

Research & Development

What NTT R&D Aims for

Message Message from the Head of Research and Development Planning

To help make people's lives more rewarding and business activities more convenient, we have been enhancing the efficiency of information and communications technology through digitalization. However, we are now faced with unprecedented challenges such as pandemics, there are still walls to be broken through. For the solution to these problems and the development of a sustainable society in the future, it is imperative to create entirely new values not only by quantifying tangible information but also by incorporating and utilizing different ways of perceiving things and recognizing the diversity of all beings in the world.

To achieve the above, we need to have an even more powerful information processing infrastructure. The volume of traffic on the Internet continues to rise and will, in time, exceed the limit of the current processing capacity. Also, enormous energy consumption will become an unavoidable problem. What are required now to ensure advancement of humankind are innovations that will break through these limitations.

To provide a solution, NTT R&D has proposed the concept of Innovative Optical and Wireless Network (IOWN), a future communication infrastructure that will enable environmentally friendly, sustainable growth and diversity-tolerant total optimization. This concept is characterized by ultra-high capacity, ultra-low latency, and ultra-low power consumption, which are made possible through adoption of photonic and other innovative technologies.

Utilizing this innovation, we have formulated a new environment and energy vision "NTT Green Innovation Toward 2040" to simultaneously achieve zero environmental impact and economic growth. We aim to achieve carbon neutrality by 2040.

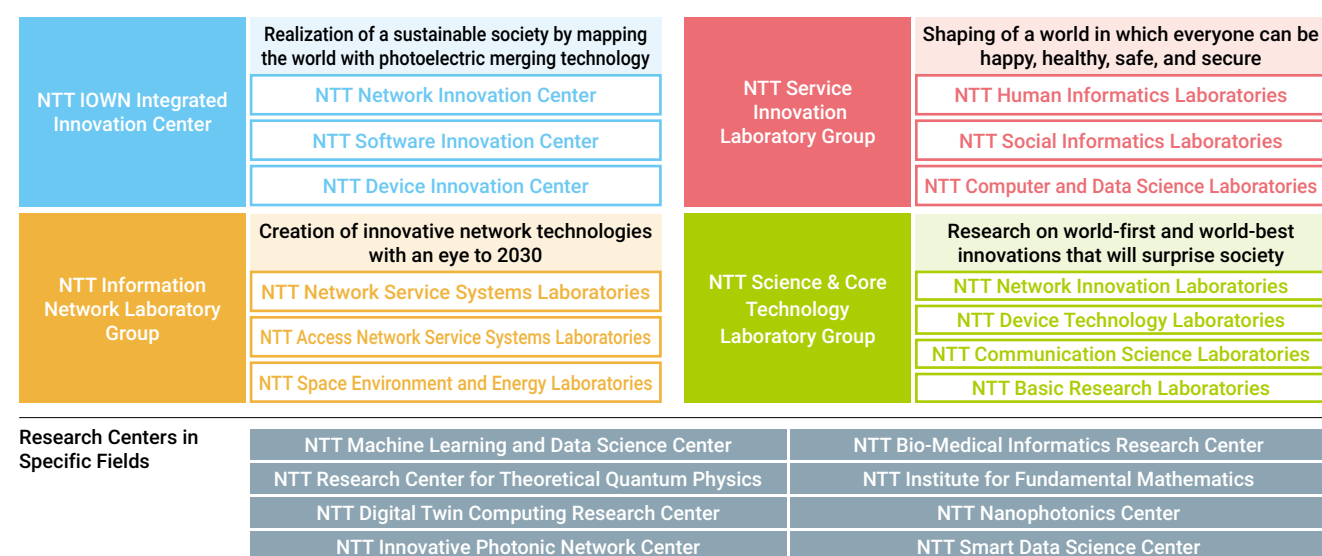
When processing power is boosted by IOWN, the computation required for interactions between digital twins and for long-term forecasting of their behavior will become available, leading to highly accurate future prediction and resolution of various social issues. We see happiness not as an instantaneous event but, rather, as an integral value that can be sustained from the past into the future. The aim is to ensure comprehensive and sustainable "well-being" for all members of society.

As it works to realize IOWN, NTT R&D will address social issues and will research and develop transformative technologies that will bring about a smart world in which everyone can benefit from technology without even noticing it.



Katsuhiko Kawazoe
Executive Vice President
Head of Research and Development Planning

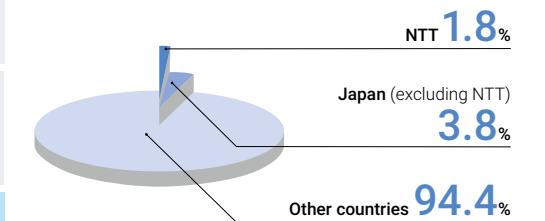
Research and Development System



R&D by the Numbers

NTT Laboratories		
Number of patents Some 18,000	Number of research and development staff Some 2,300	Number of IEEE Fellows 43 (including those retired)
Number of papers and presentations at academic conferences Some 1,900 / year	Received IEEE Milestones 4 times	
Standardization Activities		
Participation in de jure standardization organizations, such as ITU (FY2020)	Degree of participation in de jure international standardization meetings (FY 2020)	
Participants to domestic / international SDO Total 192	Members of domestic committees Total 262	1,093 person-days (excluding preparatory studies)

Percentage of contributions submitted to ITU-T (2017–2020 study period)



Estimated from the former study period (2017–2020) data of ITU-T and of the Ministry of Public Management, Home Affairs, Posts and Telecommunications, Japan.

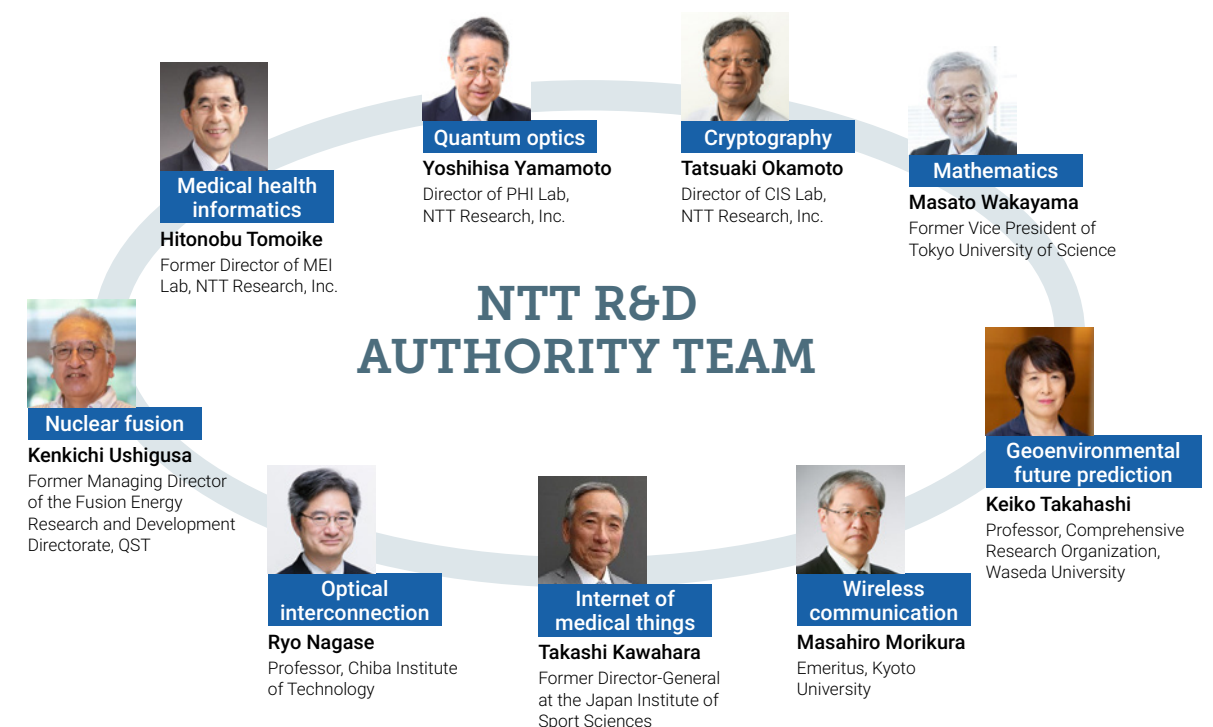
For more information on awards, please refer to the NTT corporate website.
<https://www.rd.ntt/e/news/?cat=Awards>

NTT R&D Authority Team

NTT assembled researchers who are known authorities in their respective fields to form the NTT R&D Authority Team. These researchers take part in R&D activities at NTT to contribute to the realization of IOWN and help shape our vision after realizing this concept. Specifically, they are responsible for driving research in their fields of expertise by directing, providing guidance, and advising activities regarding research themes.

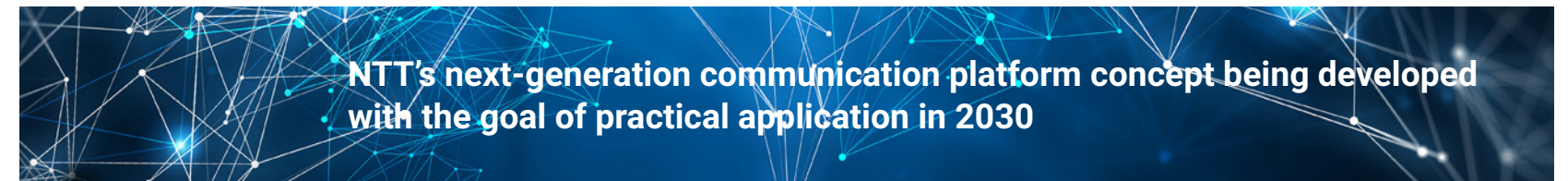
As one facet of our efforts to accelerate R&D from a long-term perspective, NTT established the Institute for Fundamental Mathematics.* This research center is overseen by Dr. Masato Wakayama, a member of the NTT R&D Authority Team who serves as the Fundamental Mathematics Research Principal. It will work on establishing a basic theoretical framework for modern mathematics and will accelerate research towards innovation in quantum technology by challenging to uncover the basic principles behind the superior power of quantum computing. It will also seek to contribute to NTT's R&D aimed at realizing IOWN by proposing the use of modern mathematics in groundbreaking new approaches to addressing various research problems, including the elucidation of unknown diseases and the discovery of new drugs.

NTT has established the Institute for Fundamental Mathematics
Advancing the pace of exploration into the unexplored principles of quantum computing
<https://group.ntt/en/newsrelease/2021/10/01/211001a.html>



IOWN

**Innovative Optical and
 Wireless Network**



Current Environment and Challenges

The spread of the internet and smartphones has fundamentally transformed society. Today, IoT devices and various other articles encountered in our daily lives are linked to one another. These changes can be seen in a move away from standardized offices to diverse work styles that are free of restrictions of location, allowing people to work at home or at shared offices. Moreover, the act of ordering products and services online, as opposed to making purchases at a physical store, has become commonplace. In this manner, the internet is now an integral part of our everyday lives. These changes have led to exponential growth in the amount of data traffic on the internet, and this increased data traffic has turned attention toward the issues surrounding the limits of the transmission and processing capabilities of existing telecommunications systems and of the rising amount of energy consumed by IT equipment. At the same time, it has become difficult to further increase the density of large-scale integrated circuits and other semiconductors, which have previously been increasing in density in line with Moore's law. These limits mean that the information society will no longer be able to continue growing in the same manner as it has thus far.

Meanwhile, the impact of ICT infrastructure on global warming indicates a need to pursue carbon neutrality. Accomplishing this important goal, however, is not feasible with existing technologies, and we must therefore look for some type of breakthrough innovation. It could even be said that the technology required for the future development of humanity is the one that will allow us to achieve carbon neutrality while also achieving economic growth.

Technologies Underpinning Social Infrastructure

Against this backdrop, NTT is advocating its IOWN concept as a new form of communication infrastructure for shaping our future. IOWN prescribes a network and information processing infrastructure that utilizes optical and other innovative technologies to realize ultra-high capacity, ultra-low latency, and ultra-low power consumption and thereby allow us to harness the various types of information whose processing requires capabilities exceeding those of our existing infrastructure. We are currently in the process of discussing and conducting verification tests with our partners with the goal of finalizing the specifications for the 2024 iteration of this infrastructure and moving toward its full-scale realization in 2030.

Through IOWN, we aim to achieve a number of objectives. These include substantially reducing power consumption amounts, providing processing capacity that can handle the increased computing needs created by broader-width communications, and enabling the real-time sharing of data that surpasses the scope of human senses collected from various sensors through high-capacity, low-latency communications. In addition, we look to utilize resources in a manner that exceeds industry and regional

Low power consumption	High quality and high capacity	Low latency
Power efficiency: 100 times higher*	Transmission capacity: 125 times higher	End-to-end delay: 1/200*
Transmission media: Optical fiber cables Transmission systems: Light (wavelength) throughput Information processing platform: Photonics-electrics convergence devices	<ul style="list-style-type: none"> Wavelength (optical signal) 	<ul style="list-style-type: none"> Transmission per wavelength No queueing No data compression Wavelength A: High-capacity video (uncompressed) Wavelength B: No latency / Speech
Various information communication services are provided using 1/100th of power consumption.	In an instant (0.3 sec), 10,000 two-hour movies can be downloaded (with 5G, one movie can be downloaded in three seconds).	Video is transmitted in real-time without the latency experienced with digital TV or satellite broadcast.

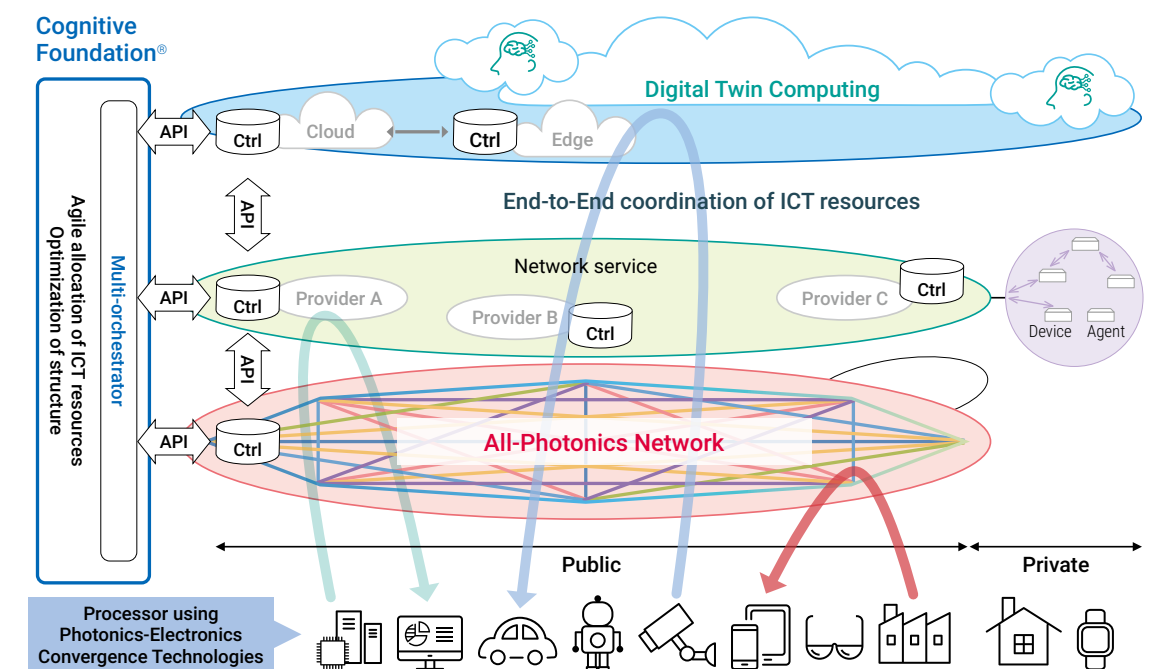
* Target power efficiency for the photonics part

* Latency target value in video traffic not requiring compression in the same prefecture

NTT's next-generation communication platform concept being developed with the goal of practical application in 2030

boundaries through multi-orchestration functions that realize integrated management of a range of resources. To accomplish these objectives, IOWN proposes infrastructure comprised of three main technology components.

These technology components are all-photonic networks that use photonic-based technologies for everything from networks to terminals, the Cognitive Foundation® service for linking and controlling various different articles, and digital twin computing for projecting future trends and promoting optimization by comparing the physical world with digital models. By combining these three technology components, IOWN will be able to demonstrate its incredible effectiveness by increasing transmission capacity by 125 times, reducing latency to one-200th of its current level, and improving power efficiency by 100 times.



IOWN GLOBAL FORUM Linking Companies and Academic Institutions across the Globe

IOWN is garnering interest from various companies and academic institutions around the world.

In response to the interest from such organizations, we established IOWN Global Forum, Inc., a new industry forum based in the United States, together with Intel Corporation and Sony Corporation in January 2020. This forum has grown to boast membership by 79 organizations as of October 31, 2021.

IOWN Global Forum's objective is to accelerate the adoption of a new communication infrastructure that will bring together an all-photonic network infrastructure including silicon photonics, edge computing, and wireless distributed computing to meet our future data and computing requirements through the development of new technologies, frameworks, specifications, and reference designs.



Smarter World Powered by IOWN

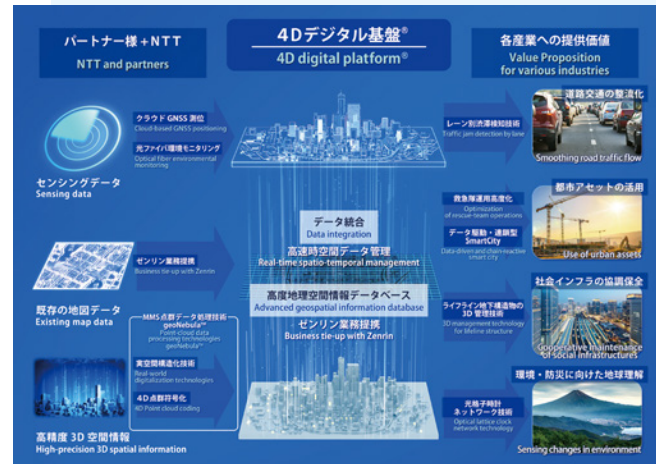
Five Kinds of Values
 That Support Our Lives



With eyes to the world after the COVID-19 pandemic, NTT is going beyond simply responding to technological trends on an individual basis in order to promote integrated technologies for realizing the society it envisions. The technologies NTT seeks to create are those that, like IOWN unveiled in 2019, support the social infrastructure that enriches people's lives. Through the architecture that forms this infrastructure, the platforms developed using this architecture, and the five values born out of these platforms, NTT looks to create a blueprint of the world to come.

1 Future Predictions and Optimization Made Possible by Integration of Diverse Sensing Data with Highly Precise Spatiotemporal Information Optimization of Cities and Mobility

Digitalization is rapidly progressing in many industries, including transportation, urban infrastructure, and manufacturing. Methodologies that entail the recreation and analysis of a variety of assets in digital spaces are expected to contribute to more efficient operations while helping address large social challenges, such as those indicated by the United Nations Sustainable Development Goals (SDGs). At the same time, services that create new value by linking data on a cross-industry basis still remain a work in progress.



4D digital platform™ is a solution to be provided through IOWN that can be used to unite and integrate 4D data, comprised of latitude, longitude, elevation, and time information, in a highly precise manner through the Advanced Geospatial Information Database, which is comprised of a wealth of highly precise semantic information. The platform can then compile this data in real-time. Through this process, the platform helps facilitate high-speed analysis and processing and highly accurate future prediction.

By combining this platform with the IoT data of various industries, it is possible to more effectively direct road traffic, optimally utilize city assets, and reduce social infrastructure maintenance costs. NTT Group is working together with partners from multiple industries to contribute to the harmony between society and the natural environment.

Areas in Which Value Is Created
 Connected cars and automated driving, smart cities, MaaS, smart infrastructure management, environment, disaster preparedness

4 Zero Environmental Impact Revitalization of the Global Environment and Realization of a Sustainable Society

There is urgent need to create a society that can cope with global environmental changes such as climate change, major disasters, and pandemics. Developing next-generation energy technologies and technologies to enable resilient environmental adaptation will reduce the burden placed on the global environment and thereby prevent environmental destruction, opening the door to a sustainable society in which humans can continue to live in harmony with the environment.

One notable energy technology built on the IOWN platform makes possible operation of nuclear fusion reactors. In July 2020, NTT established NTT Space Environment and Energy Laboratories, and we are collaborating with the International Thermonuclear Experimental Reactor (ITER) Project and Japan's National Institutes for Quantum and Radioisotope Science and Technology. Managing nuclear fusion reactions while minutely controlling the plasma and sharing experimental results requires innovations in computing and communications protocols to transmit massive amounts (petabyte level) of information to various locations at ultra-low latency. A new

communications platform like IOWN is essential to such innovation. We are also pursuing development of a more diverse energy network than ever before, including power generation from lightning and space-based solar power generation. Combining these energy technologies with weather forecasting will allow us to create a society that can respond more flexibly to changes in the environment.



Areas in Which Value Is Created
 Resilient smart cities, plasma digital twins, CO₂ negative technologies

2 Remote World Creation of a Collaborative Space That Transcends All Constraints

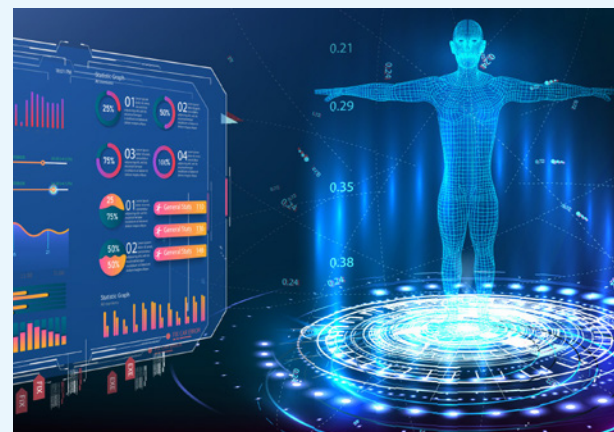
In the wake of the global COVID-19 pandemic, many industries have undertaken a clear shift toward remote activities. In addition to remote work and online education, there is also an urgent need to develop telemedicine. Meanwhile, the entertainment and sports industries demand systems that can go beyond just watching or listening online to provide value similar to that experienced in the physical world without the need to gather.

Through IOWN, we aim to enhance social and economic activities, even amid the kind of limitations imposed by the pandemic, and offer the value of the remote world. This goes beyond simply implementing various remote activities; it also includes making possible activities that transcend barriers of people's abilities, cultures, and values. The field of entertainment and sports calls for bringing realism to online live events as well as for creating environments where people can come together regardless of time or place. There is also a need to create frameworks through which people can even experience sports and entertainment by becoming other people. These innovations will lead to a society that transcends the boundaries of space, people, and culture.

Areas in Which Value Is Created
 Telemedicine, sports and entertainment viewing, remote support, multimodal communication, emotion and thought communication



3 Well-Being Fulfillment of Mind and Body through Integration of Past, Present, and Future



In the past, economic and health indicators have been used to measure human happiness and pleasure, but none of these figures can be said to reflect the multitude of human characteristics. The concept of well-being that has recently been garnering attention encompasses not only physical well-being but also mental and social well-being, and has spurred a growing number of initiatives that seek to understand human well-being through medical, hedonistic, sustainable, and other dimensions along with personal, social, and transcendental factors. Of course, this notion of well-being is deeply connected to NTT's development of IOWN and other architectures and services.

We have long viewed people as belonging to different groups, but as new architectures make it possible to rapidly process enormous amounts of data, we will be able to respond minutely to the tastes and needs of each individual. Well-being requires that people first understand their own situation, then have the ability to choose and put into practice the best options for them. NTT aims to build the foundations that will allow each individual to achieve a state of well-being, the aggregate of experiences stretching from the past to the future, at their own pace.

Areas in Which Value Is Created
 Bio-digital twins, biometric sensing, distribution optimization, safe and secure value chains

5 Secure Value Chains Realization of Safe and Secure Communication

The digitalization of society has made it possible for people to enjoy more convenient services. At the same time, the risk of cybercrime is increasing. As telemedicine becomes commonplace and digital twins make it possible for information and the human body to impact each other, cybercrime could have life-and-death implications.

That is why NTT wants to create a platform that can support a safe and secure society. In order to exchange large amounts of information remotely and with peace of mind, we need to build trust in a different manner than before. Value chains that allow companies to share information across industries are required in order to further advance digitization, and we will also need an environment that enables secure communication between public organizations and companies around the world. Safe and secure communication will only be achieved when we ensure stronger security that leverages the merits of IOWN's high-capacity and high-speed communications platform.

Areas in Which Value Is Created
 Smart cities, remote work, supply and demand forecasting systems, value chain reform



Key to Realization of IOWN

Creation and Utilization of Photonics-Electronics Convergence Technology

Message Message from the Head of NTT IOWN Integrated Innovation Center

The creation and utilization of photonics-electronics convergence technology that combines optical and electric signals will be key to the realization of IOWN. The NTT IOWN Integrated Innovation Center was established on July 1, 2021, in order to accelerate the creation and utilization of these technologies. The word "center" was chosen for the name of this organization, as opposed to "laboratory," and this decision has significant meaning. In advancing research and development, we view laboratories as organizations focused on the research side of the equation. The IIC, meanwhile, is meant to devote more attention to the development side, specifically seamlessly linking research to development and moving innovations along the process up until the stage directly before commercial development by operating companies. The IIC was dubbed a center to signify this function.

Of particular importance to the process of realizing IOWN will be photonics-electronics converged devices.

We have prepared a five-generation road map to guide the R&D of photonics-electronics converged devices as we seek to create innovative technologies and quickly bring these technologies to practical application. Initiatives are already underway based on this road map (see Figure 1). In the past, NTT has succeeded in achieving practical application of coherent optical subassemblies (COSAs), which are miniature communication modules with optical interface functions for converting optical and electric signals. The Company recently built upon this success with the development of optical-electric co-packages that integrate COSAs, which have traditionally been used as standalone components, with digital signal processors (see Figure 2). These new co-packages make it possible to reduce both the size and power consumption of optical interfaces. We will first move ahead with the practical application of these co-packages in data center interconnects in order to reduce energy consumption. In the future, we will work to apply optical wiring to make interconnect between and within chips by further converting optical and electric signals. We thereby aim to create information processing infrastructure with ultra-low levels of latency and electricity consumption.

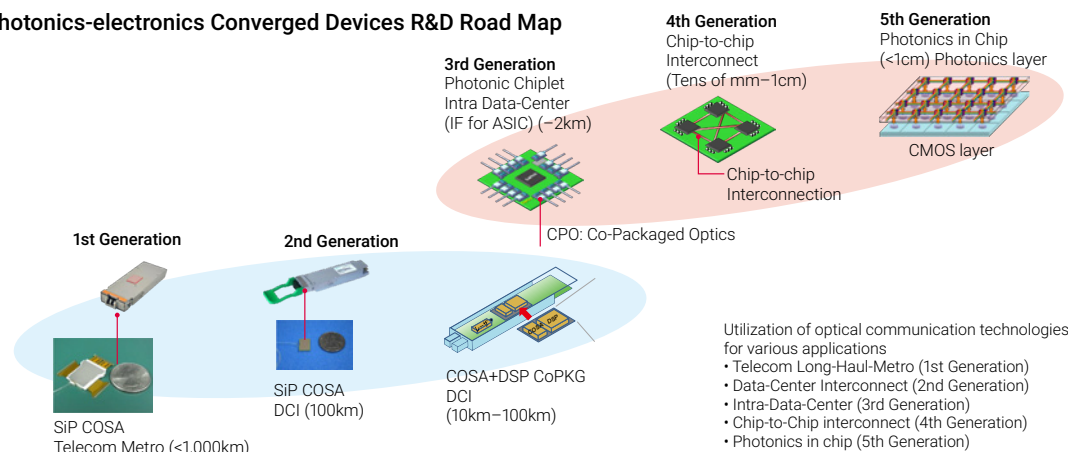
I previously worked at Fujitsu. Prior to my appointment as head of the IIC, I had the opportunity to speak with President Sawada, during which he stated that accelerating initiatives for realizing IOWN would require the ideas and experience of people from outside of NTT. The converting of optic and electricity, two different forms of energy, is an innovative idea that could only be



Hidehiro Tsukano
 Head of NTT IOWN Integrated Innovation Center

Hidehiro Tsukano joined Fujitsu Limited in 1981, where he was assigned to a division responsible for procuring semiconductors and other items. He became general manager of this company's Corporate Strategy Office in 2001 and then senior executive vice president and chief financial officer in 2017. Mr. Tsukano has also held the position of chief strategy officer and has overseen all areas of operations as assistant to the president, before becoming vice chairman in 2019. He later became consultant to Advanced Technology Corporation in 2020 and then senior advisor to NTT's research and development planning function before assuming his current position in July 2021.

Figure 1: Photonics-electronics Converged Devices R&D Road Map

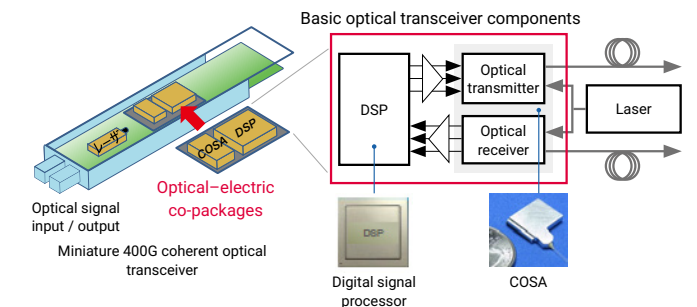


Global technological game changer and revitalization of Japan's technological prowess.

produced by NTT, with its long history of emphasizing basic research. My mission is to ensure that this new idea can be effectively developed into a tangible form. I was raised in a culture that differs from NTT's rather homogeneous one. As such, I believe the new insight, experience, thinking, and ideas I bring to NTT will be a powerful asset to accomplishing this mission.

Photonics-electronics convergence technology is thought to be a technological innovation the likes of which only comes once every 50 years. I hope that NTT, with its expertise in these technologies, will be able to dominate the global market by capitalizing on the ultra-low levels of latency and power consumption made possible by these technologies. Supporting NTT in this endeavor is the very reason for the IIC's existence. I like to express this sentiment with phrases like "global technological game changer" and "revitalization of Japan's technological prowess."

Figure 2: Photonics-electronics Converged Devices Development Status



IOWN Rollout Plan

FY	2021-2022		2023-2025		2026-2030	
	Field verification	Advanced services for early adopters	Deploying to specific applications / areas	Phased expansion	Wired-and-Wireless Convergence (WWC) services	▲ Photonics-electronics convergence devices for mobile equipment
Rollout Plan	<ul style="list-style-type: none"> ■ Establishment of the IOWN Integrated Innovation Center ■ Strengthening manufacturing technologies of photonics-electronics convergence devices (Establishment of NTT Electronics Cross Technologies Corp.) ◆ Cloud gaming for eSports (Low-latency connections) ◆ Real-world sports viewing remotely (Ultra-realistic video transmission/ Low-latency connections) 	<ul style="list-style-type: none"> ◆ Traffic flow management ◆ Quantum cryptographic communication ◆ Super White BOX (Next-generation computing platform) ● Space data center, etc. 	<ul style="list-style-type: none"> ■ Osaka / Kansai Expo (5G / IOWN exhibition, demonstration) ▲ Smart city projects (Phase 1) ▲ Level 3 autonomous driving of agricultural machinery ▲ Connected car safe driving support 	<ul style="list-style-type: none"> ▲ (Phase 2) ▲ Other smart city projects 	<ul style="list-style-type: none"> ▲ Photonics-electronics convergence devices for mobile equipment ▲ Optical loop for access network (Reliability / Flexibility / Extendability) 	<ul style="list-style-type: none"> ▲ Autonomous driving / Precise group control of robots
Digital Twin Computing	Collection and analysis of massive sensor data	High-speed spatiotemporal searching for tens of millions of vehicles	Event-driven, real-time AI analytical processing technology	Centimeter-level understanding of vehicle position and precise prediction of traffic volume in cities and mountain areas		
Cognitive Foundation	Prediction of wireless communication quality affected by hand-over / masking	Integrated resource control for immediate responses to demand changes (including wireless communications)				
Disaggregated Computing	Super White BOX: Step 0 (Optical direct path)	Super White BOX: Step 1 (Optical backplane)		Super White BOX: Step 2 (Full optical)		
All-Photonics Network	Direct optical connection (Hundreds of Gbps / Non-dynamic routing)	Post-quantum cryptographic communication	Direct optical connection (Hundreds of Gbps / Semi-dynamic routing)	High-precision clock time distribution	Remote optical path switching	WWC core network
			Optical transceivers for APN	On-board co-packaged optical transceiver		Direct optical connection (1Tbps / On demand)
					Photonics-electronics convergence processor	

**Unified with Business Strategy and R&D Strategy
 Based on Medium-Term Management Strategy**

Intellectual Property Strategy

We believe that appropriately protecting our intellectual property, created through R&D, and rightfully using the intellectual property of others is an important step on the path to a sustainable society.

Message Message from the Head of NTT Intellectual Property Center

NTT is accelerating R&D for solving challenging problems in its Innovative Optical and Wireless Network (IOWN) while envisioning a world where IOWN is a reality. IOWN cannot be made a reality by NTT Group acting alone, and requires global collaboration with trustworthy partners. Such collaboration will greatly augment the business activities of NTT Group as it contributes to the realization of a sustainable society while advancing digital transformation (DX) and CSR. To this end, it has become more important to formulate and execute an intellectual property strategy in tune with the times, and appropriately protect the fruits of R&D as intellectual property, while respecting the intellectual property rights of others.

Kenichi Minami, Head of NTT Intellectual Property Center

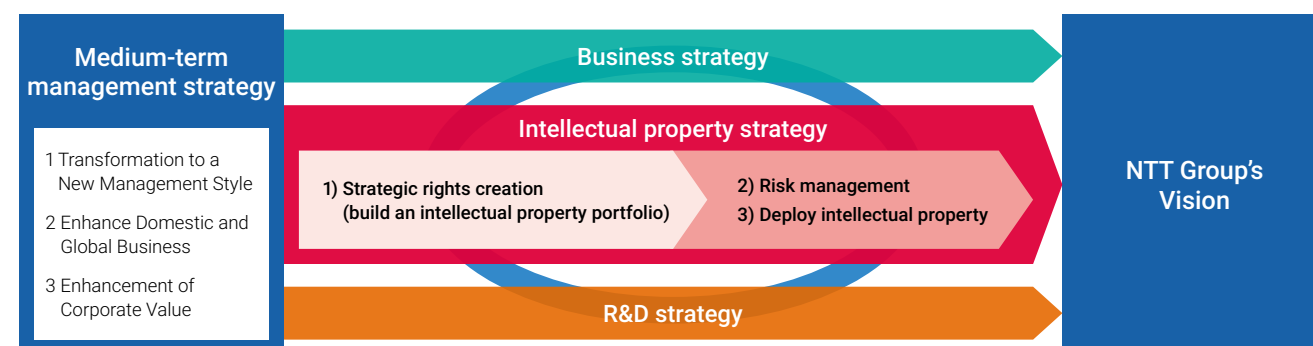
Formulate and Advance Intellectual Property Strategy

The NTT Intellectual Property Center is NTT Group's core organization for managing intellectual property. The Center aims to secure competitive advantages by proactively and appropriately protecting and managing intellectual property rights (i.e., patents), or internal expertise, from the results of R&D, the source of all business activities.

NTT aims to share the benefits of its R&D by broadly licensing out its technologies that help advance industry and technologies can be standardized and used throughout society. When deploying the results of R&D in their operations, each company in NTT Group respects the intellectual property rights of other companies.

With our intellectual property strategy as the basis of these activities, we take a three-pronged approach to formulating and advancing our business strategies and R&D strategy, based on our medium-term business strategy and vision: (1) develop strategic intellectual property rights, (2) manage risks, and (3) deploy the intellectual property we own.

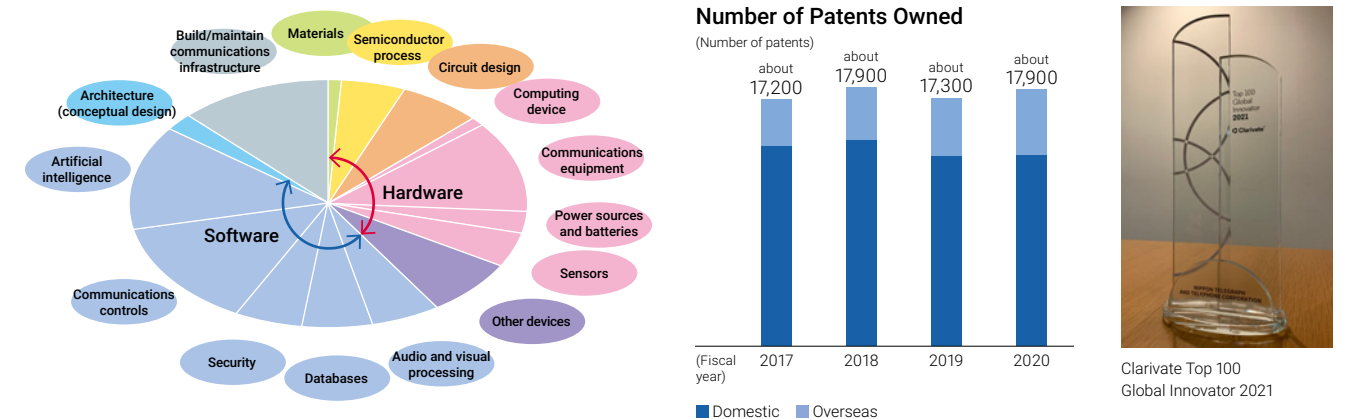
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| <p>① Strengthening our competitiveness with strategic rights creation (build an intellectual property portfolio)</p> | <ul style="list-style-type: none"> Build an intellectual property portfolio through the strategic development of intellectual property rights from fruits of R&D activities, based on technologies and anticipated business models |
| <p>② Risk management that protects our intellectual property rights and respects the rights of others</p> | <ul style="list-style-type: none"> When Group companies deploy the results of R&D in their operations, we examine the intellectual property rights of others inside and outside Japan up until the stage where R&D results are applied in order to avoid infringing on the rights of third parties Reduce business risk and comply with laws and regulations related to intellectual property rights, by sharing among Group companies information about intellectual property trends and their impact, such as revisions to systems around the world, cases of conflict and court decisions |
| <p>③ Develop business and partners through broad deployment of intellectual property rights</p> | <ul style="list-style-type: none"> Deploy intellectual property in business to help our customers and society, and to secure competitive advantages in business Proactively engage in activities to standardize intellectual property |



Intellectual Property Portfolio (Technology Field / Patent Ownership)

The results of R&D, which plays a major role in the creation of intellectual property for NTT Group, has translated into ownership of approximately 17,900 patents around the world in a wide range of technological fields. NTT Intellectual Property Center is putting more effort into filing patent application in foreign countries with the intention of reinforcing the global operations of NTT Group.

Clarivate Analytics, which analyzes trends in intellectual property based on patent filings, has selected the NTT Group as a Clarivate Top 100 Global Innovator, which names the world's most innovative companies and institutions, for ten consecutive years, in recognition of NTT Group's activities and track record on this front.



Intellectual Property That Contributes to DX at Customers



To advance DX projects outlined in NTT Group's vision, NTT Group offers services that utilize the fruits of its R&D efforts that are protected by patents.

WinActor, which is offered by NTT Advanced Technology, is a software robot that can automate a large volume of work performed by people. Using technologies for generating and editing automation scenarios that was developed by NTT R&D, WinActor is an RPA tool made in Japan that boasts the top share of the domestic market with more than 6,700 companies using the tool, which enables DX regardless of sector type or business scale, such as client companies and local governments.

In recognition of this track record, WinActor has received awards including the 9th Technological Business Innovation Award (Screening Committee Special Prize) from the Japan Techno-Economics Society, and the 9th ICT Business Commendation Award from the Telecommunications Association.



For more information, please refer to the WinActor website.
<https://winactor.biz/en/>

