White Paper
Networks in the 6G Era

Introduction

The 2020s started with the disruption caused by the COVID-19 pandemic, which changed life as we know it. And as conflicts continue to rage around the world with no resolution in sight, new geopolitical risks are emerging one after another, casting a dark shadow over our very existence. Meanwhile, generative AI and other new technologies are bringing about major adjustments to our lives and practices. It is hard to know what life will be like in 2030 and what kind of environment will we find ourselves in. Events and situations that we cannot yet predict may occur. Their effect on our daily lives will give rise to issues and needs that will in turn sow the seeds for the creation of a new wave of services. And new technologies may emerge, providing opportunities for people to innovate and pave the way to a more prosperous society.

6G is currently being considered in depth by many enterprises and organizations as the next-generation network architecture to evolve from 5G. It is anticipated that 6G will not only be an extension of the existing value offerings, including handling ever greater volume of traffic, but will also bring new value to networks that was not possible in 5G. In addition, new networks are expected to contribute to the enrichment of society by helping to solve increasingly complex social problems.

This white paper presents Fujitsu's perspective on the role that networks will play in the future society of 2030, and describes the technological development that Fujitsu will conduct to help create such a society.

February 2024

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1. Society in 2030

Many new digital technologies have emerged around us. People have accepted and adopted these technologies, and they have progressively changed the way society works. For example, e-commerce (electronic commerce) has changed how business transactions are structured, and social media channels have changed how communication is structured.

However, while technology has made our lives more convenient, it is also true that a ‘barrier’ exists between those who can use technology and those who cannot. It is therefore in everyone’s best interests that the barriers created by technology be removed by technology. From now on, technology should be adapted to the way we each live, broad-based rather than the field of a select few. It is imperative that we create a barrier-free society where everyone reaps the benefits that technology offers and everyone prospers.

By 2030, we will have a better command of technology than ever before. Innovation will lead to a society in which all people prosper. A society enriched in this way will generate further innovation, ushering in a new social story.

Designed utilizing the latest advanced technologies, we refer to this prosperous society of 2030 as ‘the Digitalized Future Society.’ It is a society where technology will continue to drive innovation, our diverse values will be underpinned by trust, and everyone will be advancing toward their dreams. In the Digitalized Future Society, technology will do more than simply empower us. The more technologically adept we all become, the more we benefit and the more this drives technological evolution.

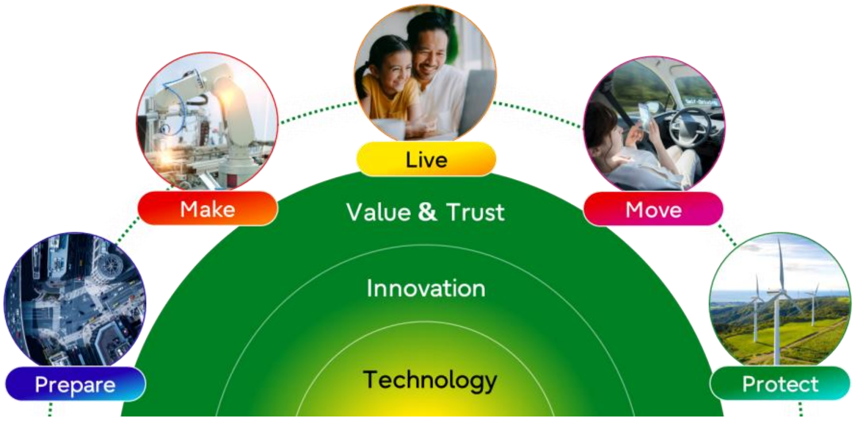


Figure 1 Digitalized Future Society

This white paper starts by visualizing what the Digitalized Future Society of 2030 might look like, using the five perspectives of *Make*, *Move*, *Live*, *Prepare*, and *Protect* as examples of scenarios encompassing our daily lives.

(1) Make

The increasing uptake of sensors and robots at *Make* sites such as factories and farms will boost work and production efficiency.

The automation of work on the factory floor will be driven by widespread use of robots and other devices. In particular, the improved performance of sensor technologies is expected to lead to greater automation of processes that previously relied on skilled workers and manual labor. The real factory floor could be replicated in a digital space and production line problems identified by analyzing work processes and the condition of plant and equipment. This would allow appropriate measures to be taken in advance, such as replacing machinery or making changes to the production line. The entire supply chain could also be optimized in accordance with sales of the final product, including the products manufactured at the factory, the suppliers that produce the components for them, and the next-stage and subsequent suppliers.

Meanwhile, the agricultural sector will also see greater automation with unattended farming using farm robots, and drones to automate the application of pesticides and fertilizers. The increasing use of satellite imagery, cameras and sensors will make it easier to monitor and analyze information on crop growth to adjust both the timing of work processes and the yield. It will also be possible to adjust yield in response to trends in consumer demand. Agricultural overproduction, and price volatility resulting from a mismatch between crop supply and demand, may turn out to be a thing of the past.

(2) Move

By 2030, the process of going out or traveling will be much more pleasant experience; everyone will find they can get out and about more easily.

The Digitalized Future Society will allow you to make the most of your time on the *Move*. You will be able to enjoy eating as you travel from place to place, or continue watching a movie that you were previously watching at home, as if still enjoying the comforts of home. This will allow optimal use of time and effectively blur the boundary between your living space and the spaces in which you move.

The automobile as a means of transportation will also evolve further, with various devices installed on the road and in vehicles sharing information back and forth about the immediate environment. This will facilitate control of driving speed and other factors, which will not only resolve traffic congestion, but also greatly improve driver and pedestrian safety.

In a future that has evolved beyond this, even children and the elderly will be able to travel stress-free to their destination, no matter where they go or how unfamiliar they are with the available transportation options. Everyone will be able to get around in a car, effectively eliminating current barriers for the mobility-impaired and those who are otherwise unable to go shopping.

People will be able to take advantage of a variety of high-quality services while remaining in their familiar surroundings. For example, technologies such as telehealth and distance education will ensure that residents of remote, small towns have access to the same level of medical and educational services as residents of large cities.

(3) Live

By the year 2030, our neighborhoods will not only offer more convenience, but *Live* spaces will also be more pleasant, dramatically improving our living standards.

It will be possible to employ technology to maintain and manage the various buildings and facilities in our townships with minimal human intervention. For example, sensors and drones will constantly monitor the condition of buildings and facilities to automatically determine when it is time to perform preventive maintenance, replacements, or repairs. Plumbing and wiring inside and outside buildings will be maintained by remote-controlled or autonomous robots.

In our *Live* environment, it could transpire that we will be able to use virtual technology to augment space, creating much cozier spaces by faithfully reproducing the colors, sounds, smells, and appearances of real spaces in a way that does not convey an unpleasant or unnatural feeling. For example, while in your living room, you could use virtual technology to create a forest where you can settle down with a good book and a cup of coffee while birds twitter and chirp around you.

Or, perhaps, it will be possible to reproduce soccer stadium sound effects and visuals, allowing you to share in the excitement and exuberance of the game along with other spectators.

(4) Prepare

Each time changes occur in the social environment as a result of incidents, accidents, and natural disasters (floods, volcanic eruptions, earthquakes, localized downpours), the emphasis on responding to such changes increases, as does the importance placed on quickly identifying the signs and planning accordingly. By 2030, technology will have made further progress toward solving these challenges.

Technology capable of identifying the signs of a natural disaster is key to solving the issues surrounding disaster preparedness. Identifying the signs makes it possible to analyze images from satellites and drones, and data from sensors deployed in the natural environment (forests, rivers, coastlines). These signs and warnings can then be promptly communicated to the public, properly timed so that people can *Prepare*.

Natural disasters and changes in the social environment can greatly affect a company's business environment. It is therefore important to have a risk management plan that takes both flexible capital investment and business recovery and restructuring into account to minimize potential damage. In the future, it will be possible to ensure uninterrupted business continuity by using digital twin technology to monitor the effectiveness of capital investment and business recovery and restructuring.

In this way, by simulating possible events in advance in the digital space, society as a whole will be able to hone not only its ability to recognize the signs of imminent crisis, but also its ability to minimize the impact of a crisis after it has occurred, including its ability to avoid or prevent further danger, or rapidly recover from the after-effects.

(5) Protect

Considerations to *Protect*, the environment are essential in all aspects of our lives if we hope to build a sustainable society.

By 2030, there will likely be systems for reducing the environmental load – systems that will share and replicate environment-related information in real-time in the digital space, analyze it, and process it as necessary.

For example, the optimal operation of energy supply facilities will be facilitated by using the digital space for collecting and analyzing such high-precision weather information as cloud positions and wind measurements, and information such as the charge/discharge status of electric vehicles and residential storage batteries. This will contribute greatly to stabilizing energy supply and demand.

In addition, the air conditioners and other systems we use will be autonomously controlled over a wide area without human intervention, in response to temperature and other conditions such as the level of pressure on energy supplies.

2. Networks Supporting the Digitalized Future Society

Digitalized Future Society and technology

In the previous section, we looked at the Digitalized Future Society of 2030 through the lens of the five perspectives of *Make*, *Move*, *Live*, *Prepare*, and *Protect*.

The remainder of this white paper looks at the technologies required to make the Digitalized Future Society a reality.

Figure 2 The technologies that will support the Digitalized Future Society

The technologies required for each perspective cover a wide spectrum.

The smart factory is a typical *Make* solution. The technologies that go into implementing a smart factory include, for example, the many sensors and cameras used on production lines, the analytics technologies that enable the real-time incremental improvement of work and manufacturing processes based on the data collected from these devices, and the remote control of manufacturing equipment and transport vehicles. These technologies are still finding their way into factories today, but the introduction of more accurate sensors and cameras and the automation and unattended operation of production processes is expected to show a stronger increase by 2030. Implementing such modes of operation will require real-time machine control based on information from sensors and cameras and, accordingly, networks with higher capacity and lower latency.

Smart agriculture will increasingly require technologies such as vast numbers of sensors and cameras for use on farms, analytics technologies for analyzing the data collected from such devices, and farm robots. Implementing these increasingly complex solutions will require higher capacity networks connected in greater numbers.

Autonomous driving is a typical *Move* solution. Information on ever-changing situational conditions needs to be shared back and forth between vehicles and the traffic infrastructure, and between vehicles themselves, in order to control vehicular direction and speed. For example, at intersections with poor visibility, accident prevention can be further improved by acquiring the type of information from other vehicles and traffic infrastructure that cannot be obtained from in-vehicle cameras and sensors alone. Implementing autonomous driving systems with this level of convenience and safety requires that the network transfer data reliably and in real time.

Another *Move* solution is Mobility as a Service (MaaS), which optimally combines mobility service users with multiple transport modes, such as buses and taxis, thereby improving both the convenience for people on the move and the operating efficiency of each mode of transport. MaaS requires a digital twin for mobility to replicate, analyze, and predict the dynamically changing information on the status of vehicles and roads, in real-time in the digital space. The digital twin is needed to perform real-time simulations that reflect the needs of mobility service users and the state of the transport modes available, offering users suggestions on the optimal combination of these. This will require networks to have even more connections and lower latency.

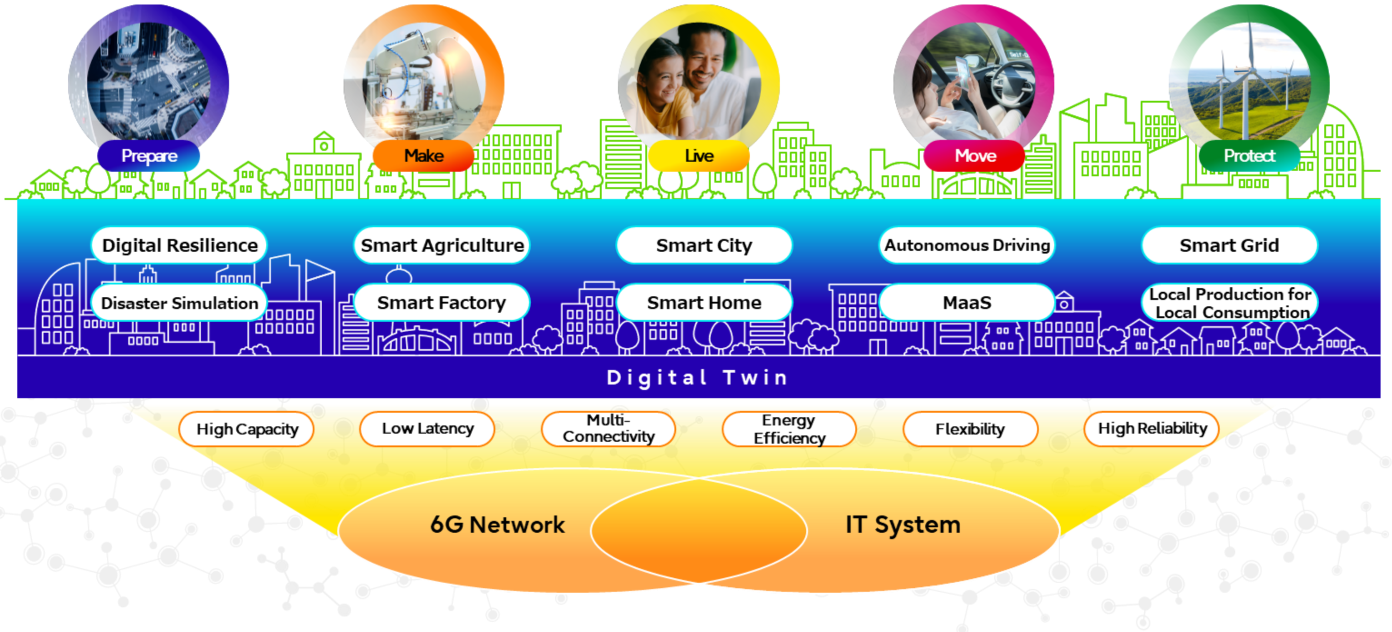


Figure 3 Solutions and network requirements for the Digitalized Future Society

While discussion of network requirements in the text above is based on *Make* and *Move* as examples, the other perspectives also require advanced networks. Table 1 shows what networks need to offer in order to implement each of the perspectives that will make up the Digitalized Future Society of 2030.

Table 1 Requirements of the network

Item	Examples of requirements of the network
High capacity	● High capacity to deliver advanced video analysis and high-volume data communication using high-definition video
Low latency	● Low latency required for real-time control between driverless vehicles, real-time control of autonomous factory machines, etc.
Multi-connectivity	● Multi-connectivity to collect information from numerous sensors installed over a wide area, such as on farms
Energy efficiency	● The ability to curb the increases in power consumption associated with larger network capacity and multi-connectivity ➢ Low power consumption by individual components of the network ➢ Controlling low power consumption across the entire network
Flexibility	● Flexibility to optimally adjust to changing environments and access ICT resources as needed ● Automation that allows network construction and configuration to be performed with as little human intervention as possible ● Autonomous detection of faults (congestion, failures, etc.) and recovery across a wide area
High reliability	● Scalability to enable communication anywhere, including over non-terrestrial networks (NTN) ● Versatility to provide connections to and between devices, not only communication devices such as smartphones, but also many other devices including factory machinery, cars, sensors, etc. ● Availability that maintains a certain level of quality, regardless of network status during communication ● Trust (authenticity, etc.) assurance among the people, data, and systems connected to the network

High-performance 5G networks feature **high capacity**, **low latency**, and **multi-connectivity**. Further improvement of these performance features is very important for 6G as well. Fujitsu is also developing a number of high-performance technologies to improve the performance of network functions and systems as an extension of 5G.

We believe that **energy efficiency** and **flexibility** should be treated as requirements for the network as a whole, as well as part of the agenda for individual network functions and systems.

5G-based services such as smart factories, smart agriculture, and municipal maintenance, are already in the process of implementation. However, the number of users and devices accessing these services can sometimes exceed prior expectations, causing large fluctuations in demand for IT resources. Such unexpected changes in circumstances may prevent the provision of services at a consistent level of quality. To prevent. this, it is important to have the flexibility to allocate inactive ICT resources to services in need, depending on the ever-changing situation. This flexibility is further enhanced by utilizing not only ICT resources in a single location such as a data center, but also multiple ICT resources located in geographically dispersed locations. We view this flexibility as a requirement that will be achieved through advances in ICT network architecture, to be discussed in the next section.

High reliability includes scalability and trust and is a key theme for the network as a whole. Networks will be able to connect from many different places – from the ground, from the world's oceans and from space – and from sensors and various devices such as smartphones, as well as from factory equipment, agricultural robots, cars and so on. This will enable more people to enjoy more services than ever before, and from every conceivable place. It will be crucial to provide those services with high quality and trust at all times.

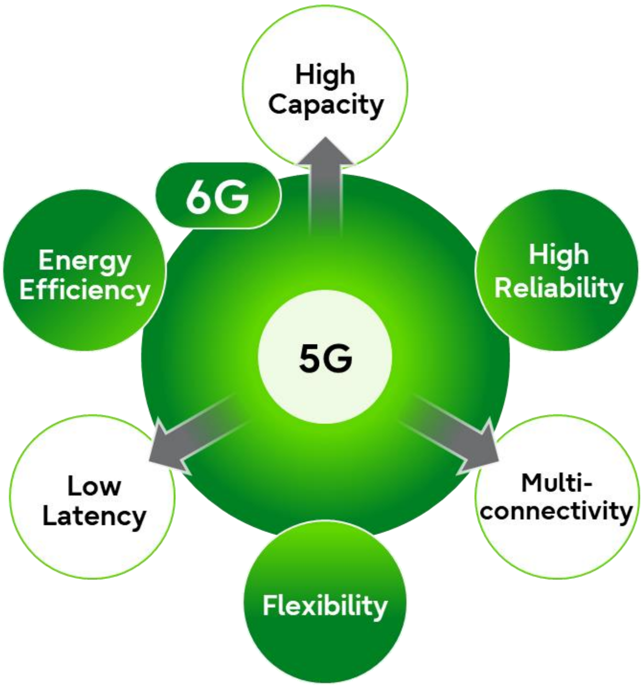


Figure 4 Requirements of the network

Impact on the network

It is hard to know what impact these differing requirements will have on the network. Figure 5 and Table 2 show the parts of the current network that are particularly affected by the various requirements.

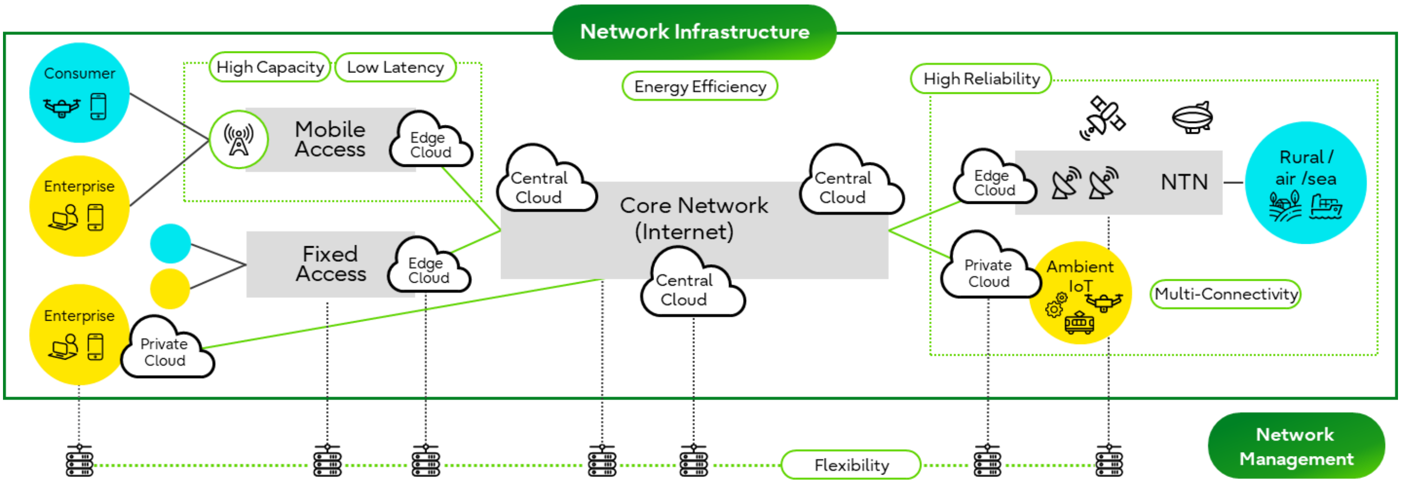


Figure 5 Impact of requirements on the network

To implement a **high-capacity** network, each of the network components--namely, wireless access, wired access, communication nodes, the core network--must be enhanced to ensure high capacity. Of particular importance is the need to increase the capacity of wireless access to transfer wireless devices that perform high-capacity data communications.

In terms of **low latency**, it is important to provide ICT infrastructure for what is known as edge computing (in which data is processed at or near user devices), as well as high-speed data transfer over the network.

High reliability requires network infrastructure that provides **multi-connectivity** to enable communication in not only the current communication areas, but also in places such as outer space and on the high seas where communication has hitherto been impossible, as well as in places with a large number of sensors and other communication devices. **Flexibility** requires network management that can respond autonomously to traffic changes and failures. **Energy efficiency** involves not only energy efficiency for individual communication nodes that make up the network, but also network operation and management to minimize power consumption for the network as a whole.

Table 2 Impact of requirements on the network

Requirements	Impact on the current network
High capacity	● Wireless and wired access networks capable of transferring high-volume data to cater to devices that perform high-capacity data communications ● Communication nodes capable of processing large amounts of data ● A core network that enables the transfer of large amounts of data
Low latency	● Communication nodes capable of high-speed processing of large amounts of data ● Network-edge data processing designed to process data at or near user devices
Multi-connectivity	● Wireless access to enable connectivity with sensors installed in large numbers over a wide area
Energy efficiency	● Energy efficiency for individual communication nodes. In particular, energy-efficient base stations, which account for a large proportion of the power consumed in mobile networks. ● Energy-efficient computer systems that serve as platforms for virtualized networks ● Energy efficiency in network operations at the end-to-end network level
Flexibility	● Network management that flexibly responds to traffic changes, including short-term traffic changes (sudden load changes) and long-term traffic changes that do not degrade the quality of communications to users ● Common and abstracted network management and control interfaces across vendors to simplify equipment from different vendors and complex networks ● Automatic network control that allows network devices to be configured while the network is under construction, and configuration changes resulting from faults (congestion, failures, etc.) during network operation to be implemented with as little human intervention as possible
High reliability	● Expansion of communication area coverage to enable communication anywhere including over non-terrestrial areas such as non-terrestrial networks (NTNs), and wireless access to accommodate a variety of devices and sensors ● Dynamic network quality control (including trust assurance among the people and data connected to the network) to maintain a certain level of quality, regardless of network status during communication

3. Network Architecture in the 6G Era

Distribution of ICT infrastructure

The ICT infrastructure for delivering services in the Digitalized Future Society is ubiquitous throughout the world. For example, enterprises and local governments may be provided with on-premises cloud-based services, or they may be able to use clouds in large-scale data centers (central cloud) or the WAN's edge clouds. In the Digitalized Future Society, it will be important to make effective use of such ubiquitous ICT resources to provide high-quality energy-efficient services at low cost.

For example, if users require low-latency services, building the system on an edge cloud near users will reduce latency. However, if this increases the processing load on the edge cloud, it will be possible to divide the processing between the edge clouds and central cloud to reduce the load.

If the number of users increases during service provision or if the network becomes congested, this may prevent the delivery of high-quality services to users. If so, it will be important to reconfigure the ICT system or change the traffic route to maintain quality.

To provide such flexibility, it will be necessary to change the configuration settings for individual components of the end-to-end ICT system (network functions, computers, etc.) in response to changes in the environment. The ICT system will need to have the autonomy of control over detecting environmental changes and automatically modifying the system's configuration without human intervention.

In end-to-end ICT systems, the concepts of disaggregation and orchestration are key to providing the level of flexibility and autonomy that enables efficient use of infrastructure in different locations and successful tracking of changes in the environment.

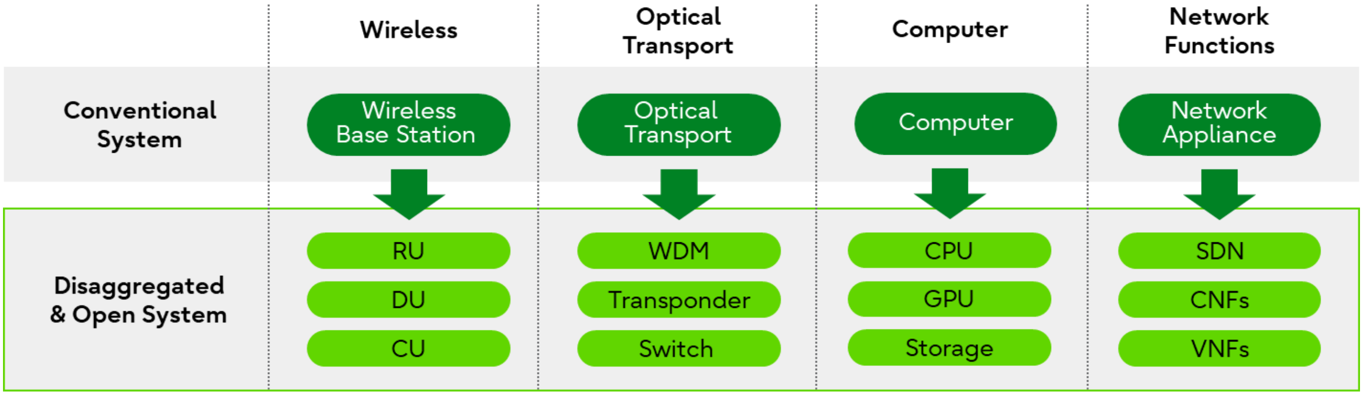
Disaggregation

Traditionally, network devices such as base stations, switches, and routers have mainly been provided as hardware appliances. Today, however, disaggregation is gaining traction; network devices are decomposed into a number of components and then reconfigured into a combination of the requisite components. For example, in the optical transport area, an optical transport system is broken down into components such as WDM, transponders, and switches. By providing open interfaces between these components, it is now becoming possible to freely combine components from the same or different vendors to reconfigure the optical transport system. In the wireless area, Open RAN is an ongoing effort to decompose base stations into components such as RU (Radio Unit), DU (Distributed Unit), and CU (Central Unit), and open the interfaces between those components.

In addition, advances in network virtualization now enable software-defined network functions to be deployed as applications on general-purpose computers. For example, in the 5G mobile core network, it is now easy to combine functions because the mobile core can be decomposed into various functions, allowing each to be used as a microservice.

Computers running these virtualized network functions can now also be decomposed into CPU, GPU, storage, and other components, facilitating disaggregated computing in which systems are optimally reconfigured according to load and other factors.

This type of disaggregation is being applied in various fields. In each case, the system and functions are decomposed into several components and the requisite components are combined according to the application and purpose to provide an optimal configuration that satisfies requirements such as high quality and low power consumption. Disaggregated computing is expected to be the new ICT infrastructure in the 6G era, replacing dedicated equipment and general-purpose computers conventionally used as computing resources for network infrastructure.



	Wireless	Optical Transport	Computer	Network Functions
Conventional System	Wireless Base Station	Optical Transport	Computer	Network Appliance
Disaggregated & Open System	RU DU CU	WDM Transponder Switch	CPU GPU Storage	SDN CNFs VNFs

Figure 6 Example of network disaggregation

Orchestration

As mentioned above, computer and network ICT infrastructure is distributed network-wide, including to enterprise sites and on-premises locations, telco edge clouds, and the central cloud via the internet. Coordinated linkage and use of this geo-distributed ICT infrastructure improves quality and reduces system costs. In other words, dynamically deploying network functions on computing resources according to the network requirements of the service to be implemented allows effective use of hardware resources while still meeting the requirements (Figure 7).

The end-to-end deployment and operation of network functions and IT system functions described here is known as orchestration.

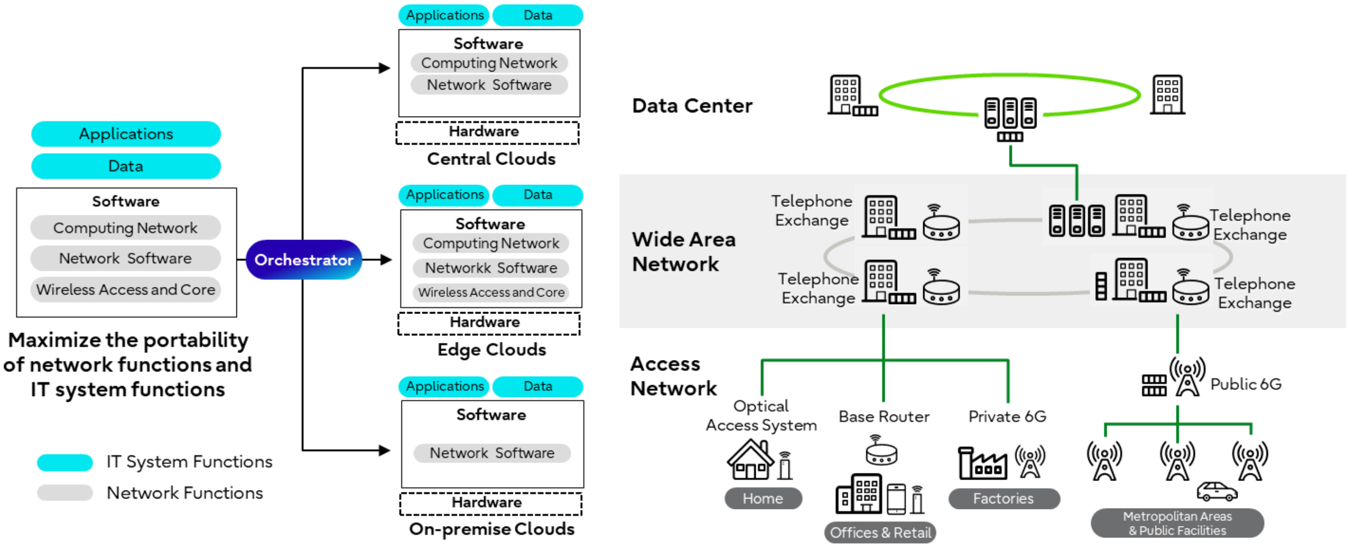


Figure 7 Orchestration

Evolution of network architecture

Virtualization of networks that implement network functions on general-purpose computers is similar to the IT system configurations implemented in the cloud. This means that IT system functions and network functions can both be implemented on a computer. This consequently makes it more efficient to architecturally integrate and manage both the network and the IT system. In other words, we believe that network functions and IT system functions will be integrated into two domains: hardware, which cannot be physically moved, and software, which is portable. The hardware domain will aim to deliver high performance using computers connected by a combination of optical transport systems and wireless access systems. The software domain will deliver a range of network functions, as well as functions such as processing data from devices to implement IT systems. This integrated IT system and network architecture will allow network and IT system functions to be implemented effectively, while maximizing hardware performance.

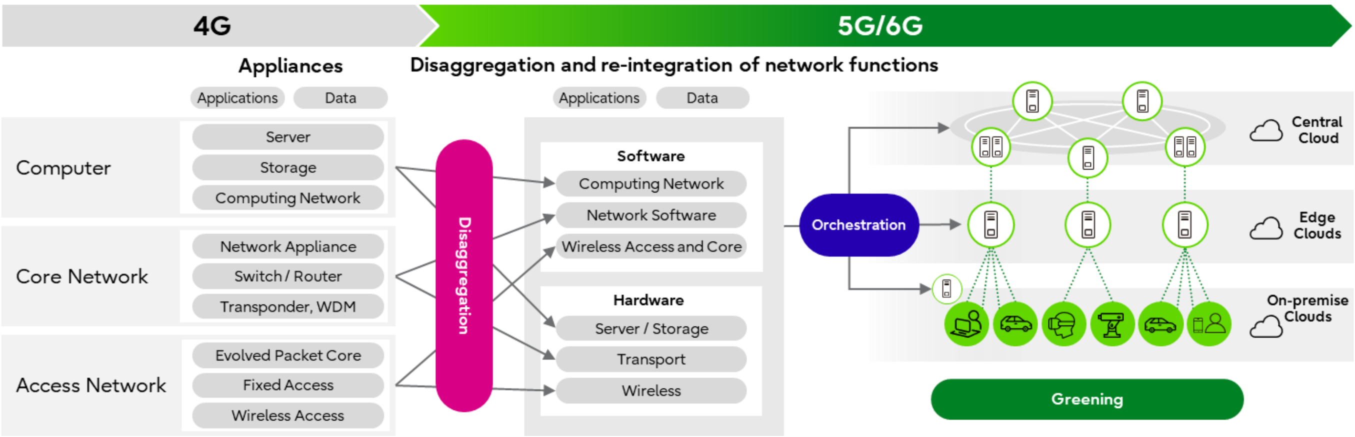


Figure 8 Evolution of network architecture (Example: Mobile network)

Figure 9 shows a network infrastructure consisting of a combination of hardware and software. The hardware domain comprises computer resources such as the CPU, GPU and storage; WDM, transponders and switches as Optical Transport hardware; and RUs and mobile devices as Wireless hardware. The more technology advances, the more this will develop performance in the hardware domain.

The software domain consists of mobile base station functions (CUs, DUs, etc.) implemented on computers, as well as network applications such as security and routing. In addition, with the growth of edge computing, data from cameras and sensors will be increasingly processed within the network. Functions for collecting and processing IoT data, and functions that provide the IoT data to other systems, will grow in importance in the future.

An end-to-end ICT infrastructure consists of a combination of these hardware and software components; the way they are mixed and matched differs depending on the infrastructure provider. For example, one infrastructure provider may deploy network software in the edge cloud, while another may run it on the central cloud. Given that hardware and software are disaggregated, infrastructure providers are free to configure the infrastructure in whichever way they want.

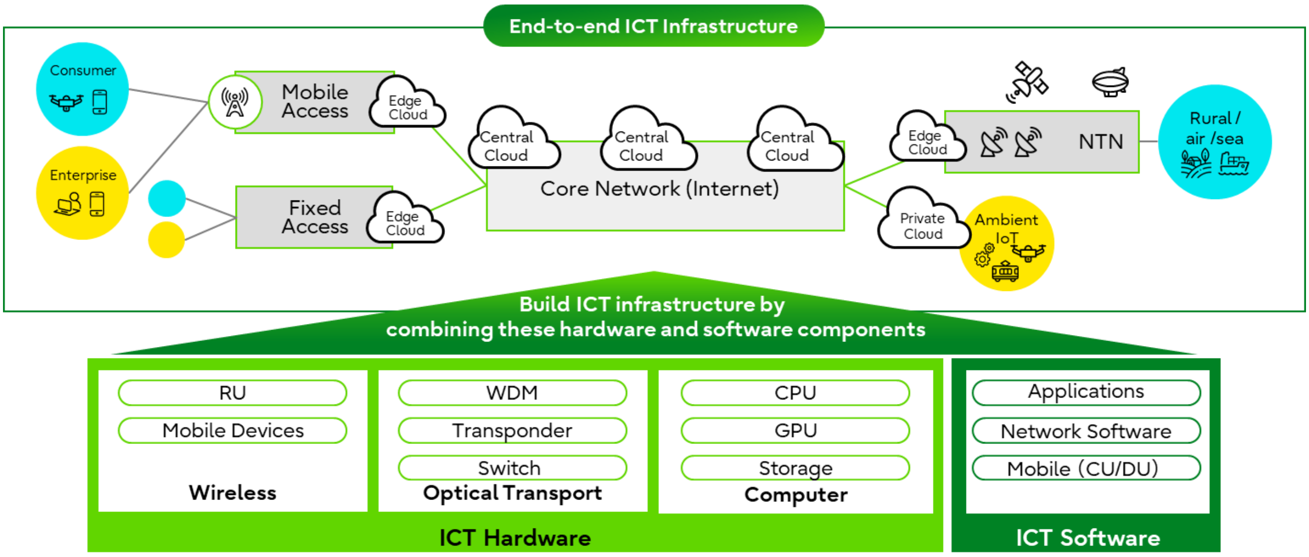


Figure 9 Network platform

ICT architecture in the 6G era

As mentioned above, services in the Digitalized Future Society will be delivered using ubiquitous ICT infrastructure, provided by a range of operators in various locations. ICT service providers therefore need to capitalize on this by skillfully mixing and matching the different infrastructure solutions. In so doing, it is better for them to be able to see the whole ICT infrastructure system, without being overly aware of the operators and their locations. In other words, we believe that the goal of ICT infrastructure should be to enable the ICT infrastructure user to handle the entire system centrally, building or changing it with ease.

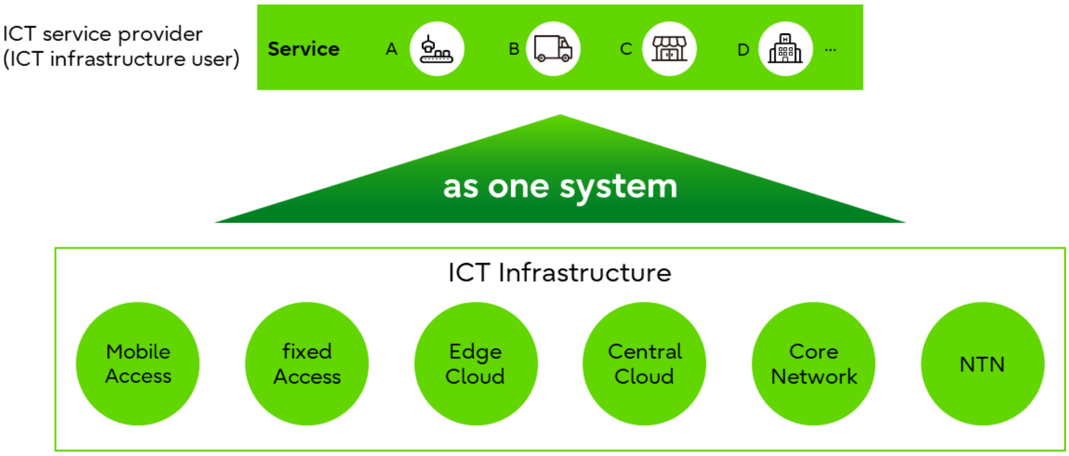


Figure 10 Utilization of ICT Infrastructure

Figure 11 is an example of the proposed ICT concept. ICT infrastructure includes edge clouds and central clouds, along with the networks that connect them. The infrastructure may be provided by multiple ICT infrastructure operators, not necessarily by a single operator. Meanwhile, it is important for the ICT infrastructure user to be able to use the infrastructure through an abstract API without being aware of the individual operators and systems.

Second, multiple ICT services run simultaneously on the ICT infrastructure. These services have different end-to-end functionality and performance requirements. The ICT infrastructure must therefore provide functionality and performance to simultaneously cater to multiple service requirements.

In addition, the status of services and ICT infrastructure dynamically changes during actual ICT infrastructure operation. For instance, the types of service may increase, as may the required performance and functionality. The performance of the ICT infrastructure also changes as a result of infrastructure increases or decreases, failures, etc.

ICT infrastructure needs to be managed across systems and operators to address these challenges. Furthermore, the end-to-end ICT infrastructure required for each service is provisioned on software as a 'virtual end-to-end network', and AI and other technologies are used to simulate and configure the state of the infrastructure. This makes it possible to predict how individual services will be affected by changes in service requirements and the state of the infrastructure, and to also predict how the ICT infrastructure should be changed. The results of these predictions allow the ICT infrastructure to be maintained in an optimal state.

Thus, we believe that future ICT infrastructure will trend towards providing flexibility through integrated management of networks and computer infrastructures that involve a range of different operators and locations, as well as offering ICT service providers an easy-to-use ICT infrastructure that can be viewed as a single entity.

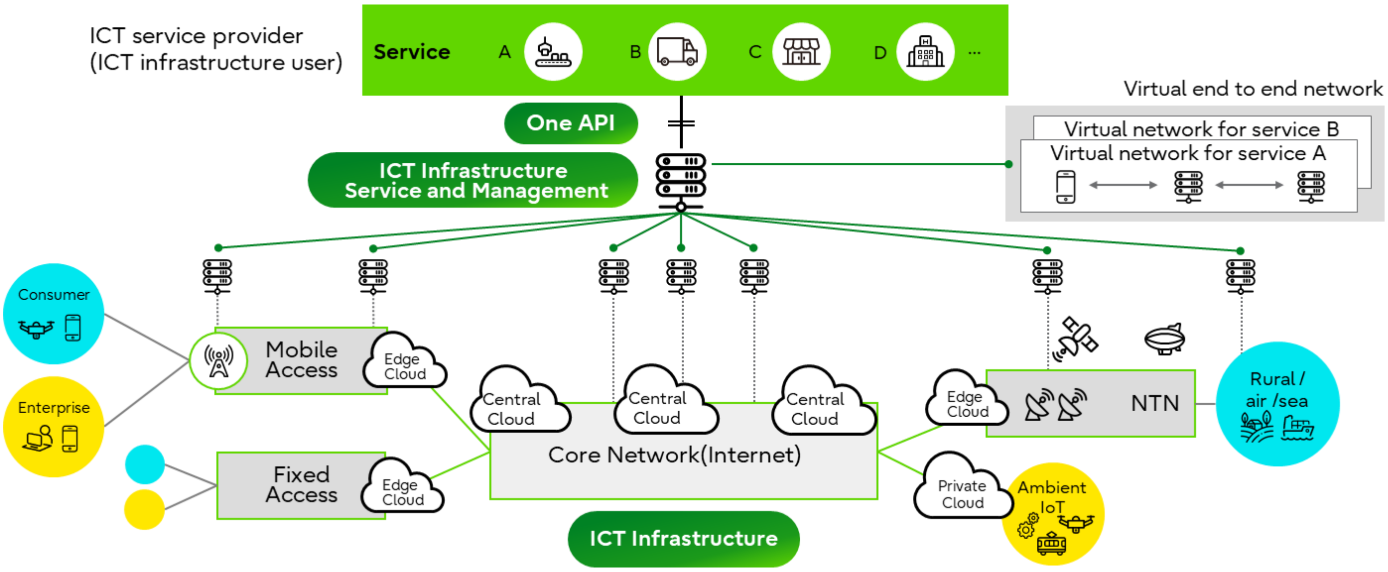


Figure 11 ICT infrastructure architecture in the 6G era

4. Underlying Network Technologies

This section focuses on the technologies that Fujitsu is developing in the hardware and software domains shown in the network architecture in the previous section.

Network Technology Trends

The three core technologies required to implement end-to-end, high-performance, high-quality, flexible networks are open and disaggregated network technology, intelligent network technology, and green technology.

To ensure that disaggregated network functions can be made optimally available end-to-end to meet requirements, the interfaces between the respective functions must first be open to make the system easily buildable. Next, intelligence in operations management is required to reconstruct network functions to meet requirements on ubiquitous ICT infrastructure such as edge and central clouds in various locations, and ensure that the network is safe, secure, and easy to operate. Finally, in environmentally friendly networks, it is important that they be compact and energy efficient, while still offering performance and quality. The power needs of a 6G network will be greater than 5G as 6G provides higher-capacity data transmission. For this reason, the power consumption of the entire network infrastructure will have to be significantly curbed through innovations in green technology.

It will then be possible to provide an end-to-end optimized network based on intelligently built and run network functions that are open and disaggregated, as well as green.

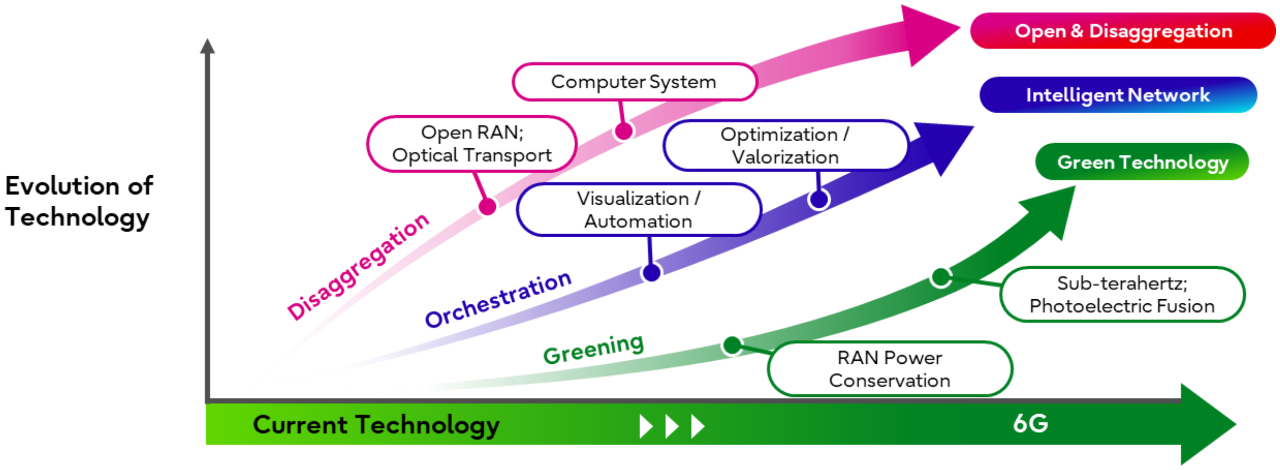


Figure 12 Network technology development trends

Open and Disaggregation

There are two important points to note about network disaggregation. The first is that disaggregated functions are implemented in either the hardware or the software, but in both cases, open interfaces are provided between functions. This is to ensure interoperability between functions provided by different vendors. The second is that each disaggregated network function is software-defined and can be implemented on a virtualization platform. Having virtualized network functions makes it easy to flexibly add, update, or delete network functions.

Figure 13 shows Fujitsu's approach to network openness and disaggregation in the field of optical transport. The conventional optical transport system is an all-in-one-box type system that integrates WDM (the lambda block in the above figure), transponders (transport block), and switches (switch block). Disaggregating those functionalities, opening the interfaces between functions, and opening the monitoring and control interfaces for functions will make it possible to flexibly build systems and functions from a range of vendors, and monitor and control them, in accordance with system requirements[1].

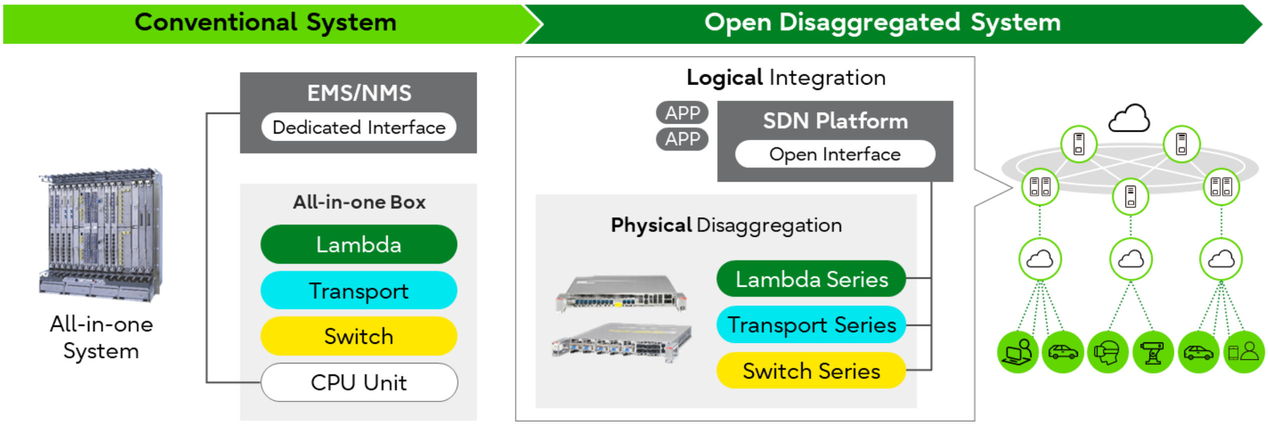


Figure 13 Open and disaggregated optical transport

Figure 14 shows the configuration of the software-defined base station that Fujitsu is currently working on. In the case of conventional base stations, the system is decomposed into functional components comprising the RU that handles the radio part, the CU/DU that performs digital signal processing, and the Radio Access Network Intelligent Controller/Service Management and Orchestration (RIC/SMO) that controls and manages the base station and network. Opening the interface between the functional components enables vendor interoperability. Moreover, having a software-defined configuration for the CU/DU conventionally provided as appliances and implementing them on a virtualization platform facilitates the configuration of a flexible network. In preparation for 6G, Fujitsu will develop a compact, energy-efficient, high-performance, highly flexible network by combining these open and disaggregated network functions with green technology (mentioned below).

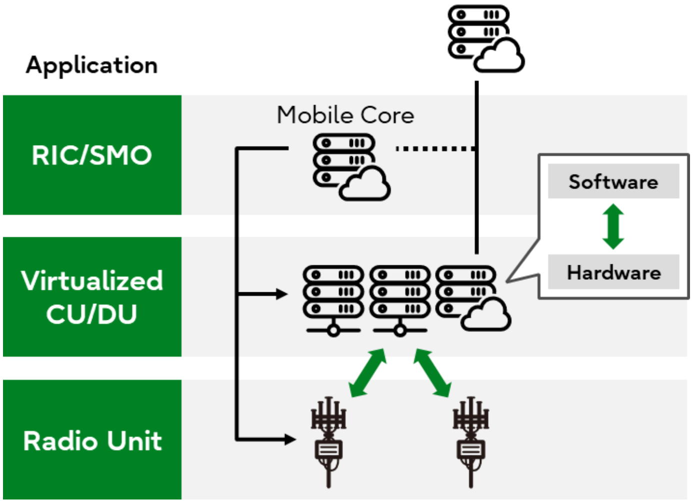


Figure 14 Software-defined mobile base station

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[1] 1FINITY Optical Networking for Digital Transformation
https://marketing.us.fujitsu.com/rs/407-MTR-501/images/1FINITY%20Brochure_08062020.pdf

Figure 15 and Figure 16 illustrate the disaggregated computing currently being developed by Fujitsu. In conventional computers (for example servers), the number of resources (CPUs, GPUs, storage, etc.) and the processing power are designated for each server. Thus, if a computer does not have enough processing power to run a certain application, this can be addressed by adding more servers. For example, at present, if a GPU does not have enough processing power, the number of servers needs to be increased, even though there is adequate storage capacity. Disaggregated computing provides a computing system with high use efficiency by flexibly scaling the number of units on a resource-by-resource basis. In other words, the system is made to function as if it were a single virtual server, pooling the requisite resources according to the application load. This is not limited to resource sharing among neighboring servers in a data center, but is also aimed at the sharing of resources between geographically dispersed servers to maintain efficient infrastructure operation. For this type of resource sharing to take place among servers, data needs to be transferred at high speed between the resources of different computers. This can be addressed by using direct device-to-device[2] transfer without CPU technology that allows direct communication between devices without CPU intervention, or by using photoelectric fusion technology, which will be discussed later.

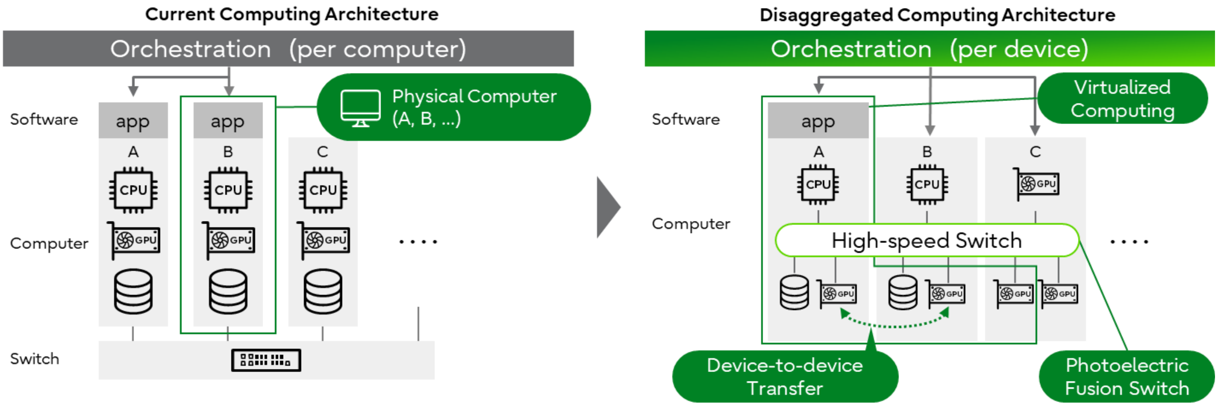

Figure 15 Disaggregated Computing

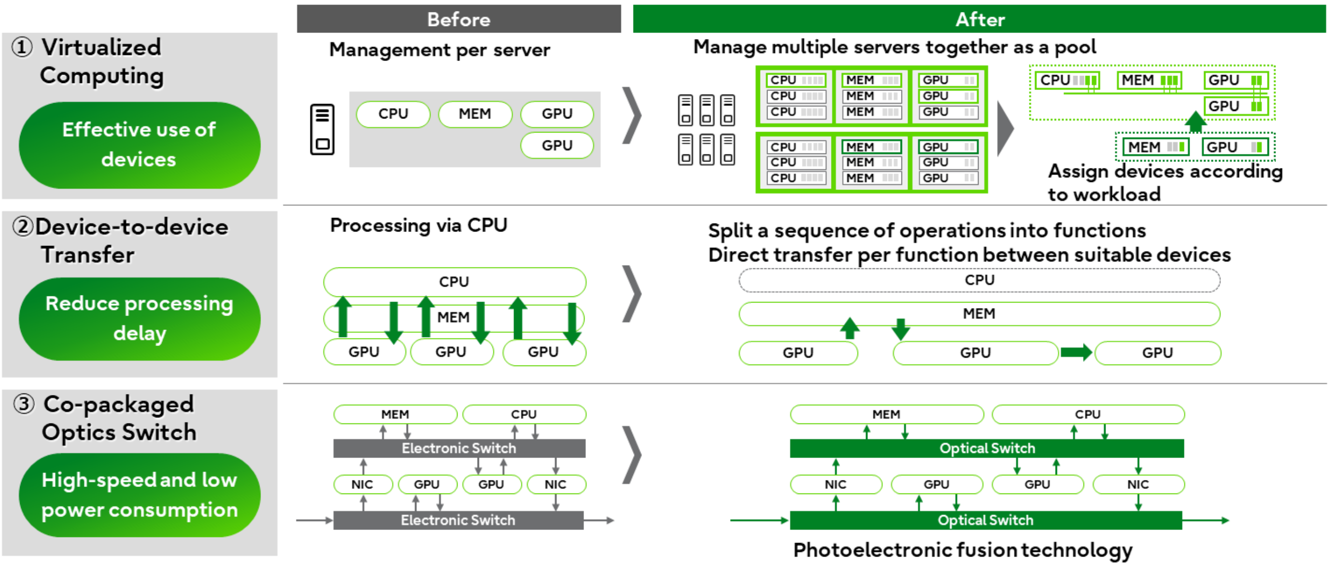

Figure 16 Features of Disaggregated Computing

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[2] The devices mentioned here refer to GPUs, FPGAs, memory, etc.

Intelligent Networks

The quality of the network utilized by users depends on the performance of the individual systems and functions and the usage of network paths. It will therefore be important to integrate the monitoring and control of the network and the IT systems used by users, from the devices to the cloud. In a network that uses a combination of proprietary vendor systems, integrated operation and management of the network as a whole is exceedingly complicated because its management depends on the individual systems. It therefore follows that opening and standardizing the monitoring and control interfaces for the vendors' systems and functions will facilitate end-to-end network operation and management between the various vendors and across the different optical transport, wireless and computer areas. In addition, collecting data on the status of networks in relation to the usage of and service quality from individual systems, and using AI and other tools to analyze that data, will enable dynamic analysis-based operation and management activities including the manipulation of system settings.

Figure 17 shows the phases involved in developing end-to-end network operation and management technology. Phase 1 enables visualization of the status of the individual system resources that make up the network and automated construction and maintenance of alarm displays, etc.

Having the monitoring and control interfaces open and standardized between individual systems and functions, and having centralized end-to-end monitoring, allows the network status to be comprehensively visualized end-to-end. It will be possible to analyze whether the status of each of the systems and functions is satisfactory, and to analyze the deployment of the appropriate resources and the use of appropriate setting values for all systems and functions (Phase 2). This would enable, for example, optimization to reduce the power consumption of the entire network, or to improve the quality of the user experience. This example of reducing network power consumption will be discussed in the next section on green technology.

Furthermore, exposing the end-to-end network status to the IT system allows the IT system to use this information. For example, information such as which parts of the network are congested and where users are most concentrated can be used and reflected in the IT system. In terms of operation and management, this also permits the integrated management of IT system resources and network resources (Phase 3).

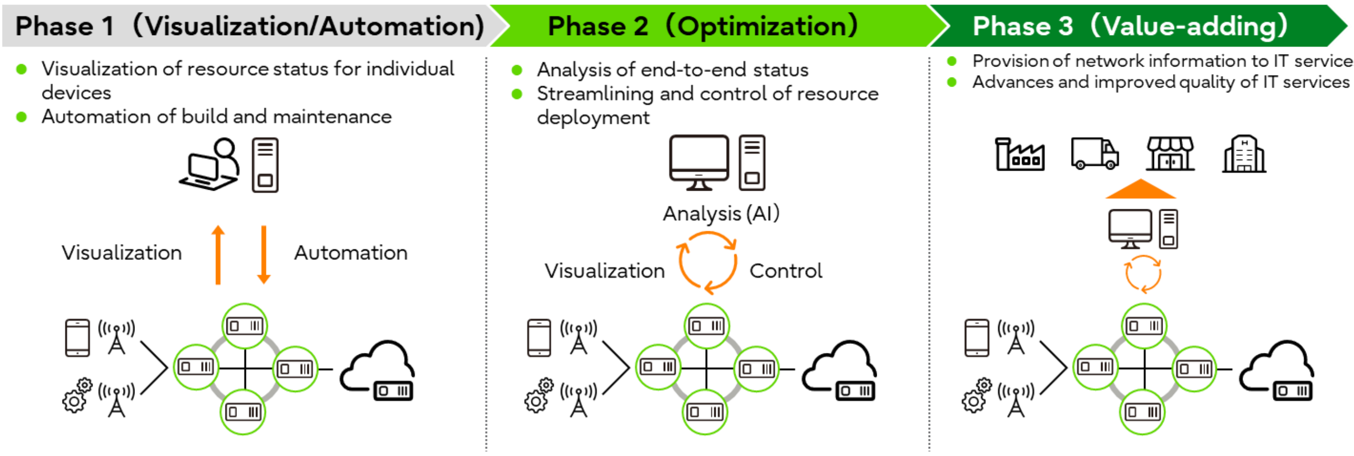


Figure 17 Network automation, optimization, and value-adding

Green Technology

Compactness and energy efficiency in the areas of wireless hardware, optical transport hardware, and computer hardware will be of primary importance for green technologies aiming to have minimal environmental impact. It will also be important to reduce power consumption throughout the network via the intelligent operation and management discussed above.

In the area of wireless hardware, we are developing wireless technologies that utilize frequencies in the millimeter-wave range and sub-terahertz range, which are higher than those of 5G. Using frequencies in the higher-frequency millimeter-wave and sub-terahertz wave ranges enables faster data transfer than is currently possible with microwaves (which are now used mainly in mobile communications). However, using ordinary silicon semiconductors in the high-frequency range leads to problems such as the inability to increase amplifier output (Figure 18). Fujitsu aims to implement a high-speed low-power RU containing a transmitter-receiver that uses High-Electron Mobility Transistors (HEMTs) fabricated from compound semiconductors such as gallium nitride (GaN) and indium phosphide (InP).

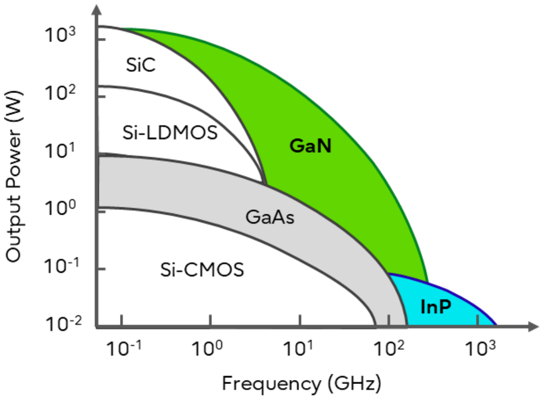
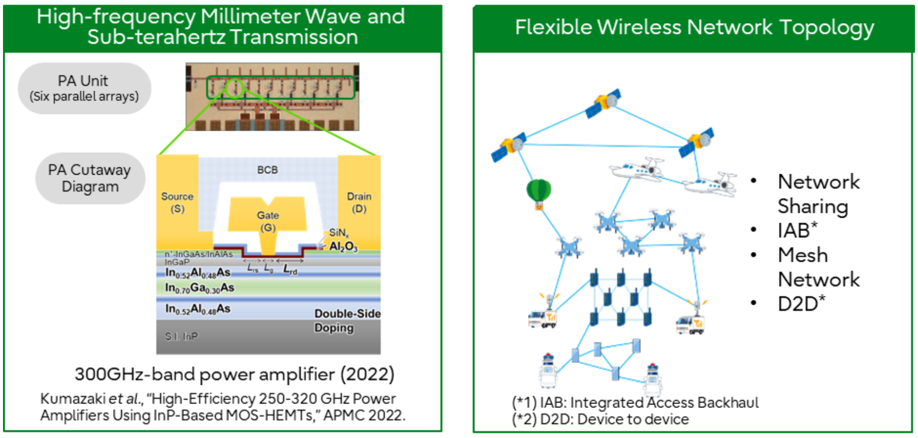


Figure 18 Operating frequencies and amplifier outputs

Further, to enable efficient network deployment and communication in the current coverage area as well as in a range of different locations (e.g., inside buildings, underground, aerial), we are also developing network topologies to build energy-efficient networks using technologies such as Integrated Access and Backhaul (IAB), mesh networks, mobile base stations, and network sharing.



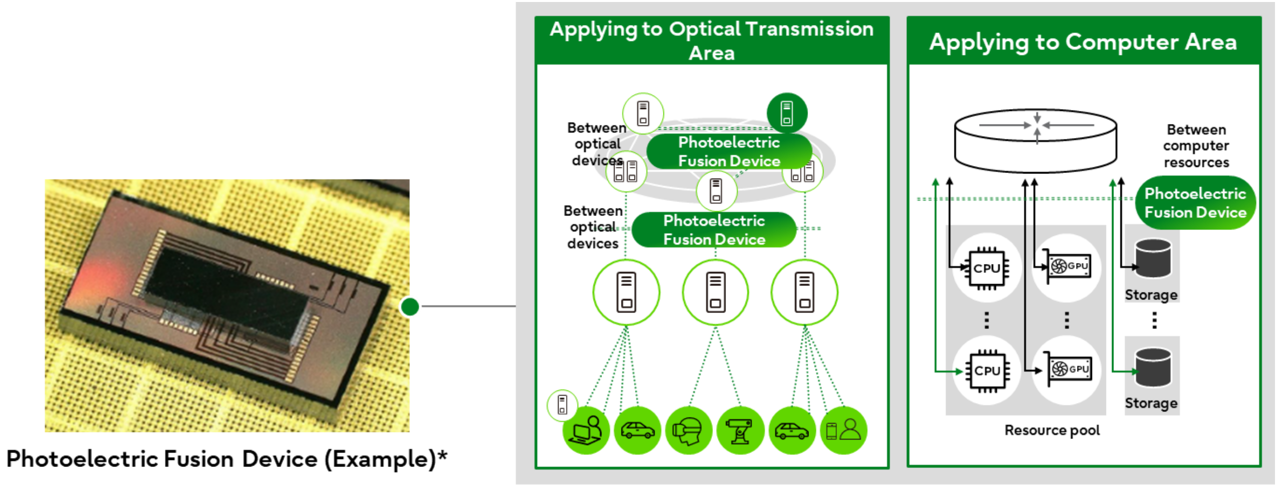
300GHz-band power amplifier (2022)

Kumazaki *et al.*, "High-Efficiency 250-320 GHz Power Amplifiers Using InP-Based MOS-HEMTs," APMC 2022.

(*1) IAB: Integrated Access Backhaul
(*2) D2D: Device to device

Figure 19 Green technology (Wireless)

As part of designing a compact, energy-efficient optical transport network, Fujitsu is engaged in developing all-photonics network transport technology to enable the network processing that is conventionally performed electrically to be implemented at the optical layer as much as possible. Given that the electrical parts of systems in existing optical transport networks are implemented using silicon semiconductors and the optical parts are implemented using compound semiconductors, they are each enclosed in discrete semiconductor packages. Photoelectric fusion technology sets out to achieve compactness and low power consumption by implementing processing at the optical level and processing at the electrical level in the same semiconductor package. Using photoelectric fusion devices in optical transport systems as well as in computer systems makes the systems generally more compact and energy efficient.



* This technology is based on results obtained from a project, JPNP13004,14004,16007 commissioned by the New Energy and Industrial Technology Development Organization (NEDO)

Figure 20 Photoelectric fusion technology

Figure 21 is an example of a network that is compact and energy-efficient, yet capable of large-capacity transmission thanks to the optical devices that use this photoelectric fusion technology being employed in optical amplifier subsystems and transponder subsystems, and also in optical transport systems that combine these subsystems. In the future, Fujitsu aims to develop an all-photonics network capable of end-to-end optical processing by gradually replacing the parts currently processed electrically.

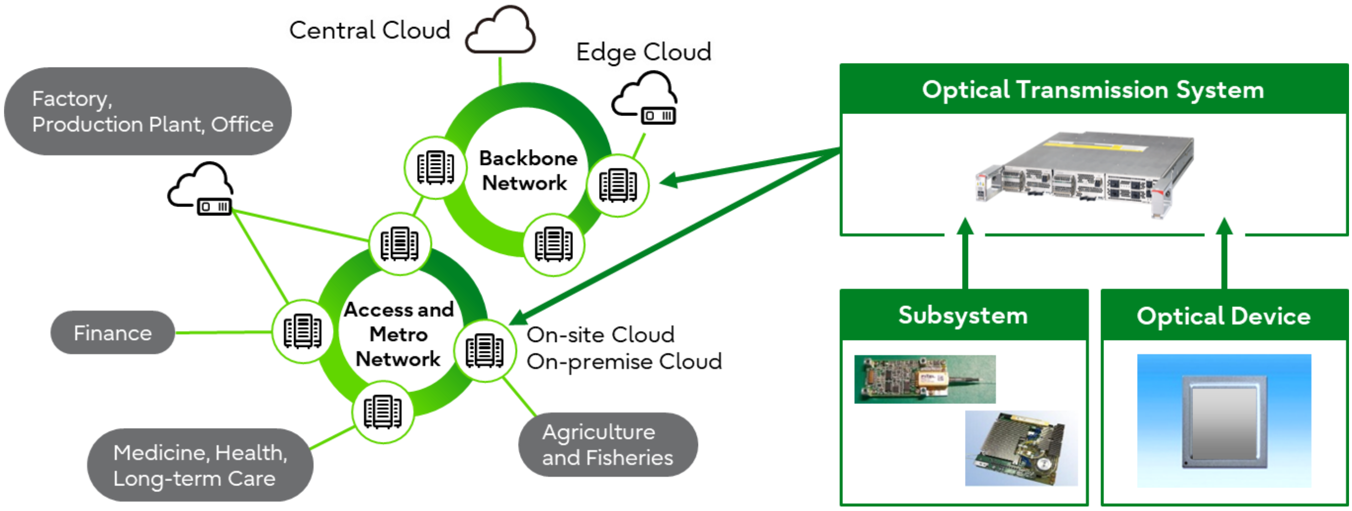


Figure 21 Use of photoelectric fusion technology in an optical transport network

When the individual systems and functions shown above are combined to build and operate a network, it is also important to make the overall network greener. Figure 22 shows an example of the reduction in energy consumption obtained through network greening in a radio access network (RAN). As mentioned above, the RAN consists of RUs installed in indoor and outdoor applications and CUs/DUs implemented mainly by software in the cloud. Network usage by mobile users constantly fluctuates, depending on the location and time. The number of users may drop quite low at certain times of the day, for example, at night when office buildings are vacated, or there may be situations when many users congregate at specific locations at specific times, such as during events. When the number of users drops extremely low, power consumption can then be reduced by limiting RU operation. In addition, by sharing hardware resources (computers) for CUs/DUs configured in the cloud, it is possible to keep power consumption to the bare minimum by running the number of resources appropriate to the load. Fujitsu's future goal is for the network to be able to reduce excess computer resources by tracking and predicting the movements of network users and the usage of IT services deployed on the network.

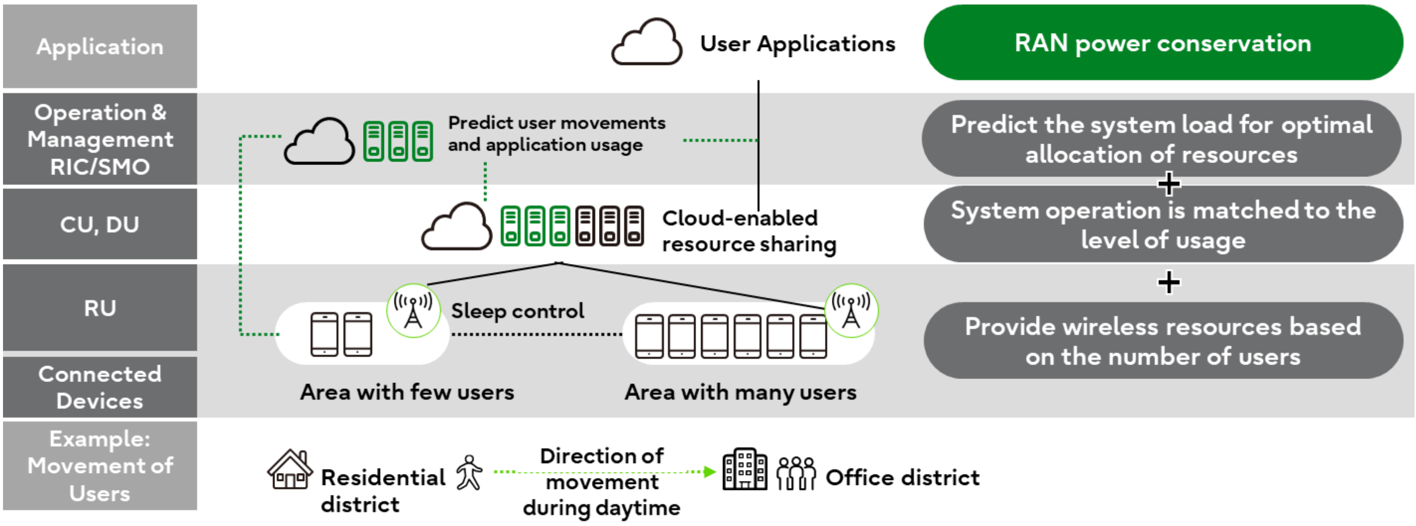


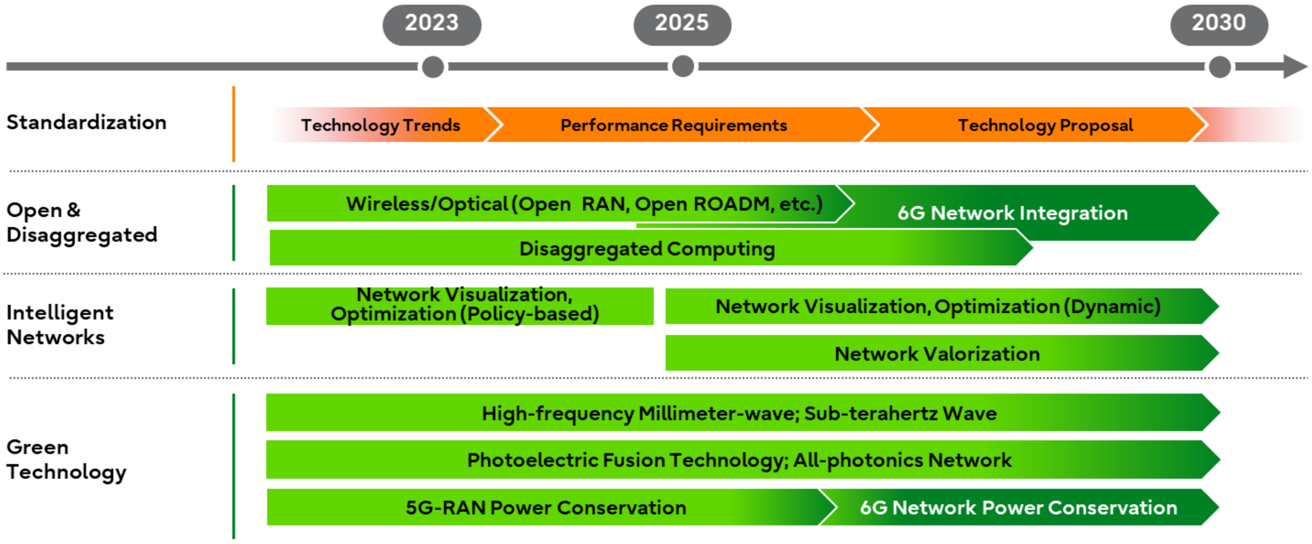
Figure 22 Reduction in RAN power consumption

Technology Development Roadmap

Figure 23 shows the technology development roadmap currently envisaged by Fujitsu. In the area of open and disaggregated architecture, we are working on network disaggregation and standardization based on existing 5G architecture, and on implementing software-defined functions. In essence, 6G will also be based on this approach, but the possibility of disruptive evolution is also under consideration.

In the field of intelligent networks, we will start with rule- and policy-based automation in regard to the operation of systems from different vendors and in different areas, and then use AI to extend this to dynamic visualization and optimization. We are also planning to develop network valorization technologies to turn data held by the network into valuable information and make it available to applications.

As part of our focus on green technology, we will continue to develop technologies such as high-frequency millimeter-wave, sub-terahertz wave, and photoelectric fusion that are compact and energy-efficient yet capable of high-capacity transmission, as well as technologies for all-photonics networks that enable end-to-end optical processing. We will also continue working on AI-based dynamic optimization, and in particular on reducing power consumption across the network.



Note: This roadmap is based on Fujitsu's current projections and is subject to change without notice.

Figure 23 Technology development roadmap

5. Conclusion

The Digitalized Future Society is a society where technology will continue to drive innovation, our diverse values will be underpinned by trust, and everyone will be advancing toward their dreams. Networks that support the Digitalized Future Society will need to embrace cutting-edge technologies by being open and disaggregated, intelligent, and green in order to deliver a characteristically high level of performance with minimal environmental impact.

Fujitsu will continue to engage in the development of these technologies, offering them to customers around the world as part of its contribution to the Digitalized Future Society.

Appendix. Market Size for Disaggregated Computing[3]

Disaggregated computing in the 6G infrastructure

In addition to dedicated equipment and general-purpose computers, disaggregated computers will also be used as computing resources to support the 6G infrastructure. The market for disaggregated computers used as 6G ICT infrastructure is forecast to grow year on year, exceeding 40% growth to reach a market size of US$20 billion by 2035.

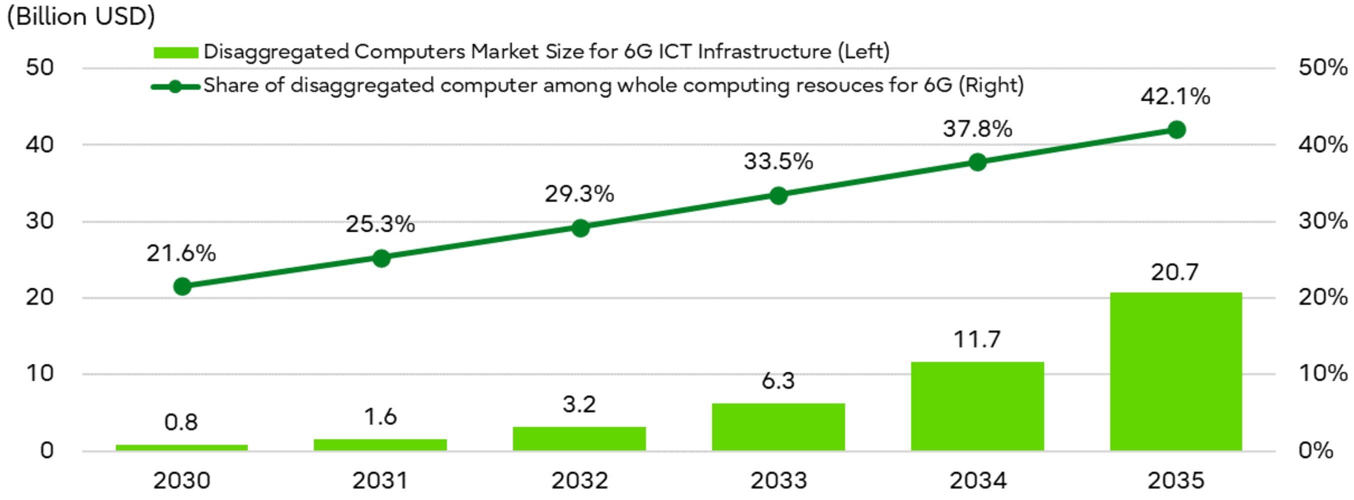


Figure A-1 Market size for disaggregated computers as ICT infrastructure for 6G from 2030 onwards

Disaggregated computing market size

Disaggregated computing is expected to be used not only for network applications such as traffic processing at base stations in the 6G infrastructure, but also as ICT infrastructure for cloud computer-based mass data storage and advanced data processing. Disaggregated computers are also expected to be used as computing resources to support the 5G infrastructure.

By around 2030, the Digitalized Future Society will be making maximal use of virtual and other technologies, permeating every aspect of our lives. This will increase the use of the edge cloud, without which the Digitalized Future Society cannot become a reality. This will act as the driving force behind the disaggregated computer market, which is forecast to expand at an annual rate of 27%, exceeding US$100 billion by 2035 (Figure A-2). One of the anticipated uses for disaggregated computing will be as a far-edge cloud placed in close proximity to devices. This is expected to account for nearly 30% of the total market size.

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[3] The figures quoted in this section are taken from "6G Market Sizing & Forecast," a study commissioned by Fujitsu and undertaken by American firm Harbor Research from September to November 2023.

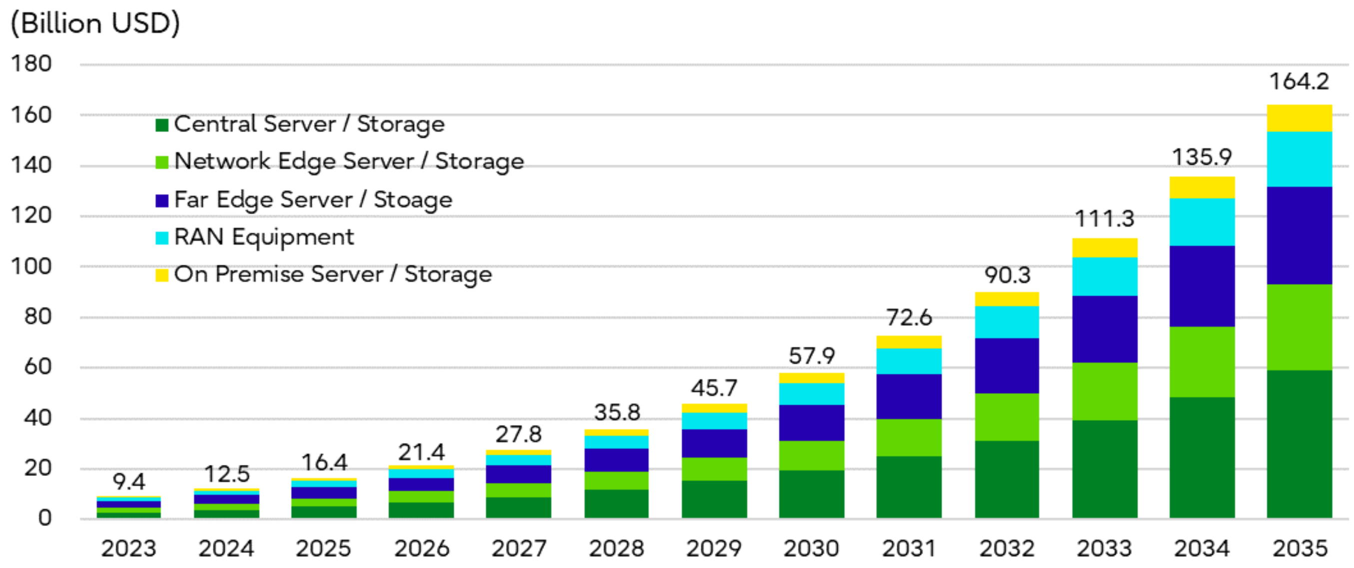

Figure A-2 Disaggregated computing market size

Table A-1 Disaggregated computing market size (Billion USD)

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Central Server / Storage	2.9	3.9	5.2	6.8	9.0	11.8	15.2	19.6	24.9	31.4	39.1	48.4	59.2
Network Edge Server / Storage	1.9	2.5	3.3	4.3	5.6	7.2	9.3	11.8	14.8	18.5	22.9	28.0	34.0
Far Edge Server / Storage	2.5	3.2	4.2	5.5	7.0	8.9	11.3	14.2	17.6	21.7	26.5	32.1	38.4
RAN Equipment	1.5	2.0	2.5	3.3	4.2	5.3	6.7	8.4	10.4	12.7	15.4	18.6	22.2
On Premise Server / Storage	0.7	0.9	1.2	1.6	2.0	2.5	3.2	4.0	4.9	6.0	7.3	8.8	10.5
Total	9.4	12.5	16.4	21.4	27.8	35.8	45.7	57.9	72.6	90.3	111.3	135.9	164.2

Notes:

- Central Server / Storage: Disaggregated computers used for large-scale data processing and storage, and for providing enterprise and consumer application services
- Near-edge Server / Storage: Disaggregated computers used for providing compute, storage, and network traffic functions and for optimizing transmission, bandwidth, and latency between the RAN and the core
- Far-edge Server / Storage: Disaggregated computers used as small, purpose-built edge ICT devices and as IoT sensing platforms for initial data analysis, conversion, and management
- RAN Equipment: Disaggregated computers that are responsible for the connection between devices and the core network, and perform policy and traffic management
- On-premise Server / Storage: Disaggregated computers used for initial data processing and storage directly connected to edge devices, user equipment, and other on-premise/edge systems

Acronyms

AI	Artificial Technology
CMOS	Complementary Metal Oxide Semiconductor
CNF	Containerized Network Function
CPU	Central Processing Unit
CU	Central Unit
D2D	Device to Device
DU	Distributed Unit
EMS	Element Management System
FPGA	Field Programmable Gate Array
GaAs	Gallium Arsenide
GaN	Gallium Nitride
GPU	Graphical Processing Unit
HEMT	High Electron Mobility Transistor
IAB	Integrated Access and Backhaul
ICT	Information and Communication Technology
InP	Indium Phosphide
IoT	Internet of Things
IT	Information Technology
LDMOS	Laterally Diffused Metal Oxide Semiconductor
MaaS	Mobility as a Service
NMS	Network Management System
NTN	Non-Terrestrial Network
PA	Power Amplifier
RAN	Radio Access Network
RIC	Radio Access Network Intelligent Controller
ROADM	Reconfigurable Optical Add/Drop Multiplexer
RU	Radio Unit
SDN	Software Defined Networking
SiC	Silicon Carbide
SMO	Service Management and Orchestration
VNF	Virtual Network Function
WAN	Wide Area Network
WDM	Wavelength Division Multiplexing

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A Note Concerning Future Projections, Forecasts and Plans

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