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FEATURE

Network Architecture, that Thinks and Evolves Itself

Interview

Cutting-edge Research on Network Architectures that Transcend the Limits of the Internet

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Network Architecture, that Thinks and Evolves Itself

Cover Photo
Upper left: (left side) Web page about Cefore, an open source software platform for information-centric networking (ICN), and its source code
(right side) Terrestrial network/Non-terrestrial network (TN/NTN) simulator
Lower right: Servers and workstations used for software development and verification experiments in the Network Architecture Laboratory

Photo Upper Left
Experiment for 4K video real-time multicast streaming via a network equipped with Cefore With it, tablets are able to play high-definition videos through broadband streams simultaneously.

Interview

Cutting-edge Research on Network Architectures that Transcend the Limits of the Internet

ASAEDA Hitoshi
Director of Network Architecture Laboratory, Network Research Institute

After working at IBM Japan, Ltd. and INRIA (French National Institute for Research in Digital Science and Technology), and as a Project Associate Professor at the Graduate School of Keio University, Dr. ASAEDA joined NICT in 2012 and has been the Director of the Network Architecture Laboratory since 2021. He has been researching and developing network protocols and working for the IETF/IRTF.
He is also a Collaborative Professor at the Graduate School of the University of Electro-Communications and a Fellow of IEICE (Institute of Electronics, Information and Communication Engineers). He holds a Ph.D. in Media and Governance.

As networks evolve from 5G to 6G and beyond, the volume of information transmitted over the networks is expected to increase exponentially owing to cutting-edge technologies, such as 4K streaming, virtual reality (VR), and generative AI. This growth could lead to information loss and transmission delays, thereby reducing the quality of services. To address these challenges, the Network Architecture Laboratory is tirelessly engaged in research and development, exploring many futuristic technologies aimed at breaking through the limits of the Internet.
This article is an interview with ASAEDA Hitoshi, head of the Network Architecture Laboratory, about the state of the art in network architecture technologies.

——First, please tell us what network architecture is.

ASAEDA Network architecture is an essential framework for providing better communication services, and it is very familiar to us. When people think of networks and the Internet, they often envision network devices such as optical fiber cables and Wi-Fi, and applications such as social media and streaming services. Network architecture is the framework that efficiently “connects” these devices and services.

To illustrate, cables are like roads, while servers and clouds that provide services are like stores. A car, representing a communication packet, travels to its destination and returns to the starting point with data. There are multiple roads, or routes, between the starting point and the destination, and network architecture technology is used to select the optimal and most reliable route for the car to carry data. However, unlike a car navigation system, network architecture technology does more than simply guides cars or packets along the optimal route. It also works to prevent data loss or transmission delays, identifies problems in data transmission, and helps packets avoid potential issues. When we use Internet services, we unknowingly rely on the network architecture.

Interview

Cutting-edge Research on Network Architectures that Transcend the Limits of the Internet

——In recent years, Internet architecture has been regarded as increasingly important. What is the reason for this?

ASAEDA The number of devices connected to a network is increasing yearly, and their performance is improving. With the spread of 4K-level real-time streaming and generative AI, the volume of data flowing through networks is also increasing yearly, creating an increased demand for fast response, high performance, broadband, and low latency in networks. To support these evolving services, a network architecture that enables efficient data processing and transfer is required. A well-known example of such a core system is the cloud. For a cloud system, a huge group of servers is placed in a data center where a large amount of data is stored and processed, usually near urban areas. The cloud is a convenient system accessible from anywhere with a network connection, but heavy loads owing to heavy traffic may cause delays in data transmission. Another issue is the large amount of electricity that cloud systems consume. To address these issues, a technique called edge computing can be used to shift some cloud functions to the user side, and it is the task of network architecture to help incorporate such auxiliary techniques to reduce transmission delays.

Research Subjects

——What kinds of research are you working on at your Network Architecture Laboratory?

ASAEDA One area of research in our laboratory focuses on AI-based network control automation technology. There are various types of AI, each with specific characteristics. We designed and implemented a system that uses different types of AIs to accurately assess the state of the network. Based on the state identified, our system controls resources on servers, ensuring even distribution of loads and detecting signs of network equipment failure to avoid impacts on services. Implementing large-scale network control using AI is an urgent issue owing to the serious labor shortage in recent years. I have heard that the domestic telecommunications carrier we conducted joint research with has put AI-based large-scale network control into practical operation since last year.

Second research area is the development of delay-guaranteed routers. We are researching in-network computing to advance the edge computing I mentioned earlier, aiming to eliminate fluctuations in data transmission and effectively improve data quality. Therefore, regarding routers used in networks, we are investigating how to make the processing functions in the routers flexibly programmable while suppressing delays and fluctuations in data transmission to a certain range.

Thirdly, as part of our research on in-network computing, we are exploring high-quality multicast streaming for advanced remote conferences and remote classes. With the research outcomes, we successfully demonstrated 4K video streaming on smartphones and tablets at this year's Open House event. In the demonstration, we used a technique called information-centric networking (ICN), which enabled multiple connected devices to play 4K-quality videos simultaneously.

Finally, our fourth research area includes distributed ledger technology, commonly known as blockchains. As you know, blockchain is a technique used for virtual currencies that ensures information reliability without administrators. We are researching mechanisms that control access rights depending on the attributes of the person handling the information, keeping it decentralized and distributed.

——Please tell me in brief how ICN works.

ASAEDA For the current Internet, data transmission occurs on a one-to-one basis using Internet protocol (IP) addresses. However, for ICN, data transmission is based on the *name* of the content specified in a packet. You can imagine the content name as being equivalent to a URL. Routers forwarding data can identify the content they are forwarding from its name. Thus, when a router receives multiple requests for the same content, it copies the incoming content and sends the copies to the requestors. The router does not need to ask the upstream servers to forward the same content multiple times. This means that ICN allows efficient multicast streaming; it is an excellent technique that reduces traffic load on servers and bandwidth consumption on networks and enables synchronous content delivery.

——It seems like a novel idea totally different from conventional telecommunication architectures.

ASAEDA Actually, there was a time that many worldwide researchers were exploring ways to develop new network protocols to address various issues led by TCP/IP. During that time, ICN attracted attention as a promising candidate for the new protocol. However, replacing TCP/IP, which is so widely used, presents significant challenges; rather, it is more realistic to consider techniques that help overcome the limits of conventional TCP/IP-based communications. For this reason, we are researching an ICN-based network architecture that runs on top of IP networks.

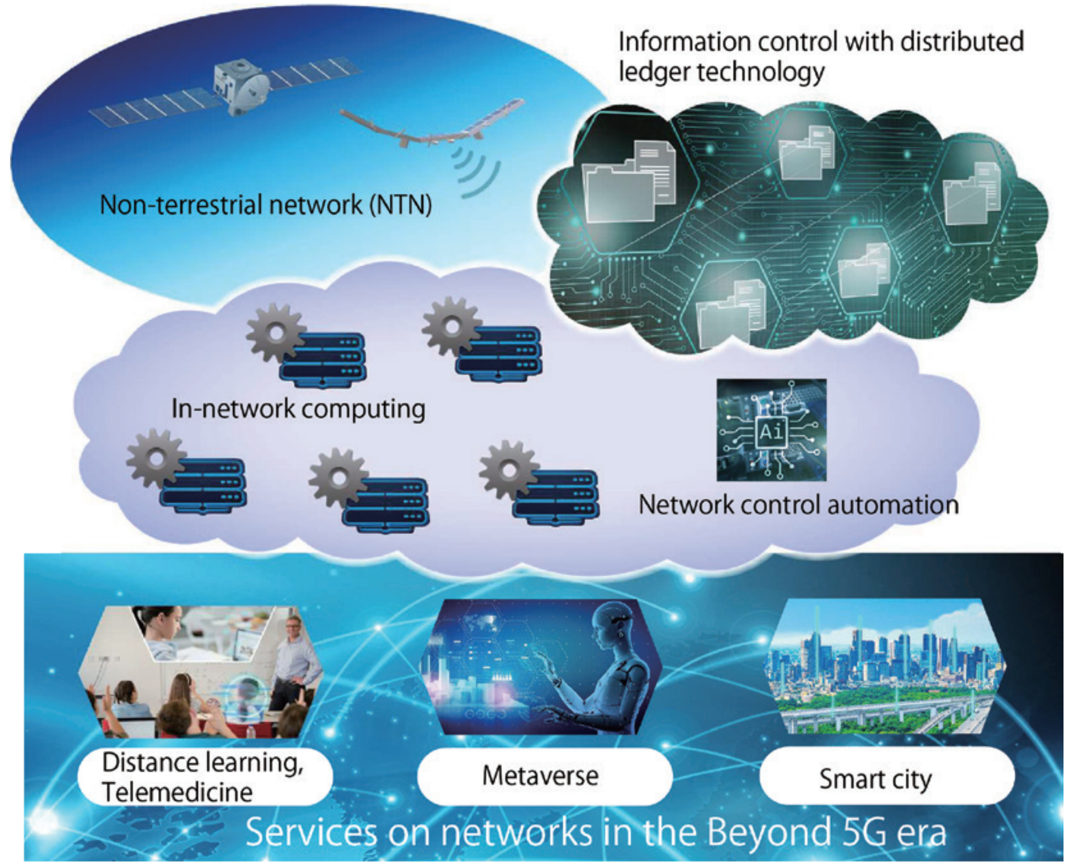

Figure Network architecture to connect services

We believe the research outcomes will enable ICN to be applied to 4K streaming, VR, metaverse, and spatial computing. While VR is expected to be used in many ways, it faces the issue of VR sickness caused by gaps owing to slight delays and fluctuations in data transmission. It'll be possible to mitigate the problem by stabilizing the fluctuations through synchronization between peers using the multicast function of ICN.

To run ICN and evaluate it on the actual networks, we have developed a software platform called *Cefore* implementing ICN and opened it as open-source software. It is already being used in academic institutions and universities. The February 2024 issue of the technical magazine, *Interface*, featured ICN and Cefore on over 40 pages, making ICN and Cefore known to the public.

——For the implementation of new telecommunication technologies in society, international standardization seems important.

ASAEDA Exactly. We are actively involved in ITU-T and IETF/IRTF, which are organizations for international standardization in telecommunications. At ITU-T, we contribute to establishing system configurations and network architecture, and at IETF/IRTF, we are involved in determining protocol specifications for formats of messages and procedures for data transmission in the global networks.

New Network Services Require New Network Architecture

——Please tell me about the direction of your future research.

ASAEDA Network architecture is the foundation for connecting "people" and "information." It covers many areas, including cloud and edge computing, data transmission stabilization, and security and privacy protection. Also, it covers not only technologies that will be implemented in society in a short term but also those under development with a long-term vision for the next 10–20 years.

In parallel, networks are expanding to include non-terrestrial networks using satellites and base stations called HAPS (high-altitude platform stations) in the sky. We have started our research on QKD (quantum key distribution) networks, on which many research and experiments have been conducted recently. In addition, we are exploring human-centered platforms for cybernetic avatars, getting into the Moonshot R&D Program*. In the research, we aim to create a new society where people coexist with avatars and robots, free from temporal, spatial, and physical constraints. Such a society will require new types of network architecture.

While carefully identifying social demand, we intend to contribute to society through both research that should be demonstrated in a short period and advanced research that looks to the future.

* Moonshot Research and Development Program promoted by JST.
Program by the Cabinet Office to help researchers create disruptive innovations.

Intent-Based Networking

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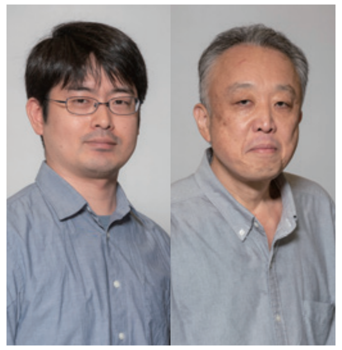

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Network services and the network infrastructures that support them are constantly changing and evolving, and their mechanisms and controls are correspondingly becoming increasingly complex. While this burden has until recently been borne by network and operations managers, issues foreseeable in the future are also being studied to alleviate these growing burdens. Given this state of affairs, technologies that reduce labor and automate operations related to networks and services have been attracting attention in recent years. In this article, we discuss Intent-Based Networking (IBN) technology, which automatically converts the requirements that network managers have for their network (hereinafter referred to as "network intent") into their corresponding network settings.

What is IBN?

Typically, in order to guarantee the quality and functionality of network services, tenants – which can be operators, administrators, etc. – need to manually configure the devices that provide the functions. For example, network tenants have to define and configure the methods used to select devices that make up the network, to make connections between devices, and to define and configure the policies that govern the operation of network services. However, as network services and infrastructures have changed and evolved, error-free creation and configuration has become increasingly difficult.

To address this issue, recent investigations are focusing on technology that will enable network tenants to simply define the requirements of the network services, namely the qualities and functions they want their network services and network infrastructure to provide, rather than having to manually instructing their devices themselves. In other words, by providing high-level (including natural language level) definitions of requirements that they must satisfy, low-level instructions are automatically created based on those definitions. IBN is a network control technology that enables these types of schemes. The high-level network requirements constitute the network intent. To put it in slightly more complex terms, network management has shifted from the imperative paradigm that has been used in traditional

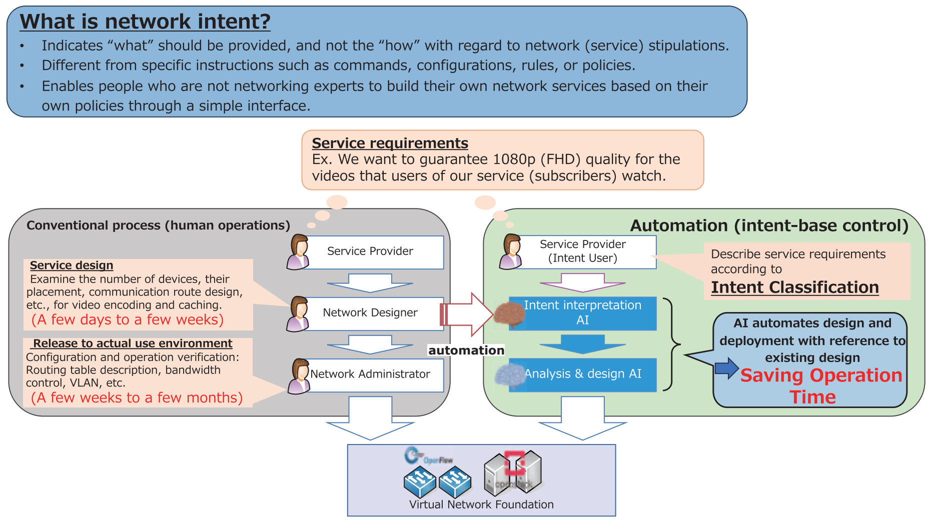

Figure 1 Intent-based Networking

> "Maximize network utilization as much as possible without causing degradation to service levels (latency, loss, etc.) by more than 20% from the historical average."

Figure 2 Example of Network Intent

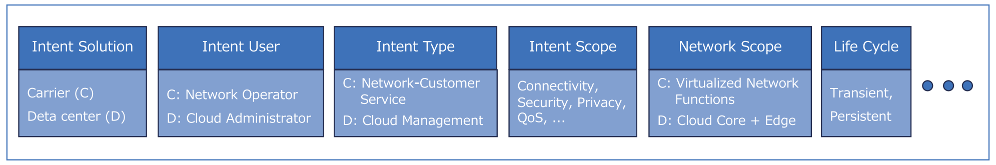

Figure 3 Intent Classification (partial excerpt)

environments to a declarative one that does not directly deal with individual devices or commands (= abstract) (Figure 1). Attempts are being made to apply artificial intelligence (AI) and machine learning (ML) to convert high-level network intent into actual commands, making AI and ML essential technologies for IBN.

Functions of IBN

The following functions are needed to achieve IBN:

· Network intent description model.
· AI and ML for generating interpretations from these descriptions.
· A system management functions (SDN/NFV[*1]) with IBN.

Network intent is typically expressed in natural language. IBN interprets this to extract the elements and policies of the target network service and network infrastructure. This process is done in two stages.

For example, let's consider a network intent that is expressed in a sentence like the one shown in Figure 2.

When IBN receives this text, it first outputs the following intermediate code:

```
f_do_while(
  target(get_network_usage, maximized),
  f_not(
   f_deteriorated(
    get_service_levels,
    f_n_ge('20/100')(f_prod(get_service_levels_
    historical_mean))
   )
  )
)
```

This code means that three functions will be used: get_network_usage (get network usage rate), get_service_levels (get service levels), and get_service_levels_historical_mean (get historical service levels). Additionally, f_n_ge(A)(B) is for calculating A × B.

IBN then uses this intermediate code to output instructions that correspond to the target network services and devices available on the network infrastructure. Below is a part of this (several dozen lines of such settings will be needed for this example).

```
nsd:
df:
 - id: default-df
   vnf-profile:
  - id: AUTO
     vnfd-parameter-metric: bandwidth
     vnfd-parameter-goal: max
     vnfd-parameter-constraint-function: mean
     vnfd-parameter-constraint-bounary: 20 / 100
```

NICT's efforts

Natural language is used to express network intent, and this will not be successfully converted automatically unless the information needed to create and configure network services and infrastructure is clearly expressed. Given this, we took part in the development of and contributed to the publication of the IRTF RFC9316 [1] specifications for categorizing network intent. RFC9316 defines what needs to be identified as network intent and how to identify it.

Please see Figure 3 for an example. In Figure 3, the network to be managed is identified as the Intent Solution. Here we use a telecommunications carrier's network (Carrier) and a network in a data center (Data Center) as examples. The items that should be expressed as network intent are common to each Intent Solution, but their specific descriptions vary depending on the type of network. For example, the network intent issuer (User Type) is described as Network Operator in a Carrier, but as Cloud Administrator in a Data Center.

We are also working to standardize the IBN user interface. This will enable a wide variety of businesses to expand and incorporate IBN into their own network management systems. This includes, for example, functions for expanding the policies that can be referred to as network intent, and evaluating the accuracy of network services built from network intent. Furthermore, in order to promote the spread of IBN, we are also developing a system for adding IBN functionality to network automation system OSDM[*2].

Going forward

Research and development is still ongoing on determining how to describe and interpret network intent when managing environments that include a mixture of network services and network infrastructures with different policies. One solution being considered is distributed collaborative AI, which involves preparing an individual AI for individual policies and having these different AIs work together. By linking distributed collaborative AI with OSDM[*2], we can expand the scope of network management using IBN, and expect to see the automation of network management going forward.

Footnotes

＊1 Software Defined Networking/Network Function Virtualization
＊2 Opensource "Distributed" NFV Management and Orchestration
This is a system that extends the open source NFV operation system OSM to a distributed collaborative system.

References

[1] C. Li, O. Havel, A. Olariu, P. Martinez-Julia, J. Nobre, and D. Lopez, "Intent Classification," IRTF RFC 9316, Oct. 2022, https://datatracker.ietf.org/doc/rfc9316/

In-network Computing to Enable Data-oriented Services

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After completing the doctoral course at a graduate school, Dr. MATSUZONO worked as a post-doctoral fellow at INRIA. Entered NICT in 2013. Engaged in R&D in information-centric networking, quantum key distribution network architecture, in-network computing. Ph.D.(Media and Governance).

In the beyond 5G era, diverse network services will coexist. To respond to the societal changes brought about by the new normal, networks must ensure communication quality (low latency, high bandwidth, and reliability) and security required by different services and applications. However, on the current Internet, these processing functions are frequently performed in the cloud or on servers far from the user, thereby limiting the maintenance of the quality of communication services. Therefore, in-network computing, which distributes various processing functions, such as real-time video processing, communication prediction using AI, temporary data storage (caching) functions, and encryption functions within the network, has been attracting attention. This article discusses research into in-network computing enabled by expanding the open-source software "Cefore" to enhance information-centric networking (ICN*1) [1].

ICN-based in-network Computing

As the demand for remote working and distance learning grows and virtual reality and mixed reality technologies evolve, network requirements, such as stability, low latency, and scalability of broadband communications, are becoming more demanding. In-network computing is becoming crucial for addressing this issue because it can simultaneously transfer and process data within the network while flexibly satisfying quality requirements. For example, networking technologies must help reduce the rapidly increasing volume of data communications while improving communication performance. These technologies include transcoding, which converts video quality according to communication conditions and user environments, and in-network caching, which temporarily stores frequently accessed content within the network and sends it to users.

To effectively use limited resources and ensure stable service operations, we should flexibly use multiple network devices and deliver data for processing to devices that are best suited for the given situation. We are studying network architecture that enables efficient and effective in-network computing, focusing on ICN, which communicates using URL-like content identifiers that indicate information or the content itself instead of the IP addresses of devices.

Elastic Service Function Chaining Technology

Network softwarization technologies such as SDN*2 and NFV*3 are essential for the current Internet. Recently, extensive research has been conducted on service function chaining (SFC) using these technologies to flexibly chain functions that network equipment provides. Although using software to build networks should help reduce the costs of network construction and operation for telecommunications carriers and other organizations, challenges still exist to be overcome before it can be achieved. We proposed, designed, and developed a new platform, function offloading network (FON*5), that flexibly offloads (migrates) functions implemented in network equipment according to communication volume and service requirements and conducted demonstration tests on the internal experimental network of the NICT (Figure 1). The offloading network uses Cefore to enable flexible traffic control according to the conditions such as the characteristics and priority of the service. The performance of the system was evaluated using a generic video streaming application. As demonstrated in the application, in-network computing functions, such as in-network caching and multicasting, considerably improved the user's quality of experience (QoE*6) by playing high-quality videos [2] (Figure 2) while reducing server loads.

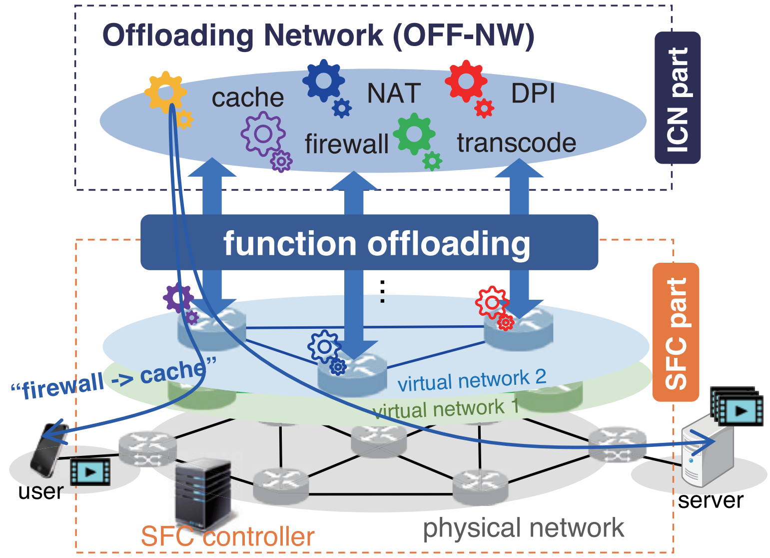

Figure 1 Network configuration including function offloading network (FON) (excerpted from [2])

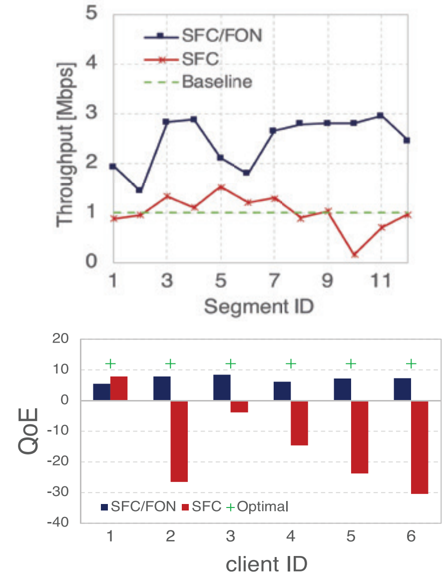

Figure2 Comparison of throughput and quality of experience (QoE) of existing method (service function chaining [SFC]) and proposed method (SFC/FON) (excerpted from [2])

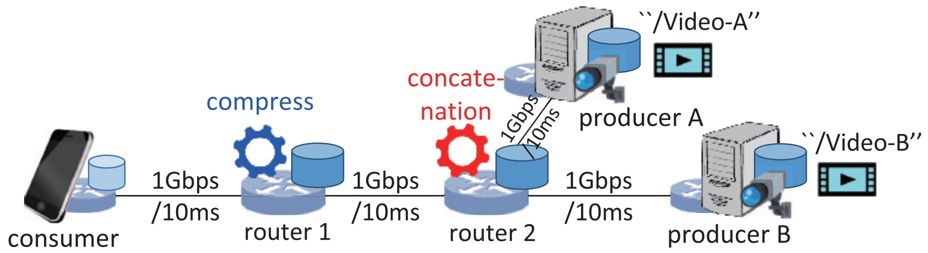

Figure 3 Router concatenating and compressing video content (excerpted from [3])

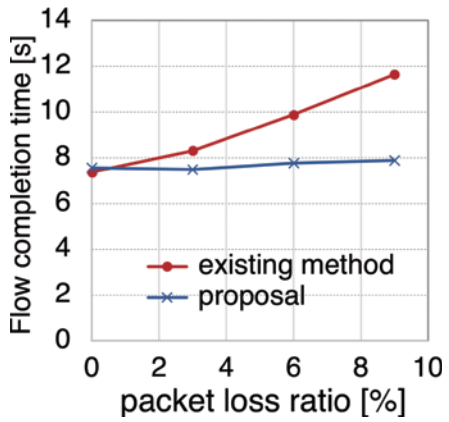

Figure 4 Effect of high-speed recovery from packet loss in a network (excerpted from [3])

High-speed Data Transport Technology using in-network Computing

We improved the QoE by reducing the time required for data transmission and computing. In addition to FON, we are studying and developing high-speed data transport technology that, with high-speed recovery for packet loss within the network, reduces data transmission and processing times according to service characteristics. Routers along the path determine the information characteristics by evaluating the contents of packets being transmitted and by identifying the names given to these packets. For example, to maintain high-quality service without compromising the QoE, loss detection and recovery can be preferentially performed during video transmission of high-priority information (audio data and keyframes), which has a low tolerance to interruptions. As such, this technology should have applications in future services such as remote medicine and telepresence.

Our tests were conducted using actual equipment assuming a service comprising multiple functions: video concatenation and compression (Figure 3). In these tests, we demonstrated that the time required to acquire data and complete processing with existing methods would increase according to the increment of the packet loss rate. In contrast, our proposed method could complete processing quickly by performing high-speed loss recovery inside the network [3] (Figure 4).

Future Prospects

We will continue our research for efficient network architecture to achieve ultralow latency and highly reliable in-network computing technology for the metaverse era to enable mass sensor and robot control, cross-reality (XR), and other innovative technologies.

Footnotes

- ＊1 Information-Centric Networking
- ＊2 Software-Defined Networking
- ＊3 Network-Function Virtualization
- ＊4 Service Function Chaining
- ＊5 Function Offloading Network
- ＊6 Quality of Experience

Reference

[1] H. Asaeda, K. Matsuzono, Y. Hayamizu, H. H. Hlaing, and A. Ooka, "A Survey of Information-Centric Networking: The Quest for Innovation," IEICE Trans. Commun., v ol. E107-B, No.1, Jan. 2024.

[2] Y. Hayamizu, K. Matsuzono, T. Hirayama, and H. Asaeda, "Design and Implementation of ICN-Based Elastic Function Offloading Network for SFC," Proc. IEEE NetSoft, Tokyo, Japan, Jun. 2021.

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Programmable Router Achieving Predictable Performance

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In the Beyond 5G era, it is expected that applications and services that require high-quality communications with ultra-high speed, large capacity, and ultra-low latency (one-tenth compared to 5G services) as well as simultaneous connections of many terminals will be provided. This article introduces a latency-guaranteed programmable router that implements computing functions on a field-programmable gate array (FPGA) to guarantee ultra-low latency, particularly in terms of transmission jitter.

Latency-Guaranteed Programmable Hardware Routers

For increasingly diverse and sophisticated applications and services, there are high expectations for the use of in-network computing, which improves end-to-end communication quality by processing data appropriately in the network. On the other hand, it has been pointed out that one of the issues with in-network computing is the possibility of increased processing latency in the routers in the network, and especially, increased jitter in data transmission. In particular, processing disorder between the packet forwarding and the in-network computing functions causes a large jitter in the time to transfer packets from an input to an output port in a router, and thus, it will be difficult to meet the communication quality and latency performance required by services and applications. This can cause problems such as disruptions in the playback of live contents and increased latency in cloud services. To solve this problem, we are engaged in research and development on latency-guaranteed programmable routers using an FPGA.

FPGAs are a type of programmable hardware device that can be programmed with functions repeatedly like software, but they also offer the high speed and low latency of hardware processing. This prevents irregular processing latency caused by CPU interrupts and other factors, enabling stable and highly reliable communications. Due to strict constraints on hardware resources, however, the functions are executed by dedicated circuits, and thus, FPGAs are not as flexible as software programs. Therefore, it is necessary to select functions that are used frequently as in-network computing and implement them efficiently in FPGA-based programmable routers to enable hardware processing of many forwarded packets (Figure 1) and to guarantee latency and jitter performance, thereby aiming to realize a variety of services and applications.

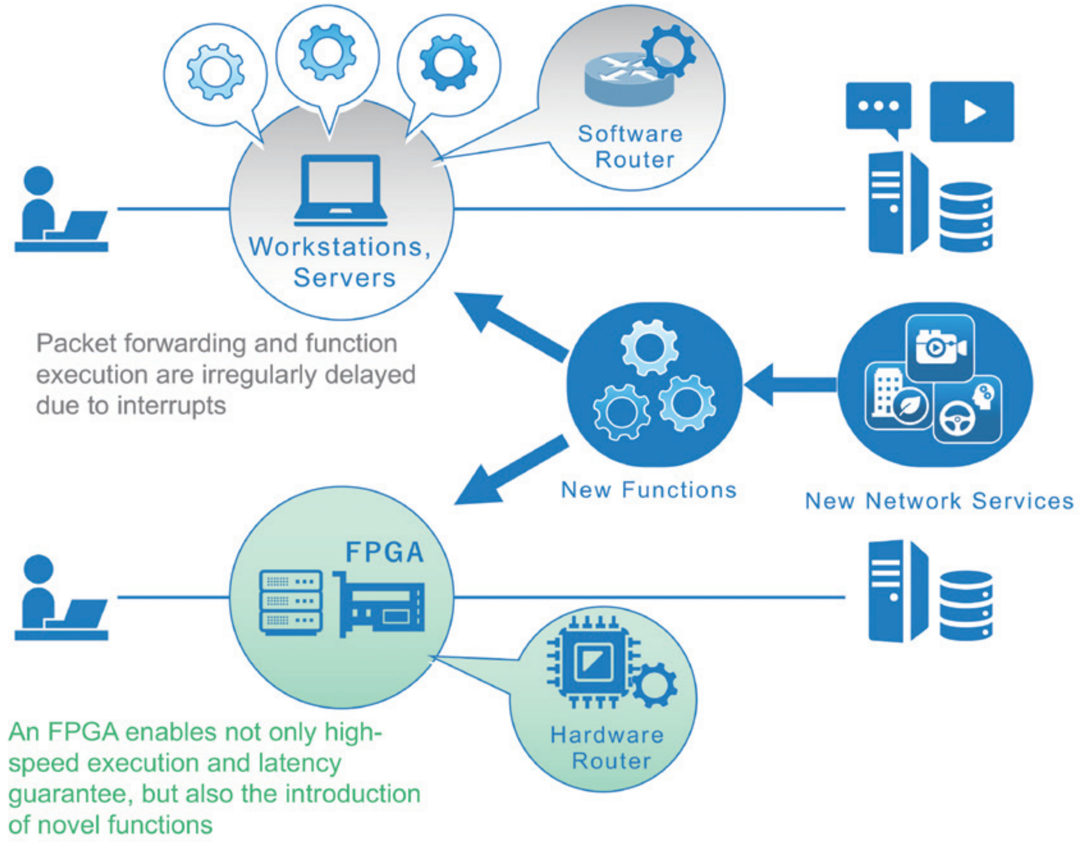

Figure 1 Schematic of an FPGA-based latency-guaranteed programmable router

Implementation under Development

We are engaged in research and development on latency-guaranteed programmable routers that aim to stabilize in-network computing by implementing on an FPGA in-network caching, multicast, and security functions that are made available by information-centric networking (ICN).

In this research, we designed and developed data transmission performance for guaranteed latency using an FPGA board called NetFPGA-SUME (Figure 2). To implement high-performance ICN functions on an FPGA, which have strict constraints on hardware resources, it is necessary to implement a content management table that stores and updates large amounts of content names, and a cache that stores large amounts of content. While IP routers can use content addressable memory (CAM) to accelerate conventional internal processing, CAM is generally limited in capacity and is therefore not suitable for implementing a content management table and cache. To solve this problem, we implemented a hash table and cache area for fast data retrieval and updates on inexpensive, high-capacity DRAMs. Our implementation enables parallel access across multiple DRAM banks by devising memory mapping for DRAMs with slow access speeds, thereby realizing high-speed data transmission. Evaluation of our FPGA router implementation has shown that it can achieve a throughput of 2.8 Mpps, a maximum latency of 4.6 µs, and a latency jitter of 270 ns for a 10-Gbps interface*. The minimized latency and jitter are expected to stabilize communication quality and improve the performance of various services.

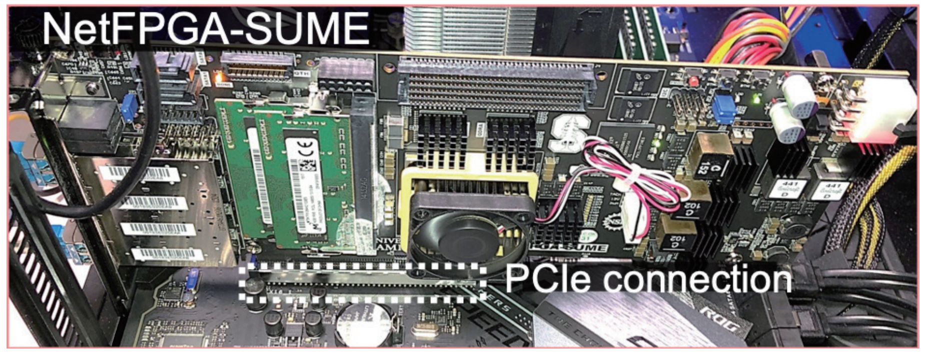

Figure 2 NetFPGA-SUME with ICN functions implemented

Future Prospects

In the Beyond 5G era, it is essential to realize advanced in-network computing. In addition to achieving the research outcomes to date, in the future, it will be necessary to research and develop programmable routers that can operate in conjunction with software routers for more complex processing requirements. Specifically, taking the realization of an AI-driven society as an example, there are issues such as increasing computation costs of AI-powered routers and bandwidth congestion due to increased traffic accompanying the spread of AI. We will continue to research and develop elemental technologies to realize latency-guaranteed programmable routers, such as technologies for responding to unforeseen requests and routing dynamic requests.

＊ A. Ooka and H. Asaeda, "CCNx Router on FPGA Accelerator Achieving Predictable Performance", Proc. ACM ICN 2023, Oct. 2023, Reykjavik, Iceland.

Trustable Networks utilizing Distributed Ledger Technologies

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Since 2011, He has been a research manager of NICT. His research interests include technologies for distributed network systems and applications.
He is a member of the IPSJ, IEICE, and IEEE. Ph.D (Engineering).

Under the vision of Society 5.0, in which social issues are solved by digital technologies through systems that highly integrate cyberspace and physical space, efforts are advancing to achieve transformation into a so-called data-driven society.

Data Distribution in a Data-Driven Society

In a data-driven society, a mechanism is required for data owners (organizations and individuals) to provide or utilize data securely according to their own policies so that a wide variety of applications can efficiently utilize vast amounts of data. It has been pointed out, however, that the conventional approach of uploading all data to the cloud via networks raises concerns regarding network traffic as well as confidentiality and privacy protection. For this reason, extensive research and development is underway to realize an autonomous decentralized data distribution architecture. In this architecture, data is maintained and managed autonomously by servers under the data owner's control, with data distribution through the coordination of these servers. In this form of data distribution, a major issue is how to maintain the integrity, authenticity, and availability of data while preventing malicious attacks such as the distribution of fraudulent data.

Conventional Technologies and Issues

Distributed ledger technology (DLT), represented by blockchain, has been attracting attention as a technology that enables multiple data owners to share and distribute data on an equal footing, maintaining data integrity, authenticity, and high availability. One of its key advantages is eliminating the risk of system-wide failure that typically occurs when a single point of failure compromises traditional centralized systems. DLT is a system that authenticates synchronized data on nodes (computers or servers) in a distributed network and can support transparency of authority and traceability of responsibility, and is also used for virtual currency implementation and other applications. In a blockchain, data to be stored must be synchronized to all nodes, which increases communication and storage costs when handling large amounts of data. For this reason, it is common to store only hash values of data in a blockchain, and to use an external storage (called an off-chain storage) that stores data itself in conjunction with the blockchain, thereby reducing communication and storage costs.

When considering inter-company collaboration and medical applications, however, a function is required that allows the data owner to explicitly control the data disclosure destination to protect confidentiality and privacy. In general, when the geographic location where data is stored is in another country or region, it is subject to restrictions imposed by laws and regulations depending on its location, and therefore, a function to limit the geographic scope of data distribution (data distribution scope) is also necessary. As transaction data on a blockchain is supposed to be disclosed to public, this data distribution function must be realized by off-chain storage. While the InterPlanetary File System (IPFS) [1] is widely used for off-chain storage, it has significant limitations. Not only does it lack comprehensive support for these capabilities, but it also suffers from high latency due to the substantial communication traffic generated during data retrieval.

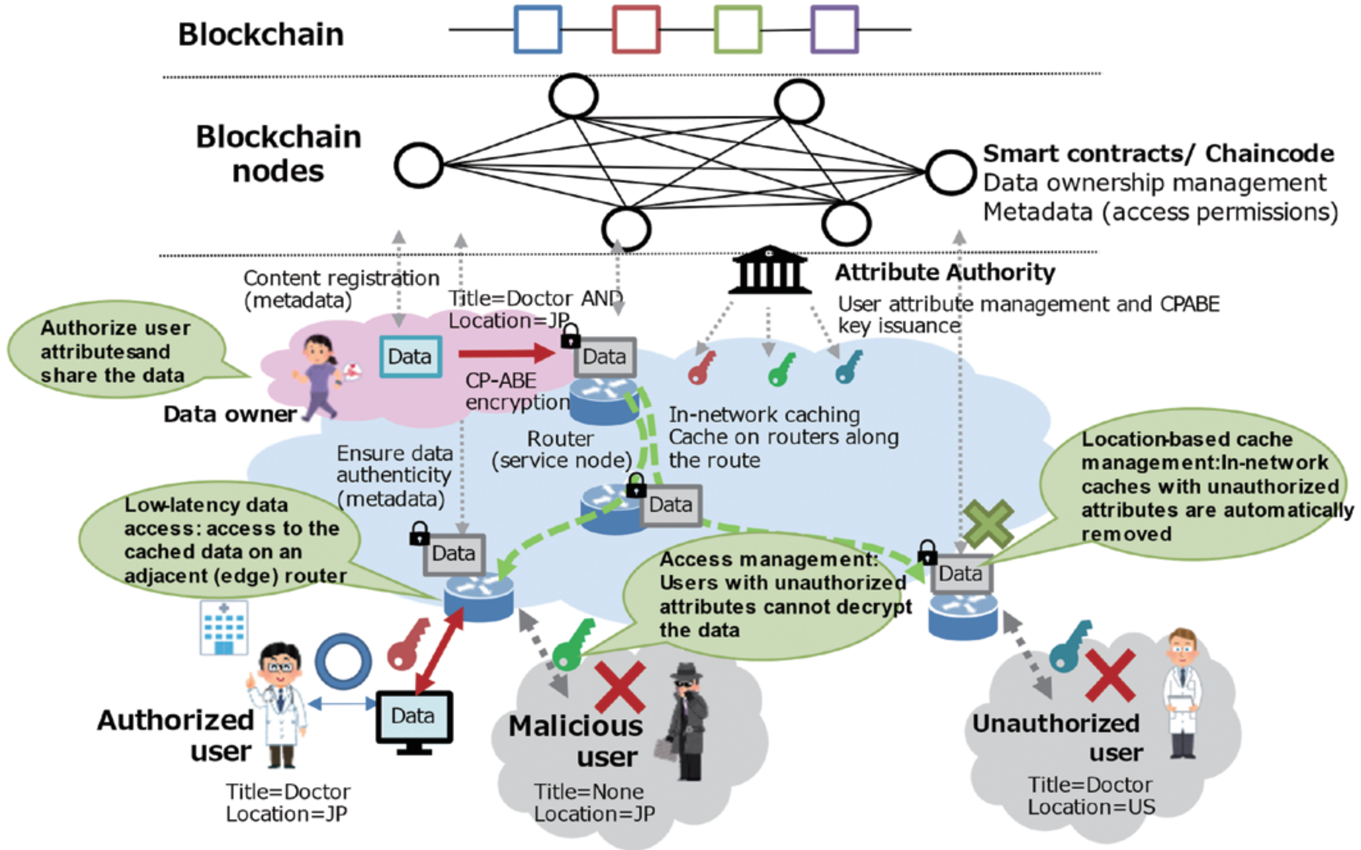

Figure Example of data distribution in UCINC

UCINC

To address the above issues, we are working on the design and implementation of an in-network storage configuration scheme called User-Centric In-Network Caching (UCINC) [2]. UCINC combines attribute-based encryption and in-network computing, to control data distribution scope and enhance data access efficiency. In UCINC, routers installed in the network have the ability to store content data as a cache, enabling data senders to reduce data distribution load and improve response latency. In addition, an attribute-based encryption scheme called Ciphertext-Policy Attribute-Based Encryption (CP-ABE) is used to enable selective data disclosure, where access is granted or restricted according to privileges based on user attributes. Furthermore, it has an external cache management function that does not hold caches outside of authorized networks, enabling control of data distribution scope.

The figure shows an example of UCINC-based distribution for data that only users with the attributes of Location = JP (residing in Japan) and Title = Doctor are authorized to access. When users with authorized attributes access the data, the data is temporarily stored in the cache areas of neighboring routers to enable high-speed access. However, even if other users access the same router, they cannot decrypt or display the cached data unless they possess the required attributes. In addition, caches on routers that do not have users with permitted attributes under them are automatically removed, which satisfies the geographical limitation of the data distribution scope.

This not only provides security benefits, but also eliminates waste in network resources, as only accessible data is stored in the neighboring networks.

Future Prospects

This function is being implemented on the NICT's integrated testbed and will be provided as off-chain storage for blockchains with high-speed access.

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[1] D. Trautwein, A. Raman, G. Tyson, I. Castro, W. Scott, M. Schubotz, B. Gipp, and Y. Psaras, "Design and Evaluation of IPFS: A Storage Layer for the Decentralized Web," Proc. ACM SIGCOMM, Aug. 2022.
[2] H. Yamanaka, Y. Teranishi, Y. Hayamizu, A. Ooka, K. Matsuzono, R. Li, and H. Asaeda, "User-centric In-network Caching Mechanism for Off-chain Storage with Blockchain," Proc. IEEE International Conference on Communications (ICC), Jun. 2022.

Contributions to International Standardization at the ITU and IETF

Network Architecture Laboratory, Network Research Institute
Research Manager **Ved P. Kafle**
Director **ASAEDA Hitoshi**

Batteries are the same all over the world, so why do we have different power outlets? Have you ever thought about this? "Interoperability" is what allows us to connect products from any manufacturer to a power outlet, and the thing that we need to maintain this interoperability is "standard specifications." When we consider the global market, manufacturing or using products that conform to internationally approved standard specifications (hereinafter referred to as "international standards") offers great benefits to both manufacturers and users. The same is true in the research we do; that is, in order to widely deploy the results of our research throughout society, the key is to link the specifications and methods of a proposed technology with international standards.

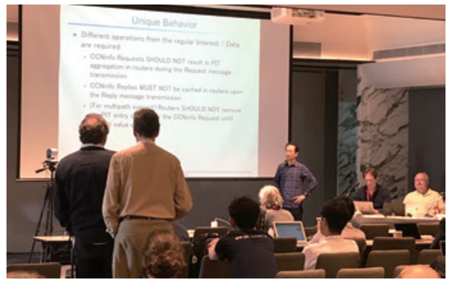
The Network Architecture Laboratory is engaged in standardization activities at international standardization organizations such as the International Telecommunication Union (ITU) and the Internet Engineering Task Force (IETF). Here, we describe the roles of the ITU and IETF, the differences in their standardization work, and their respective characteristics.

The ITU's activities are broad, and it engages in the standardization of ICT architecture and technologies in general. The sector in which we mainly operate, the ITU Telecommunication Standardization Sector (ITU-T), is responsible for preparing standardization documents called ITU-T Recommendations. Its themes include: (1) telecommunications networks (fixed, mobile, and satellite) and services, (2) multimedia systems, cybersecurity and privacy protection, (3) devices and services associated with the Internet of Things (IoT), and (4) artificial intelligence (AI) and machine learning applications in telecommunications for network control and administration. The ITU also deals with issues other than technical standards, such as frequency management and international telecommunications regulation, which are carried out within a framework that includes member states and various industrial sectors. The standardization process within the ITU is a formal process, consisting of the submission of standardization proposals (contributions) and a formal approval mechanism.

We have contributed to the development of ITU-T Recommendations on advanced network architectures, beyond-5G systems, AI and machine learning based network architectures, IoT directory services, and integrated control of terrestrial and non-terrestrial networks.

In contrast, the IETF's scope of activities deals mainly only with technical aspects of the Internet and network operations, with a particular focus on detailed specifications of communication protocols such as IP, TCP/UDP, and QUIC, packet formats, and interfaces. The IETF is a bottom-up organization and therefore more open, such that anyone is able to propose specifications called Internet Drafts (hereafter referred to as I-Ds). I-Ds are communicated and discussed via the mailing lists of applicable working groups, and those that are deemed to require further discussion are discussed at the triannual IETF meetings. Specifications are reiteratively improved based on these discussions, and after a consensus is reached among the working groups and area directors, they are approved for standardization or valuable information as a Request for Comments (RFC). The IETF's consensus-building process does not involve voting to decide whether or not something should be standardized, but rather determines whether or not standardization should be approved based on its motto, "Rough consensus and running code" (a rough consensus and software programs that are actually functional) (That being said, discussions via mailing lists and meetings are often heated, and a "rough consensus" is not easy to achieve).

Plenary session at ITU-T Study Group 13



Standardization discussions at the IETF meeting

In addition to our activities in the Internet Research Task Force (IRTF), a sister organization of the IETF, we have been involved in the development of specifications (RFCs) for protocols such as multicast, mobile communications, network administration, and Information-Centric Networking (ICN).

Through our contributions to the ITU and IETF/IRTF, we are committed to continue promoting international standardization efforts that ensure interconnectivity and operability between diverse networks and devices, and to the global deployment of advanced network technologies and services.

Ved P. Kafle

Research Manager
Network Architecture Laboratory,
Network Research Institute

Joined NICT in 2006 after completing the Ph.D. degree, and has held his current position since March 2018. Currently engaged in new network architecture research, and in international standardization activities at the ITU-T. Awarded the 2023 Information and Communications Technology Award (TTC Chairman's Award). Ph.D. (Informatics)

Network Security and Privacy by Design: Toward the Realization of Reliable Network Services

Htet Htet Hlaing

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Network Architecture Laboratory,
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Ph.D. (Engineering)

Biography

1991 Born in Myanmar
2016 Completed a master's degree at Yangon Technological University
2021 Received a Ph.D. from the Graduate School of Natural Science and Technology, Kanazawa University
2022 Joined NICT

AWARDS

2024 Best Tutorial Paper Award by IEICE Communication Society (co-author)

Q&As

Q What is good about being a researcher?

A What inspires me about being a researcher is the constant challenge and the opportunity to innovate. It is incredibly satisfying to discover new insights and create solutions that have a positive impact. What's more, the joy of getting my paper accepted and seeing my work recognized makes the experience truly enjoyable.

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

A For aspiring researchers out there, I would advise you to stay passionate and dedicated to your field of study. Surround yourself with mentors and colleagues who become your research family, offering invaluable support, sharing knowledge, and celebrating achievements together.

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

A Beyond my research, I find great joy in practicing "Ikebana." I started taking an Ikebana class five years ago, and it has been a wonderful way to engage with a new tradition and express my creativity with flowers.

The modern world is experiencing explosive growth in interconnected devices and data generation. This "data deluge" powers a wide range of services, from the Internet of Everything (IoE) that connects everyday objects to the sophisticated networks of smart cities. Yet, with this progress comes a growing concern: security and privacy. As we move beyond 5G towards the next generation of wireless technology, 6G, the need for robust security measures becomes paramount to build trust and protect sensitive information within this expanding infrastructure.

Traditional security solutions, typically implemented as separate layers, include measures such as encrypting communication channels between the sender and receiver each time communication is initiated. While this protects the content (data) packets, these solutions struggle with the exponential growth of data transfers and the evolving threat landscape, introducing significant latency and overhead that degrade overall network performance.

My research, therefore, shifts toward "network security and privacy by design," by integrating security and privacy measures directly into the core network architecture. The proposed technology empowers scalable encryption and fine-grained access control by directly associating information security functions within the "content" itself rather than the traditional "communication channel," which facilitates the development of secure and reliable network services.

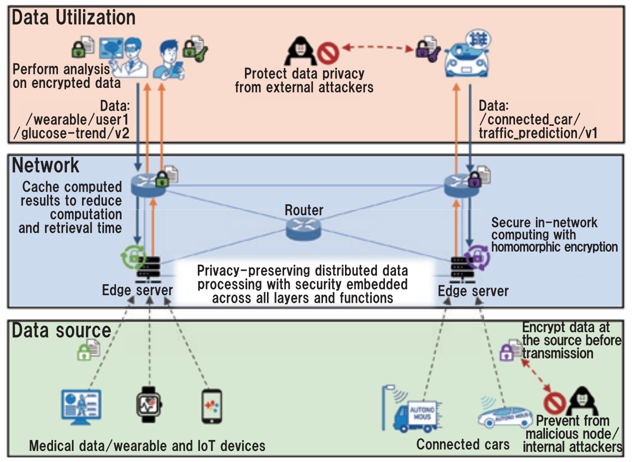

Figure
Trustworthy and Reliable Network Services through Security and Privacy by Design

I am currently engaged in research exploring the potential of homomorphic encryption —a powerful technique that allows computations to be performed on encrypted data without decryption, proactively ensuring data confidentiality throughout its entire lifecycle. The approach is synergistically enhanced by integrating with information-centric networking (ICN) technology, which utilizes a data-centric protocol focused on content delivery, enabling efficient in-network computing and caching (a temporary data storage function) for reduced latency and improved data access. This comprehensive solution achieves a fundamental transition toward the realization of privacy-preserving distributed data processing that seamlessly balances privacy and the efficiency of network resources. Our next steps involve comprehensive development and validation to confirm the efficacy of this approach, as well as ongoing refinements to ensure its seamless integration into real-world applications.

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