White Paper

Photonic Disaggregated Computing to Support ICT Infrastructure in the 6G Era

Introduction

The world is steadily advancing towards a digital future society where AI, IoT, CPS and other state-of-the-art technologies will be integrated into ICT systems to deliver high-quality experiences for users to enjoy anywhere, anytime. This digital future society will require high-performance, flexible ICT infrastructure to support rapidly evolving ICT services.

In the field of networking, technologies such as all-optical networks, high-frequency radio networks, and non-terrestrial networks (NTN) are attracting attention as technologies that will increase infrastructure performance in the future. In addition to software-defined technologies such as network virtualization, there are also technologies being developed to promote infrastructure flexibility, including disaggregation which involves decoupling and reassembling hardware components into functions.

Disaggregated computing is a technology that creates a pool of the component devices of a computer, then combines the necessary devices from the pool to function as a logical computer tailored to ICT service requirements. By extending this concept to the network level across sites, and integrating ICT devices distributed across a network, the entire network can be thought of as a single virtual computer.

The concept also requires optical transfer technology for high-speed, large-capacity data transfer between devices across sites, as well as infrastructure integration management technology for easy handling of diverse ICT infrastructures.

An infrastructure that uses high-speed optical transfer technology to implement network-wide disaggregated computing, namely, an end-to-end ICT infrastructure that is configured based on photonic disaggregated computing, offers a highly performant and flexible infrastructure that can then be used for delivering the myriad ICT services that will evolve in the future.

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1. Future ICT

The evolution of technologies as diverse as IoT, social media, and AI is changing the fabric of society. Connecting devices such as sensors, robots, and drones to a network has made agriculture and industry more efficient, while the growth and spread of social media that draws on images and video has diversified the ways people engage in entertainment. In particular, generative AI has been developing in leaps and bounds in recent years, not merely improving the performance and efficiency of services, but also stamping its mark on fields characteristically defined by human creativity. The future will doubtless see many different services supported by such state-of-the-art technologies. Mixing and matching these new services is also expected to produce a highly digitalized society, a “digital future society,” that will further enrich our lives.

For example, real-time, high-resolution video and data sharing will enable telehealth such as diagnostic and surgical support from remote locations, live music and esports that generate a ‘you are there’ sense of presence, and immersive education. In addition, digital twinning that replicates real-world scenarios, and advanced robot control including collaborative robot control, will make it possible to improve production efficiency and quality at factories and construction sites. Power optimization using renewable energy and wide-area power control, and IoT-based environmental monitoring of homes and roads will contribute to the implementation of smart cities and smart homes. Technologies like these that will make up the digital future society are being actively investigated through a range of forums and standardization bodies that have 6G and other next-generation ICT targets in their sights.

Implementing this “digital future society” will require the development firstly of services that utilize the latest technologies, and secondly, ICT infrastructure such as computers and networks to support these services. The ICT infrastructure will require more advanced functionality and greater performance including, for instance, storage for accumulating the vast amounts of data spread around the world, CPUs and GPUs for high-speed processing of that data, and networks for high-speed data collection and transmission.

Figure 1 Technology in the digital future society

2. Evolution of Systems

In recent years, cloud computing and virtualization have revolutionized computer systems and are now making rapid inroads in the networking space as well. Network devices such as base stations, switches, and routers were provided as hardware appliances, but are now provided as software functions that run on top of general-purpose computer hardware. Network virtualization has made networks very easy to use, often allowing new networks to be installed or new functions to be added or modified simply by changing the software. And this network software is now being deployed on datacenter clouds.

As servers and peripheral devices become more sophisticated, there is an increasing trend in datacenters to use optical technologies for the rack-to-rack and server-to-server interfaces that connect these devices. Servers that have traditionally been fixedly connected by metal cables via top-of-rack (ToR) switches are now increasingly being connected by optical cables, as well as by fiber optic network interface cards (NICs). This has dramatically improved data transfer speeds and increased overall datacenter efficiency.

However, network virtualization has also given rise to new challenges. For example, using software to process functions that were previously processed by hardware does not achieve the same performance as hardware-based processing and devices consume more power. In addition, some network functions require real-time processing with low latency, but software-based processing may not be able to satisfy these requirements. To address this issue, performance can be improved and latency reduced by using offload processing, which transfers some software functions to be processed by specialized hardware such as GPUs or FPGAs. This is also called "semi-dedicated" processing; it continues to use general-purpose hardware, with specialized processing programmed into the firmware installed in that hardware to provide dedicated functions that are application service-dependent.

Another challenge when it comes to network virtualization is the efficient use of equipment. With general computer hardware, for example servers, the maximum number of physical components and devices that make up the server, including CPUs, GPUs, and storage, and their processing performance are fixed for each server. Thus, for example, if the capacity of the GPU is too low, alternative measures such as adding more servers will be necessary, even though storage capacity is adequate. Hardware disaggregation has been adopted in recent years as an approach to address this problem. As a method for separating computer hardware into its component resources (devices), hardware disaggregation allows hardware to be added or removed on a resource-by-resource basis. By reassembling these disaggregated computer devices based on their utilization rate and throughput capacity, it is possible to deliver computer systems with higher utilization efficiency.

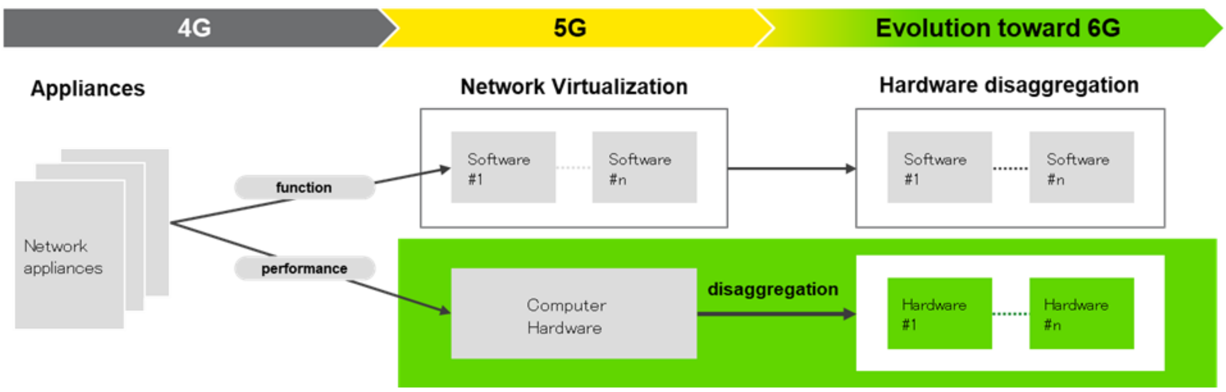

Figure 2 Evolution of network systems

3. Disaggregated Computing

Hardware disaggregation, discussed in the previous section, makes it possible to arbitrarily combine the different hardware components of a computer, device by device. This approach means that devices can be shared across one physical computer or across multiple computers. That is to say, the hardware devices necessary to implement a particular application service can be combined from multiple shared computers and regarded as one logical computer. Rather than physically adding or removing hardware, this logical computer can be scaled up or down through software. In other words, software can be used to dynamically add or remove devices according to the hardware usage needs of the application service.

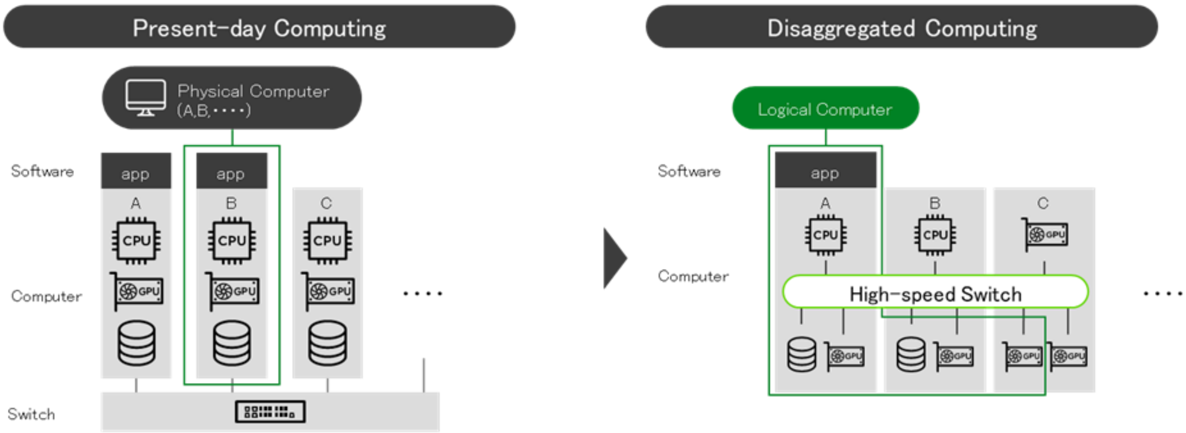

Figure 3 Disaggregated computer

ICT infrastructure configured according to this disaggregated computing approach can deliver highly flexible systems. For example, if an application is to be processed by the host CPU and its peripheral devices, and a specialized device, say, a GPU, lacks the necessary processing capacity, any available GPU mounted in the same chassis or neighboring chassis can be used as if it were a device directly connected to the CPU.

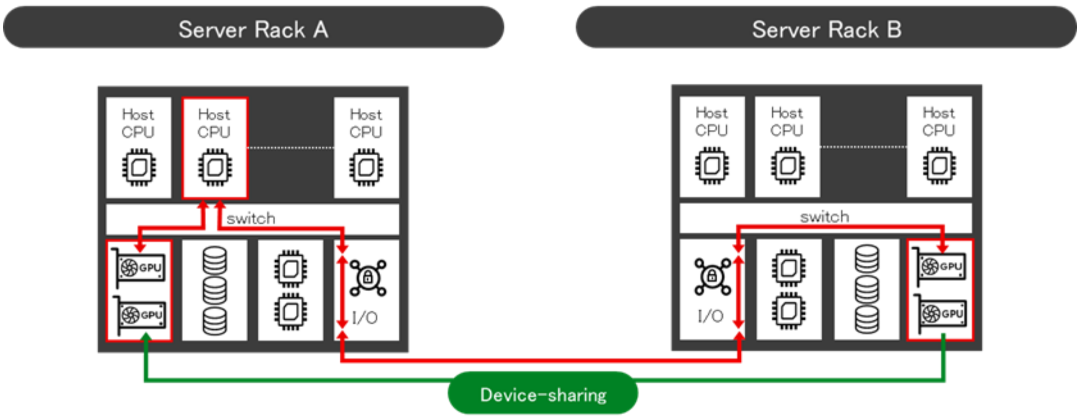

Figure 4 Device-sharing in a disaggregated computer

4. Photonic Disaggregated Computing

We are in an era where ICT infrastructure is found in diverse locations around the world, including on-premise and edge clouds in the field and at centralized cloud-based locations such as large-scale datacenters. In the digital future society, making efficient use of such ubiquitous ICT infrastructure will be critical to providing high-quality services at low cost. For example, if the number of users increases during service provision, this can lead to server and network congestion, thus preventing the delivery of high-quality services to users. In such cases, it is vital to maintain quality by taking steps such as reconfiguring the ICT system.

As mentioned above, disaggregated computing combines computer components at the device level to create a logical computer, making it a very suitable ICT infrastructure for providing flexible ICT systems. Moreover, this logical computer can be configured even more flexibly by combining devices not only from the same datacenter, but also from different datacenters. This requires low-latency, high-capacity connections between devices and between datacenters, which can be achieved by using optical interconnects across datacenters and device-to-device. This is called photonic disaggregated computing, whereby network-wide distributed devices are connected via optical interconnects and combined to form a single logical computer.

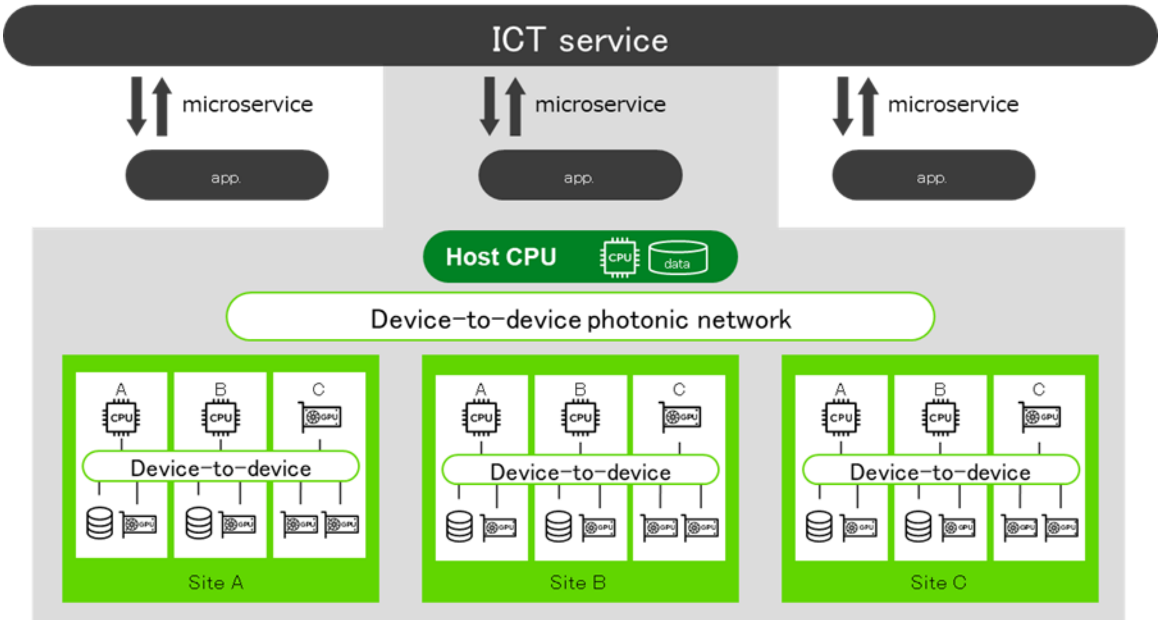

Figure 5 Photonic disaggregated computing

Photonic disaggregated computing enables a single logical computer to be configured at the network level, which could have the following advantageous effects on the ICT infrastructure:

- Improved efficiency of ICT infrastructure: Because devices such as CPUs and GPUs are combined from a single server, or from devices around a server, or from devices across datacenters to form a logical computer, the entire network becomes an extremely efficient infrastructure in terms of usability.
- Scalability: Devices required for implementing a particular system can be used across datacenters, resulting in an infrastructure that provides highly scalable systems, small to large.
- High-quality system: ICT infrastructure can be scaled up to provide users with a high-quality system, even when servers and networks become congested due to more users accessing the system and more traffic.

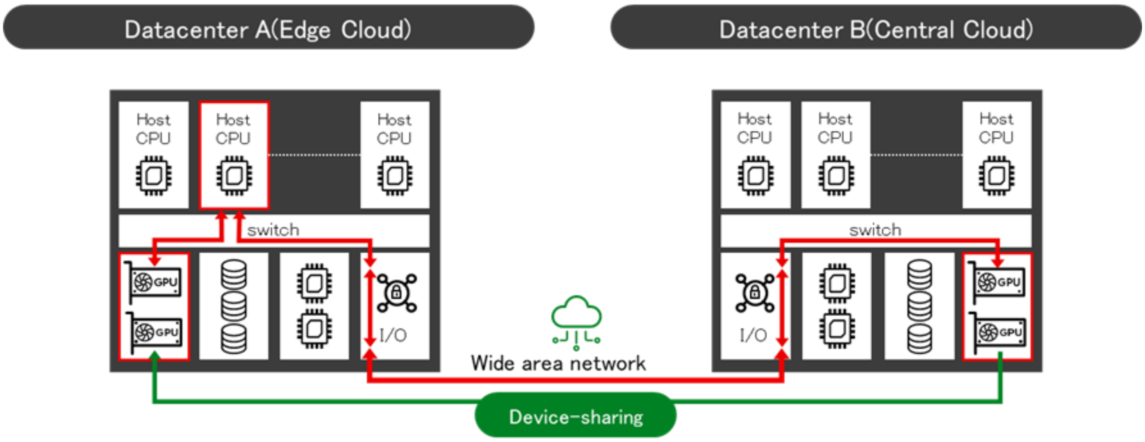

Figure 6 Sharing of devices across datacenters

Figure 7 illustrates an example of photonic disaggregated computing applied in a mobile system. In mobile systems, the frequency and volume of terminal accesses have different characteristics depending on the district or area. For example, in a central business district, access tends to be more frequent during the day when there are more subscribers, while in residential areas, access tends to be more frequent at night. IT infrastructure (e.g., edge clouds) with base stations serving business districts does not require as much mobile processing capacity at night as it does during the day. Devices used for mobile processing during the day can therefore be used for other purposes at night. Conversely, residential areas require less mobile processing capacity during the day, allowing some spare devices to be used for non-mobile purposes. In this way, the ICT infrastructure can be used efficiently by flexibly allocating devices according to the characteristics of the application service.

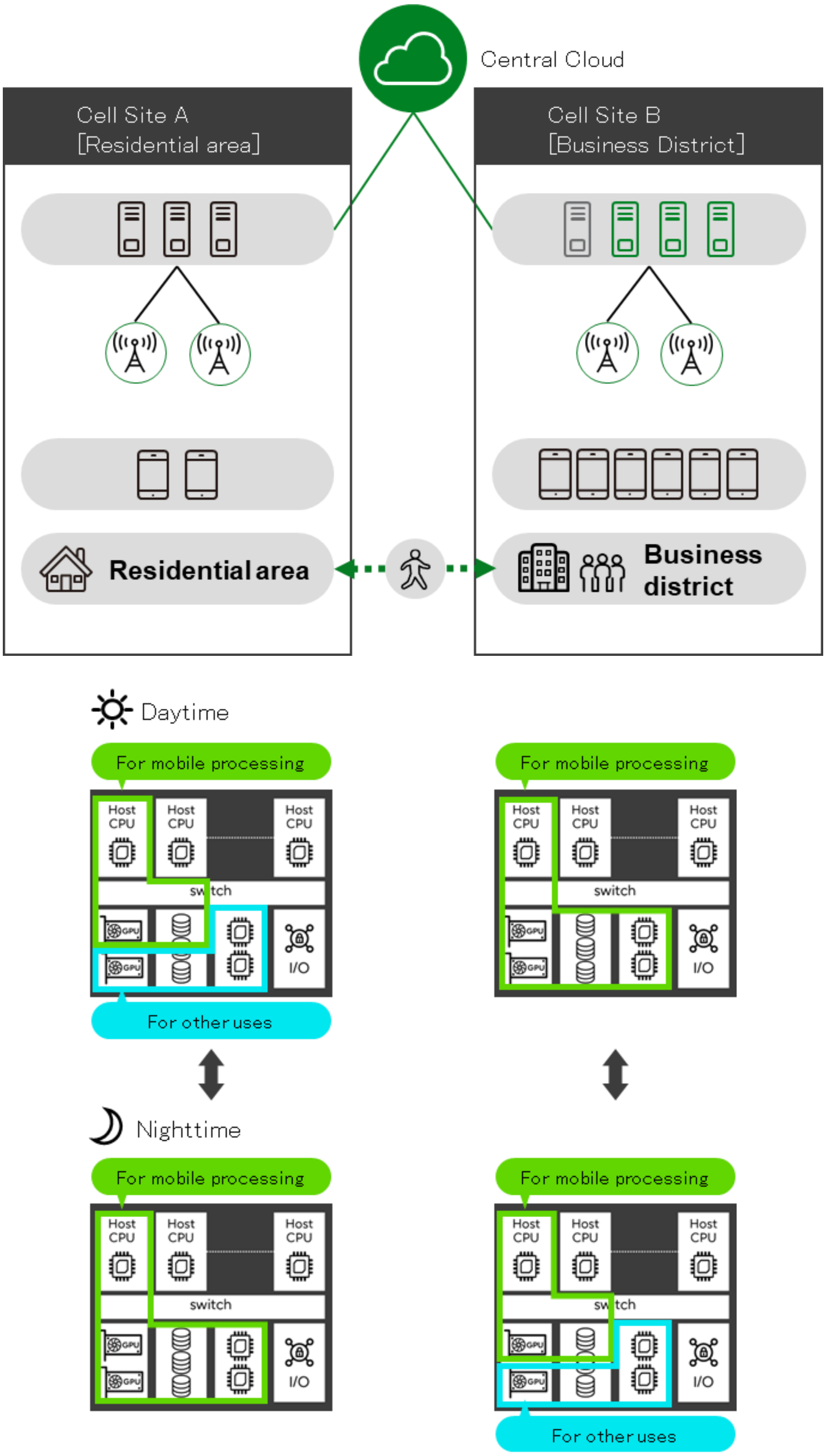

Figure 7 Application of photonic disaggregated computing in a mobile system

Photonic disaggregated computing can provide a very flexible ICT infrastructure, but achieving this requires configuration settings to be changed whenever necessary for individual components of an end-to-end ICT system (network functions, computers, etc.), to reflect environmental changes. It is also important for the ICT system to be autonomous in its control, that is, to detect changes in conditions and automatically change its configuration without human intervention. This calls for ICT infrastructure management to handle ICT devices at the network level and configure and manage the logical computer.

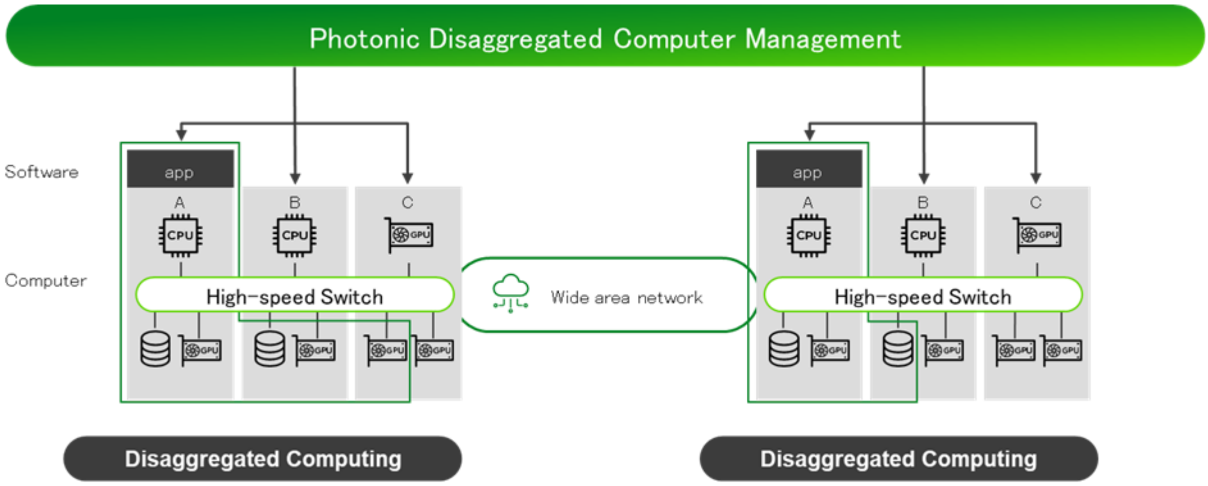

Figure 8 Photonic disaggregated computer management

5. ICT Infrastructure in the 6G Era

ICT infrastructure is provided by various different entities, including cloud providers, network operators, and individual companies. ICT service providers sometimes implement services on their own proprietary ICT infrastructure, and sometimes on the ICT infrastructure of other entities. In the latter case, the ICT service provider cum ICT infrastructure user will have to make 'end-to-end ICT infrastructure' available by combining the ICT infrastructures of various entities to the extent necessary for the relevant service.

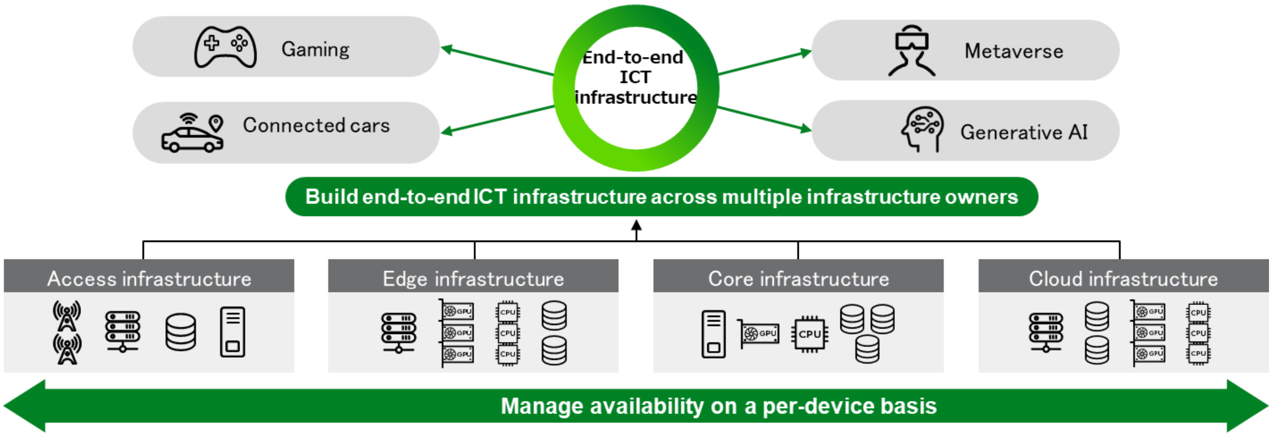

Figure 9 End-to-end ICT infrastructure

When using the ICT infrastructure of different entities, it is important that each ICT infrastructure be easy to use. For example, infrastructure users can configure infrastructure settings in the same way even if different infrastructure providers are involved, and can make settings without having to consciously think about the hardware of individual infrastructures. ICT infrastructure integration management is required to achieve this, providing integrated management across devices and service providers. ICT infrastructure integration management provides ICT infrastructure users with an abstract API that is agnostic to infrastructure providers and hardware devices, allowing users to configure their infrastructure in a uniform manner. The requisite end-to-end ICT infrastructure is also prepared and managed as 'virtual ICT infrastructure' on software for each of the ICT infrastructure user's services, with the requisite settings made to the ICT infrastructure. In addition, AI and other tools are used to predict how individual services will be impacted by changes in service requirements and infrastructure conditions, and how the ICT infrastructure should be adjusted. The results of simulations like this can be used to maintain the ICT infrastructure in an optimal state.

However, in order to implement ICT infrastructure integration management, the following issues need to be resolved:

- There needs to be integration between entities to provide hardware and software resources and quality as APIs, even for the systems of different entities;
- There needs to be collaboration between layers to centrally handle computing systems (servers, storage, intra-datacenter networks, etc.), wide-area networks (wireless access, core networks, etc.), and different systems and layers;
- Resource optimization and control need to be automated to ensure appropriate resource allocation through integrated monitoring of the usage of resources such as applications, CPUs, GPUs, memory, storage, and networks;
- There need to be functions to compatibly manage infrastructure newly added to the existing infrastructure already in operation.

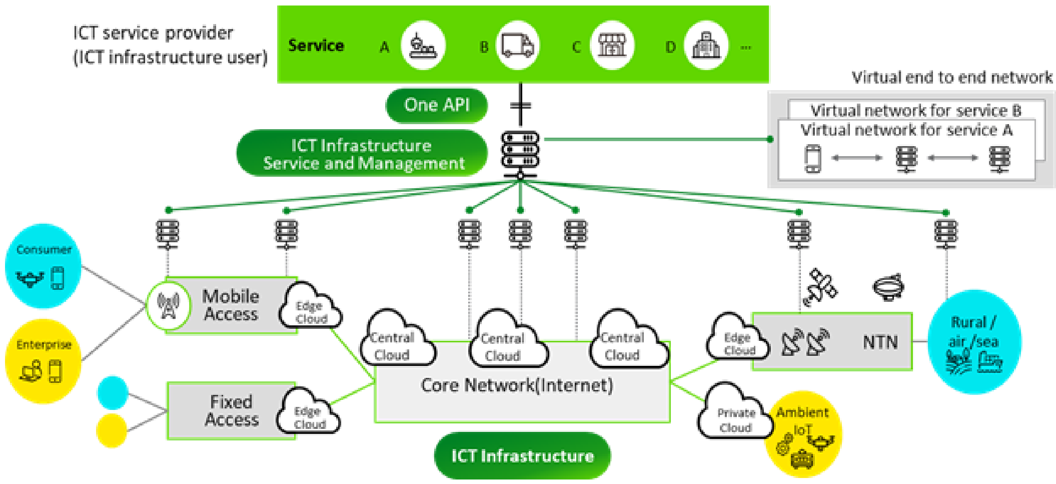

Figure 10 ICT infrastructure integration management

The ICT infrastructure consists of edge, central and other clouds, as well as core networks that connect clouds, and access networks that connect service users (e.g., smartphones and IoT devices) to clouds. Photonic disaggregated computing management, described in the previous chapter, changes the configuration settings for individual components of the end-to-end ICT system (network functions, computers, etc.) in response to changes in the environment. When this happens, the computer network settings and the settings of access networks with service users also need to be changed. ICT infrastructure integration management works in conjunction with photonic disaggregated computer management to provide the optimal ICT infrastructure for the service at the device level, across providers and devices.

In other words, an end-to-end ICT infrastructure consisting of photonic disaggregated computer-based cloud infrastructure, high-performance optical transmission between clouds, and network-wide infrastructure integration management will enable the implementation of a high-performance, low-cost, flexible infrastructure. This will facilitate the provision of the myriad ICT services that will evolve in the future.

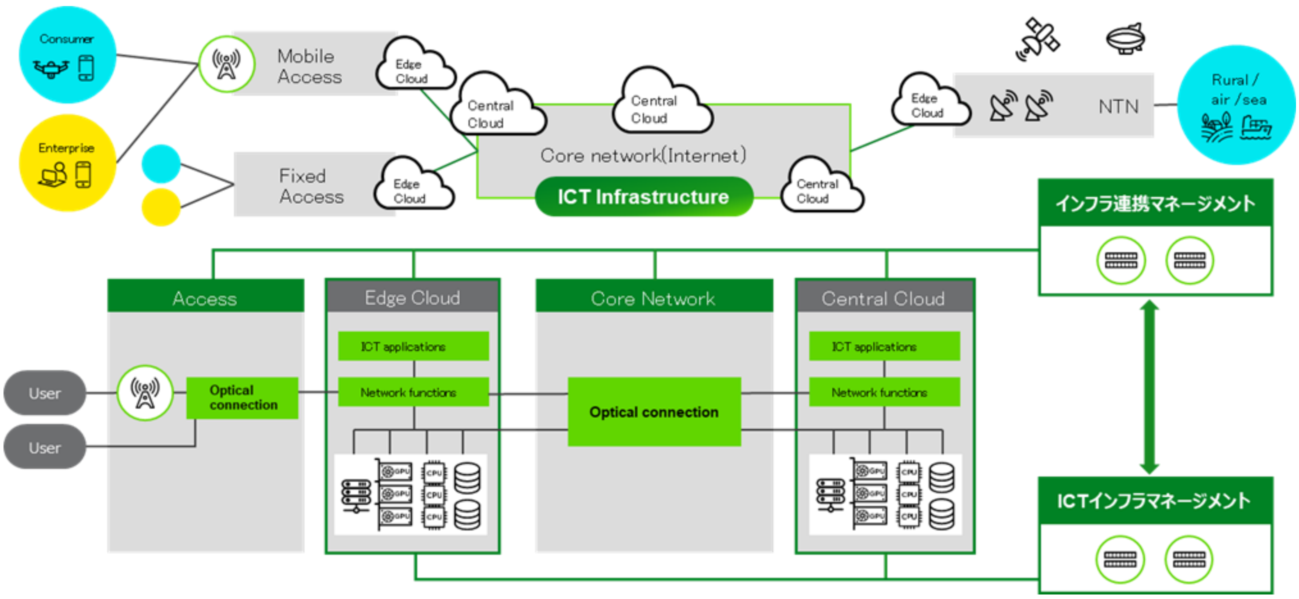

Figure 11 End-to-end ICT infrastructure based on photonic disaggregated computing

6. Summary

The development of the digital future society is underway, with AI, IoT, CPS and other cutting-edge technologies incorporated into systems to provide users with high-quality experiences anytime, anywhere. To flexibly support rapidly evolving ICT services, it will be important to build high-performance, low-cost ICT infrastructures by mixing and matching ubiquitous ICT infrastructures with ease. End-to-end ICT infrastructures consisting of photonic disaggregated computing and other technologies for sharing hardware devices across servers and datacenters, optical high-performance transmission between datacenters, and infrastructure integration management for managing this on a network-wide basis will play an important role in supporting the myriad ICT services that will evolve in the future.

Acronyms

AI	Artificial Intelligence
CPS	Cyber-Physical System
CPU	Central Processing Unit
FPGA	Field Programmable Gate Array
GPU	Graphical Processing Unit
ICT	Information and Communication Technology
IoT	Internet of Things
NIC	Network Interface Card
NTN	Non-Terrestrial Network
ToR	Top of Rack

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