operation of the "CHOCO TEI (watch camera)", a compact factory IoT device.

In this interoperability experiment, the P2P/P2MP configurations with a view to applying APN to the access system revealed the feasibility of a core/metro system via APN equipment and opened up the prospect of an APN that merges the access and metro systems.

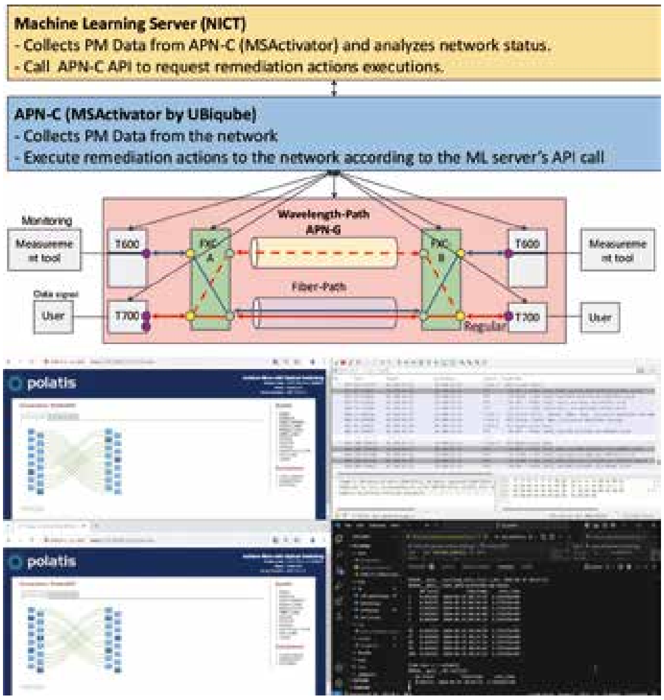
3.3 Interoperability Experiment 2

Interoperability experiment 2, titled "Closed loop control based on ML analysis of network information," incorporated an NICT-developed machine learning system in an experimental system and conducted a closed-loop control experiment of switch control according to optical network quality. An overview of this experiment is shown in Figure 6. Here, MSActivator, the orchestrator, periodically monitored network status at APN-related equipment and filtered essential information for input into a machine-learning server. Then, using this input time-series data

■ **Figure 5: Three types of transmission paths in interoperability experiment 1**



■ Figure 6: Closed-loop control by machine learning



on network status, the machine-learning server determined that path switching was necessary, switched fiber paths in collaboration with the orchestrator, and succeeded in verifying a sequence of control functions for controlling various types of equipment via the API of the MSActivator. In the future, the plan is to enhance telemetry information collection technology and machine learning servers toward efficient autonomous control of optical networks with no human intervention.

3.4 Interoperability Experiment 3

Interoperability Experiment 3, titled "Network failure simulation and visualization with closed loop control," involved the construction of a data plane at the Yagami Campus and K2 Campus of Keio University (see Figure 7). It performed a closed-loop control experiment by inserting a pseudo failure simulator for testing purposes in the network to generate failures such as pseudo packet loss, detecting those failures by a security sensor, and having the orchestrator instruct operations to be performed. This experiment artificially lost partial packets as pseudo failures that could be caused by silent failures that are difficult to detect by communications equipment itself and detected such packet losses by a security sensor. In this way, the experiment opened up a path toward the prevention of large-scale failures by automatically identifying silent failures.

4. Conclusion

This article provided an overview of iPOP2024 celebrating its 20th anniversary and introduced Showcase interoperability experiments that are one of its main features. This is an extremely unique conference that has been held in an ongoing manner in Japan that, while targeting optical networks, has also contributed to industry and the formulation of new standards. The iPOP Showcase, in particular, has been providing valuable opportunities for organizations to hold interoperability experiments. In addition, some of the results of these experiments are being presented at other international conferences, used by individual companies for studies toward standardization, etc.

Next time, the plan is to hold iPOP2025 at NICT (Koganei City in Tokyo) on July 17th and 18th, 2025. The period for submitting applications for holding exhibits, presenting technical lectures, etc. will run from March to April as usual. Exhibitors on the silver level or higher may participate in Showcase—it is hoped that many new companies will participate in the 2025 and future interoperability experiments.

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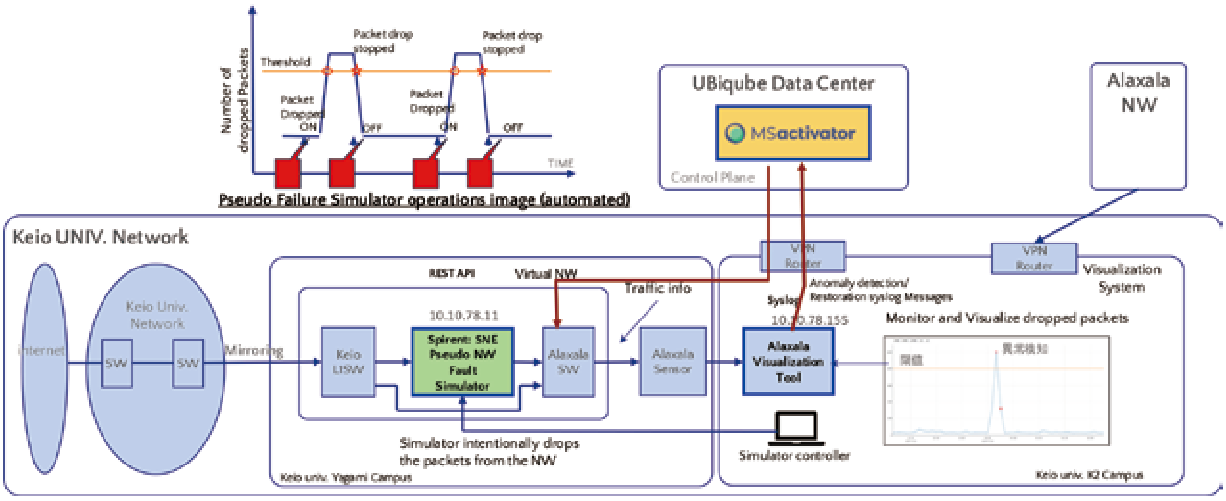
■ Figure 7: Automatic control experiment by packet-loss simulation and detection system



World's First Successful Experiment Using a Quantum Computer for Future Massive Connectivity

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1. Background

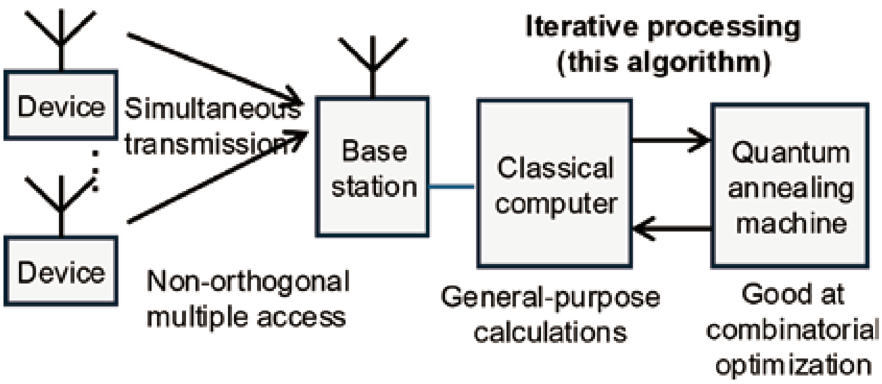
International discussions on next-generation mobile communications systems are underway amid the spread of the fifth-generation mobile communications system (5G). In November 2023, ITU-R Recommendation M.2160[1] was issued describing usage scenarios and functions expected of mobile communications systems for 2030 and beyond. This Recommendation, while extending the three usage scenarios of ultra-high-speed communications, low latency and high reliability, and massive connectivity in 5G, added the three usage scenarios of integrated sensing and communications, use of artificial intelligence (AI), and ubiquitous connectivity. In terms of many-device connectivity, it describes an increase in the degree of connected devices from 106 devices/km^2 in 5G to a range of 10^6 to 10^8 devices/km^2 in next-generation mobile communications systems. This progress is expected to lead to the creation of novel applications in a variety of fields including smart cities, transportation, logistics, healthcare, energy, environmental monitoring, and agriculture. Non-orthogonal multiple access (NOMA)[2] is a technology now attracting attention as a means of improving connectivity by allocating the mobile communications resources of time and frequency to multiple devices while allowing interference between them. When using NOMA on the uplink, signal separation processing is necessary considering the inter-device interference at the base station, but this processing creates an issue in that computational complexity increases exponentially.

2. Signal processing technology using quantum annealing

The quantum annealing machine has recently been attracting attention as a computer that can solve combinatorial optimization problems at high speed. Quantum computers can be broadly divided into “gate-type” and “annealing-type,” and an annealing-type of quantum computer is called a quantum annealing machine. Professor Hidetoshi Nishimori of Tokyo Institute of Technology established the theoretical foundation of the “annealing-type” in 1998. Additionally, D-Wave Systems in Canada commercialized the quantum annealing machine for the first time in the world in May 2011. Quantum annealing (QA), which is analogous to the annealing process in metallurgy, is a technique that explores an optimal solution through time evolution using quantum fluctuations. To initiate QA, we set quantum fluctuation dominant to explore diverse solutions. Then, we gradually reduce those quantum fluctuations, guiding QA towards a single solution. By executing this process slowly, QA can achieve the optimal solution.

Quantum annealing machines are designed for solving combinatorial optimization problems but not suited for general-purpose calculations. Signal separation processing in NOMA involves not only large-scale combinatorial optimization problems but also general-purpose calculations such as demodulation and decoding. Therefore, applying QA to NOMA requires the development of a practical method that effectively leverages

Figure 1: Signal processing using quantum annealing (when applied to non-orthogonal multiple access)



quantum annealing machines.

At NICT, we have developed a new quantum-digital hybrid algorithm that integrates the quantum annealing machine with classical digital computers[3]. This algorithm enhances computational efficiency and applicability across various areas of signal processing. In this algorithm, we utilize the quantum annealing machine as a sampler that generates diverse solutions. After QA sampling on the order of microseconds, we perform post-processing for the obtained samples using a classical computer. Through this approach, our algorithm can accurately capture the desired probability distribution even with a limited number of samples (Figure 1). Our algorithm offers the advantage of being directly applicable to conventional digital communication systems that include signal processing on the classical computer, such as error-correcting code decoding. Furthermore, as shown in the figure, it can also be applied to sequential processing, where iterative operations are performed between the quantum annealing machine and the classical computer.

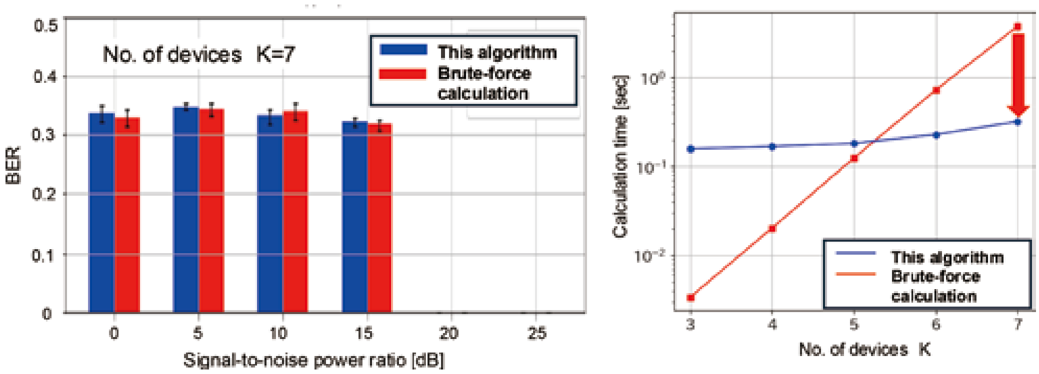
3. Experiment and evaluation

We applied the proposed algorithm to signal separation at a base station in an uplink NOMA system. Let M and K represent the modulation order of transmitted signals and the number of simultaneously connected devices, respectively. Thus, the number of possible received signal combinations is given as M^K, meaning that computational complexity increases exponentially as K grows. Additionally, when K exceeds the number of antennas at the base station, the uplink NOMA system is in an "overloaded state," making the signal separation particularly challenging. While many previous studies have investigated the application of QA to signal separation processing (such as [4] and [5]), our algorithm can be effectively applied to such overload systems.

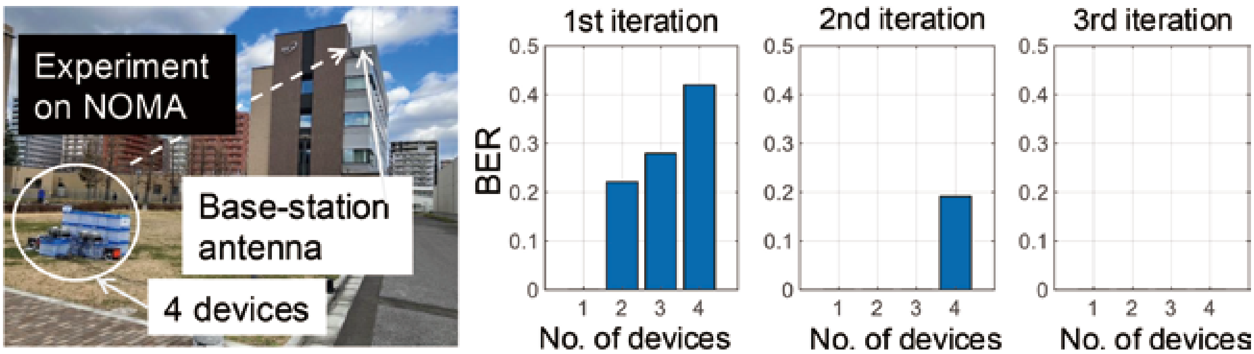
We first evaluated the performance of the proposed algorithm through numerical simulations. We generated transmission signals from multiple devices, superposed them, and simulated the received signal at the base station. Then, we applied the proposed algorithm to signal separation processing. We used the D-Wave quantum annealing machine to obtain samples. The obtained samples were post-processed on a classical computer to calculate the log-likelihood ratio (LLR) of each codeword bit. Finally, error correction decoding and error detection were performed for each device, completing the signal separation process. After error detection, we generated replicas of the received signals for correctly detected devices and subtracted them from the received signal. Then, we performed combinatorial optimization processing using the quantum annealing machine in the iterative process. Annealing time in the quantum annealing machine was set to 20 μs and the number of samplings to 1,000. In our simulation, the transmission signals from the devices were QPSK signals (M = 4, single carrier modulation) and turbo codes were used as error-correcting codes. The number of simultaneously connected devices K per one antenna at the base station was a maximum of 7 and the number of possible received signal combinations for K = 7 was greater than 16,000. Evaluation results showed that the proposed algorithm has comparable separation performance (bit error rate (BER) characteristics) compared with a conventional technique using only a classical computer (Figure 2 left). In addition, the results showed that the calculation time for signal separation processing when using the proposed algorithm (calculated as the integrated value of time required for quantum annealing) could be shortened to approximately 1/10 that when using only a classical computer (Figure 2 right).

After computer simulations, we developed a wireless communication experimental system implementing the proposed algorithm for a base station and demonstrated it outdoors in the field. The multiple devices transmitted QPSK signals (M = 4, single carrier modulation) at the same time and same frequency, and the base station converted the received signals into baseband signals. Then, we estimated radio-wave propagation characteristics (complex numbers) through a reference signal and performed QA samplings using the D-Wave quantum annealing machine. Here, the annealing time was 20 μs and the number of samples was set to 1,000. The number of devices was limited to four units (K = 4) because the purpose here was a proof-of-principle demonstration, and the number of base-station antennas was one. As shown in Figure 3, the results showed that signal separation without error

Figure 2: Evaluation results by computer simulation



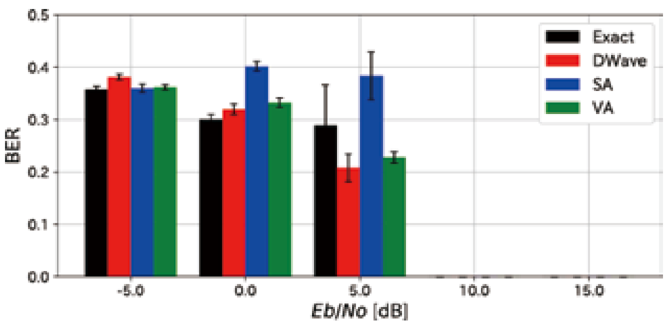
■ **Figure 3: Overview of proof-of-principle demonstration in the field (No. of devices K = 4)**



could be achieved by performing iterative processing three times between the classical computer and quantum annealing machine (signal-to-noise power ratio at the time of this experiment was approximately 26 dB). This demonstration was the world's first successful online experiment on signal separation processing using a quantum annealing machine for uplink NOMA in the field[6].

Furthermore, we are studying the application of the proposed algorithm to 5G New Radio (NR) signals to enhance multi-device connectivity performance[7]. For this purpose, we updated the algorithm to support a CP-OFDM transmission signal and multiple-input multiple-output (MIMO) systems in 5G NR. Figure 4 shows the performance evaluation obtained by the computer simulations. Here, the number of base-station antennas = 2, the number of simultaneously connected devices = 4, subcarrier interval = 15 kHz, and error-correcting code = LDPC. The results revealed that the proposed algorithm using D-Wave (labeled as "D-Wave" in the figure) exhibited BER performance equivalent to the exact calculation results ("Exact" in the figure). The results also demonstrated that the vector annealer ("VA" in the figure) and simulated annealing ("SA" in the figure) could achieve signal separation. Therefore, various types of annealing techniques can be applied to our algorithm. Additionally, we plan to conduct outdoor experiments to validate the algorithm for 5G NR systems.

■ **Figure 4: Example of application to 5G NR signals (computer simulation, number of devices K = 4)**



4. Future outlook

The algorithm proposed in this research is expected to become a fundamental technology supporting next-generation mobile communications systems. Furthermore, in addition to multiple access technologies, it shows promise for application to a variety of fields involving combinatorial optimization calculations such as large-scale beam forming and network optimization. Our goal going forward is the practical implementation of this technology by holding actual field tests and making further improvements to the algorithm.

Acknowledgments

This research was supported in part by the Quantum Leap Flagship Program (Q-LEAP) JPMXS0120319794 of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and commissioned in part by the Strategic Information and Communications R&D Promotion Programme (SCOPE) (Grant Number JP235003004) of the Ministry of Internal Affairs and Communications (MIC).

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Enhancing Digital Transformation Through Disaster Resilience: ITU and Japan's Partnership in Asia and the Pacific

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Dr. Atsuko Okuda
Regional Director
ITU Regional Office for Asia and the Pacific

The Asia and the Pacific region is prone to a multitude of hazards, ranging from typhoons to earthquakes, volcanic eruptions and wildfires. In addition to human casualties and lives lost, these events undermine hard-won socioeconomic gains of developing countries and set back development.

There is a lot that digital technology can do to improve responses to disasters and mitigate these harms. Resilient digital infrastructure is key.

When hazards – such as cyclones or volcanic eruptions – cut submarine or terrestrial cables or knock down mobile towers, communication can instantly be affected, leaving the government unable to communicate with local, national and international partners.

Infrastructure damage hinders the ability of governments to mount an effective disaster response and communicate with citizens who need urgent support. Experience has taught us that ensuring resilience in digital infrastructure and enabling communication at a time of natural disaster is a matter of life and death.

Collaborating with Japan to save lives, protect development gains

Against this backdrop, ITU's Telecommunication Development Bureau (BDT) has been collaborating with Japan's Ministry of Internal Affairs and Communications (MIC) to enhance the resilience of digital infrastructure in Asia and the Pacific.

The joint projects seek to develop infrastructure that is affordable and reliable and enables digital transformation initiatives that deliver development gains.

Over the years, the BDT-MIC cooperation has expanded, and now supports ITU membership in developing technology-based solutions for disseminating alerts and improving communications through the Early Warnings for All (EW4ALL) initiative. ITU's role in the UN-wide effort is to ensure timely dissemination of disaster alerts.

Building policy and regulatory environments for affordable connectivity

Japan is a natural partner for ITU in advancing resilient digital infrastructure across Asia and the Pacific. When the devastating earthquake struck the Noto Peninsula of Japan on January 1, 2024, the immediate issuance of disaster alerts, including tsunami warnings, by the government across all media was truly remarkable. This prompt response likely minimized casualties despite the earthquake's magnitude. The successful response was a concrete result of the lessons and good practices Japan has accumulated over years of experience with hazards.

ITU-BDT has been partnering with MIC on a number of projects targeting the development of resilient digital infrastructure among developing countries in Asia and the Pacific. Such infrastructure is expected to be affordable, reliable, and redundant and deliver development gains through digital transformation.

The first phase of the MIC-ITU project focused on the development of a National Emergency Telecommunication Plan (NETP) and policy and regulatory environments that reinforce affordable ICT connectivity.

The NETP enables the exchange of information about hazards and the use of telecommunications/ICTs to respond to them at all government levels, within communities, and between public and private organizations.

The NETP provides a snapshot of available telecom/ICT resources and lines of responsibility for mitigating disaster risk and emergency response. The project helped Kiribati, Mongolia, and Lao P.D.R develop NETPs and worked with ASEAN Coordinating Centre for Humanitarian Assistance (AHA centre) to develop an Emergency Telecommunication Network (ETN) for ASEAN countries. The project brought policy support on affordable connectivity to Tonga, Iran, Bhutan and Samoa.

Tonga is working to enhance disaster preparedness through a NETP, part of an action plan the country undertook after a comprehensive assessment of connectivity disruptions caused by undersea volcanic eruptions in January 2022.

In Bhutan, the project activities identified gaps in the resilience of the Government Data Centre of Bhutan through a detailed technical assessment and made recommendations.

In Samoa, the project supported a three-day capacity-building event on the Manono Smart Island, organized by the Ministry of Communication and Information Technology (MCIT) in collaboration with the Food and Agriculture Organization (FAO) in Dec 2023.

Building on the success of the project's first phase, the second phase deepened the engagement with member countries. It

■ Figure 1: Tonga workshop, Nukualofa, April 2023

■ Figure 2: Bhutan, Thimphu, during the visit to conduct the assessment in June 2023

■ Figure 3: Samoa, Manono, December 2023

■ Figure 4: An EW4ALL workshop in Lao PDR, Vientiane, November 2023

focused on national gaps assessment for infrastructure resilience, preparedness, service affordability and EW4ALL; a national roadmap/framework for EW4ALL; and NETP development.

Gaps assessments have been conducted for the Solomon Islands, Tonga, and the Maldives, and are to be followed by assessments in Samoa and Kiribati. These assessments were key in developing national EW4ALL roadmaps for Tonga and the Solomon Islands. Stakeholder-validation workshops in Kiribati and Samoa are in the pipeline. Fiji's NETP update has been conducted, and Tuvalu's NETP is at the final stage of development after stakeholder consultation.

Building on Japan-ITU collaboration

Recognizing the success of the cooperation, discussions are already in the final stages for the third phase of the project, which will focus on studying the feasibility of cloud-based sub-regional solutions for cell broadcast and helping countries develop comprehensive plans for using resilient digital infrastructure to mitigate hazards and emergencies.

The achievements made possible through Japan's support form the foundation of inclusive, sustainable and resilient digital transformation in Asia and the Pacific.

Building on project achievements, the developing countries in Asia and the Pacific are launching initiatives, such as Smart Islands and Smart Villages, digital inclusion, capacity development, policy and regulations, and cybersecurity, just to name a few.

These interlinked achievements will be shared widely at the upcoming Asia-Pacific Regional Development Forum (RDF) and Regional Preparatory Meeting (RPM) of ITU from 19 to 21 March 2025 in Bangkok, Thailand.

The project outcomes are expected to serve as a basis for formulating the next regional initiatives. They highlight the continuing importance of resilience in infrastructure development in this disaster-prone region.

The discussion outcomes and the proposed set of regional initiatives will feed into the upcoming World Telecommunication Development Conference (WTDC), scheduled from 17 to 28 November 2025 in Baku, Azerbaijan. In the process, the government, industry and academia outside Asia and the Pacific are expected to learn about the challenges and opportunities the region faces and about the initiatives, support and partnership between Japan and ITU.

The ITU is celebrating its 160th anniversary throughout 2025. Our work aims to set the stage for another 160 productive, meaningful, and impactful years. With such a committed and dedicated partner as MIC, we will strive to continue delivering benefits and making a positive impact on those who need it most.

= A Serial Introduction Part 3 = Winners of ITU-AJ Encouragement Awards 2024

In May every year, The ITU Association of Japan (ITU-AJ) proudly presents ITU-AJ Encouragement Awards to people who have made outstanding contributions in the field of international standardization and have helped in the ongoing development of ICT.
These Awards are also an embodiment of our sincere desire to encourage further contributions from these individuals in the future.
If you happen to run into these winners at another meeting in the future, please say hello to them.
But first, as part of the introductory series of Award Winners, allow us to introduce some of those remarkable winners.

Daiki Takeda

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Fields of activity: 4G/5G commercial development and standardization

Contributions to Evolution of Mobile Communication: From LTE to 5G

It is a great honor to have been awarded the ITU-AJ Encouragement Award 2024. I would first like to express my deep gratitude for all the support given by the ITU Association of Japan and all parties involved.

When I joined NTT DOCOMO in 2012, many mobile operators were already launching commercial LTE (Long Term Evolution) services. Simultaneously, intensive research and development efforts to advance LTE into its next phase, LTE-Advanced, were underway. However, the practical performance of key technologies for LTE-Advanced, such as MIMO (Multi-Input Multi-Output) and carrier aggregation, in real-world environments was still being investigated. I vividly remember conducting countless field measurements using radio-wave testing vehicles in diverse environments ranging from suburban to urban areas. During that time, my primary focus was to establish a solid technical foundation that would ensure faster, lower-latency, more-reliable, and more-seamless LTE-Advanced services for our customers.

In 2015, I began participating in 3GPP standardization activities and contributed to the commercial development of 5G, the fifth-generation mobile communication system aligned with the IMT-2020 radio interface. Compared to LTE/LTE-Advanced, 5G offers significantly increased communication speeds; however, it also presents challenges in leveraging higher frequencies and broader bandwidths. I focused on proposing methods for quick cell search and beam selection as well as innovative methods for reducing power consumption of user terminals. Additionally, I submitted numerous patent applications for the novel technologies that we developed through our experiments and standardization efforts. In 2023, I was deeply honored to receive the Prime Minister Prize at the National Commendation for Invention, which I believe recognizes our contribution to strengthening Japan's global competitiveness.

Currently, discussions on 6G, the next-generation mobile communication system, are underway. These discussions include exploring new values, such as sustainability, while deepening and diversifying the benefits mobile communications bring to society. Drawing on my experiences and with the support of all stakeholders, I will continue striving to enhance telecommunications infrastructure as a critical foundation of society.

Finally, I would once again like to express my sincere gratitude for this prestigious award and respectfully ask for your continued guidance and support in the future.

Wenjing Chen

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wenjing.chen.bv@nttdocomo.com https://www.docomo.ne.jp/english/
Fields of activity: ETSI ISG ZSM

Contributing to ETSI ZSM Standardization Autonomous Network

I am very honored to receive the Encouragement Award from the ITU Association of Japan. I would also like to express my gratitude to everyone at the ITU Association of Japan, ETSI ZSM, and NTT Docomo.

Since 2019, I have been participating in standardization activities for automation of network operation at ETSI ZSM.

ZSM (Zero-touch network and Service Management) is a specification study group of ETSI (European Telecommunications Standards Institute). Since its establishment in 2017, under the aim of implementing autonomous networks, many high-level work items, such as reference architectures, use cases, requirements, and life cycles between cross-domains, have been published.

Recently, I have been focusing on intent-driven closed loops and digital twins.

To implement the autonomous network established by ITU-T SG13, "intent-driven closed-loop networks/systems/management and control/etc." has/have been garnering attention. Using such a network/system/etc., users express their goals in natural languages, which is called "intent." The system translates the intent into an "attribute" in system language and uses the closed-loop to fulfill the intent all the time. I put effort into specifying the solution of intent conflicts with closed-loop and keeping discussion with other operators and vendors to approve the specifications.

Digital twins are specified in ITU-T SG11, and ZSM has a liaison paper with ITU-T. They are virtual representations of physical networks and used for simulation, integration, testing, monitoring, and maintenance. This technology deserves more attention because it will help to improve the service quality.

In addition to participating in the above-mentioned activities, I would like to participate in various activities related to autonomous-network standardization and implementation at the ITU, 3GPP, O-RAN, and TM Forum. Finally, I will strive to [future goals] and ask for your continued guidance and support in the future.

Katsumi Fujii

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Fields of activity: Electromagnetic compatibility, Calibration of RF measuring instruments

Contribution to the international standardization of EMI measurements below 30 MHz

I am truly grateful to receive this honorable award, the ITU Association of Japan's Encouragement Award. I would like to express my sincere gratitude to everyone at CISPR SC-A and all those involved in bestowing this award.

The frequency band below 30 MHz has been used for communications and broadcasting since the use of radio waves began; however, in recent years, it has come to be used for a variety of other applications, including IH-cooking equipment, wireless power transfer, and contactless IC cards (RFID). Meanwhile it has become known that inverter circuits installed in energy-saving devices generate electromagnetic noise in the frequency band below 30 MHz, and that noise can cause interference with other devices. Against this background, it has become necessary to maintain a suitable electromagnetic environment—even in the frequency band below 30 MHz—and create rules to meet this necessity. Considering those circumstances, CISPR decided to develop an international standard for measuring electromagnetic noise in the range from 9 kHz to 30 MHz.

I decided to work on formulating standards for "a method for evaluating the characteristics of test sites" and "a method for calibrating antennas," and I presented the results of my research and development at the CISPR meetings. After discussions with experts from around the world, these two proposed methods were adopted as CISPR standards. Currently, these standards are widely used as international standards necessary for commercialization in fields ranging from electronic and electrical equipment to automobiles.

I will continue to contribute to international standardization activities of CISPR that aim to maintain a radio environment in which all wireless systems can operate in harmony.

通巻四十六号

定価　一冊　一、六五〇円（本体価格　一、五〇〇円、消費税　一五〇円）　年間購読料　六、六〇〇円（本体価格　六、〇〇〇円、消費税　六〇〇円）