Progress in the Development of IOWN Technology

Masahisa Kawashima and Yosuke Aragane

Abstract

Technical improvements in full-stack layers are essential to develop a future infrastructure with higher capacity, lower latency, and lower power consumption toward a cyber-physical society. NTT announced its roadmap for this technology, the Innovative Optical and Wireless Network (IOWN), in April 2020 and has accelerated to implement the roadmap with global partners of the IOWN Global Forum (IOWN GF). IOWN GF developed and published a series of deliverables on Open All-Photonic Network (Open APN), IOWN for Mobile Network, Fiber Sensing for Open APN, Data-Centric Infrastructure, IOWN Data Hub, and a Reference Implementation Model. This article provides an overview of these deliverables and describes the growth of IOWN GF and its activities.

Keywords: All-Photonics Network, disaggregated computing, data hub, IOWN

1. Why the Innovative Optical and Wireless Network (IOWN)

A cyber-physical system is expected to provide a more productive and sustainable society. However, the capabilities of the current network and computing infrastructures cannot satisfy these requirements. Let us look at a use case for preventing collisions at road intersections by installing artificial intelligence (AI) network cameras into curve mirrors (**Fig. 1**) and the following four issues that need to be addressed.

The first issue is the processing capabilities of servers. Because there are many intersections in a city, it is necessary to upgrade server-processing capability to accommodate as many cameras as possible. Although the capabilities and efficiency of accelerators have improved, the current mechanism for receiving and sending data with AI accelerators forms a bottleneck.

The second issue is latency. The latency from capturing a dangerous situation to delivering the control command to the vehicle or person about to collide should be less than 10 ms. However, the current TCP/IP (Transmission Control Protocol/Internet Protocol) requires several round trips for the flow control to transfer image data.

The third issue is reliability. In other use cases, such as controlling drones and autonomous vehicles, communications should be connected continuously. Since high-capacity mobile communications, such as the fifth-generation mobile communication system (5G), use a high-frequency band, communication interruptions due to obstacles become more frequent.

The fourth issue is power consumption. Reducing power consumption is one of the most important social issues. We have to develop systems with as low power consumption as possible. However, according to our research, a computer infrastructure for AI analysis consumes more than 10 W of power per video stream, equivalent to the power consumed by an incandescent light bulb [1]. To reduce power consumption, it is necessary to conduct AI analysis only when there is something physically on the camera such as people and objects. This feature requires light-weight pre-processing to find the something on the camera before AI analysis. The current major technical approach tends to use edge computing for the light-weight pre-processing and reducing the response time. However, using edge computing for low-latency execution reduces the efficiency of work among datacenters and difficult to control on-demand information technology (IT) resource usage.

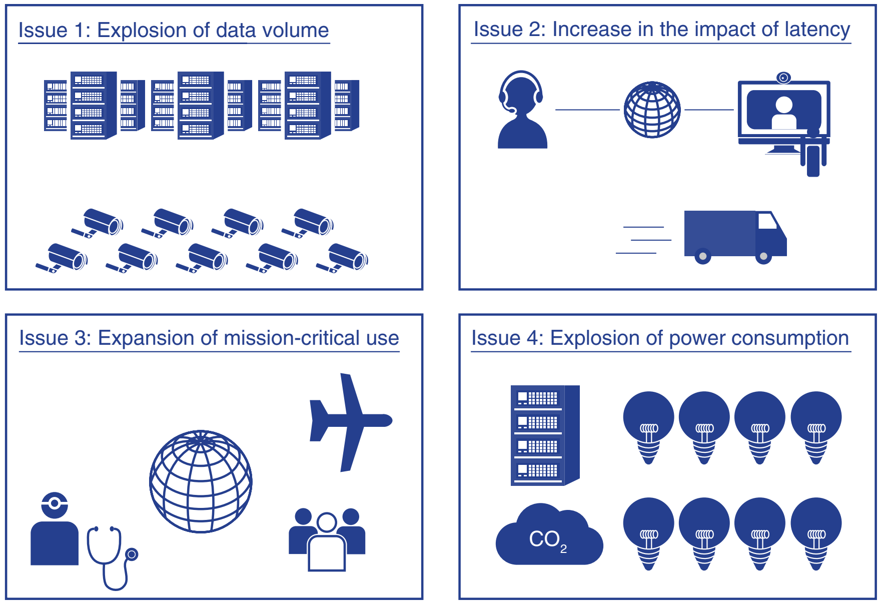


Fig. 1. Issues to be addressed.

These issues have been known in the communications and IT industries for several years, and high-speed mobile networks, such as 5G and edge computing, have been under consideration. However, in network services, packet-based transmission, which is a best-effort approach, has not been re-examined. Improvements have been made in individual layers such as communications and IT, but no matter how fast the network is, the best-effort approach requires delays for the flow control. Edge computing with the best-effort approach results in inefficient IT resource usage due to the split of work among datacenters; thus, full-stack technology is required instead of layer-dedicated improvements of technologies.

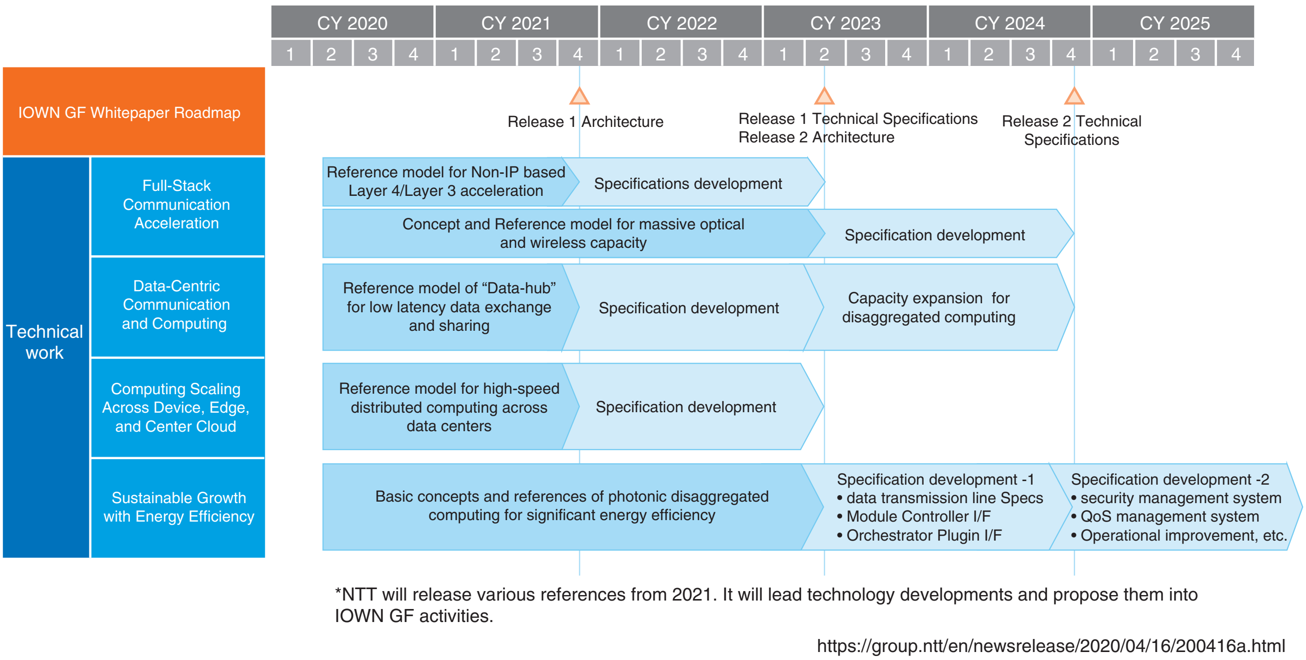
To advance full-stack technology in an open community, NTT, Intel, and Sony established the IOWN Global Forum (IOWN GF) in January 2020. In April 2020, IOWN GF published a white paper summarizing its expected innovations followed by NTT's announcement of NTT's technology development roadmap called "IOWN Technology Development Roadmap" (**Fig. 2**).

2. IOWN roadmap and IOWN GF

With the participation of many organizations worldwide, discussions at IOWN GF are accelerating. Key technologies defined in the roadmap are also being developed in collaboration with IOWN GF members. As a result of these efforts, six technical documents were published by IOWN GF [1]. The Feature Articles in this issue explain some of the key technologies described in these documents [2–4]. This section provides an overview of these documents, including their relationship to the IOWN Technology Development Roadmap. These documents are also linked to the functional structure image of IOWN, introduced in this journal in 2020 "Initiatives to Achieve the IOWN (Innovative Optical and Wireless Network) Concept" [5] (**Fig. 3**).

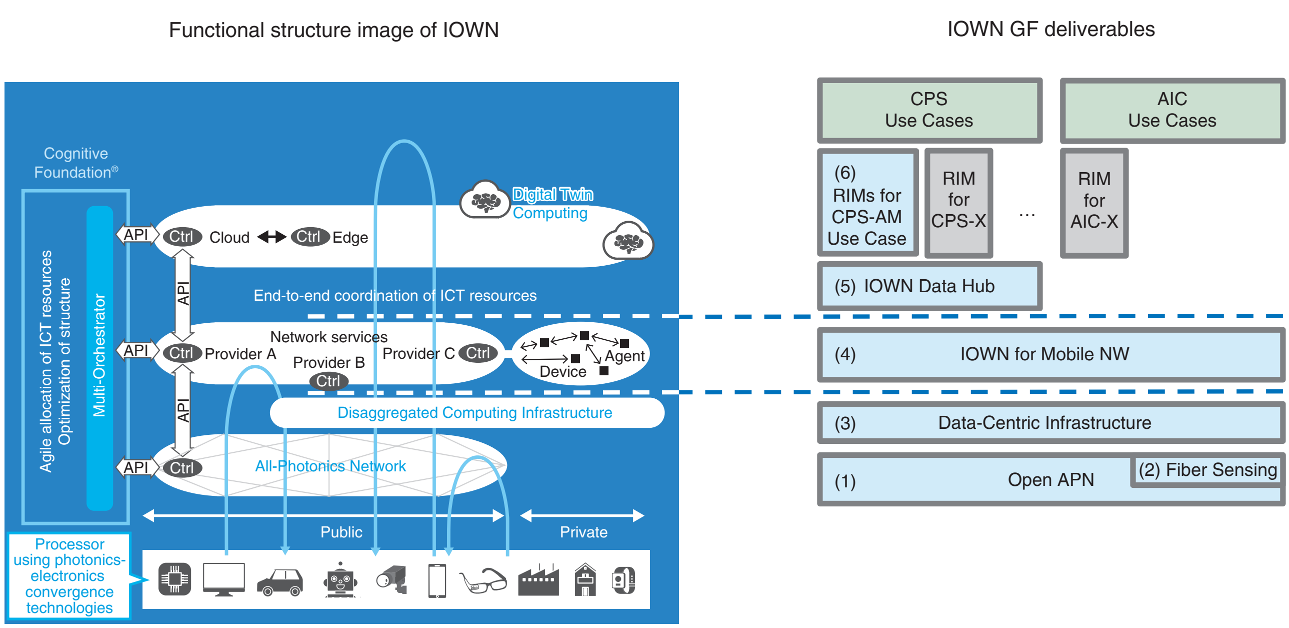
IOWN GF published two technical documents on the Open All-Photonic Network (Open APN) (Fig. 3(1)) and IOWN for Mobile Network (NW) (Fig. 3(4)). This is related to the "Concept and reference model for massive optical and wireless capacity" of the IOWN Technology Development Roadmap. The Open APN document defines an open architecture for building the All-Photonics Network (APN) with multiple vendors, which enables communication with a deterministic transmission rate and latency. The IOWN for Mobile NW document defines the building of a wireless network on IOWN infrastructure that achieves both high capacity and high reliability. It shows how the APN and disaggregated computing can be applied to the O-RAN (Open Radio Access Network) architecture.

The ability of optical fibers to propagate optical signals far away can be applied not only to data



I/F: interface
QoS: quality of service

Fig. 2. IOWN Technology Development Roadmap.



AIC: AI-integrated communication
AM: area management
API: application programming interface
CPS: cyber-physical system
Ctrl: controller
ICT: information and communication technology

Fig. 3. IOWN concept and IOWN GF activities.

communication but also to sensing. Businesses and public institutions that invest in fiber infrastructure for the APN will be able to use such fibers for sensing. The APN, which enables a large-capacity communication infrastructure, also enables the collection of sensing signals. For this technology, the architecture for adding the sensing function to the APN was also discussed in the document published as "Fiber Sensing for Open APN" (Fig. 3(2)).

IOWN GF also published a technical document on data-centric infrastructure (DCI) (Fig. 3(3)). It is related to the "Basic concepts and references of photonic disaggregated computing for significant energy efficiency" of the IOWN Technology Development Roadmap. DCI provides an efficient mechanism for sending data to the accelerators by equipping accelerators with a network input/output.

Data plane acceleration (DPA) in the DCI document presents the protocol stack and design for transferring data at high speed and low latency by using the APN between two remote DCI infrastructures. This is related to the "Reference model for non-IP based Layer 4/Layer 3 acceleration" of the IOWN Technology Development Roadmap. DPA allows multiple DCIs deployed on adjacent datacenters to share IT resources, reducing the loss due to work split among datacenters. IOWN can provide a large virtual datacenter (clustered datacenter) by combining multiple datacenters with the APN.

A clustered datacenter enables scalable and high-available database/storage with distributed database/storage among those in the cluster. IOWN GF developed this cloud-native database and storage architecture as the IOWN Data Hub (Fig. 3(5)). This is related to the "Reference model of 'Data Hub' for low-latency data exchange and sharing" of the IOWN Technology Development Roadmap. The IOWN Data Hub will be an infrastructure that connects countless data providers and data users in a cyber-physical society. In other words, the network is the database. In a cyber-physical society, we believe network infrastructure must provide not only data-transfer functions but also database functions.

IOWN GF also decided to develop reference implementation model (RIM) documents for specific use cases (Fig. 3(6)). This is related to the "Reference model for high-speed distributed computing across datacenters" of the IOWN Technology Development Roadmap. Full-stack technology should be developed focusing on the characteristics of each use case. IOWN GF has published an RIM for area management.

3. IOWN GF and its activities

3.1 Technologies and use cases

IOWN is taking on the ambitious challenge of creating an innovative infrastructure for both communications and computing. Therefore, IOWN GF needs to drive both technology development for the IOWN infrastructure and use cases of what future values those technologies can create. For developing innovative and valuable outcomes, IOWN GF established two types of Working Groups, i.e., Technology and Use Case, and Steering Committees to coordinate inter-working group activities (**Fig. 4**).

As can be seen from the member list on the IOWN GF website [6], not only companies and organizations that develop IOWN technologies but also many companies that use IOWN technologies to expand their businesses are participating. In use-case discussions, some members share the business challenges and future risks that they are facing and ask other members whether they can be addressed by IOWN GF activities or whether it is an attractive use case and something they should discuss together to address such challenges and risks.

To meet these business requirements, the Use Case Working Group tries to estimate numerical requirements such as response time, network bandwidth, and power consumption. The Use Case Working Group asks the Technology Working Group to develop innovative technologies to meet these requirements.

3.2 Native online activities

In the preparation phase for IOWN GF establishment, face-to-face meetings were considered essential to build relationships among the members and accelerate the forum activities. However, due to the COVID-19 pandemic, IOWN GF has been forced to operate fully online since its establishment. IOWN GF has been trying to determine if it can build relationships between members in this situation and have constructive discussions on how to create deliverables.

IOWN GF is a forum with diverse members from the US, Europe, and Asia, so it must consider several time zones. If an online meeting is held for 6 hours, like a normal international meeting, it will be late at night or early in the morning in some regions. IOWN GF has tried to limit the meeting time to no more than two hours to avoid late night and/or early morning scheduling for most members. The shorter meeting times resulted in more frequent meetings, so each task-force meeting has been arranged biweekly or

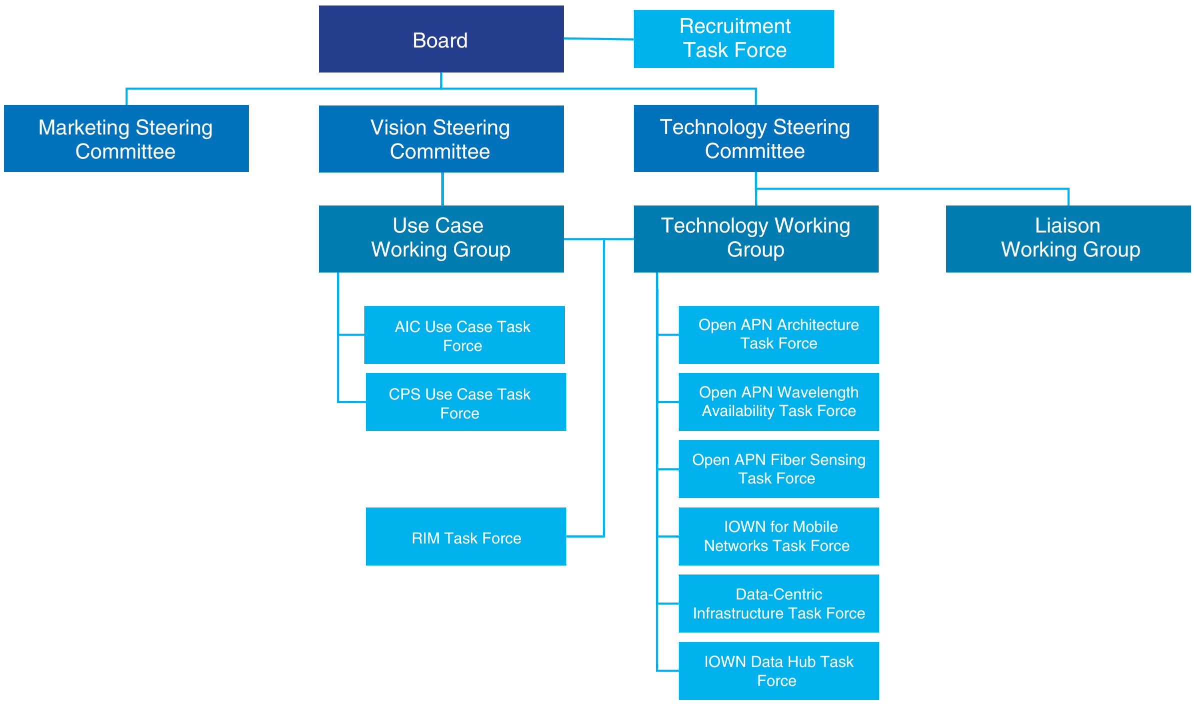


Fig. 4. IOWN GF organization.

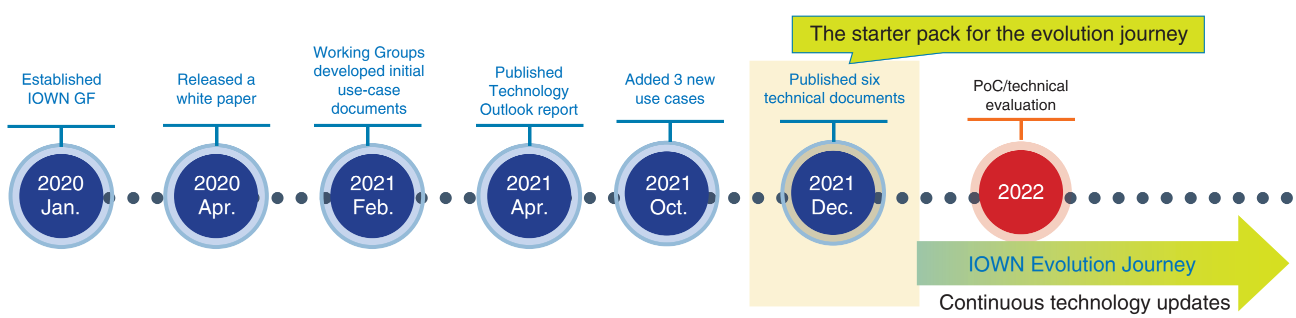


Fig. 5. IOWN GF achievements.

weekly. In these short meetings, members have been able to share their progress with each other, agree on the next action items, and provide feedback on the results of each member's activity on the action item.

This approach, however, means that it is difficult to follow the traditional document-contribution basis approach in major international organizations. It is difficult to implement a biweekly or weekly process in which each member submits a well-thought-out contribution document and takes much time to discuss and agree on each contribution. Therefore, IOWN GF has set up an online workspace; thus, members have been able to work together and develop deliverables more effectively and promptly. Despite the fact that all meetings have been online, IOWN GF has been able to frequently create and publish multiple results, including white papers, use-case documents, and technical documents, within a short period of only two years (**Fig. 5**). In addition to Working Group meetings and task-force meetings, IOWN GF has also regularly held online member meetings in which all members gather. The number of participants has grown to over 500. These results are due to the fact that IOWN GF is a native online

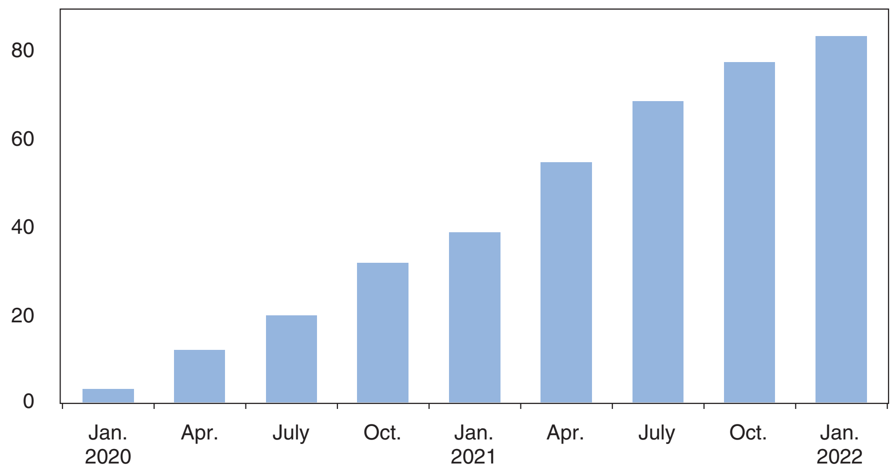


Fig. 6. Number of IOWN GF members.

organization.

3.3 Growth of activities

Through those activities and deliverables, various companies and organizations across industries have joined IOWN GF, and the number of members exceeded 80 companies/organizations at the end of 2021 (**Fig. 6**).

New members join almost every month. In December 2020, IOWN GF established a new membership for academic and research institutions (non-profits) to enable more organizations to participate in the development of IOWN technologies. Because IOWN GF uses online tools and has various task forces, it holds on-board sessions just before each member meeting to explain activities mainly to new members and supports members to smoothly participate in activities. As the number of members increases, the Board of Directors is also increasing. At the annual meeting in April 2021, Gilles Bourdon of Orange and Shingo Mizuno of Fujitsu were newly elected as Directors. Now a total of 9 Directors are responsible for decision-making for IOWN GF.

4. Plans in 2022

In less than two years since its establishment, IOWN GF has published technical documents. However, these deliverables are rough consensuses. Rather than taking the time to complete a document, it is more practical to put together a rough consensus in the short term, start a proof of concept (PoC) and technical evaluation early, and update the architectures and methodologies. Keeping agile thinking in mind, from 2022, IOWN GF will attempt to work on PoC activities and technical evaluation on the basis of published documents.

As indicated in the NTT Green Innovation toward 2040 [7] announced in 2021, NTT believes IOWN is an essential initiative for significantly reducing power consumption in its infrastructure. To achieve significant power savings, it is not enough to simply replace the infrastructure with an IOWN-based one but to redesign applications to take advantage of IOWN effectively and make operations more intelligent. In parallel with PoC activities, NTT will redesign applications and make operations more intelligent.

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He received a Ph.D. in electrical engineering from Waseda University, Tokyo, in 1994 and M.Sc. in technology management from MIT's Sloan School of Management, USA, in 2002. He is currently leading NTT's research and development (R&D) on IOWN as the head of IOWN Development Office. He is also serving as the chair of the Technology Working Group at IOWN Global Forum. He has been working as a bridge between technologies and businesses since he joined NTT in 1994. His expertise includes high-speed networking, software-defined networking, cloud/edge computing, AI, and data management. He is currently exploring innovative means of implementing digital-twin applications by leveraging the evolution of optical communication and optoelectronics integration technologies.

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He received an M.S. and Ph.D. from Tokyo Institute of Technology in 1997 and 2005. Since joining NTT in 1997, he has researched in the field of human factors in cyber security. He was a manager of NTT Secure Platform Laboratories to develop security R&D strategies and of NTT-CERT (Computer Security Incident Response and Readiness Coordination Team), the representative computer security incident response team (CSIRT) of NTT Group to establish global CSIRT service teams. Since 2016, he has been the chief security producer in NTT R&D planning department of NTT headquarters office, where he has been promoting security-related technologies and business across NTT Groups. Since 2019, he has been the vice president of IOWN Development Office to lead the establishment and operation of IOWN GF.