Assessing Photoelectric Fusion Technologies:

Market Potential and Strategic Insights from NTT's IOWN Case

by

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Abstract

This thesis investigates the rapid evolution of technology in response to surging internet traffic, projected to increase from 33 zettabytes in 2018 to 175 zettabytes by 2025, and data processing demands, anticipated to exceed 180 zettabytes by the same year. The escalating requirements for more robust communication and data processing systems are emphasized, especially as AI advances necessitate substantial computational resources, increasing energy consumption. This highlights the challenges of enhancing performance while maintaining energy efficiency, suggesting the limits of Moore's Law and Dennard scaling. The thesis explores the adoption of silicon photonics as a significant innovation, shifting from electrical to optical signals, particularly within Nippon Telegraph and Telephone Public Corporation (NTT)'s Innovative Optical and Wireless Network (IOWN) initiative. It analyzes the strategic, operational, and market engagement approaches of NTT, focusing on competitive threats, potential collaborations, and strategies to foster third-party development. The conclusion underscores NTT's potential to transform telecommunications and data processing through photonics and AI technologies.

Keywords: Silicon Photonics, Photoelectric Fusion, NTT, IOWN, Optical Network, AI, 6G, IoT, Digital Transformation, Computing, Energy Consumption

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Chapter 1: Introduction

1-1. Background

Digital technology and Artificial Intelligence (AI) are set to play a crucial role in the evolution of our society for several reasons. Their importance is anchored in their ability to drive innovation, efficiency, and connectivity in virtually every aspect of our lives. For example, the digital economy is a major driver of economic growth. It opens up new markets, creates jobs, and fosters innovation. AI contributes by enabling the development of new products and services, optimizing supply chains, and improving market research, thus stimulating economic activity. Also, Digital and AI technologies offer tools to address wide-ranging social challenges, including poverty, inequality, and access to services. They can help in designing targeted interventions, improving service delivery, and ensuring that resources are allocated where they are most needed.

On the other hand, the burgeoning economic and social imperatives have catalyzed swift advancements in AI and digital technologies. Looking ahead, the evolution of our digital landscape will necessitate the development of advanced information processing and communication technologies capable of handling vast data volumes with unparalleled speed. However, this escalation in data processing capabilities is paralleled by a surge in energy consumption, potentially inflating operational costs for businesses. In addition, the global race to combat climate change is intensifying, with countries that have set decarbonization targets representing 90% of the world's GDP. There is a growing competition for investments in Europe, the U.S., and other nations that support Green Transformation (GX), a strategy that harmonizes emission reduction with economic growth.

This underscores the necessity for companies to vie for development opportunities while adhering to the energy emission regulations set forth by each country. Consequently, there is a pressing need for groundbreaking innovations that promise faster data processing capabilities while simultaneously reducing electricity usage compared to existing technological infrastructures. In this context, photoelectric fusion technology emerges as a particularly promising solution, drawing significant interest from the industry for its potential to revolutionize data processing efficiency and energy consumption.

1-2. Research Objective

This thesis examines the strategic implications and competitive dynamics of silicon photonics technology within the semiconductor and ICT industry. Silicon photonics integrates optical components such as waveguides, switches, modulators, and photodetectors onto a silicon substrate, offering a solution to the escalating demand for faster data processing amidst rising data volumes and energy costs. Specifically, the study focuses on NTT's implementation of silicon photonics in its Innovative Optical and Wireless Network IOWN initiative, which seeks to drastically enhance data transmission speeds and reduce energy consumption.

The objective is to analyze how NTT leverages this technology to maintain competitive advantage in an environment where rapid technological advancements and increased market entry are pervasive. Furthermore, the thesis explores the broader application of silicon photonics in areas such as semiconductor, Cloud, and AI, assessing the strategic positioning and business model impacts for the companies involved. Through this exploration, the research aims to identify and critique the strategic decisions and potential of silicon photonics in transforming communication and computing infrastructure from the IOWN perspectives.

1-3. Methodology

In this thesis, we will utilize publicly accessible company documents, scholarly articles, and datasets to delineate the contours of NTT's IOWN initiative, alongside market trends, competitors, and ancillary service providers. This comprehensive approach will facilitate the establishment of benchmarks and the assessment of current progress. Subsequently, leveraging this collated information, the competitive dynamics will be scrutinized through the lens of the PEST, Value Chain, Dependency Structure Matrix, investment performance, and Michael Porter's Five Forces Analysis from macro and micro evaluation perspectives. The strategic implications derived from this analytical exercise will be thoroughly examined.

1-4. Structure of the Thesis

In Chapter 1, the thesis begins by clarifying the background and objectives, setting the stage for the in-depth analysis that follows. Chapter 2 details the outline of NTT's IOWN initiative, focusing on its research and development targets, the roadmap for both research activities and commercialization, and the strategies being implemented. In Chapter 3, the thesis adopts Harvard Professor Francis J. Aguilar's perspective that external environments shape organizational contexts, conducting a macro-analysis on the political, economic, social, and technological factors surrounding ICT, AI, and semiconductors. Chapter 4 utilizes the Value Chain framework proposed by Harvard Business School Professor Michael E. Porter to evaluate how various activities in companies adapting silicon photonics in the ICT sector contribute quantitatively and qualitatively to final value, examining NTT's priorities within this field and using a Design Structure Matrix (DSM) to analyze potential value segments that might involve competitors or partners. Chapter 5 leverages Porter's Five Forces analysis to investigate aspects such as Return on Invested Capital (ROIC), Weighted Average Cost of Capital (WACC), and the competitive environment within the industry, including the power dynamics of buyers and suppliers, the threat of new entrants, and the threat of substitutes. Finally, Chapter 6 concludes the thesis by reviewing NTT's strategic direction based on the analyses conducted in the preceding chapters.

Chapter 2: Introduction to the IOWN Initiative

2-1. IONW Concept

The IOWN concept is designed to revolutionize how information is shared and processed across society. By distributing and processing vast amounts of data in real time, IOWN aims to facilitate the sharing of diverse perspectives and experiences in a fair and non-discriminatory manner. This enhanced connectivity is expected to foster social behaviors rooted in empathy and understanding, thereby enriching the relationships between individuals and between individuals and society. This connectivity upgrade, in turn, may influence and elevate personal values. Also, central to the IOWN concept is the capacity for future prediction. This entails leveraging the established network of communication entities to generate new value through predictive insights. Unlike the relatively simple predictions possible with current technology, the IOWN framework aims to achieve predictions that are significantly more accurate and faster. This predictive ability could profoundly change how to approach the future, enabling proactive responses to anticipated challenges and opportunities.

2-2. Implementation Method

NTT's IOWN initiative represents a visionary transformation in communication and computing technologies aimed at creating a smarter world. This initiative envisions a shift from current electronic-based systems to an innovative infrastructure based predominantly on optical technologies, which will drastically increase speed, capacity, and energy efficiency across global networks. According to the NTT IOWN Technology Report (2023), the system comprises three key components (Fig. 2.1): the "All-Photonics Network," which integrates photonics-based technology across everything from networks to terminals; "Digital Twin Computing," which enables future predictions by merging the real and digital worlds; and the "Cognitive Foundation," which facilitates seamless connectivity and control over all elements. The details are as follows;

“All-Photonics Network (APN): The All-Photonics Network (APN) is a core component of the IOWN initiative, focusing on transforming the fundamental nature of data transmission infrastructures. By replacing electronic components with optical ones, APN aims to achieve significantly lower power consumption and higher data transmission capacities. This shift involves deploying new photonic devices, circuits, and system architectures that integrate lasers, detectors, modulators, and other optical components directly onto silicon platforms. These advancements will facilitate data transfers at speeds several orders of magnitude faster than current capabilities, with experimental setups demonstrating terabit-per-second transfer rates over dense wavelength division multiplexing (DWDM) systems."

"Digital Twin Computing (DTC): Digital Twin Computing (DTC) extends beyond mere replication of physical objects into the digital realm; it enables real-time synchronization between the physical and digital worlds, enhancing decision-making and process optimization. DTC utilizes high-speed data analytics and machine learning algorithms to process and interpret vast amounts of data generated by sensors and IoT devices. This enables dynamic modeling that can predict outcomes, optimize performance, and implement preventive measures in industrial and urban applications. An essential part of DTC is the development of scalable virtual environments that can simulate complex physical systems and predict the impact of various scenarios in a controlled and safe manner."

"Cognitive Foundation (CF): The Cognitive Foundation orchestrates and harmonizes a diverse array of ICT resources, including data centers, cloud services, and network infrastructure. It employs a multi-orchestrator framework to manage these resources effectively, utilizing AI to make real-time adjustments and optimizations. This layer of the IOWN framework ensures that resources are allocated efficiently, balancing load dynamically and anticipating future demands based on predictive analytics. The Cognitive Foundation is critical in managing the increased complexity and scale of network functions virtualization (NFV) and software-defined networking (SDN), which are integral to modern ICT systems."

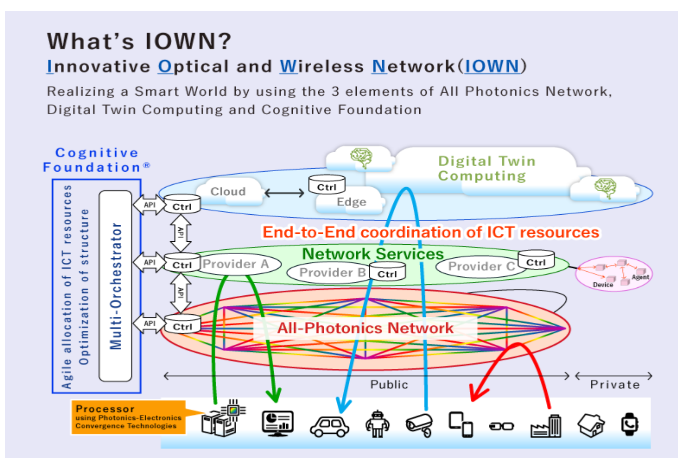

Fig. 2.1 Functional configuration image of the IOWN concept.

From NTT R&D Web Site: https://www.rd.ntt/e/iown/0001.html

2-3. R&D Roadmap

This initiative is centered around enhancing data communication capabilities by developing high-speed communication methods for Layers 4 and 3 of the ISO OSI reference model (Fig. 2.2) . Specifically, by 2021, advancements were targeted at reducing packet propagation delays and significantly shortening large data transfer times compared to traditional TCP/IP methods. Furthermore, the roadmap includes increasing the capacity of optical and wireless access by 2023 to support the growing volume of communications.

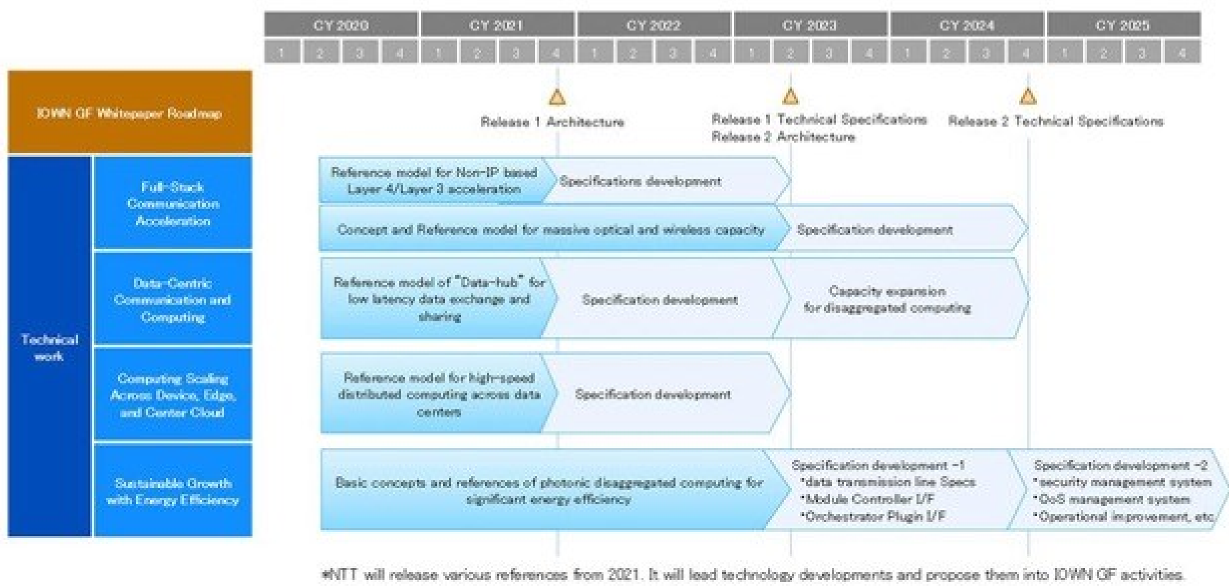

Fig. 2.2 IOWN a technology development roadmap: Technology development roadmap for realizing the IOWN concept (n.d.). From NTT R&D Web Site: https://www.rd.ntt/e/iown/0005.html

The cognitive foundation data hub, part of the IOWN's data-centric ICT infrastructure, was developed to facilitate efficient and low-latency data exchange and sharing among a widespread network of sensor nodes and AI analysis nodes. This infrastructure aims to break away from traditional IP-based systems, enabling a variety of communication methods, including non-IP, and accelerating the transition to a data-centric architecture where multiple systems are interconnected seamlessly (Fig. 2.3).

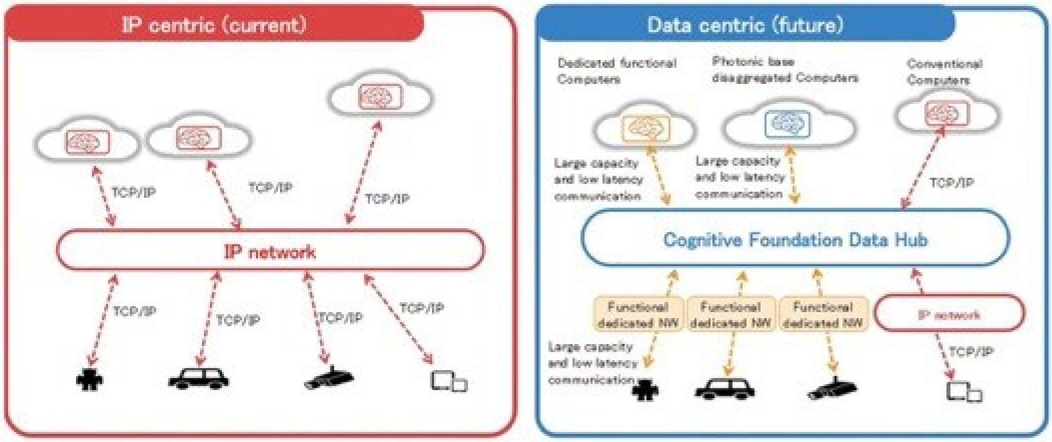

Fig. 2.3 CF Data Hub and Data-Centric.

From NTT R&D Web Site: https://www.rd.ntt/e/iown/0005.html

Another critical aspect of the IOWN concept is photonic disaggregated computing, which represents a paradigm shift from traditional server-based computing infrastructures to a server-less architecture based on photonic data transmission paths (Fig. 2.4). This new architecture, planned for realization by 2023, allows for dynamic coupling of computing modules such as memory and AI processing devices, connected through a high-capacity, high-speed photonic network. This setup facilitates flexible computing infrastructure that can dynamically adapt to computing demands and significantly enhance performance. Leveraging NTT's photonics-electronics convergence technology, the transition from electronic to photonic data transmission within modules, and between packages and chips, is expected to dramatically improve energy efficiency.

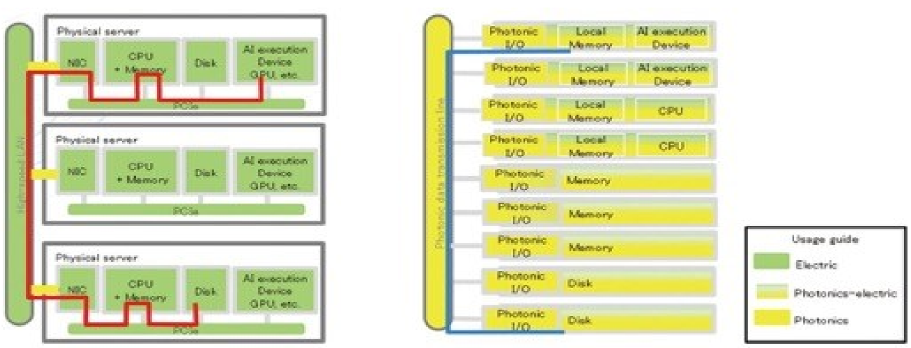

Fig. 2.4 Photonic disaggregated computing.

2-4. R&D Directions

The core of the direction of IOWN innovation is the convergence of photonic and electronic technologies, which is transforming the landscape of network infrastructure. Photonic networks that integrate time division multiplexing (TDM) and wavelength division multiplexing (WDM) with electronic systems are now capable of supporting over 100 Gbit/s per wavelength. Innovations in digital coherent technology and the development of high-performance digital signal processing (DSP) integrated circuits are crucial for enhancing communication over thousands of kilometers without significant loss of signal integrity (Fig. 2.5).

Significant research and development efforts are being directed at enhancing the performance and reducing the size, cost, and power consumption of network devices through silicon photonics. This technology merges electronic circuits with optical components on a silicon chip, leading to the development of ultra-compact, highly functional systems. Furthermore, advancements in device-level integration and the digital mock-up of hardware systems are enabling more efficient design processes that minimize cost and maximize performance.

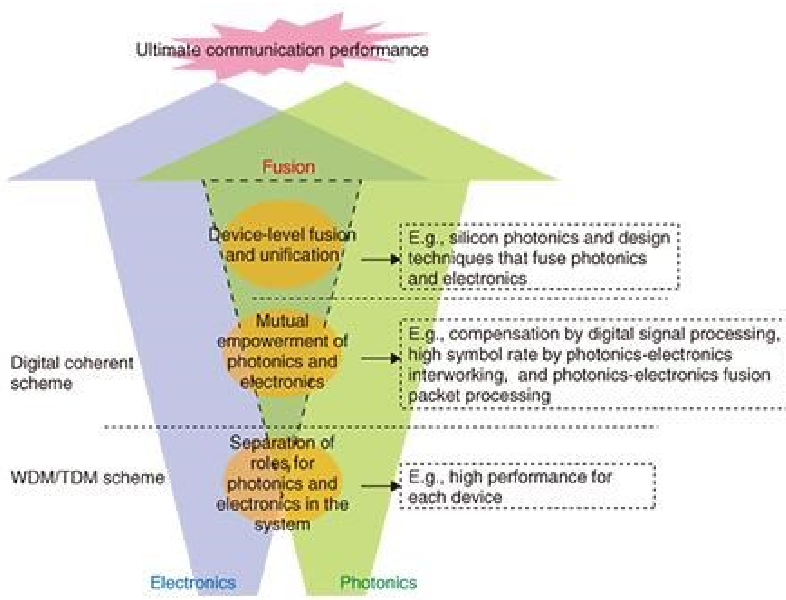

Fig.2.5. Fusion of photonic and electronic technology: NTT Technical Review, Jan. 2016, pp. 2

2-5. IOWN Commercialization Roadmap

The commercialization roadmap for the IOWN initiative spans several development phases extending beyond 2030 (Fig 2.6.). Starting in fiscal 2023, the roadmap includes the launch of compact, low-power network devices capable of 400 Gbit/s, progressing to 800 Gbit/s by 2025. This miniaturization aids in reducing the size and power consumption of network equipment, such as transmission devices. By 2025, the roadmap anticipates the commercialization of devices facilitating optical connections between boards and external interfaces, transitioning into computing applications. Subsequent phases focus on the integration of optoelectronic fusion technology, to achieve chip-to-chip connections by 2029 and intra-chip optical connections by 2030.

These advancements aim to significantly enhance power efficiency, targeting a 13-fold increase in APN services and an 8-fold increase in server efficiency by 2025, with a 125-fold increase in capacity by 2029. Ultimately, by 2030, IOWN 4.0 seeks to achieve a 100-fold improvement in overall power efficiency, a 125-fold increase in capacity, and a reduction in latency to one two-hundredth of current levels (Fig. 2.7).

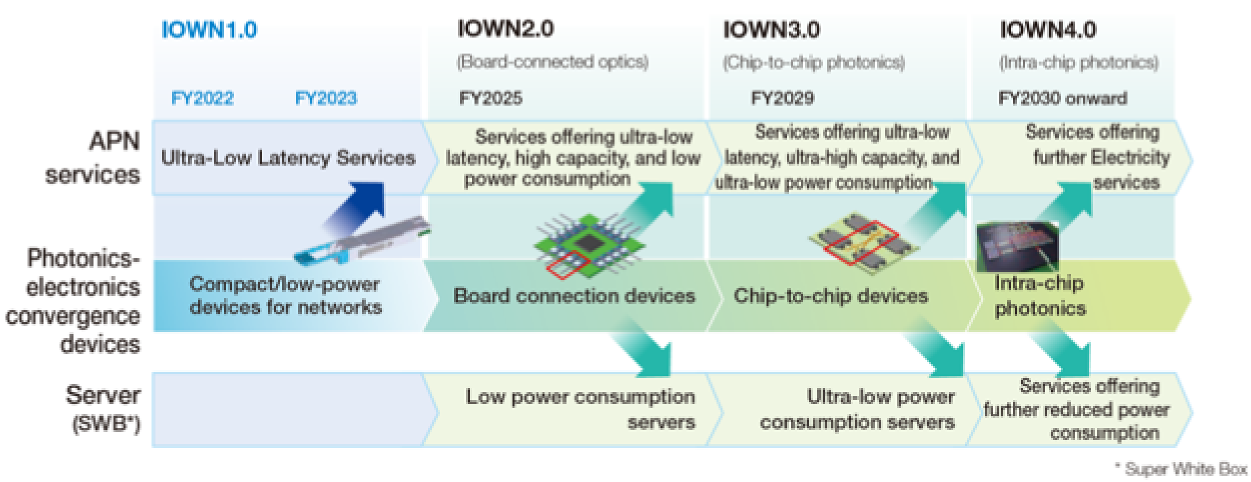

Fig. 2.6. Future Developments of Photonics-Electronics Convergence Devices: Innovative Optical and Wireless. From NTT R&D Web Site: https://group.ntt/en/csr/group/iown.html

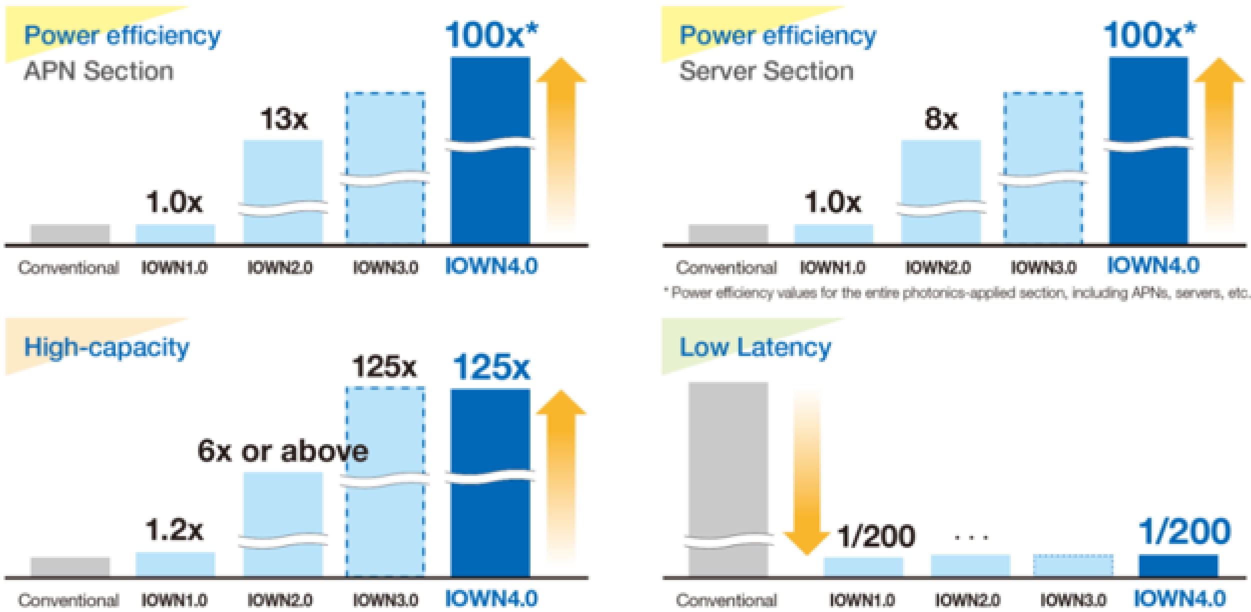

Fig. 2.7. IOWN Performance Targets: Innovative Optical and Wireless Network.

From NTT R&D Web Site: https://group.ntt/en/csr/group/iown.html

2-6. Global Open Innovation

To foster these advancements, NTT, along with Intel Corporation and Sony Corporation, established the IOWN Global Forum in January 2020. This international non-profit organization is dedicated to developing innovative technological frameworks, technical specifications, and reference architectures to advance new communication infrastructures under the IOWN initiative.

The Forum's efforts are not just limited to technological considerations but also encompass examining use cases to depict and materialize a smarter world more concretely. The Forum operates through two working groups: the Use Case Working Group, which solidifies applications aligned with the smart world vision and estimates potential business impacts and technical requirements; and the Technology Working Group, which discusses technical solutions including reference architectures, protocols, interfaces, and specifications. These groups work collaboratively to propel the IOWN vision toward realization (Fig. 2.8).

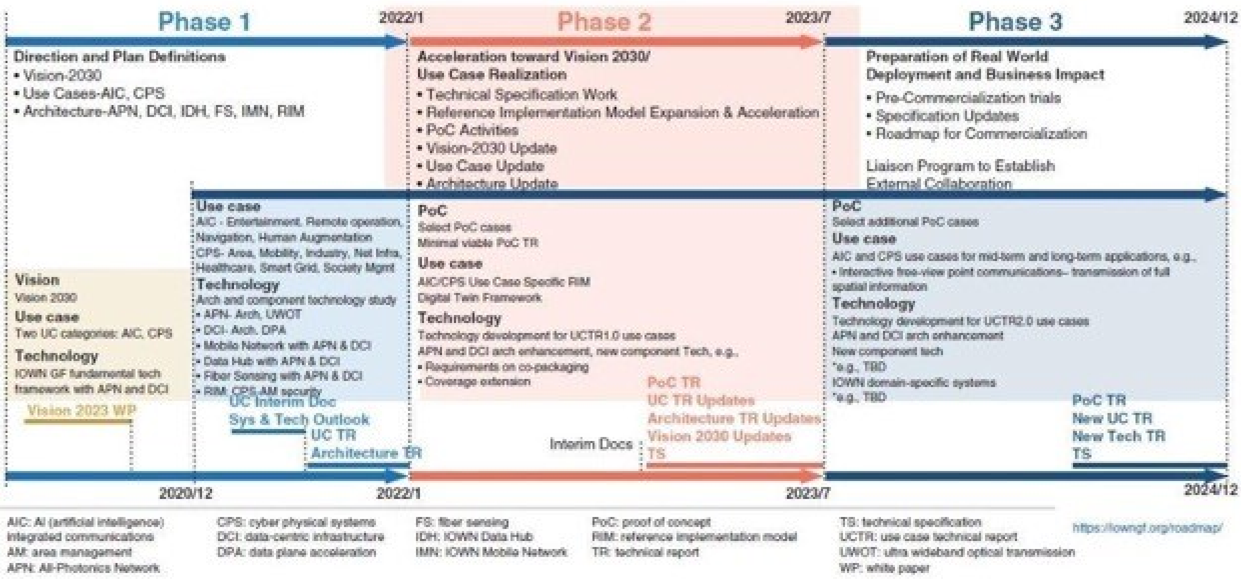

Fig. 2.8. IOWN Global Forum Vision 2030 Roadmap: Latest Activities in the IOWN Global Forum.

From NTT R&D Web Site: https://group.ntt/en/csr/group/iown.html

Chapter3: PEST Analysis

Political, economic, socio-cultural, and technological (PEST) analysis, originally coined as economic, technical, political, and social factors (ETPS) by Harvard professor Francis J. Aguilar, represents a significant development in the systematic evaluation of external business environments. In his seminal 1967 work "Scanning the Business Environment," Aguilar introduced the framework emphasizing the Economic, Technical, Political, and Social dimensions as fundamental determinants shaping organizational contexts (Aguilar, 1967). This conceptualization has been pivotal in understanding how these dimensions interact to influence strategic decision-making processes in business.

3-1. Political Assessments

Some examine the complex interplay between firms' research and development (R&D) activities and regulatory policies, particularly environmental regulations, and their impact on innovation. Historically, the literature has predominantly focused on the constraints these regulations impose on firms, often hypothesizing that such constraints increase operational costs and reduce competitiveness. Notably, seminal works by Porter (1991) and Porter and van der Linde (1995) challenge this perspective, proposing that well-designed environmental regulations can stimulate innovations that not only offset the increased costs but also enhance the international competitiveness of firms within regulated environments.

Porter's hypothesis, suggesting that stringent but appropriately structured regulations can serve as a catalyst for innovation—termed "innovation offsets"—has spurred further quantitative research. Studies such as those by Jaffe and Palmer (1997) utilized panel data from U.S. manufacturing sectors to show a direct correlation between environmental regulations and increased R&D spending. Similarly, Bunnermeier and Cohen (2003) demonstrated that increased pollution abatement expenditures positively correlate with greater environmental innovation, while enhanced regulatory enforcement alone does not boost innovation, and industries facing international competition are more likely to innovate, driven by global market pressures to adopt cleaner technologies.

Environmental Regulations as Risks and Opportunities

Environmental regulations have evolved significantly from broadly addressing pollution to now focusing on reducing CO2 emissions. Modern companies are particularly targeted to lower emissions by minimizing electricity use both in production processes and during product operation. According to the Ministry of Foreign Affairs of Japan (2022), under the Paris Agreement, which was adopted in December 2015 and entered into force in November 2016, all signatory nations are required to submit and regularly update their greenhouse gas emission reduction targets every five years, known as "nationally determined contributions" (NDCs), as stipulated in Article 4.2 and the COP21 decision (Table 3.1).

Before the Paris Agreement, COP19 in Warsaw mandated that countries prepare an "intended nationally determined contribution" (INDC) for their post-2020 targets well ahead of COP21. Many submitted their INDCs in 2015, which transitioned to NDCs upon the agreement's finalization. Furthermore, during the U.S.-hosted Climate Summit on April 22, 2021, held virtually, several countries presented ambitious targets aligned with achieving carbon neutrality by 2050—a commitment shared by 125 countries and one region, representing 37.7% of global CO2 emissions. Additionally, China, which accounts for 28.2% of the world's CO2 emissions, pledged at the 2020 UN General Assembly to reach carbon neutrality by 2060.

Table 3.1.

2030 emission reduction targets by country

Country, region	Aims of 2030	Net zero in 2050
Japan	▲46% (compared to FY2013) (We will continue to take on the challenge of reaching 50%)	declared
Argentina	Annual emission limit set at 359 million tons	declared
Australia	▲43% (compared to 2005)	declared
Brazil	▲50% (compared to 2005)	declared
Canada	▲40 ~ ▲45% (compared to 2005)	declared
China	(1) Aim to peak CO2 emissions before 2030 (2) Reduce CO2 emissions per GDP by 65% or more (compared to 2005)	net zero CO2 emissions by 2060
France, Germany, Italy, EU	▲55% or more (compared to 1990)	declared
India	▲45% reduction in emissions per GDP (compared to 2005)	net zero in 2070
Indonesia	▲31.89% (BAU ratio) (unconditional) ▲43.2% (BAU ratio) (conditional payment)	net zero in 2060
South Korea	▲40% (compared to 2018)	declared
Mexico	▲22% (BAU ratio) (unconditional) ▲36% (BAU ratio) (conditional payment)	declared
Russia	70% (▲30%) of 1990 emissions	net zero in 2060
Saudi Arabia	278 million tons reduction (compared to 2019)	net zero in 2060
South Africa	350-420 million tons of emissions from 2026 to 2030	declared
Turkey	Max ▲21% (BAU ratio)	no decrlared
U.K.	More than ▲68% (compared to 1990)	declared
U.S.	▲50~▲52% (compared to 2005)	declared

Note: Data from the Ministry of Foreign Affairs of Japan: https://www.mofa.go.jp/mofaj/ic/ch/page1w_000121.html

These stringent regulations could impose significant costs on industries to modify existing manufacturing processes. However, they also offer an opportunity for companies that proactively adapt to gain a competitive advantage in the global market. Japan exemplifies this through its development of advanced environmental and energy-saving technologies following the oil crisis and stricter pollution regulations (Cabinet Office of Japan, 2022).

Notably, Japan's 1978 Emission Regulations, akin to the U.S. Muskie Act of 1970, set some of the toughest standards for automobile emissions at the time. Despite industry opposition citing potential harm to international competitiveness, public support for emission control pushed the regulations forward. These regulations prompted technological advancements that not only met but exceeded standards, propelling Japanese automobiles to the forefront of environmental friendliness during the 1970s. Similarly, as discussed in the following section on Technology Assessments, while the operation of the data center leads to increased power consumption due to the expanding volume of data processing, today's companies can leverage stringent environmental regulations as a catalyst for innovation and market leadership, mirroring the automobile industry's experience from decades earlier.

International Trade & Innovation

Export trade restrictions on advanced technology can also have a significant impact on industries with large supply chains, as well as on corporate research and development (R&D) and business development. In examining the impact of export trade restrictions on advanced technologies, several key aspects emerge from the academic literature.

Dunning (2000) identifies a significant trend in the global economy over the past two decades starting from 1970: the growing importance of all forms of intellectual capital in corporate activities. Within this context, he highlights two key phenomena to illustrate the globalization of firms: 1) the increasing share of R&D expenditures by foreign subsidiaries of multinational enterprises (MNEs), and 2) the rapid expansion of these expenditures compared to those made by local firms in foreign countries.

Additionally, many scholars have noted the relatively fast pace at which MNEs' foreign subsidiaries are increasing their R&D spending. For instance, Gassmann and Zedtwitz (199) observe that from 1985 to 1993, U.S. companies expanded their overseas R&D investments three times faster than their domestic R&D investments. They also confirm a rapid increase in R&D investments by foreign-owned subsidiaries within the U.S. during the same period.

Furthermore, Akcigit et al. (2018) utilize a dynamic general equilibrium growth model to show that although tariffs may offer short-term welfare benefits, R&D subsidies prove more effective for sustaining long-term competitiveness and welfare in a globalized economy, advocating for a strategic mix of lower tariffs and aggressive R&D subsidies to optimize policy in competitive international markets. Ernst (2014) in "Trade and Innovation in Global Networks—Regional Policy Implications" explores how integration into global production and innovation networks can both enhance and erode regional innovation capacities, emphasizing the necessity for proactive policy strategies that foster beneficial two-way interactions and address the complex impacts of globalization on regional economic structures and innovation strategies.

Coelli, et al. (2022) analyze the effects of the 1990s trade liberalization on innovation, showing that tariff reductions significantly increased firm-level innovation across 65 countries, without compromising patent quality, thus underscoring the dynamic benefits of trade policies in fostering economic growth and innovation.

Vulnerabilities in the Semiconductor Global Supply Chain System

The technological elements involved in IOWN span a wide range of products from semiconductors and computers to telecommunications, cloud services, automobiles, PCs, and smartphones. These products are developed through international collaboration in R&D and manufacturing, especially for semiconductors, meaning that these sectors have a risk of international trade vulnerability.

Qualcomm & Accenture (2022) released a report titled "Harnessing the Power of the Global Semiconductor Value Chain," which assesses the impacts of the COVID-19 pandemic, natural disasters, and disruptions in energy supply on the semiconductor industry. The thesis of the report argues that a thorough understanding of these disruptions is crucial for mitigating current and future semiconductor shortages by examining the state of the global semiconductor supply chain.

The analysis highlights that the semiconductor industry has become a deeply interconnected network of global partnerships essential for the production of a single semiconductor chip, underscoring its nature as a globally interdependent supply chain (Fig. 3.1). The report posits that no single country or company can achieve complete autonomy in semiconductor production in the foreseeable future due to the intricate and collaborative nature of the industry. The development of the fabless/foundry model, which allows companies to outsource labor-intensive manufacturing, exemplifies the necessity for cooperation among thousands of global suppliers.

Furthermore, the report explores how multinationals operating within these delicate and complex value chains face business continuity risks stemming from geopolitical tensions that can lead to trade restrictions.

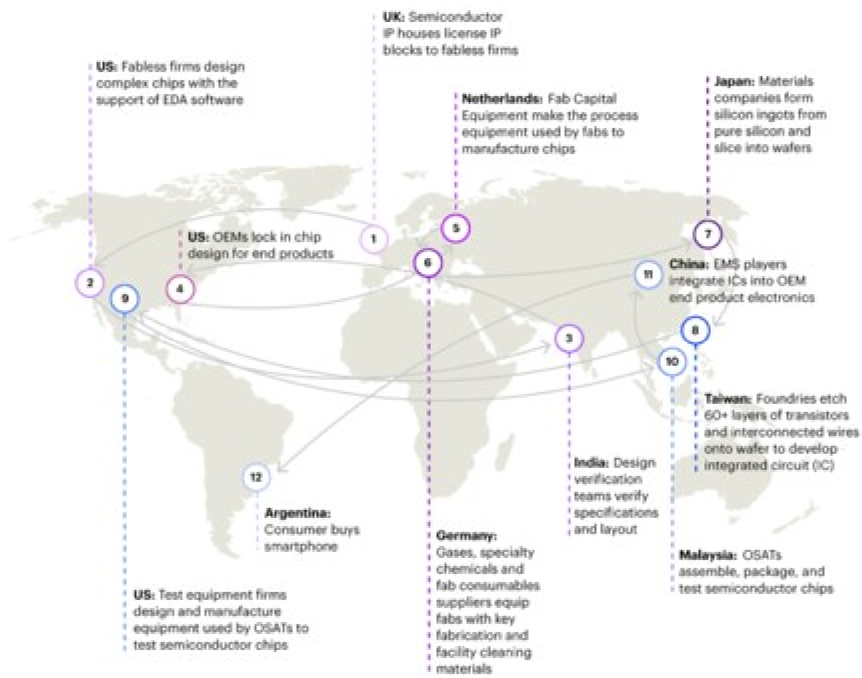

Fig. 3-1. Illustrative flows within the global semiconductor value chain. From Qualcomm Web Site: https://www.qualcomm.com/news/onq/2022/02/how-harness-power-semiconductor-value-chain

Tension in U.S.-China relations

This dynamic has become particularly pronounced with the rise of emerging technologies such as AI and quantum computing, which are heavily reliant on semiconductors. Trade policies and industrial strategies concerning semiconductors are now closely tied to national security considerations.

For instance, a report (CNN, 2023) references how semiconductor shortages, influenced by Western economic sanctions and third-country procurements, have impacted Russia's military capabilities in the ongoing conflict in Ukraine. Others (Shivakumar, S., & Wessner, C., 2022) also discuss the broader strategic importance of semiconductor technology, particularly in military contexts where AI's ability to process vast amounts of data supports critical decision-making in combat scenarios. It warns that if the U.S. does not expedite the integration of AI into its military strategies, it risks losing its technological edge to other nations within the next decade.

For manufacturers and operators of semiconductors, communication equipment, and computer devices, a primary concern is the competition in advanced technology development between the U.S. and China, along with the accompanying trade restrictions. These factors necessitate significant decisions regarding the research and development, production, and distribution routes for multinational corporations.

The “Made in China 2025” (State Council of the People's Republic of China, 2015) outlines a comprehensive strategic blueprint aimed at elevating the nation's manufacturing sector to a dominant global position by the year 2025. This policy delineates nine strategic missions, including enhancing the innovation capacity of the manufacturing industry, integrating information technology and industrialization, strengthening fundamental industrial capabilities, and promoting brand quality. It also emphasizes the importance of green manufacturing, breakthroughs in key areas, structural adjustments to the manufacturing sector, the development of service-oriented manufacturing, and increasing the internationalization of manufacturing. The policy prioritizes "improving innovation capacity" as a fundamental theme.

Under this priority, schemes like "national technology innovation demonstration enterprises" and "enterprise technology centers" are implemented to bolster innovation with incentives such as duty-free imports for R&D machinery and eligibility for national research projects. Additionally, the government plans to establish numerous "manufacturing innovation centers" that focus on ubiquitous technologies such as IT, AI in manufacturing, and new materials. These centers are envisioned as hubs for technological development, industrialization, and human resource development. Internationally, the strategy has raised significant concerns.

On the other hand, in a 2018 speech at the Hudson Institute, U.S. Vice President Pence critiqued "China Made in China 2025" as an attempt by China to control a major share of the world's advanced industries, viewing it as a direct challenge to U.S. economic supremacy (The Hudson Institute, 2018). According to the Australian Strategic Policy Institute, China leads the world in seven out of ten categories within the "Artificial Intelligence, Computing, and Communications" sector. These categories include AI algorithms and hardware accelerators, as well as advanced high-frequency communications technologies such as 5G. In these areas, China has surpassed the U.S., which leads in the remaining three categories (ASPI's Critical Technology Tracker, 2023). It is natural for the U.S. to feel threatened by China's advancements in cutting-edge technologies, including artificial intelligence.

However, the U.S. itself relies on Taiwan for the manufacture of chips using 5nm to 7nm processes essential for AI systems and also depends on Taiwan, China, and Singapore for the backend processes of semiconductor assembly, testing, and packaging (OSAT). This offshoring of critical semiconductor manufacturing processes introduces security risks, including the potential infiltration of counterfeit devices and vulnerabilities to disruptions in distant supply chains caused by natural disasters or geopolitical conflicts.

Over the past two years, the U.S. has implemented two significant measures. The first was the strengthening of semiconductor export controls to China in October 2022. This involved revisions to the Export Administration Regulations (EAR), targeting high-performance computing (HPC) semiconductors with computational capabilities of 4800 TOPS and memory bandwidths exceeding 600 gigabytes per second, their design software, computers equipped with these HPC semiconductors, and semiconductor manufacturing equipment (Anderson Mōri & Tomotsune, 2023).

In October 2023, the scope of controlled manufacturing equipment was further expanded. These actions have hindered China's access to advanced chips and its ability to develop advanced chip manufacturing capabilities. The regulations broadly impact the supply of manufacturing processes, technologies, and materials for advanced chips, compelling China to localize the entire production process (Kiuchi, T. ,2023). Japan and the Netherlands have coordinated with the U.S. in these measures, with Japan amending its so-called "Goods etc. Ordinance" in May 2023 to strengthen export controls on semiconductor manufacturing equipment used in cleaning and etching processes (Ministry of Economy, Trade and Industry of Japan, 2023.

Conversely, to strengthen domestic advanced chip manufacturing capabilities, the U.S. enacted the CHIPS & Science Act in August 2022, which provides a total of $52.7 billion in funding under the previously enacted CHIPS for America Act. The initial grant solicitation for investments in semiconductor manufacturing facilities began in March 2023, followed by solicitations in June and October for investments exceeding and under $300 million, respectively. This financial support has spurred domestic investment in the semiconductor industry and advanced the reshoring of these manufacturing capabilities.

For example, major semiconductor companies have made significant investments in the United States. In September 2022, the month following the enactment of the CHIPS and Science Act, Intel initiated a groundbreaking ceremony for a new semiconductor manufacturing facility in Ohio, representing an investment of over $20 billion. In October, Micron announced plans to construct a semiconductor manufacturing facility in New York State, with potential investments up to $100 billion. Additionally, in December, TSMC announced the establishment of a second factory in Arizona. Furthermore, in October 2022, the Japanese company JX Nippon Mining & Metals held a groundbreaking ceremony for a factory in Arizona that will produce sputtering targets for semiconductors, among other activities. (JETRO Regional Analysis Report, 2023).

In response, China has already referred the U.S. export restrictions to the World Trade Organization's dispute resolution process (Reuters, 2023). The self-sufficiency rate of the U.S. in 2021 was only 16.7%, with foreign companies accounting for 60% of this figure.

Moreover, the U.S. and other countries' semiconductor export control regulations have made it increasingly difficult for China's semiconductor industry to procure manufacturing equipment, placing significant pressure on it. Nonetheless, in 2022, China's semiconductor market was valued at $180.3 billion, accounting for 32.4% of the global market total of $555.9 billion, continuing its position as the largest in the world (IC Insights, 2022).

Additionally, major Chinese semiconductor companies like SMIC (Semiconductor Manufacturing International Corporation) are investing in legacy semiconductor areas. In August last year, Huawei announced that its new smartphones would be equipped with advanced 7-nanometer semiconductors manufactured by SMIC, marking continued progress in domestic production.

Furthermore, the strengthening of U.S. regulations has also raised concerns among American companies. CEOs of three major U.S. semiconductor companies (Intel, Qualcomm, NVIDIA) met with several U.S. government officials on July 17 to discuss the proposed enhancements to semiconductor regulations against China. Although the details of the meeting were not disclosed, the Semiconductor Industry Association (SIA) issued a statement on the same day expressing concern about the potential for additional measures regarding U.S. semiconductor export controls to China. The statement warned that repeated excessive restrictions on the U.S. semiconductor industry's access to the Chinese market could undermine U.S. competitiveness, disrupt supply chains, introduce significant market uncertainties, and potentially provoke continued retaliatory measures from China. The SIA urged both the U.S. and Chinese governments to alleviate tensions and seek solutions through dialogue rather than escalating them further (Kiuchi, T.,2023).

Considering the military and politically induced disruptions and the ongoing unstable situation in semiconductor supply chains, NTT's decision-making regarding with whom and in which countries to engage in R&D, manufacturing, development, and sales channels in the field of semiconductor photonics-electronics convergence should carefully avoid falling under such regulatory restrictions.

3-2. Economic Assessments

Economic trends and industry dynamics play a pivotal role in shaping corporate strategic decision-making. For instance, Numerous studies have reported that R&D expenditures are pro-cyclical. Rafferty and Funk (2004) used firm-level data on R&D and demonstrated a strong positive correlation between a company's sales and its R&D spending, arguing that this indicates R&D expenditures are pro-cyclical. Comin and Gertler (2004) contended that, particularly in the medium term, R&D spending in the United States exhibits pro-cyclical characteristics. Wälde and Woitek (2004) analyzed R&D expenditures across the G7 countries and concluded that it is reasonable to believe there is strong evidence that R&D spending is not counter-cyclical but rather pro-cyclical.

Also, the inflation rate is seen as one of the indicators for measuring economic cycles. Inflation diminishes the value of savings and investment returns on a real basis, making it a hidden threat to investors. Investors aim for long-term increases in purchasing power, but inflation makes this goal more difficult to achieve. This is because to boost real purchasing power, investment returns must consistently exceed the rate of inflation. Even if the pre-inflation investment return is 2%, in an environment with a 3% inflation rate, the real return after adjusting for inflation would be negative 1%. Moreover, the inflation rate also impacts the business environment for companies.

For example, inflation impacts on the cost of entry for companies. Higher inflation increases the cost of purchasing or leasing equipment and property. This means that initial investments required to enter a new market could become substantially more expensive, potentially delaying or deterring entry. Also, it can drive up the prices of raw materials and intermediate goods. If a company relies on these inputs, its cost of goods sold (COGS) may increase, affecting overall profitability. From a financing cost perspective, inflation often leads central banks to raise interest rates to control economic overheating. Higher interest rates can make borrowing more expensive, which might limit a company’s ability to fund new projects or expansions through debt.

As the cost of capital increases, the expected return on investment (ROI) for new projects needs to be higher to justify the financial risk. This can make new entries less attractive. Furthermore, it reduces consumer purchasing power, which can lead to decreased demand for non-essential goods and services. Companies need to assess whether the market conditions are favorable for introducing new products or entering new markets. Additionally, it can increase the price sensitivity of customers, who may defer purchases, switch to cheaper alternatives, or reduce consumption. This can affect the sales volume expected from the new market entry.

For managers aiming to enhance corporate value, addressing business risks directly linked to performance fluctuations, such as demand variability, is one of the critical management challenges. This is because corporate value is assessed by applying a discount rate that reflects corporate risk to its future cash flows. It is understood that this corporate risk is related to the cost structure adopted by managers (Ono & Sakurai, 2015; Lev, 1974). This relationship suggests that choosing a particular cost structure can potentially manage the business risk associated with demand fluctuations.

Inflation Risk and Market Behavior

Since the IOWN project, being a cutting-edge technology initiative aimed at developing an innovative optical and wireless network, would require substantial capital for research, development, and deployment of infrastructure, inflation can increase the cost of these components, particularly if they involve sophisticated technology or materials that are subject to price volatility.

Also, day-to-day operational costs, including maintenance and labor, could increase as the general price level rises. This could affect the project's long-term financial sustainability. Furthermore, higher inflation may lead to higher interest rates, which can increase the cost of borrowing. This might affect how easily NTT can secure financing for the IOWN project, or influence the return on investment expected by stakeholders, potentially requiring adjustments in project scale or timelines. We will summarize current inflation expectations to analyze these opportunities and risks as follows.

Inflation's Impact on NTT's IOWN Plan

According to the International Monetary Fund's (IMF) revision (2024), the global economy is projected to grow by 3.1% in 2024 and 3.2% in 2025. This growth is slightly above earlier predictions due to unexpected resilience in the U.S., some major emerging markets, and fiscal support in China, meaning that market-side demand would be expected to increase, which serves as a positive factor for the development and introduction of new technologies like the IOWN.

However, growth forecasts remain below the historical average of 3.8% from 2000 to 2019, constrained by high central bank policy rates, fiscal consolidation, and tepid productivity growth. Most countries shown in the graph experienced a rising inflation trend throughout 2022, with a peak around mid-2022 followed by a gradual decline towards the end of the year. The inflation trends across these regions suggest significant inflationary pressures through 2022, which were somewhat synchronized across major economies except for Japan. Japan's inflation rate remains notably lower than in Western countries. The peak in mid-2022 could be attributed to various global economic pressures such as supply chain disruptions, post-pandemic recovery demand, and energy price increases, particularly noted in European countries. Global inflation is expected to decelerate, with the general inflation rate forecasted to fall to 5.8% in 2024 and 4.4% in 2025.

NTT has announced in its medium-term management plan that it plans to invest 8 trillion yen in new areas, including IOWN, over the next five years through 2027 (NTT 2023). As inflation subsides, the costs associated with R&D personnel, equipment purchases, and depreciation are expected to decrease, which could reduce NTT's financial burden. However, for global initiatives like IOWN, it's important to note that inflation rates remain high in various countries. Therefore, investment activities should be conducted with this economic context in mind.

On the other hand, the inflation decline reflects resolved supply-side issues and ongoing tight monetary policies. The gradual decline in the latter part of the year might indicate the effects of monetary policy adjustments, such as interest rate hikes by central banks aimed at controlling inflation. It is expected that the Federal Reserve will maintain the current policy interest rate for the foreseeable future, keeping an eye on inflation trends. As inflation slows, to avoid an increase in real interest rates, it is projected that the Fed will begin cutting rates in July 2024, with a total of two cuts (each by 0.25%) expected within the year. Given the persistently high core inflation, the ECB is expected to keep its policy interest rates unchanged for now.

However, as the European economy shows signs of stagnation, the ECB is anticipated to start reducing rates in June 2024, with subsequent cuts of 0.25% each quarter. Due to the lack of vigor in the Japanese economy, the BOJ is likely to maintain its current monetary policy for the time being. It is expected that any rate hikes will occur at a slow pace, with an increase of 0.25% each in April and October of 2025 (Mitsui Sumitomo DS Asset Management, 2024). While other regions might see decreased pressure to lower interest rates, policy rates remain high overall, which could negatively impact funding for initiatives like NTT's IOWN.

Energy Market Impact on NTT's IOWN Plan

In addition, according to the Agency for Natural Resources and Energy of Japan (2023), the upheaval in global energy markets, which is one of the inflation factors, has had a significant impact on the prices of natural gas and LNG, particularly notable in key indices like the Japan

Korea Marker (JKM). From 2021, JKM prices showed an upward trend and experienced frequent spikes, reaching a record high of approximately $85/MMBtu on March 7, 2022, following Russia's invasion of Ukraine. This price was about 14 times higher than the previous year's rate of around $6/MMBtu.

Similarly, European natural gas price indices such as the Title Transfer Facility (TTF) and National Balancing Point (NBP) also reached all-time highs on August 26, 2022, largely due to concerns over disruptions in supplies from Nord Stream from Russia to Europe. Although prices for JKM, TTF, and NBP have since declined, the outlook remains uncertain, influenced by the ongoing conflict in Ukraine and global energy supply and demand dynamics. Crude oil prices also experienced significant fluctuations due to the effects of embargoes and other disruptions.

On March 8, 2022, the benchmark Brent crude oil price reached about $128 per barrel, nearly double the price from a year earlier at approximately $68 per barrel. Although prices have since decreased, they have stabilized around $80 per barrel, which is still higher compared to pre-2021 levels. Coal prices, particularly for Australian thermal coal, have also soared. The ban on imports of Russian coal, coupled with the surge in natural gas prices, has increased demand for coal as a fuel for power generation, especially in Europe.

Additionally, major disruptions in coal production and transportation in Australia due to heavy rains in February-March and July 2022 have further driven up coal prices. In Indonesia, another major coal-exporting country, the spike in natural gas prices led to increased domestic demand for coal as a fuel for power generation, prompting temporary export suspensions and contributing to the global rise in coal prices. However, entering 2023, coal prices have shown a downward trend, influenced by a mild winter in Europe and increased operation of wind power facilities.

Given the rising energy costs and the uncertainty about the future, the market (including businesses and investors) is likely to pursue more energy-efficient technologies. In this context, NTT's IOWN initiative stands to benefit.

Green Bond Market Opportunity

This advantage also extends to the capital markets. One example is the issuance of green bonds. Green bonds are debt securities issued by corporations or municipalities to raise funds specifically for environmental improvement projects, such as the transition from fossil fuels to renewable energy sources like solar and wind power. The scope of these projects also includes energy conservation, pollution prevention, water resource management, greenhouse gas emissions reduction, and climate change mitigation. The focus on Environmental, Social, and Governance (ESG) aspects, aligned with the Sustainable Development Goals (SDGs), has led to the expansion of the green bond market.

Investors increasingly consider social responsibility and ESG criteria in their investment decisions, beyond just economic returns. Companies that manage their operations with these considerations in mind can benefit from favorable financing conditions and enhanced corporate image. They may also secure funds at more advantageous interest rates. However, the use of funds from green bonds must be clearly defined and transparent, although green bonds are not legally defined and operate on a self-disclosure basis by issuers. The Green Bond Principles (GBP) serve as guidelines for this. Despite the benefits, a limitation is that the funds raised are restricted in use, which may inhibit investment flexibility (International Finance Corporation, 2021).

According to the Goldman Sachs Report (2023), continued market growth is expected in Europe, the US, and emerging markets. The green bond market has grown significantly, averaging about 90% annual growth from 2016 to 2021. Estimates suggest that green bond issuance could reach €600 billion in 2023, potentially expanding the market to over €2 trillion as more sovereigns and corporates increase their environmental commitments

This growth is driven by bond issuers financing the energy transition, investors seeking returns while supporting environmental initiatives, and policymakers who promote green investments through incentives and impact standards. The transition to a sustainable economy requires considerable capital, with an estimated $9.4 trillion needed annually to achieve a net zero global economy by 2050. Green bonds play a key role in mobilizing this capital.

In 2023, NTT issued its second green bond of the year. The proceeds are being used to promote the company's shift to green electricity through the use of renewable energy, advance research and development for IOWN aimed at drastically reducing power consumption, implement an internal carbon pricing system and enhance environmental energy initiatives and information disclosure. The bonds, with maturities ranging from three to ten years, amount to a total of 220 billion yen. This issuance brings NTT's total green bonds issued to over 1.4 trillion yen, making it the third largest globally, following Germany's Volkswagen and France's energy company.

Furthermore, while the construction, water, and energy industries are active in issuing green bonds, the ICT industry has lagged behind, giving NTT a competitive advantage by being a pioneer in utilizing this financing market.

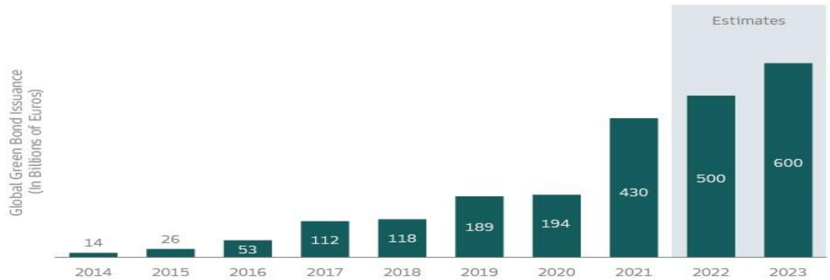

Fig. 3-3 Source Data from Goldman Sachs Asset Management and Bloomberg. Estimates are for the full year 2022 and 2023.

3-3. Social Assessments

ICT has significantly transformed people's lifestyles in numerous ways, affecting everything from daily communication to how we work, learn, and entertain ourselves. For example, ICT has revolutionized personal and professional communication. Email, instant messaging, social media platforms, and video conferencing have made it easier to stay connected across vast distances in real time, fostering global interactions and relationships. The internet, a major component of ICT, provides vast amounts of information at one's fingertips. This democratization of information access has empowered individuals by allowing them to learn, make informed decisions, and participate more actively in their societies.

From an industrial perspective, ICT has also impacted transportation through innovations like GPS for navigation, ride-sharing apps, and the emergence of autonomous vehicles, which promise to redefine future mobility. The advent of ICT has led to the digitalization of many workplaces. Remote work, which became particularly prominent during the COVID-19 pandemic, is facilitated by ICT tools that allow people to work from virtually anywhere. This has also led to changes in work-life balance and has opened up global job opportunities. ICT technology, which has had a significant impact on our society, continues to evolve with the advent of AI and the digital era. It is important to investigate what effects these developments will have going forward.

Global Population Projections

The United Nations (2022) has released its latest global population projections. The current global population of approximately 7.3 billion is expected to rise to 9.7 billion by 2050, surpassing last year's forecast by about 150 million. Furthermore, the population is projected to reach 11.2 billion by 2100. The most significant population growth will occur in Africa, followed by Asia.

Globally, aging populations are becoming more prevalent due to increased life expectancy and declining birth rates. In advanced countries, the number of elderly people surpassed the number of children in 1998, and this trend is expected to become global by 2045. According to 2021 World Bank statistics (2022), Monaco has the highest aging rate at 35.97%, followed by Japan at 29.79%, Italy at 23.68%, Finland at 22.89%, and Portugal at 22.56%. The UN predicts that the global average birth rate per woman, currently at 2.5, will decrease to an average of 2.0 by the end of the 21st century. The most significant decline in birth rates is expected in developing countries, where it is forecasted to drop from 4.3 to 2.1 by 2100. Both

China and India, which are significant markets due to their large populations, are entering phases of declining birth rates. In 2022, China's population decreased for the first time, reaching 1.42589 billion. In 2023, India is expected to surpass China as the country with the world's largest population. China's population is projected to decline further to 1.41561 billion by 2030, 1.37756 billion by 2040, and 1.31264 billion by 2050. India's population is expected to peak at 1.69698 billion in 2063 before it begins to decrease. According to the Institute for Health Metrics and Evaluation (2024) showed the global fertility rate nearly halved to 2.4 in 2017 - and their study, published in the Lancet, projects it will fall below 1.7 by 2100 (Fig. 3.4).

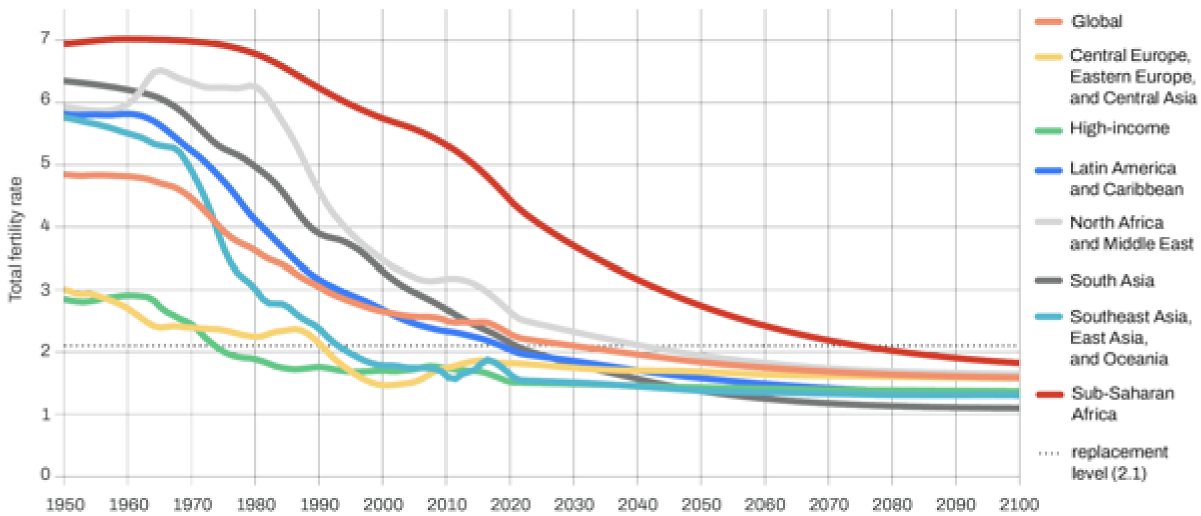

Fig. 3.4 Global Fertility Rate. Source from Institute for Health Metrics and Evaluation.

From https://www.healthdata.org/research-analysis/library/fertility-forecasts-and-their-implications-population-growth

Advanced Technology Risk and Opportunities with Society

In these global trends, new technologies such as AI, robotics, and autonomous driving hold potential as solutions. For example, with AI, a study analyzing the technical potential of AI and machines to replace human jobs across 701 occupations highlighted that 47% of the workforce is employed in jobs highly susceptible to automation in the U.S. (Frey, C. B. & Osborne, M. A. ,2013). When this research is applied to Japan (Nomura Research Institute, 2015), which is experiencing an aging population, a similar trend is observed, with 49% of jobs at high risk of being replaced by AI and automation. The societal consensus on the impact of AI's proliferation encompasses two primary effects: the improvement of operational efficiency and productivity, and the creation of new jobs and businesses, alongside the alteration in the volume of tasks that underpin employment.

The introduction of AI tends to reduce the volume of tasks in jobs where it is applied, primarily due to its efficiency and productivity enhancements. Conversely, AI's role in creating new jobs and businesses is expected to increase task volumes in newly created roles that involve deploying and utilizing AI technology.

The ideal scenario is a society where the newly created task volume exceeds the reduced volume, leading to an overall increase in tasks, highlighting the significant role and impact of AI in generating new business and job opportunities. Although the employment environment in Japan is improving, significant barriers remain, such as non-participation in the workforce due to childbirth and childcare. Achieving higher productivity while reducing working hours is essential.

The efficient use of AI can facilitate high-productivity work and flexible work arrangements like telecommuting, thereby expanding opportunities for women and other underrepresented groups in the workforce. In a world that requires such advanced social systems, technologies like IOWN, which provides ultra-high-speed communication, will become essential as a backbone for a new generation of societal infrastructure. In this context, the global aging population could be seen as a positive factor, driving the need for and adoption of such sophisticated technologies. This could facilitate more efficient healthcare services, enhanced accessibility, and improved overall quality of life for the elderly.

While new technologies like AI are increasingly necessary in society, they also bring about concerns and dissatisfaction among users. Addressing these concerns is crucial for social stability. Ensuring transparency in how these technologies operate, safeguarding data privacy, and promoting digital literacy can help build trust and acceptance. Additionally, involving diverse stakeholders in the development and regulatory processes can ensure that these technologies are used ethically and benefit all segments of society. The following data (Fig. 3.5) reflects a landscape where AI adopters are considerably more concerned about the implications of AI than prepared for them. Cybersecurity ranks as the greatest concern among global artificial intelligence adopters, with 62 percent of them reporting to be major or extremely concerned and only 39 percent being fully prepared to deal with cybersecurity vulnerabilities related to AI. Also, a high level of concern (57%) exists regarding the consequences of using personal data without consent, highlighting the ethical and legal implications of AI in data management. To enhance social stability, efforts could focus on improving cybersecurity measures, developing robust ethical guidelines, ensuring regulatory compliance, and increasing transparency in AI operations. Addressing these concerns proactively can help in mitigating the potential negative impacts of AI on society.

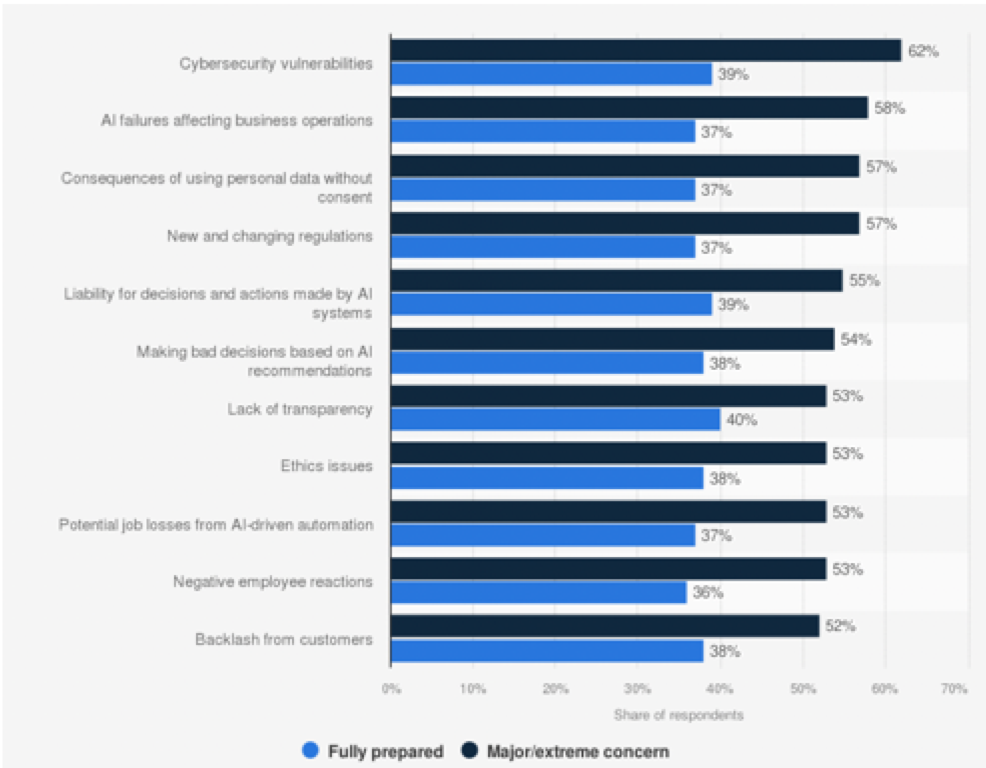

Fig. 3.5 Global AI adopters' areas of preparedness and concern 2020. From Statista 2024.

To solve these issues, each country's approach to data protection emphasizes maintaining control over data within their jurisdictions while allowing for international transfers under strict conditions, reflecting a global emphasis on privacy and security (Table 3.2).

Table 3.2

*Governance on **C**ross-Border Data Flow in Various Countries*

Country	Key Regulations	Year	Key Details of Data Protection Activities
European Union	General Data Protection Regulation (GDPR)	2016	Prohibits data transfers outside the EU unless conditions are met. Key mechanisms include adequacy decisions, binding corporate rules, standard contractual clauses, codes of conduct, certification mechanisms, or specific exceptions under Article 49 for situations not covered by other mechanisms.
United States	Electronic Communications Privacy Act (ECPA)	1986	Protects wire, oral, and electronic communications while they are being made, are in transit, and when they are stored on computers. The Act applies to email, telephone conversations, and data stored electronically.
	Gramm-Leach-Bliley Act (GLBA)	1999	Requires financial institutions to explain their information-sharing practices to their customers and to safeguard sensitive data. Does not include specific provisions for international data transfers.
	Health Insurance Portability and Accountability Act (HIPAA)	1996	Protects sensitive patient health information from being disclosed without the patient's consent or knowledge. The Rule is primarily concerned with the protection and confidential handling of protected health information.
Canada	Personal Information Protection and Electronic Documents Act	2000	Requires that personal information is protected and electronic documents are preserved. Transfers across borders must ensure similar protection levels as provided under Canadian law.
Australia	Privacy Act	1988	Includes the Australian Privacy Principles (APPs) which apply to the public sector, private sector organizations, and others. Requires that personal information only be transferred overseas where adequate safeguards exist.
New Zealand	Privacy Act 2020	2020	Introduces privacy principles that govern the collection, use, and disclosure of personal information by agencies. Includes provisions specifically aimed at the safety and security of personal information transferred out of New Zealand.

Singapore	Personal Data Protection Act (PDPA)	2012	Governs the collection, use, and disclosure of personal data by organizations. It provides for the protection of individual's personal data by regulating the proper management of personal data. Requires adequate protection for data transferred internationally.
South Korea	Personal Information Protection Act	2011	Focuses on the protection of personal data processed by both public and private sector entities. Prohibits the transfer of personal information outside of South Korea unless explicit consent is obtained or it meets specific conditions necessary for legal compliance.
China	Cybersecurity Law	2017	Requires critical information infrastructure operators to store personal and important data collected and produced in mainland China within China. Cross-border transfer is permitted only after a security assessment.
	Personal Information Protection Law	2021	Enhances control over the processing of personal data by operators and imposes strict requirements for data processing and cross-border data transfer, including a security assessment process for important data before it is transmitted abroad.

Note: Organized and compiled based on information from the institutional survey related to cross-border data flow in data governance in various countries (Nomura Research Institute, 2022)

On October 30, 2023, G7 leaders stated the Hiroshima AI Process. This statement welcomed the guidelines titled "Hiroshima Process International Guidelines for Organizations Developing Advanced AI Systems" and "Hiroshima Process International Code of Conduct for Organizations Developing Advanced AI Systems." The Code of Conduct outlines recommended actions for implementing these guidelines (The White House, 2023). On December 1, 2023, a G7 Digital and Technology Ministers' Meeting was held to discuss the Hiroshima AI Process. This meeting included G7 ministers, as well as representatives from the EU, OECD, and GPAI. It also presented the results of a survey asking participants about specific risks associated with generative AI. The survey highlighted that all G7 countries identified "disinformation and resultant manipulation" as a risk, followed by "intellectual property rights infringement" and "threats to privacy" which were considered threats by six countries. Conversely, "long-term existential threats" and "negative environmental impacts" were not considered threats (G7 Hiroshima Summit, 2023). In advancing IOWN and other similar technologies, it is crucial to consider international norms and national laws concerning data handling and system architecture. This approach ensures compliance and promotes trust in the deployment of these technologies.

Table 3.3

Progress in AI Regulations and Guidance by Major Countries

Country	Main Regulatory Law/Guidance	Main Actions
Japan	Draft AI Business Guidelines	Guidelines defining codes of conduct for AI developers and providers, to be officially published in March 2024
USA	Executive Order on Safe, Secure, and Trustworthy AI	Mandates sharing of information on robust AI development and guidance on AI detectors for generated content
EU	AI Regulation Act	Establishes transparency obligations for banned AI apps and generative AI development; fines for violations.
UK	New Processes for the Safety of Frontier AI	Establishes an AI Safety Institute and creates generative AI guidance for civil servants
Canada	Guardrails for Generative AI in Canada – Implementation Code	Mandates measures against deepfakes and recommends quality assessment of training data
China	Interim Regulations on the Management of Generative AI Services	Bans the creation of content that damages the national image and requires algorithm registration when using generative AI in public opinion service

Note: Description was as of December 2023. Organized and presented based on reports and documents released by each country. For further details, please refer to the Reference page.

3-4. Technology Assessments

This section will explore NTT's IOWN technology capability with the evolution of computer processing power and energy efficiency, one of the important figures of merits in this field, providing an overview of the technological trajectory to the present day. It will highlight the existing challenges and current state of the field while proposing the initiative as a potential solution to these obstacles. This discussion will be illustrated with case studies that demonstrate the practical applications of silicon photonics in enhancing computing performance.

Computer Historical Advancement and the Limit

The processing capabilities of Central Processing Units (CPUs) and Graphics Processing Units (GPUs)—the latter gaining prominence due to their critical role in artificial intelligence (AI)—can be quantified using the metrics of FLOPs (Floating Point Operations per Second) and GFLOPs (GigaFLOPs). Historical data reveal a significant improvement in these metrics over time, suggesting a substantial rise in computational power. This enhancement in energy efficiency largely stems from advancements in hardware technologies, particularly through miniaturization.

Gordon Moore in 1965, has been a guiding principle in the semiconductor industry, predicting that the number of transistors on a microchip doubles approximately every two years ($p = 2^{n}/^{2}$), while the cost of computers is halved (Moore, G. E., 1965). This exponential growth has driven the incredible increases in processing power and cost reductions that characterize the modern digital age. Alongside Moore's Law, Dennard's Scaling has been crucial in advancing computational efficiency. Formulated by Robert Dennard in 1974, it states that as transistors are made smaller, their power density remains constant, thus enabling lower power consumption while improving performance. This principle has allowed for the design of smaller, faster, and more energy-efficient microchips (Robert Dennard et al., 1974). However, in recent years, the breakdown of Dennard's Scaling—due to issues like leakage current and heat density as transistor sizes shrink—has led to increased power consumption and thermal challenges, complicating the trade-offs between computational power and energy efficiency (McMenamin, A., 2013).

Jonathan Koomey developed Koomey's law, based on Moore's law, to describe the increasing efficiency of computer computations per unit of energy. This law states that the number of computations per joule of energy doubles approximately every 1.57 years a trend that has remained relatively stable since the 1950s. However, Koomey observed in 2011 that this rate had slowed to every 2.6 years since 2000. He attributed this slowdown to the end of Dennard's law, which had enhanced the efficiency of shrinking electronics until about 2005, and to the deceleration of Moore's law, which tracks reductions in the size of electronic components (Koomey, J., et al., 2011). This change is significant because whereas a doubling every 1.5 years result in a 100-fold increase in efficiency over ten years, a doubling every 2.5 years yields only a 16-fold increase (Naffziger, S., & Koomey, J. , 2016).

The following figure (Fig. 3.6) presents data on the Microprocessor Trend over a span of 50 years. It reveals a deceleration in the growth rates of Single-Thread Performance, Frequency, and Typical Power compared to the growth of Transistors and Number of Logical Cores. These observations deviate from Moore's Law and Dennard's Scaling, suggesting the possibility of the end of these laws.

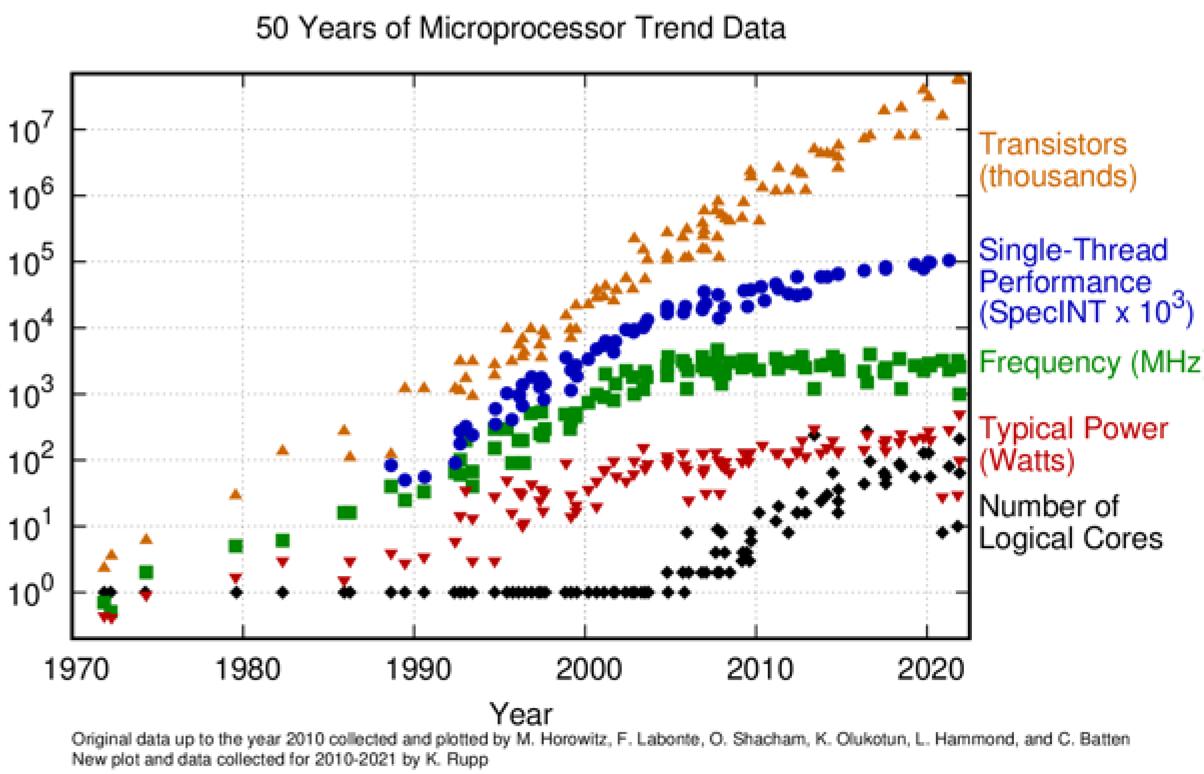

Fig. 3.6. 50 Years of Microprocessor Trend Data. Data from GitHub https://github.com/karlrupp/microprocessor-trend-data

Evolution of Computer Performance Required in the AI era

Despite these challenges, the burgeoning demand for AI applications and broader digital transformation with the IoT is driving an exponential need for more advanced computing and transmission technologies. Furthermore, these must not only be faster but also more energy-efficient to sustain the escalating computational demands of AI, particularly in machine learning and large language models (LLMs).

In a comprehensive study, Sevilla et al. (2022) analyze the escalation in compute requirements for machine learning across three distinct eras. During the Pre Deep Learning Era (before 2010), compute growth was steady, doubling approximately every 20 months, aligned with Moore's Law. A significant shift occurred with the onset of the Deep Learning Era, post-2010, where compute needs doubled every 6 months, driven by advances in deep learning technologies. The transition to the Large-Scale Era around late 2015 marked another surge, as training for massive models began requiring 10 to 100 times more computing, with doubling times of roughly 9.9 months. This period is characterized by substantial investments in larger-scale models, particularly evident in tasks requiring sophisticated natural language processing. The trends are illustrating the exponential rise in training computing, reflecting the growing computational demands that underpin modern machine learning advancements.

Also, Mehonic and Kenyon (2022) discuss the unsustainable energy consumption of modern computing systems, particularly those supporting advanced AI applications. They highlight the rapid increase in computing demands, doubling every two months, and the environmental costs associated with it (Fig. 3.7.). The authors advocate for a shift towards neuromorphic computing, which mimics the brain's architecture by integrating memory and processing, thus reducing energy use and enhancing efficiency. They argue that current computing methods cannot sustain the growing demands of AI, positioning neuromorphic systems as a vital, sustainable alternative for future advancements in AI technology. Also, the energy required for training state-of-the-art AI models has more than doubled in less time than previously, with significant implications for CO_2 emissions (Strubell, et al. 2019).

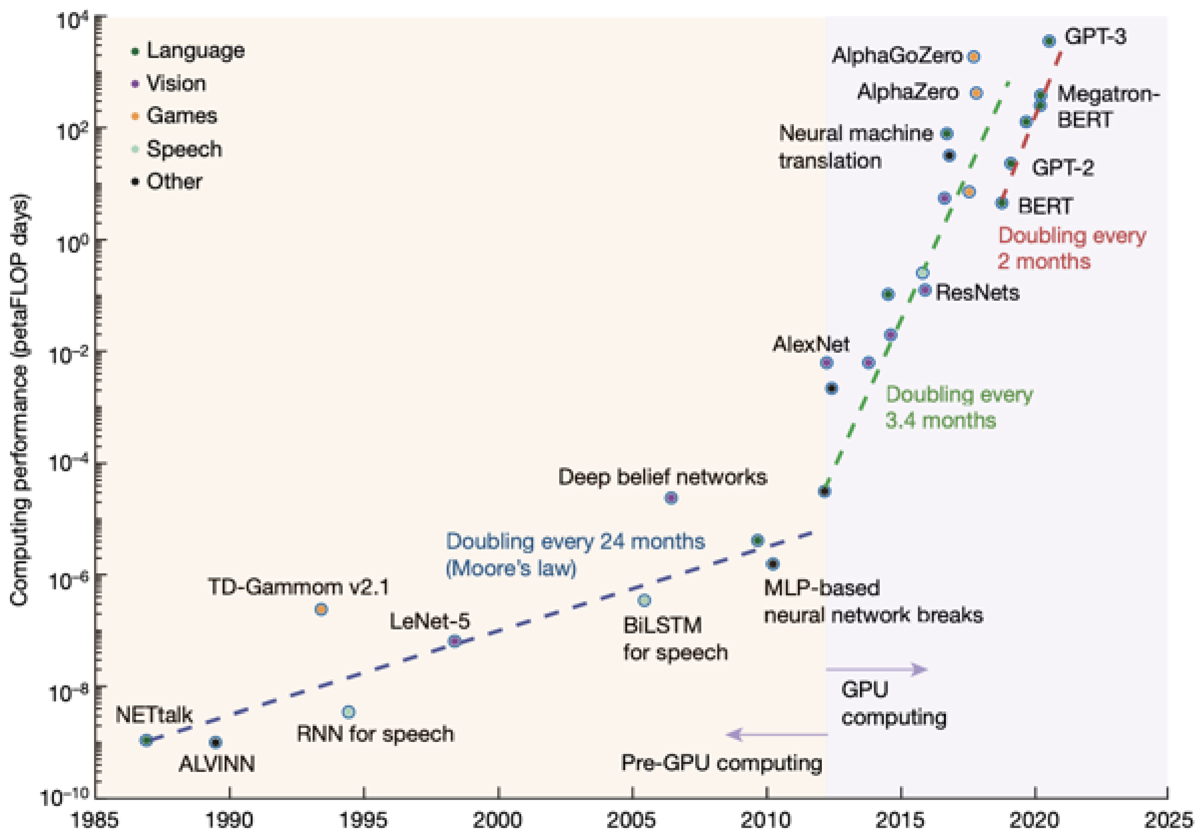

Fig. 3.7. Computing power demands..From Mehonic, A., & Kenyon, A. J. (2022).

These technologies will be instrumental in the development of new financial services leveraging ICT and the realization of automated driving through AI. This transformative wave is expected to bring about significant changes in our daily lives, fostering the emergence of diverse values. The exponential growth of data creation, capture, replication, and consumption on a global scale underscores the magnitude of this digital revolution. Forecasts (IDC, 203) indicate that the total volume of data surged to 64.2 zettabytes in 2020, with projections suggesting a staggering increase to over 180 zettabytes by 2025 (Fig. 3.8). Notably, the year 2020 witnessed a remarkable spike in data generation and replication, surpassing previous estimates. This surge was largely propelled by the heightened demand triggered by the COVID-19 pandemic, as remote work, online learning, and home entertainment became more prevalent.

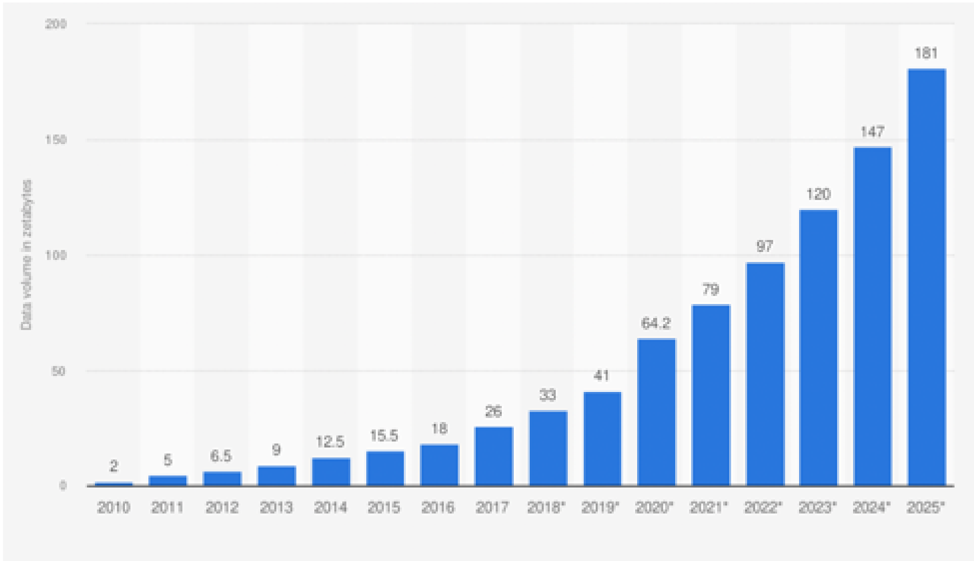

Fig. 3.8. Amount of data created, consumed, and stored 2010-2020,

with forecasts to 2025.From Statista 2024.

In this evolving landscape, the transmission and processing of vast amounts of information pose formidable challenges. Existing information and communication systems are ill-equipped to handle this burgeoning influx of data. Projections indicate a staggering 5.3-fold increase in global internet traffic volume in a mere seven years, soaring from 33 zettabytes in 2018 to an anticipated 175 zettabytes by 2025 (Fig.3.9).

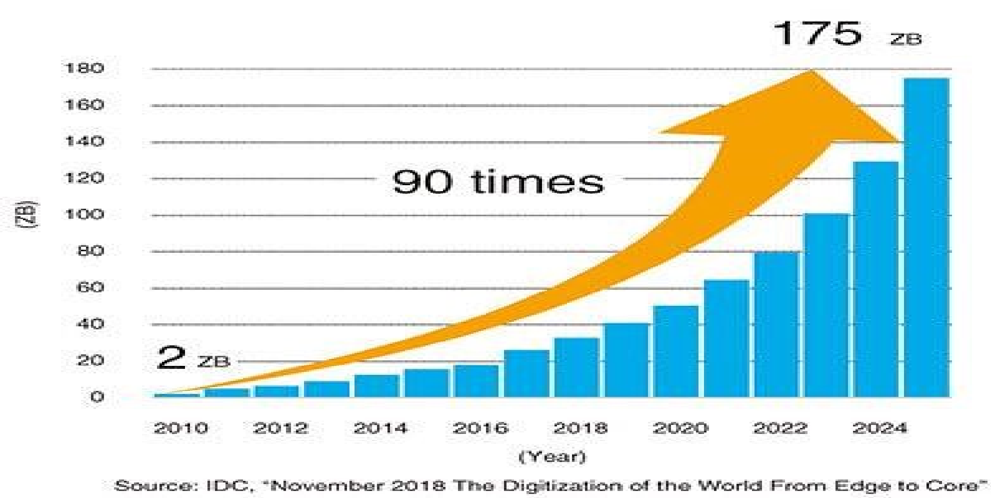

Fig. 3-9. Transmitting and processing a huge amount of information from 2010-2020,

with forecasts to 2024. From NTT R&D Web Site.

Energy Consumption in the ICT Sector

Recent research underscores a significant shift in ICT power consumption patterns. According to a projection by Andrae & Edler (2015), a significant trend across all scenarios is the shift in electricity usage from consumer devices to communication networks and data centers. This is expected to intensify with technological advancements and increased data traffic. In the worst-case scenario, ICT could account for as much as 51% of global electricity by 2030 if improvements in electricity efficiency do not keep pace with increases in data traffic and device usage.

Despite the high demand, the growth in renewable energy generation is anticipated to meet the electricity demands of communication technology. However, in the worst-case scenario, ICT's electricity usage could contribute up to 23% of global greenhouse gas emissions by 2030 (Fig.10). They document stresses the importance of ongoing improvements in electricity efficiency across various sectors of communication technology to mitigate potential negative impacts on energy consumption and environmental sustainability.

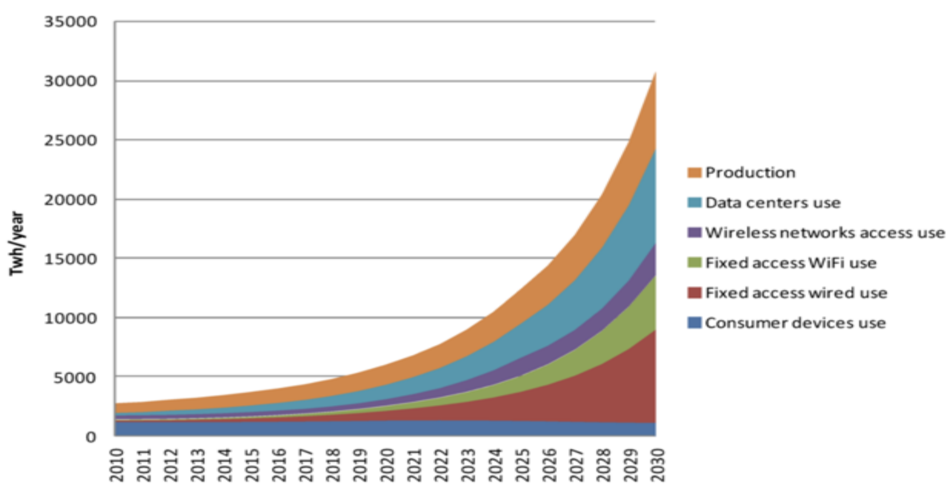

Fig. 3.10. Trends per CT category for worst-case global electricity usage 2010–2030.

From Global Electricity Usage of Communication Technology Trends to 2030 (2015)

According to a report by the Low Carbon Society (2020), the worldwide growth of data centers is driven by the exponential increase in IP traffic anticipated to rise by 30 times by 2030 and 4,000 times by 2050 compared to today's levels. This growth is linked directly to the broader advancement of the information society, which includes more intensive use of internet services, cloud computing, and an increase in data-intensive applications like AI and big data analytics.

The worldwide growth of data centers is driven by the exponential increase in IP traffic anticipated to rise by 30 times by 2030 and 4,000 times by 2050 compared to today's levels. This growth is linked directly to the broader advancement of the information society, which includes more intensive use of internet services, cloud computing, and an increase in data-intensive applications like AI and big data analytics. It projects that global energy consumption by data centers could reach 3,000 TWh by 2030 and as high as 500,000 TWh by 2050 if current trends continue (Table 3.4). Among them, server are currently responsible for about 50% of the data center energy use, with projections indicating an increase to 60-80% in the future. On the other hand, power supply and cooling systems account for approximately 25-30% and 10% of energy use, respectively.

These figures represent a significant challenge in terms of sustainability and environmental impact. While there have been advancements in energy efficiency, particularly in reducing the Power Usage Effectiveness (PUE) ratio in data centers, the massive increase in data processed and stored means that absolute energy use continues to rise. This highlights a critical need for ongoing improvement in energy efficiency technologies.

Table 3.4.

Electricity consumption predictions for data centers, broken down by component, and the proportion attributed to AI from 2018 to 2030.

				Global		
				2018	2030	2050
IP traffic			ZB	11	170	20,200
Power consumptions of data centers			TWh	190	3,300	504,000
Power consumptions of servers		- basic task	TWh	90	450	53,000
		- AI task	TWh	23	1,740	231,000
		- total	TWh	113	2,190	384,000
	CPUs	- basic task	TWh	60	280	33,000
		- AI task	TWh	16	1,230	251,000
		- total	TWh	77	1,600	284,000
	Memories	- basic task	TWh	22	110	13,000
		- AI task	TWh	7	360	44,000
		- total	TWh	29	470	57,000
	Power supply etc	- basic task	TWh	8	50	7,000
		- AI task	TWh	3	230	37,000
		- total	TWh	11	280	44,000
Power consumptions of storages			TWh	17	430	51,000
Power consumptions of switches			TWh	10	120	18,000
Power supply, cooling, etc			TWh	43	440	66,000

Note: Created based on data from Low Carbon Society (2020).

Silicon photonics integrates optical components directly onto silicon substrates, facilitating faster data transmission at significantly lower power levels than traditional electronic components. This technology addresses the challenges posed by the breakdown of Moore's Law and Dennard's Scaling by providing an alternative pathway for continuing performance enhancement without proportional increases in power consumption. This technology leverages the mature, highly scalable infrastructure of silicon semiconductor manufacturing, making it both cost-effective and highly integrative with existing technology (Shekhar, et al., 2024).

Silicon photonics has progressed from small-scale integration (SSI) with 1-10 components per photonic integrated circuit (PIC) to large-scale integration (LSI) hosting 500 to 10,000 components. This mirrors CMOS technology evolution, significantly enhancing capabilities in optical communication and computing. The medium-scale integration (MSI) era marked by the adoption of Mach-Zehnder modulators for single and multi-wavelength capabilities in data centers has shown substantial performance gains, specifically in the development of microring-modulator-based intensity-modulated direct-detect (IMDD) transceivers demonstrating multiplexing and energy-efficiency benefits.

Silicon photonics has showcased reductions in power consumption through innovations like coherent and microring-modulator-based IMDD transceivers, crucial for scaling data center operations sustainably. Silicon photonics utilizes traditional CMOS materials such as aluminum, copper, and germanium, integrated seamlessly with existing semiconductor processes, enhancing performance while reducing power consumption. Compared to traditional materials like lithium niobate or III-V semiconductors, silicon photonics offers cost-effectiveness and manufacturability advantages due to compatibility with standard semiconductor manufacturing, promoting integration with electronic circuits on single chip. Predicted to scale from millions to billions of units, silicon photonics is expected to further drive performance and reduce power usage, outpacing traditional photonic materials in telecommunications and emerging fields like biosensing and photonic computing.

Chapter Conclusion

Chapter 3 employs the Aguilar's PEST framework, which emphasizing the Economic, Technical, Political, and Social dimensions as fundamental determinants shaping organizational contexts to analyze the external environment affecting NTT's IOWN initiative. This comprehensive analysis helps understand the broader context in which NTT operates, enabling better strategic planning.

Currently, environmental regulations have evolved to focus on reducing CO2 emissions, targeting modern companies to lower emissions by minimizing electricity use in production processes and product operation. Regulations such as the Paris Agreement require countries to submit and update their greenhouse gas emission reduction targets regularly. While these regulations impose costs, they offer opportunities for companies like NTT, which purse energy efficient products, that adapt proactively, enhancing global market competitiveness. Also, export trade restrictions on advanced technology impact industries, especially on the semiconductor industry within the tension in US-China relationship, has big impact on not only, the industry large supply chains, but also company's R&D and manufacturing locations. Usually, multinational enterprises (MNEs) are increasing their R&D and manufacturing investments in foreign subsidiaries, enhancing global innovation capacities. However, within this political tension, companies also need to consider resource allocation that avoids risk rather than looking for the optimal solution for innovation.

In the IOWN economic environment, although inflation has stabilized at a high level, the persistently high policy interest rates remain a concern. These rates increase the financial burden associated with financing and depreciation within the context of the substantial 8 trillion yen investment plan. The green bond market has grown significantly, driven by the need to finance the transition to a sustainable economy, funding projects focused on energy conservation, pollution prevention, and climate change mitigation. NTT has issued green bonds to promote its shift to green electricity, advance R&D for IOWN, and implement environmental initiatives, positioning itself advantageously in the green bond market. Additionally, a market that has faced soaring energy prices will greatly benefit from energy-efficient technologies like IOWN, making this an optimal time for its launch.

Also, we confirmed that the digital economy and AI drive economic growth, creating new markets and fostering innovation from social needs as well. They offer tools to address social challenges like poverty, inequality, and access to services, especially in coming aging society. One the other hand, the increasing demand for data processing and AI advancements is paralleled by a surge in energy consumption, necessitating innovation to enhance performance while reducing electricity usage like the IOWN. In addition, people feel concerns about AI including cybersecurity, data privacy, and ethical implications. Thus, addressing these concerns is crucial for social stability, requiring transparency, robust ethical guidelines, and stakeholder involvement, and the IOWN concept also needs to be promoted in accordance with the regulations and standards issued by each country.

Finally, silicon photonics integrates optical components onto a silicon substrate, addressing the need for faster data processing and reduced energy consumption. Historical advancements in computer processing power (Moore's Law, Dennard's Scaling) are reaching limits, necessitating new approaches like silicon photonics for continued performance and energy efficiency improvements. Also, The shift from electrical to optical signaling, as envisioned by NTT, represents a revolutionary approach with potential for substantial improvements in energy efficiency and performance.

Chapter 4: Value Chain and Stakeholder Analysis

Value chain analysis is a crucial tool for strategic planning because it helps organizations understand the specific activities through which they create value for their customers and gain competitive advantage. Also, the analysis helps businesses identify how different players compete and cooperate.

Porter, M. E. (1985) introduced the concept of the value chain. Michael Porter describes how competitive advantage can be achieved by organizations through identifying and optimizing the various activities in their value chain. Gereffi, et al. (2005) discussed the definitions and frameworks for understanding value chains and production networks, particularly in the context of globalization and technological advancements.

NTT's IOWN initiative aims to revolutionize the current technological infrastructure by replacing systems that rely on electrical signals with those utilizing optical signals. This transformation involves a diverse array and complex system of stakeholders from the IT, telecommunications, and semiconductor industries, which both compete and collaborate within this sector. The adoption of this optical signal-based infrastructure is anticipated to extend across various other sectors, including healthcare, automotive, energy, civil engineering, and finance, leveraging technologies such as IoT, digital services, and AI. However, transforming the existing value chain into a new one presents significant challenges.

This session will explore the emerging value chain and identify critical processes where NTT can significantly contribute to value creation. Understanding the dynamics between competitors and collaborators is crucial for strategically allocating limited resources to realize this vision. We will define and analyze the value-adding processes involved in transitioning from an electrical to an optical signal-based infrastructure using silicon photonics technology.

4-1. Value Chain in Silicon Photonics Industry

The value chain of the silicon photonics market in the IT sector is intricate and involves several key stages and players like the following Table 4.1. Silicon photonics, a technology that integrates optical components with silicon electronic circuits, is driving significant advancements in data transmission speeds and efficiency, particularly in data centers, telecommunications, and high-performance computing.

The value chain typically begins with the designing of Photonic Integrated Circuits (PICs) representing the conceptual, initial, and most critical phase in which companies and research entities concentrate on creating devices that consolidate multiple photonic functions onto a single chip.

Then, raw material suppliers and component manufacturers provide the foundational elements necessary for silicon photonics products. This includes silicon wafers and other semiconductor materials.

Next in the value chain are the companies that design and manufacture the photonic chips, which are essential for the technology's functionality. These chips are then integrated into various devices and systems by original equipment manufacturers (OEMs) and system integrators. Companies that specialize in the assembly, testing, and packaging of silicon photonics components play a critical role in ensuring the quality and performance of the final products. Once assembled and tested, these components are integrated into the equipment modules like transceivers, routers, switches, and servers, and storages, then, delivered to various end-users in industries such as telecommunications, data centers, and cloud service providers.

Additionally, these services are utilized across a broad spectrum of industries, such as finance, healthcare, manufacturing, agriculture, and civil engineering. In this context, the value generated by silicon photonics is expected to permeate all sectors.

The shift from traditional electric processes to those involving silicon photonics in the value chain not only involves changes at the technical level but also requires adaptations in business processes and strategies. From the R&D phase, where new designs and materials are conceptualized and tested, through the prototyping phase, where these ideas are materialized and iteratively refined, to the production phase, where these technologies are manufactured at scale and implemented in operational environments, each step is crucial. This progression ensures the technology not only meets but exceeds the current capabilities of traditional systems, thereby transforming the landscape of telecommunications, computing, and data management. Several companies are key players across these nodes, driving innovation and market growth.

For example, major corporations like Intel, Cisco, and IBM are heavily involved in the development and application of silicon photonics technology. These companies not only develop the foundational technology but also apply it in various advanced computing and data transmission products. Also, the global market for silicon photonics is expected to grow significantly, driven by the demand for high-speed data transmission and the ongoing deployment of 5G technology, which relies heavily on the capabilities that silicon photonics can offer. The tables below show details of each value chain, and what transformations are expected by silicon photonics based on some papers.

Table 4.1.

Value Chain in the Silicon Photonics Market and How the Technology Would Change the Existing Values

Value Chain	Description
PIC Design	<u>*Function:*</u> *This phase is the conceptual, initial and most critical phase where companies and research entities focus on designing Photonic Integrated Circuits (PICs) which are devices that integrate multiple photonic functions, such as generating, manipulating, and detecting light, onto a single chip. The design involves laying out the plan for how light will be manipulated on the chip to perform various functions such as transmitting, modulating, and detecting light. Also, the designs need to take into account not just performance but also manufacturability, yield, and integration with other electronic components.* <u>*Transformation from traditional electric to silicon photonics technology*</u> *Traditional electronic circuit design could be augmented or replaced by PICs that are capable of handling higher data rates with lower power consumption and reduced heat dissipation. This shift would involve more sophisticated design tools and simulation software that could significantly accelerate the R&D phase, reducing time-to-market for new technologies.* <u>*Work Process*</u>*:* ● *Design Software: Use of CAD tools for designing photonic integrated circuits.* ● *Simulation: Employing software to simulate the behavior of light within designed circuits to ensure efficiency and performance before manufacturing.* ● *Prototyping: Creating prototypes of designs to test concepts in practical scenarios.*

	Players: *Typically, these are semiconductor firms with strong R&D capabilities in optical technologies, such as Intel, Broadcom, and IBM. Innovation in integration techniques, focus on reducing optical losses, and expertise in electronic-photonic design convergence. They often invest heavily in software tools for simulation and modeling to streamline the design of complex photonic circuits.*
SOI Substrate	*Function* Silicon-On-Insulator (SOI) substrates form the base on which PICs are built. * SOI substrates are a type of semiconductor material used in the manufacturing of integrated circuits and consist of a thin layer of silicon separated from the bulk silicon by an insulating layer of silicon dioxide. *Transformation from traditional electric to silicon photonics technology* *SOI substrates in place of traditional silicon wafers in electronics manufacturing can lead to devices with better performance characteristics such as higher speed and lower power leakage. This substrate is especially beneficial for high-frequency applications, directly impacting the efficiency of devices in power-sensitive environments like mobile devices and data centers.* *Work Process* ● *Material Preparation: Production of pure silicon and layering it with an insulator, typically silicon dioxide.* ● *Wafer Fabrication: Manufacturing of silicon wafers that serve as the base for photonic circuits.* ● *Quality Control: Rigorous testing to ensure the substrates meet the necessary specifications for photonic applications.*

	<u>*Players:*</u> *Companies like Soitec and Shin-Etsu Chemical specialize in creating high-quality substrates that provide a critical foundation for PICs. Their products are known for high performance, specifically tailored properties like thickness uniformity and thermal conductivity, which are essential for efficient photonic applications.*
Epi-wafer Suppliers:	<u>*Function*</u> *This phase provides wafers that have additional semiconductor layers grown on top of the base substrate. The epitaxial growth process is critical for creating the active regions of photonic devices where light is generated or manipulated. It's a complex process that requires precision and control to ensure the layers have the right composition and thickness.* <u>*Transformation from traditional electric to silicon photonics technology*</u> *The introduction of epitaxial wafers in manufacturing could lead to the production of more complex and efficient semiconductor devices. Epitaxial layers allow for the precise control of the electronic properties of these layers, essential for the functionality of high-performance photonic devices like lasers and detectors.* <u>*Work Process*</u> ● *Material Preparation: Production of pure silicon and layering it with an insulator, typically silicon dioxide.* ● *Wafer Fabrication: Manufacturing of silicon wafers that serve as the base for photonic circuits.* ● *Quality Control: Rigorous testing to ensure the substrates meet the necessary specifications for photonic applications.* <u>*Players*</u> *Companies like IQE, Episil-Precision, and GlobalWafers provide wafers with precise epitaxial layers necessary for photonic devices. Key attributes*

	include control over layer thickness and dopant concentrations, crucial for the functionality of photonic components
Foundry and Fabs:	<u>*Function:*</u> *Foundries and fabrication plants (fabs) are where the actual PICs are manufactured. They take the designs from the PIC Design segment and use various processes such as lithography, etching, and deposition to create the photonic circuits on the wafer. This segment is characterized by high capital expenditure due to the sophisticated equipment required for manufacturing.* <u>*Work Process:*</u> ● *Photolithography: Applying patterns onto the wafer to define areas where the semiconductor will be modified.* ● *Etching: Removing selected areas of the semiconductor layers to create the photonic structures.* ● *Testing and Packaging: Assessment of the integrated photonic components' functionality and their subsequent packaging for protection and integration.* <u>*Technical Benchmark:*</u> *Silicon photonics requires foundries and fabs to adopt new manufacturing techniques such as advanced lithography and etching specific to optical components. These processes enable the integration of optical and electronic components on the same chip, which could revolutionize how processors and other critical components are manufactured.* <u>*Players:*</u> *Companies like TSMC, GlobalFoundries, and Samusung offer specialized fabrication services for photonics, including advanced lithography and etching techniques tailored to optical components. They focus on scalability, yield improvement, and integrating photonic components with electronic circuits.*

Transceiver Integrator:	<u>*Function:*</u> This phase integrates the photonic components with electronic components to create transceivers. Transceivers convert electrical signals into optical signals and vice versa, which are then used for high-speed data transmission. This requires expertise in both electronics and photonics to ensure efficient and reliable integration. <u>*Work Process:*</u> ● *Component Assembly: Assembling photonic components such as lasers, modulators, and photodetectors into a cohesive transceiver module.* ● *Signal Testing: Testing for effective conversion of electronic signals to optical signals and vice versa.* ● *System Integration: Ensuring that the transceiver modules can be integrated into larger systems like network equipment.* <u>*Transformation from traditional electric to silicon photonics technology*</u> *By integrating photonic components with electronic circuits to create transceivers, the data transmission speeds can be dramatically increased. This integration is crucial for applications in telecommunications and data center operations, where bandwidth and speed are increasingly critical.* <u>*Players:*</u> *Companies like NeoPhotonics, Cisco, and Finisar (now part of II-VI)* *excel in integrating various photonic and electronic elements to create complete transceiver modules. Strengths include high-speed signal processing, reliability, and the ability to scale up production for market demands.*
Equipment:	<u>*Function:*</u>

	Equipment manufacturers produce the networking hardware that uses silicon photonics technology, such as routers, switches, and servers. They are crucial for deploying silicon photonics in data centers and telecommunications networks. This segment has a direct impact on the performance and efficiency of IT infrastructure. *<u>Work Process & Players:</u>* ● *Routers and Switches like Cisco and Juniper: Manufacturing devices that direct data on a network using silicon photonics for high-speed data transfer.* ● *Servers and IoT Device: Building servers and IoT device that utilize photonic technology for faster data processing and reduced heat generation.* ● *Data Centers and Telecommunications Networks: Constructing infrastructure that supports vast amounts of data traffic with enhanced speed and efficiency through photonic technology.* *<u>Transformation from traditional electric to silicon photonics technology</u>* *The deployment of silicon photonics in the manufacturing of routers, switches, servers, and IoT equipment can enhance the capabilities of these devices, making them capable of supporting higher data rates and reducing latency. This is particularly impactful for data centers and telecommunications networks, pushing forward the capabilities of cloud computing and 5G technologies*. *Players:* *Manufacturers like Cisco, Juniper Networks, and Nokia, incorporate silicon photonics into data networking equipment like routers, switches, and optical transport systems. They focus on performance, energy efficiency, and reducing the footprint of network hardware.*

Operators (Customers)	<u>*Function:*</u> *This is the end-user segment of the value chain, consisting of cloud service providers, data center operators, and telecommunications companies, end so on. They deploy the equipment enabled by silicon photonics to provide services to the end-users.* <u>*Transformation from traditional electric to silicon photonics technology*</u> *For operators, leveraging equipment enabled by silicon photonics means being able to offer faster, more reliable services. As data traffic continues to grow exponentially, the demand for high-performance equipment that can handle this increase is paramount. Silicon photonics can meet these demands, enabling operators to improve their network infrastructure and service offerings.* <u>*Work Process*</u> ● *Telecommunications Companies: Deployment of photonic-based systems to improve network infrastructure for consumer and business communications.* ● *Data Center Operators: Utilization of photonics for managing and processing large datasets, improving server uptime and network reliability.* ● *Cloud Service Operators: Offering cloud-based services that require high-speed data processing and storage capabilities enhanced by photonics.* ● *Software Service Providers: Providing software and platform services that leverage the speed and efficiency of photonics technology.* <u>*Players:*</u> *As end-users of silicon photonics products, these operators like Verizon, AT&T, and AWS, focus on deploying cutting-edge technology to enhance their network infrastructure. They are interested in features like increased*

	bandwidth, lower energy consumption, and reduced latency in their telecommunications and data center operations.

Note: The value chain of silicon photonics within the ICT industry is shaped by several key processes, drawing insights from reputable sources such as IOSR International (2020), Suzuki, K., et al. (2020), Semiconductor Engineering (2024), Hitachi High-Tech (2024), and Tsuchizawa, T. (2011).

4-2. Stakeholder and Interdependency Analysis

The industrial structure we are examining is highly complex, characterized by a diverse array of processes and stakeholders who compete for and co-create value along the entire value from upstream to downstream activities chain as explored above. In developing a strategy for the IOWN concept at NTT, it is crucial to delineate fields where competition is advantageous versus fields where collaboration is necessary. To aid in this analysis, I have structured the dependencies of each value segment as illustrated in the Dependency Structure Matrix (DSM) below (Fig 4.1), and the details of the dependency (Table 4.2).

DSM		PIC Design (All)			SOI Substrate (All)			Epi-wafer (All)			Foundry & Fabs (All)			Transceiver (All)			Equipment (All)			Operators (All)			
		Design Software	Simulation	Prototyping	Material Preparation	Wafer Fabrication	Quality Control	Epitaxial Growth	Doping	Layer Verification	Photolithography	Etching	Testing and Packaging	Component Assembly	Signal Testing	System Integration	Routers and Switches	Servers	IoT Equipment	Telecommunications Companies	Data Center Operators	Cloud Service Operators	Software Service Providers
PIC Design	Design Software	2	x		x	x								x	x	x	x	x	x	x	x	x	x
	Simulation	x	2	x				x	x					x	x	x	x	x	x	x	x	x	x
	Prototyping		x	2									x	x	x	x	x	x	x	x	x	x	x
SOI Substrate	Material Preparation	x				x								x	x	x	x	x	x				
	Wafer Fabrication	x			x		x							x	x	x	x	x	x				
	Quality Control					x		x						x	x	x	x	x	x				
Epi-wafer	Epitaxial Growth		x				x		x		x	x	x	x	x	x							
	Doping		x					x		x	x	x	x	x	x	x							
	Layer Verification								x		x	x	x	x	x	x							
Foundry & Fabs	Photolithography							x	x	x		x	x	x	x	x	x	x	x				
	Etching							x	x	x	x		x	x	x	x	x	x	x				
	Testing and Packaging			x				x	x	x	x	x		x	x	x	x	x	x				
Transceiver	Component Assembly	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x
	Signal Testing	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x	x	x
	System Integration	x	x	x	x	x	x	x	x	x	x	x	x	x	x	2	x	x	x	x	x	x	x
Equipment	Routers and Switches	x	x	x	x	x	x				x	x	x	x	x	x				x	x	x	x
	Server	x	x	x	x	x	x				x	x	x	x	x	x				x	x	x	x
	IoT Equipment	x	x	x	x	x	x				x	x	x	x	x	x				x	x	x	x
Operators	Telecommunications Companies	x	x	x										x	x	x	x	x	x	1	x	x	x
	Data Center Operators	x	x	x										x	x	x	x	x	x	x	1	x	x
	Cloud Service Operators	x	x	x										x	x	x	x	x	x	x	x	1	x
	Software Service Providers	x	x	x										x	x	x	x	x	x	x	x	x	

Fig 4.1. DSM interdependency analysis. The areas described as "1" with blue hatching, where NTT has established business operations, seek to bolster its competitive edge through the application of photonics technology. The areas defined as "2" with gray hatching, a target for market entry, explore new opportunities by leveraging R&D outcomes under the IOWN concept. Mutual dependencies within these areas of the value chain are marked by "X". Green area with "X" means the existing and new businesses have synergy effects.

Table 4.2

The Interdependent Relationships of the Value Chain of Silicon Photonics within the ICT Industry

PIC Design	Depends on: ● **Equipment Manufacturers** and **Transceiver Integrators** rely on innovative PIC designs for the functionality of devices like routers, switches, and servers. High-performance PICs enable more efficient and faster devices. ● **Operators** need advanced PIC designs to meet the growing demands for data speed and network reliability.	
	Design Software	Depends on: ● Specifications and parameters that come from **Material Preparation** and **Wafer Fabrication** processes to ensure the design is compatible with the substrate capabilities.
	Simulation	Depends on: ● **Design Software** outputs to model how light interacts within the designed circuits. ● **Epitaxial Growth** and **Doping** results to accurately simulate the optical properties of the
	Prototyping	Depends on: ● **Simulation** results to build prototypes that reflect the designed performance characteristics. ● **Testing and Packaging** processes to validate prototype functionality before full production
SOI Substrate	● **Transceiver Integrators** need high-quality SOI substrates to ensure that the photonic circuits perform optimally. Substrate quality directly affects the efficiency and reliability of photonic devices. ● **Equipment Manufacturers** require these substrates to build devices that can operate at higher speeds with lower power consumption.	

	Material Preparation	Depends on: ● Inputs from **Design Software** to understand the required substrate specifications for the PIC
	Wafer Fabrication	Depends on: ● **Material Preparation** to provide the base materials needed for creating substrates.
	Quality Control	Depends on: ● **Wafer Fabrication** to ensure the wafers meet all specified quality standards before they are sent to the Epi-wafer Suppliers.
Epi-wafer Suppliers	● **Foundry and Fabs** depend on epi-wafers with precisely controlled layer properties for creating effective photonic devices. The performance of the final PICs is heavily influenced by the quality of these epi-wafers. ● **Transceiver Integrators** use these materials in devices where the optical properties of the layers are crucial for the conversion and handling of light signals.	
	Epitaxial Growth	Depends on: **Quality Control** in the SOI Substrate phase to ensure the substrates are ready for epitaxial layering.
	Doping	Depends on: **Epitaxial Growth** to have completed the layer deposition as the doping modifies these layers for desired electronic properties.
	Layer Verification	Depends on:

<table>
<tr><td></td><td></td><td>Doping to confirm that the impurities are correctly infused and the layers are functional for photonic operations.</td></tr>
<tr><td rowspan="4">Foundry and Fabs</td><td colspan="2">Transceiver Integrators rely on foundries and fabs to manufacture PICs with the exact specifications derived from the design phase. Any defects in fabrication can lead to significant performance issues in transceivers.
Equipment Manufacturers depend on the outputs from foundries for the assembly of high-quality and reliable optical components into their hardware.</td></tr>
<tr><td>Photolithography</td><td>Depends on:

Layer Verification to ensure the layers are correctly prepared for patterning.</td></tr>
<tr><td>Etching</td><td>Depends on:

Photolithography for the patterns that dictate where to etch the wafers.</td></tr>
<tr><td>Testing and Packaging</td><td>Depends on:

Etching to verify that the structures are correctly formed and function as intended.</td></tr>
<tr><td rowspan="2">Transceiver Integrators</td><td colspan="2">Depends on
PIC Design, SOI Substrate, and Epi-wafer Suppliers for the basic components and materials to build transceivers that meet specific technical standards.
Operators depend on the integrated transceivers for deploying in networks, affecting the overall network performance and capability.</td></tr>
<tr><td>Component Assembly</td><td>Depends on:

Testing and Packaging from Foundry and Fabs to receive components that are ready for assembly.</td></tr>
</table>

<table>
<tr><td rowspan="2"></td><td>Signal Testing</td><td>Depends on:

Component Assembly to ensure the assembled transceivers can convert signals effectively.</td></tr>
<tr><td>System Integration</td><td>Depends on:

Signal Testing to confirm that the components work within larger systems without issues</td></tr>
<tr><td>Equipment Manufacturers</td><td colspan="2">Depends on

● Transceiver Integrators which produce the integrated transceivers and other photonic components for assembling into final products like routers and switches. Especially, System Integration is important to incorporate transceivers that meet the performance criteria for high-speed data transmission.

● Operators’ requirements on this equipment for constructing modern, efficient, and high-speed data centers and telecommunication networks.</td></tr>
<tr><td>Operators</td><td colspan="2">● Directly influence the requirements for all upstream processes by setting the standards and expectations for network performance and reliability. Their needs drive the demand for more advanced silicon photonics technology, influencing both Equipment Manufacturers and Transceiver Integrators in terms of what products are developed and brought to market.

● Especially, equipment manufactured to deploy in their respective environments and ensure their networks and services can handle the enhanced capabilities provided by silicon photonics technology.</td></tr>
</table>

Note: Created based on Fig. 4.1 and Table 4-1.

NTT is already operational in the “1” region, prompting the question of how to expand its market share under the IOWN framework. Strategic options in this domain include engaging in full-scale competition with existing market players, collaborating in niche areas like R&D and product development while competing elsewhere, and isolating R&D and product development efforts from market pressures by segregating the target market segments with competitors to maintain current market share. Moreover, formulating responses to new market entrants and substitutes is critical. Conversely, in the “2” fields, NTT, as a new market entrant, must choose between surpassing existing competitors and collaborating with them to facilitate market entry.

The interactions between colored areas and “X” suggest that NTT's IOWN concept is interdependent with other market players in terms of business, product, and technology. These interdependencies influence cost structures for suppliers and pricing strategies for buyers, shaping the power dynamics and partnership opportunities within the market. Additionally, one value area might likely integrate into another to minimize costs and maximize revenue. A common strategy among vertically integrated companies is to consolidate their position through mergers and acquisitions of suppliers and customers.

4-3. The Scope of Creating Values by NTT

There are four types of research and development fields where NTT is trying to enter within these value chains: Semiconductor Devices, IT Equipment, Communication Networks, and ICT Solutions (Fig 4-2.)

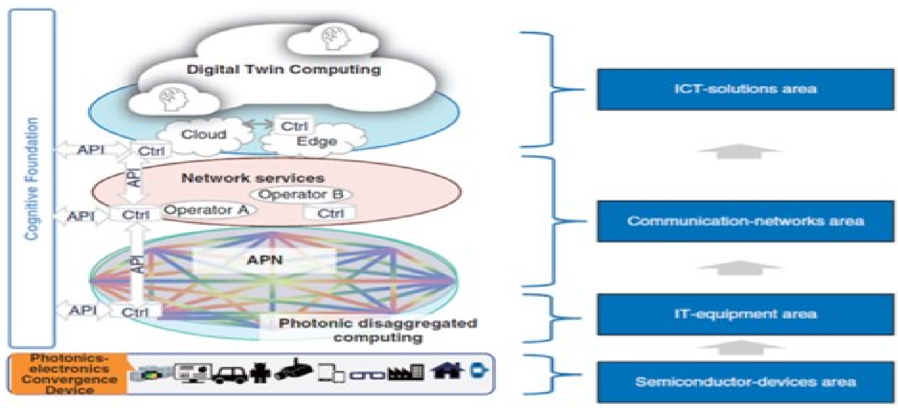

Fig. 4.2. 4 areas targeting the deployment of IOWN. From NTT Web Site:
https://www.rd.ntt/e/research/JN202311_23714.html

Semiconductor Device Domain

NTT Laboratories is focused on the research and development of "photoelectronic convergence technology," which merges circuits handling electrical and optical signals. This technology is part of our PIC Design activities, encompassing Design Software, Simulation, and Prototyping. The Labs have successfully prototyped these technologies and are incorporating the advancements into photoelectronic convergence devices for commercialization. Photoelectronic convergence technology, by merging optical and electrical circuits, aims to enhance performance through miniaturization, cost reduction, increased speed, and lower power consumption. The application scope of optical technology broadens as the integration scale of photoelectronic circuits expands, potentially extending to the optical transmitter/receiver sections within a single LSI chip in the future (Fig. 4.3).

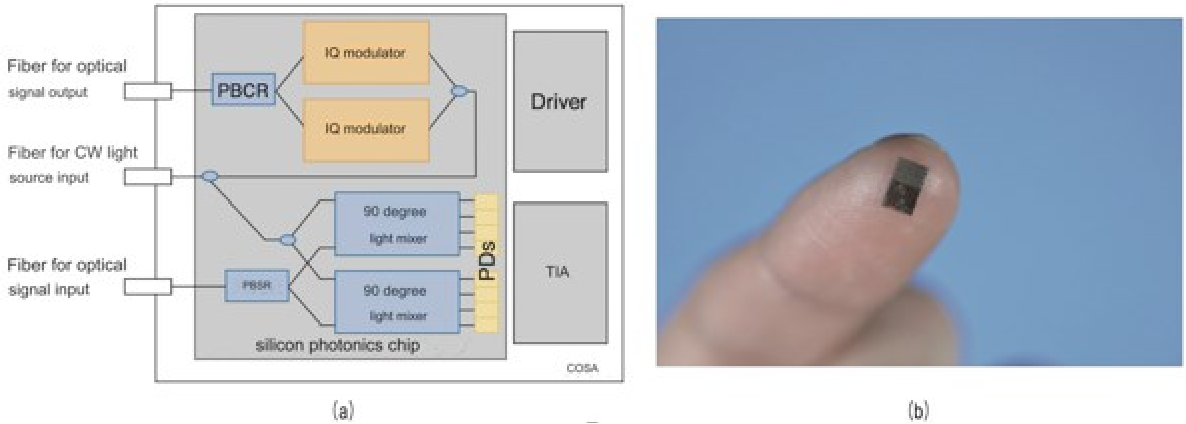

Fig. 4.3. (a) Conceptual diagram of COSA, and (b) Exterior photograph of the silicon photonic chip.

From NTT Technical Review, p12 (August, 2020)

IT Equipment Area

NTT Laboratories has proposed a novel computing architecture, Optical Disaggregated Computing, which leverages the unique properties of light to connect accelerators via optical interconnects (Fig 4.4). This architecture bypasses CPU bottlenecks, improving both performance and power efficiency. Unlike traditional architectures that enhance servers, this approach optimizes accelerator allocation based on specific application needs, thereby enhancing energy utilization.

Currently, we are developing the Super White Box (SWB) system based on this architecture, aiming to achieve carbon neutrality within the NTT Group and offering it as a server system or service platform to external parties. The transition to optoelectronic fusion devices is an incremental innovation process, beginning with silicon photonics-based compact optical modules as a first step and advancing to direct optical transmission elements around the central LSI in subsequent steps.

Initially aimed at computer-to-computer communication, the focus has shifted toward more localized applications like intra-device and board interconnects, with the prospect of integrating light-based operations within computing systems. The envisioned rack-scale intra-computer connections in disaggregated computers, which exceed several meters in transmission distance, benefit significantly from the conversion of electricity to light near the LSI. This is facilitated by the high-speed, high-density, low-power optoelectronic fusion devices of STEP2 and STEP3, enabling computers to achieve high processing performance with reduced power consumption, overcoming the limitations of electrical transmission.

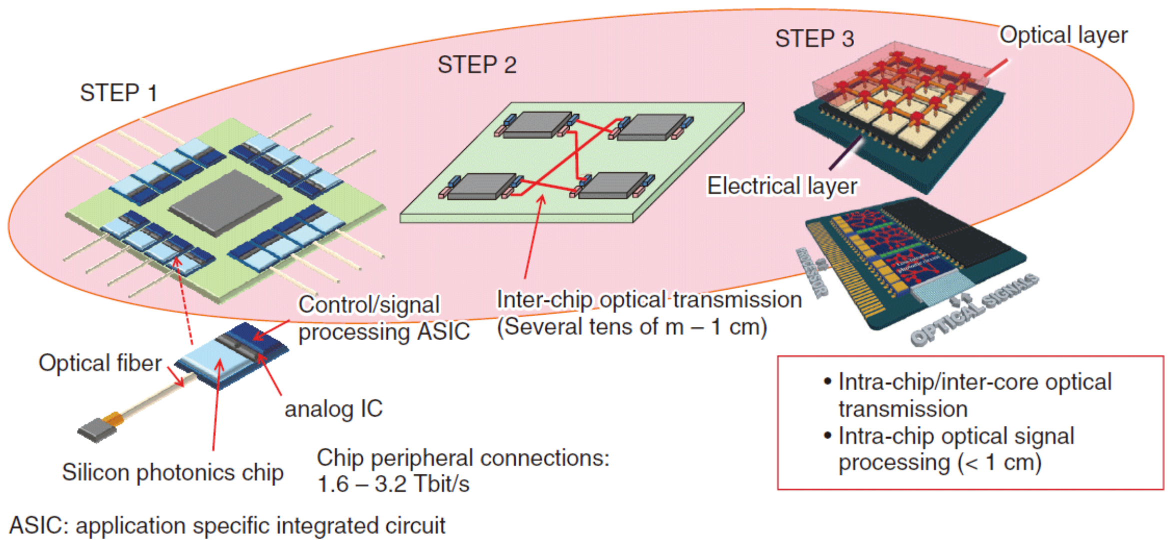

Fig. 4.4. Photonics Integration Device Roadmap from NTT Technical Review (August 2020) p8

Communication Network Domain

Employing optoelectronic devices and SWB technologies, NTT is transforming network services to offer capabilities beyond those possible with traditional technologies (Fig. 4.5). An example is the APN IOWN1.0, launched in March 2023 by NTT East and West, which supports high-capacity and low-latency connections ideal for applications such as telemedicine and smart factories. Future enhancements of APN IOWN will focus on reducing setup times, increasing capacity, and ensuring quality service for applications like data center interconnects and 6G communications.

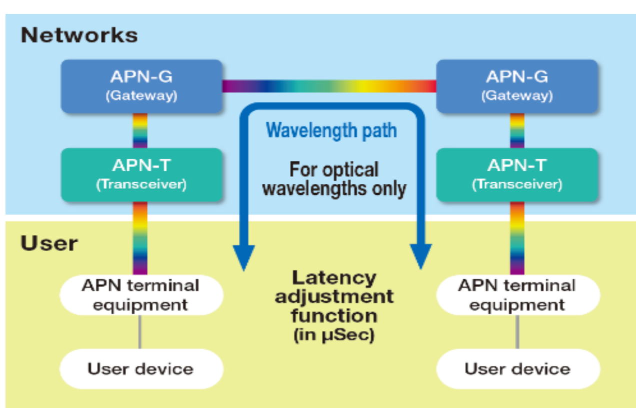

Fig. 4.5 Image of APN IOWN1.0.

From NTT Web Site: https://www.rd.ntt/e/research/JN202311_23714.html

ICT Solutions Domain

Alongside the IOWN infrastructure, NTT Laboratories is developing advanced security and data processing technologies. These include virtual data lakes for efficient data access, data brokers for seamless data transmission, and data sandboxes for confidential inter-organizational algorithm execution (Fig 4.6). The IOWN Platform combines these technologies with the IOWN infrastructure to enable real-time processing and secure data distribution, facilitating new business development and addressing industry-specific challenges. This comprehensive approach not only enhances the value of IOWN technology but also promotes its application across various sectors, supported by expert consultation and training.

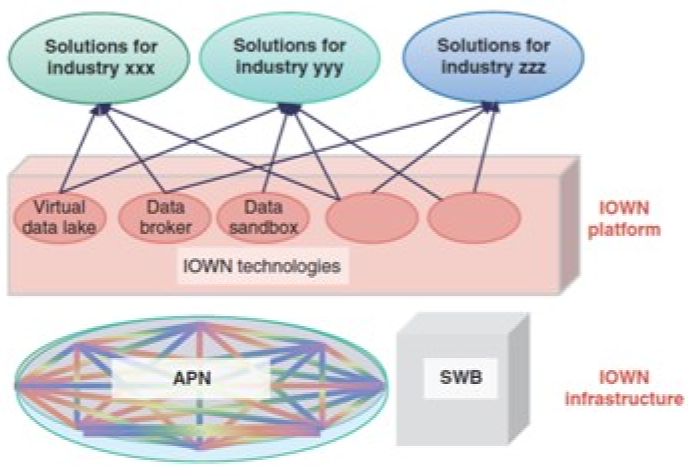

Fig. 4.6 Development as a solution service. From NTT Web Site: https://www.rd.ntt/e/research/JN202311_23714.html

Chapter Conclusion

Chapter 4 provides a comprehensive analysis of the value chain and stakeholder dynamics in the silicon photonics industry, highlighting NTT's strategic initiatives and collaborations to drive innovation and value creation within the IOWN framework.

First, it was found that the implementation of silicon photonics technology in the existing ICT value chain creates various added values. For example, the initial and most critical phase is where companies design Photonic Integrated Circuits (PICs) integrating multiple photonic functions onto a single chip. Traditional electronic circuit designs are augmented or replaced by PICs, handling higher data rates with lower power consumption and heat dissipation.

Moreover, it became clear that these ICT value chains involve complex collaborations with stakeholders to produce final products. For instance, when NTT enters the PIC domain, it must coordinate with multiple stakeholders for R&D, product specifications, manufacturing, and sales. In the design phase, specifications and parameters come from material preparation and wafer fabrication processes vendors to ensure the design is compatible with the substrate capabilities. Simulations use design software vendor outputs to model how light interacts within the designed circuits, and epitaxial growth and doping results to accurately simulate the optical properties. In the prototyping phase, simulation results are used to build prototypes that reflect the designed performance characteristics, and testing and packaging processes validate prototype functionality before full production.

As an important partner, equipment manufacturers and transceiver integrators rely on innovative PIC designs for the functionality of devices like routers, switches, and servers. High-performance PICs enable more efficient and faster devices. Market operators need advanced PIC designs to meet the growing demands for data speed and network reliability. Also, as a most critical stakeholders, operators, particularly cloud service providers, are powerful players who dictate value creation across the entire ICT value chain. Their influence can determine the success of products in the market. This analysis clarifies which players NTT should collaborate with for market research, product specifications, manufacturing, and sales. Additionally, operators, particularly cloud service providers, are powerful players who dictate value creation across the entire ICT value chain. Their influence can determine the success of products in the market.

Finally, the DSM analysis helped identify the players with whom NTT has existing collaborations and those in competitive relationships in both current and new market areas. This analysis will be further explored in Chapter 5 through Porter's Five Forces analysis.

Chapter 5: Porter's Five Force Analysis

The structure-conduct-performance (SCP) model is a foundational framework in industrial organization economics that analyzes the interrelationships between the structure of an industry, the conduct (or behavior) of firms within that industry, and the resulting performance. In this model, the structure refers to the basic characteristics of the market or industry, including the number of firms, market share distribution, entry and exit barriers, product differentiation, and cost structures. The structure is considered the foundation of the model, as it sets the context in which firms operate and compete. Also, the conduct encompasses the behaviors that firms undertake within the market structure. This includes pricing strategies, advertising, research and development, product strategy, and collusion. The conduct of firms is influenced by the market structure but also reflects the strategic choices made by firms. Finally, the relates to the outcomes of market structure and firm conduct, assessed through various measures such as efficiency, profitability, innovation, and consumer welfare.

The performance aspect of the model is crucial for policy implications, as it provides an indicator of the overall health and competitiveness of the market. This model was predominantly developed and refined in the mid-20th century and serves as a theoretical basis for much antitrust regulation and policy. For example, this work by Joe S. Bain (1951) is foundational, establishing the idea that market concentration could lead to market power, influencing performance. Often credited with early formulations of the SCP paradigm, Mason's work (1939) focused on how market structure affects economic outcomes.

Richard Caves and Michael E. Porter (1977) expand on how market structure affects competitive strategies and barriers to entry. F.M. Scherer and David Ross (1990) provide a comprehensive overview of the SCP model and its implications for industrial market structure and behavior. Michael E. Porter's Five Forces Analysis (1979, 2008) is another pivotal concept in the field of strategic management and industrial organization, which helps in understanding the competitive forces that shape industry attractiveness and profitability. According to these methodologies, it is essential to examine the industry structure, corporate behavior, and the relationship between overall industry performance and corporate profitability.

This session will examine industry competition environment which shapes industry attractiveness and profitability by Porter's Five Forces Analysis to explore optimal strategy and business opportunities within the four architectural layers of the IOWN concept.

5-1. Investment Performance within the Value Chain

Michael E. Porter (2008) used Return on Invested Capital (ROIC) as a key metric to analyze the profitability and attractiveness of different industries. The rationale behind using ROIC is that it provides a measure of how well a company is using its capital to generate profits. Unlike other profitability metrics, ROIC considers the amount of capital required to generate profits, making it a more comprehensive indicator of a company's efficiency and profitability.

This paper will analyze business profitability by comparing industry metrics such as ROIC by following Porter's model, alongside enterprise value per invested capital and Weighted Average Cost of Capital (WACC). The evaluation of enterprise value relative to invested capital is particularly vital for understanding how investments maximize enterprise value. A critical component of this analysis is the comparison of ROIC against WACC across various industries. This comparison serves as a key indicator of a company's ability to create value and sustain long-term growth. The WACC, which represents the average expected rate of return demanded by all security holders (both debt and equity), functions as a benchmark or hurdle rate in capital budgeting decisions. When a company's ROIC surpasses its WACC, it signifies that the firm is generating returns higher than its capital costs, thereby creating value. Conversely, if the WACC exceeds the ROIC, it implies potential value destruction, indicating that the firm is not generating sufficient returns to cover its capital costs.

This analytical framework assists in making strategic investment decisions based on industry standards and the distinct competitive advantages of companies within those industries. For the analysis of these financial metrics, I utilized the comprehensive datasets provided by Aswath Damodaran of the NYU Stern School of Business, a renowned expert in this domain. His data encompass a wide range of industries and countries, offering a robust foundation for this study.

Investment Performance Analysis Results by Industry

The analysis of average figures from 2013 to 2022 (Table 5.1) reveals compelling trends in various sectors and regions. As a global perspective, computer services and semiconductor equipment exhibit high profitability, with return on invested capital (ROIC) figures of 21.10% and 14.98%, respectively, coupled with manageable risks, indicated by ROIC volatility rates of 7.07% and 23.53%. Moreover, they consistently outperform their weighted average cost of capital (WACC), with ROIC-WACC differentials of 12.86% and 5.40%, respectively. In contrast, sectors like software (Internet) and electronics (consumer & office), while promising, entail higher volatility and risks, with ROIC volatility rates of 46.65% for both, and lower profitability, reflected in ROIC figures of 10.71% and 8.85%, respectively. These sectors also demonstrate narrower ROIC-WACC spreads, indicating challenges in generating returns higher than capital costs. Factors such as regional stability, regulatory environment, and market maturity significantly influence volatility and EV/Invested Capital ratios within these sectors.

The telecom industry, encompassing Wireless, Services, and Equipment sectors across the US, EU, and Japan, presents a nuanced landscape characterized by regional variations in profitability, risk, and investment performance. Understanding these differences is crucial for both existing players aiming to defend their market positions and new entrants planning to penetrate these markets. The EU stands out with consistently high profitability across all sectors, particularly in Telecom Services where the ROIC is 0.2246. This suggests effective market positioning and robust sector health. Japan shows strong profitability in the Telecom Equipment sector with a ROIC of 0.2035, likely reflecting advanced technological capabilities and production efficiencies. The US displays slightly lower profitability, for example, in the Telecom (Wireless) sector with a ROIC of 0.0491, compared to the EU (0.0514) and Japan (0.0327). On the other hand, the volatility is most pronounced in the US, particularly in the Telecom (Wireless) sector with a volatility of 0.4934. This high volatility suggests a dynamic market with fluctuating returns, representing both higher risks and potential rewards. The EU and Japan show lower volatility, indicating more stable markets.

For instance, the Telecom Services sector in the EU has a volatility of 0.1911, and in Japan, it is 0.2301. For investment performance, many sectors in Japan and the EU show positive ROIC - WACC, indicating that investments are yielding returns above the cost of capital. Notably, Japan's Telecom Equipment sector has an ROIC - WACC of 0.1342, and the EU's Telecom Services sector stands at 0.1687. The US presents mixed results; for example, the Telecom (Wireless) sector has a negative ROIC - WACC of -0.0284, suggesting challenges in surpassing investment costs, possibly due to intense competition or higher operational costs. From these results, we can anticipate that new entrants may find attractive opportunities in the EU and Japan, given their lower volatility and higher profitability, such as the EU's Telecom Services sector with a ROIC of 0.2246 and ROIC - WACC of 0.1687. Their entry strategies could be region-specific, with a focus on innovative product and service offerings to capture market share in competitive environments like the US. Adapting to local market dynamics, regulatory frameworks, and consumer preferences is key for successful market penetration. In contrast, for the existing players like NTT and Cisco, innovation and customer retention are crucial in volatile markets like the US. Companies need to focus on technology advancements and enhancing customer service to protect market share.

The computer industry, specifically within the Computer Services and Computers/Peripherals sectors, shows distinct regional differences across the US, EU, and Japan in terms of profitability, risk, and investment performance. The EU significantly leads with a ROIC of 0.3962, indicating a highly profitable market. This suggests that businesses in the EU are not only well-established but also highly efficient compared to their counterparts in the US (ROIC 0.2772) and Japan (ROIC 0.0974). The sector shows relatively low volatility across all regions, with the US exhibiting the least (0.1649). This stability in returns can be appealing for new entrants looking for predictable business environments. Also, the EU stands out with the highest ROIC - WACC (0.3208), suggesting that investments in this region are generating substantial returns above the cost of capital. Conversely, Japan shows the lowest (0.0297), indicating less favorable investment conditions.Overall, in high-profit regions like the EU, existing firms should focus on maintaining their market leadership and competitive advantages, possibly through innovation and customer engagement. In lower-risk areas like the US, companies should continue to optimize operations to maintain consistent returns. For new business entry in this industry, the EU, with its high profitability and investment returns, presents a lucrative opportunity for new entrants, though they should be wary of potential competition and market saturation. Entry in Japan should be cautious, focusing on niche markets or innovative offerings to overcome lower profitability and performance metrics.

For the Computers/Peripherals sector, the US emerges as the most profitable region in this sector with a ROIC of 0.3057. This reflects strong operational efficiencies and perhaps a favorable market structure that supports higher returns. The EU experiences the highest volatility (0.4668), suggesting a dynamic and potentially unpredictable market. This could stem from rapid technological changes or aggressive competitive dynamics. From these data, the US leads with a ROIC - WACC of 0.1961, making it an attractive region for investment. The higher risk in the EU is not correspondingly rewarded, as indicated by a lower ROIC - WACC (0.0971). As a result, in volatile markets like the EU, firms should focus on risk management and innovation to stay ahead of rapid market changes. US firms should leverage their profitability advantage by investing in market expansion and technology advancements to fend off competition. On the other hand, the attractive profitability and investment performance in the US make it an appealing market for new entrants in the Computers/Peripherals sector. New entrants in the EU need to be prepared for high volatility and should consider strategies that differentiate their offerings or capitalize on emerging market trends.

The semiconductor industry shows varied dynamics across different regions, with the US typically leading in profitability and investment performance. The US leads with a ROIC of 0.1705, suggesting higher profitability within this region. The EU and Japan have lower ROIC values, 0.1019 and 0.0836 respectively, indicating less efficient returns on invested capital. Also, the EU shows the highest volatility (0.3833), indicating a potentially riskier environment for investment, compared to the US (0.2351) and Japan (0.2584). Ultimately, the US is the only region showing a positive ROIC - WACC (0.0612), suggesting that investments are generating returns above the cost of capital. Both the EU and Japan show negative values, highlighting challenges in surpassing capital costs. From these results, particularly in the US, maintaining technological leadership through continuous R&D can help sustain high profitability. In the EU, companies should focus on hedging strategies and operational efficiencies to manage high volatility and improve negative ROIC - WACC. On the other hand, given its positive investment performance, new entrants can consider the US market, particularly if they can introduce innovative technologies or cost efficiencies.

New entrants should be cautious and possibly target niche segments like the EU and Japan where they can offer distinct advantages. In the semiconductor equipment sector, the US again shows the highest ROIC (0.2410) within this sector, followed by the EU (0.1891) and Japan (0.1568) and all regions exhibiting similar levels of volatility, with the US slightly higher. This indicates a consistently dynamic market across regions. The US leads with the highest ROIC - WACC (0.1329), making it the most attractive region for investments in semiconductor equipment. From these figures, companies in the US should continue to innovate, as their lead in profitability and investment performance can attract competitors. In regions with lower profitability like Japan, companies should explore market expansion or diversification strategies to improve their financial metrics. Also, the positive investment performance indicates that the US is a viable market for new businesses, especially if they can leverage technological advancements. New entrants might benefit from forming partnerships or joint ventures in these regions like the EU and Japan to mitigate risks and capitalize on existing market structures.

In the electrical equipment sector, the US leads with a significant ROIC of 23.69%, suggesting robust sector performance. The EU follows with a ROIC of 14.97%, and Japan has the lowest at 7.33%. Both Japan and the EU exhibit high volatility, 33.31% and 33.78% respectively, compared to a lower 15.68% in the US. Overall, the US shows excellent investment conditions with an ROIC - WACC of 13.16%, while Japan faces challenges with a slightly negative ROIC - WACC of -0.09%. Regarding electronics (consumer & office), lower profitability in the US at 6.84%, with the EU performing moderately better at 12.13%, and Japan at 9.62%. As a risk, extremely high volatility in the US at 97.31% suggests a highly unstable market, in stark contrast to the more stable 14.77% in the EU. From investment performance perspective, negative ROIC - WACC in the US at -3.73%, with more favorable figures in the EU (2.77%) and Japan (1.83%). Finally, in the software (Internet & system/application) sector, exceptionally high ROIC in Japan for both software categories, with 54.50% in Internet and 28.90% in System & Application, showcasing strong sector performance. The US and EU also show healthy ROIC figures but are less than Japan. However, high volatility in all regions, particularly in the EU for Internet software at 70.55%, and Japan for System & Application at 65.95%, indicating dynamic and potentially risky markets. Ultimately, Japan shows extraordinary investment performance, especially in the Internet sector with a ROIC - WACC of 45.68%. The US and EU also show positive figures but are substantially lower than Japan.

In emerging economies, all ROIC-WACC values are negative, indicating high financial risk for introducing new technology. It is better for a new entry to avoid deployment in these regions. Instead, focus should be placed on evaluating entry into more favorable markets such as Japan, the US, and Europe, where the barriers to entry are comparatively lower.

Table 5.1

Average ROIC, WACC, the Volatility, and the Investment Performance from 2013 - 2022

Region	IOWN Business Domain	Industry Sectors	EV/Incvested Capital		ROIC		WACC		ROIC - WACC
			Av. Valuables	Av. Volatility	Av. Valuables	Av. Volatility	Av. Valuables	Av. Volatility	
		Electrical Equipment	2.56734443	27.92%	10.93%	23.86%	8.68%	22.68%	2.25%
	IT Solutions	Electronics (Consumer & Office)	1.16903958	20.87%	8.85%	46.65%	8.77%	22.50%	0.08%
		Software (Internet)	5.77787536	42.63%	10.71%	65.57%	9.59%	24.54%	1.12%
		Software (System & Application)	6.19591233	28.25%	18.23%	17.10%	9.56%	28.27%	8.67%
		Telecom (Wireless)	1.45103542	5.88%	8.64%	11.50%	6.76%	20.47%	1.88%
Global	Network & Infrastructure	Telecom. Services	1.63481167	5.45%	11.32%	15.24%	6.45%	31.68%	4.87%
		Computer Services	3.81439867	20.20%	21.10%	7.07%	8.24%	21.45%	12.86%
	IT Device	Computers/Peripherals	2.82685772	30.24%	17.43%	23.34%	9.51%	17.97%	7.92%
		Telecom. Equipment	2.54990402	15.06%	11.33%	15.96%	9.10%	19.81%	2.23%
	Semiconductor	Semiconductor	2.90076054	30.97%	14.98%	25.73%	11.28%	26.40%	3.70%
		Semiconductor Equip	3.6409991	40.61%	17.61%	23.53%	12.21%	27.32%	5.40%
		Electrical Equipment	4.55869942	27.39%	23.69%	15.68%	10.53%	37.70%	13.16%
	IT Solutions	Electronics (Consumer & Office)	2.75910701	53.25%	6.84%	97.31%	10.57%	43.11%	-3.73%
		Software (Internet)	6.03854819	49.11%	10.48%	54.00%	11.05%	42.66%	-0.57%
		Software (System & Application)	6.54069384	29.45%	19.77%	17.44%	10.51%	36.33%	9.25%
		Telecom (Wireless)	1.39041782	16.59%	4.91%	49.34%	7.75%	40.83%	-2.84%
US	Network & Infrastructure	Telecom. Services	2.05360438	10.46%	15.81%	34.36%	7.84%	47.19%	7.97%
		Computer Services	4.24825468	17.37%	27.72%	16.49%	9.52%	33.03%	18.20%
	IT Device	Computers/Peripherals	5.65193699	36.89%	30.57%	28.32%	10.97%	32.99%	19.61%
		Telecom. Equipment	3.69312986	22.45%	18.47%	16.07%	9.82%	33.39%	8.64%
	Semiconductor	Semiconductor	3.38606235	31.32%	17.05%	23.51%	10.93%	38.36%	6.12%
		Semiconductor Equip	4.00084336	44.96%	24.10%	24.36%	10.81%	35.50%	13.29%
		Electrical Equipment	3.41078787	25.29%	14.97%	33.78%	8.97%	36.69%	6.00%
	IT Solutions	Electronics (Consumer & Office)	2.20658156	19.74%	12.13%	14.77%	9.36%	40.52%	2.77%
		Software (Internet)	5.39121305	19.28%	13.39%	70.55%	7.86%	46.75%	5.54%
		Software (System & Application)	5.52874727	24.98%	22.46%	19.11%	7.84%	43.20%	14.62%
		Telecom (Wireless)	1.26972222	8.98%	5.14%	17.27%	6.02%	42.50%	-0.88%
EU	Network & Infrastructure	Telecom. Services	1.55191563	4.30%	22.46%	19.11%	5.59%	48.58%	16.87%
		Computer Services	7.06947786	31.75%	39.62%	19.39%	7.54%	42.03%	32.08%
	IT Device	Computers/Peripherals	2.81628421	32.70%	18.15%	46.68%	8.44%	45.10%	9.71%
		Telecom. Equipment	1.2743608	24.33%	7.60%	65.95%	8.38%	41.60%	-0.77%
	Semiconductor	Semiconductor	2.63476064	34.22%	10.19%	38.33%	11.12%	39.44%	-0.92%
		Semiconductor Equip	6.72817349	33.91%	18.91%	19.17%	12.46%	41.12%	6.45%
		Electrical Equipment	1.44556365	25.12%	7.33%	33.31%	7.42%	27.92%	-0.09%
	IT Solutions	Electronics (Consumer & Office)	1.15025928	16.39%	9.62%	65.81%	7.79%	24.45%	1.83%
		Software (Internet)	6.28285095	65.07%	54.50%	47.70%	8.82%	30.59%	45.68%
		Software (System & Application)	6.86940748	27.26%	28.90%	65.95%	8.95%	29.16%	19.95%
		Telecom (Wireless)	1.49912725	17.51%	7.90%	33.53%	5.38%	43.07%	2.52%
Japan	Network & Infrastructure	Telecom. Services	0.97564647	19.17%	8.92%	33.98%	5.88%	30.72%	3.04%
		Computer Services	1.81861359	17.76%	9.74%	17.53%	6.76%	26.95%	2.97%
	IT Device	Computers/Peripherals	0.9289396	14.91%	5.72%	48.05%	7.06%	29.90%	-1.34%
		Telecom. Equipment	0.61157294	18.68%	4.76%	82.67%	7.14%	24.05%	-2.38%
	Semiconductor	Semiconductor	1.6082522	27.47%	8.36%	25.84%	9.73%	34.58%	-1.37%
		Semiconductor Equip	2.9538352	37.65%	15.05%	27.66%	10.77%	36.98%	4.29%
		Electrical Equipment	2.26673632	35.72%	8.09%	26.43%	14.08%	17.83%	-5.99%
	IT Solutions	Electronics (Consumer & Office)	1.02630998	26.54%	4.69%	67.37%	13.76%	15.91%	-9.08%
		Software (Internet)	4.7749151	47.55%	12.90%	29.66%	15.68%	17.49%	-2.78%
		Software (System & Application)	4.95306678	41.04%	10.30%	60.82%	17.14%	17.39%	-6.84%
		Telecom (Wireless)	1.47159477	7.04%	10.51%	17.86%	12.68%	19.50%	-2.16%
Emerging Countries (China, India)	Network & Infrastructure	Telecom. Services	1.44878304	7.14%	10.12%	13.02%	12.06%	22.18%	-1.93%
		Computer Services	3.63546822	24.40%	17.86%	12.65%	14.45%	18.01%	3.41%
	IT Device	Computers/Peripherals	1.29983669	30.13%	11.67%	32.22%	15.64%	17.31%	-3.96%
		Telecom. Equipment	2.31584786	26.64%	5.29%	13.98%	15.94%	19.18%	-10.65%
	Semiconductor	Semiconductor	2.5311724	33.71%	14.34%	31.65%	17.64%	18.89%	-3.29%
		Semiconductor Equip	2.53060801	43.14%	11.87%	33.32%	18.20%	13.07%	-6.33%

Note: All of the results were calculated based on the original data of Aswath Damodaran's database: https://pages.stern.nyu.edu/~adamodar/New_Home_Page/dataarchived.html#corpgov>

5-2. Porter's Five Forces Analysis

Porter's Five Forces framework provides a method for analyzing the competitive forces that shape every industry and helps determine an industry's weaknesses and strengths. The framework is especially useful for evaluating whether entering into a specific industry could be profitable, or understanding whether a company can sustain its competitive advantage. This Five Forces Analysis will assess NTT's competitive positioning based on the previously analyzed Value Chain, as well as its interactions with customers, partners, and competitors. Additionally, as an introduction to the Five Forces analysis, we will summarize the potential business domain options available in advance.

Definition of Business Model

IOWN aims for an industrial transformation that replaces all elements from upstream to downstream in ICT services with optical energy instead of electrical energy, making the establishment of a business scheme highly complex. It is inefficient to cover all business areas from upstream to downstream (Fig. 5.1). Focus should instead be on areas where unique strengths can be best utilized and partnerships should be formed in other areas to develop the concept.

To simplify complexity, the semiconductor sector is defined as the upstream business, while IT device usage and related ICT services are defined as the downstream business. For each, three representative business options are summarized. There are also concepts for implementing IOWN in semiconductors or Cloud, Telecommunication, and data center environments and extending it to end-user devices like Customer Devices, IoT, and machinery (for example, replacing all components within devices like iPhones with optical energy, and converting all data processing between cloud and iPhone to optical, or transforming vehicles to use optical energy for autonomous driving). However, the immediate priority is the implementation of optical energy in the ICT domain (Router & Switch, Transceiver, Server & Storage, and the networks, data centers, and clouds that use them), and thus, due to the complexity, other considerations will not be discussed here.

Upstream Business Models:

- IP: Following the model of companies like ARM and Imagination, providing semiconductor design IP to Fabless and Integrated Device Manufacturers (IDM) and charging based on IP usage.
- Fabless: Companies like Nvidia, Qualcomm, AMD, BRPADCPM, and Apple mainly engage in fabless semiconductor design, outsourcing manufacturing to foundries, assembly, testing, and packaging companies.
- IDM (Companies like Intel, Samsung, KIOXIA, and Texas Instruments handle semiconductor design and manufacturing in-house.

Downstream Business Models:

- IT Device Maker: Companies designing or manufacturing semiconductors for new devices such as Transceivers, Routers & Switches, and Servers & Storage, which they create themselves.
- Semiconductor Distributer: Selling designed or manufactured semiconductors to companies involved in Transceivers, Routers & Switches, and Servers & Storage.
- ICT Operators: Selling IOWN-enabled Transceivers, Routers & Switches, and Servers & Storage to Cloud, Telecommunication, and data center sectors.

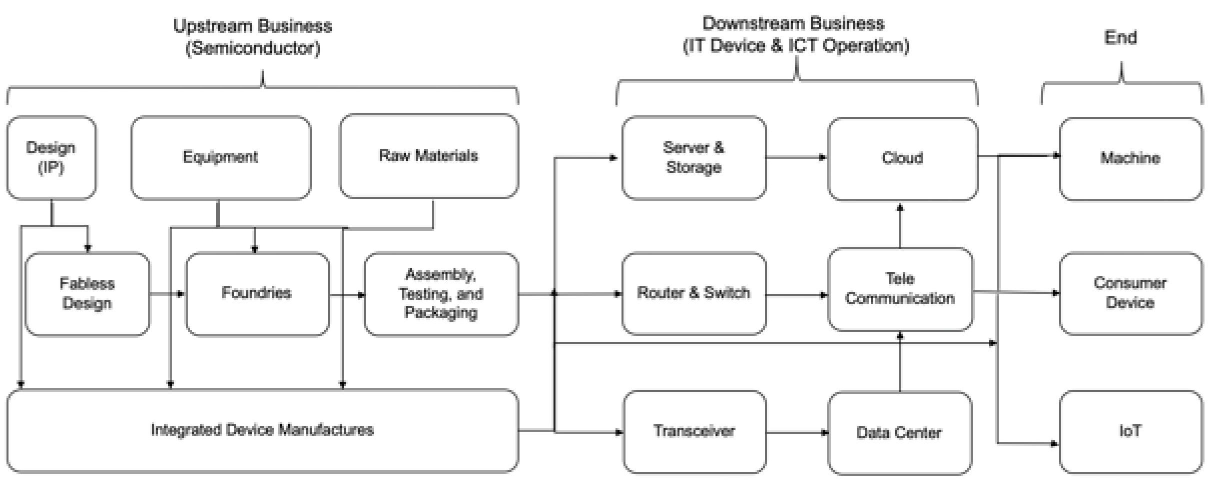

Fig. 5.-1 Business stream targeting the deployment of IOWN

5-2-1. Rivalry Among Existing Competitors

This force is the major determinant of the competitiveness of the industry. High rivalry limits the profitability of an industry. The intensity of rivalry is influenced by the rate of industry growth, the intensity of industry competition, or service characteristics, height of entry barriers, and the diversity of competitors. As discussed in Chapter 3, we will examine the competitive landscape of the semiconductor industry, especially focusing on including integrated circuit (IC) design services in silicon photonics, IT devices (optical transceiver modules as an embedded component), and ICT solutions (data centers, communications, and cloud services). This chapter examines key aspects of the industry, including the rate of industry growth, the intensity of competition, and the characteristics of services. Additionally, for the height of entry barriers and the diversity of competitors, these factors will be further explored in the section dedicated to assessing the threat of new entrants to avoid duplication and reduce the complexity of the analysis

Industry Growth

For the rate of industry growth, the higher the industry growth rate, the less hostility is expected among firms vying to capture market share. As an overview of the trend of the IT industry, according to Statista (Fig. 5.2), global spending on IT—including devices such as PCs, tablets, mobile phones, and printers, along with data center systems, enterprise software, and communication services—reached approximately $4.7 trillion in 2023. This figure is projected to rise to a remarkable $5 trillion by 2024, underscoring a robust worldwide investment in the IT and ICT industry.

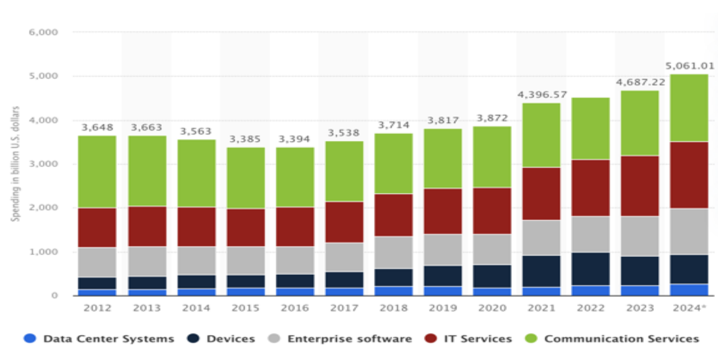

Fig. 5.2. IT spending worldwide from 2012 to 2024, by segment(in billion U.S. dollars).

From Statista 2024: https://www.statista.com/statistics/268938/global-it-spending-by-segment/

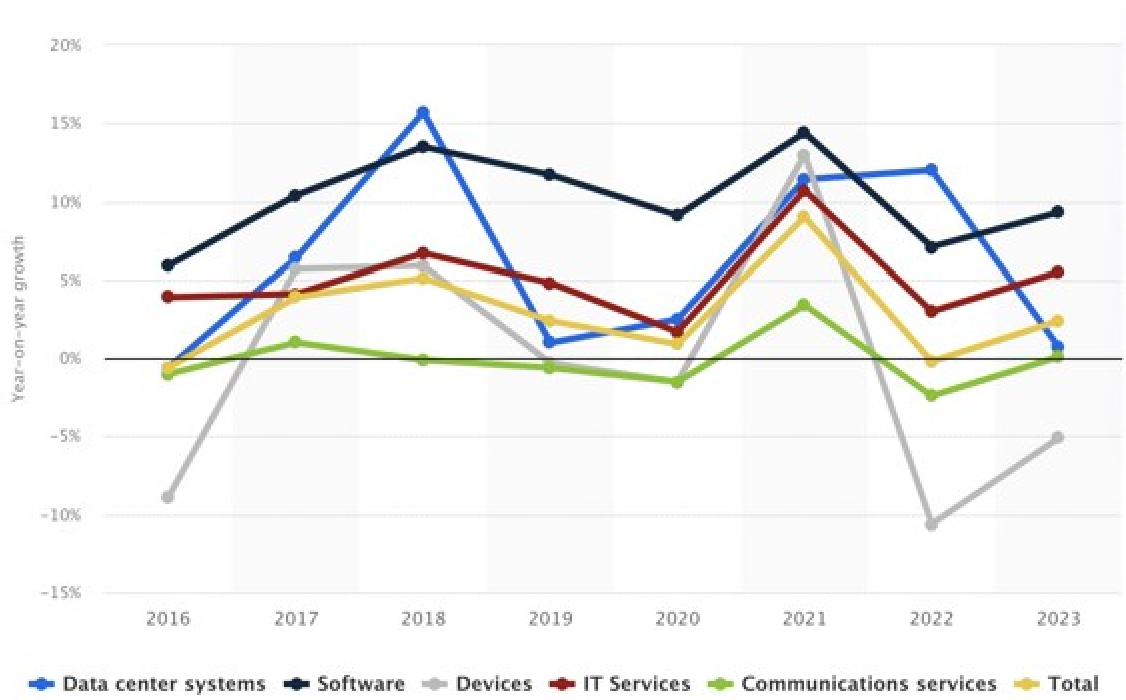

Fig. 5.3. IT spending year-over-year growth worldwide 2016-2023, by segment.

From Statista 2024: https://www.statista.com/statistics/268938/global-it-spending-by-segment/

The ICT industry has witnessed notable shifts in market dynamics from 2012 to a projected 2024, spanning various segments such as Data Center Systems, Devices, Enterprise Software, IT Services, and Communication Services. Each segment reflects unique growth trends and strategic priorities shaped by technological advancements and market demands.

Data Center Systems have exhibited a consistent increase in investment, growing from $3.648 billion in 2012 to an estimated $3.872 billion in 2024. This gradual growth is driven by the expanding need for robust data processing infrastructure, likely fueled by the proliferation of cloud computing and enhanced enterprise data services. The sustained investment suggests a strong industry focus on building data capacity to support an increasingly digital economy. Devices, encompassing spending on mobile devices, PCs, and other hardware, have shown minor fluctuations but remain a significant component of overall IT spending. From $3.663 billion in 2012, it is projected to slightly increase to $3.874 billion by 2024. This segment's relatively stable growth indicates continued consumer and business demand for personal and business computing solutions, albeit with signs of market saturation as indicated by the slowing growth rates.

In contrast, the Enterprise Software segment has demonstrated a pronounced upward trajectory, with spending increasing from $3.356 billion in 2012 to an expected $4.974 billion in

2024. This robust growth underscores businesses' increasing reliance on sophisticated software solutions for operations, customer relationship management (CRM), and resource planning, highlighting the critical role of digital tools in modern business practices.

IT Services have also seen consistent growth, rising from $3.394 billion in 2012 to a forecasted $4.534 billion in 2024. The growth in this segment reflects the escalating complexity of IT environments and a shift towards outsourcing key IT functions such as cloud migration and consulting services, indicating a broader trend of leveraging external expertise to enhance operational efficiencies.

Communication Services have experienced the least volatility among the segments, with spending rising from $3.374 billion in 2012 to an estimated $3.872 billion in 2024. Despite the modest growth, this sector remains critical, underscored by high market saturation and intense competition among major telecom companies, reflecting the foundational nature of communication services in both personal and professional spheres.

Post-2020 (Fig 5.3), all segments have shown a rebound in growth, particularly noticeable in Enterprise Software and IT Services, which experienced significant growth spikes in 2021 and 2022. This recovery likely reflects the accelerated digital transformation initiatives following the pandemic's impact, emphasizing the strategic shift towards more integrated and advanced digital solutions. In terms of industry competition, the level varies significantly across segments. Devices and Communication Services exhibit high competition due to ongoing consumer demand and rapid technological innovations. In contrast, the competition in IT Services and Software is moderate to high, with firms increasingly striving to differentiate their offerings through cutting-edge technologies such as cloud computing and AI. Data Center Systems face lower competition, constrained by the high capital requirements and long-term customer relationships that tend to stabilize market shares and limit the entry of new competitors.

Digital Transformation Prediction

According to the IDC (2024), global spending on digital transformation is projected to reach 2.15 trillion U.S. dollars, with forecasts predicting an increase to 3.9 trillion by 2027 (Fig. 5.3). Digital transformation involves the integration of digital technology into all areas of business, fundamentally altering how organizations operate and deliver value to customers. This shift includes transitioning data to cloud-based systems, adopting digital tools for communication and collaboration, and automating traditional processes.

The impetus for this rapid growth stems from multiple factors, including the COVID-19 pandemic, which significantly accelerated digital adoption in 2020 as organizations worldwide adapted to remote work. Although the pandemic has subsided, the prevalence of remote work continues to rise, further driving digital transformation. Additionally, pressures from customer demands and competitive dynamics necessitate ongoing technological advancements. By embracing digital transformation, organizations gain agility, enhance their capacity for innovation, and strengthen their resilience to market fluctuations.

As of the second half of 2021, spending on industrial digital transformation exceeded one trillion U.S. dollars across six key sectors. In recent years, firms have increasingly prioritized digital transformation, leveraging technologies such as digital twins and advanced analytics. These tools have proven crucial in helping organizations address supply chain challenges, enhance resilience, and achieve sustainability goals. This strategic emphasis on digital technology enables companies to optimize operations and adapt more effectively to evolving market demands and environmental considerations.

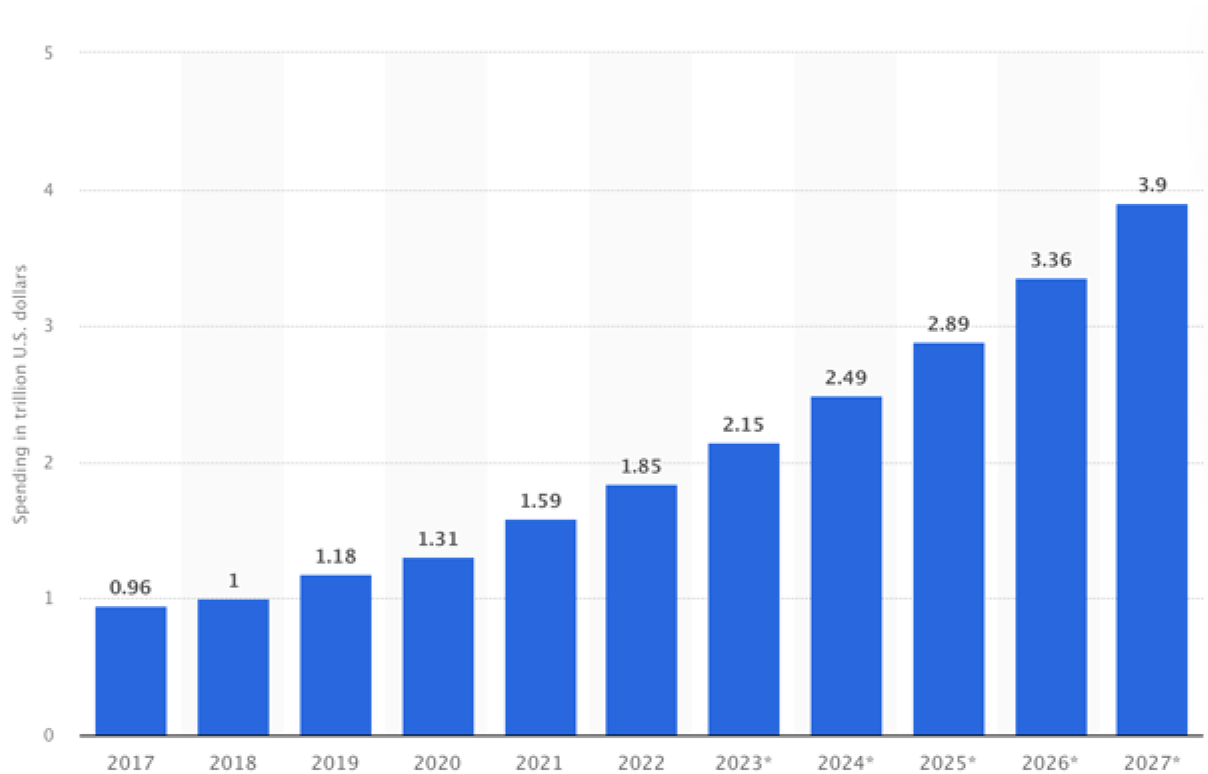

Fig. 5.3. Spending on digital transformation technologies and services worldwide from 2017 to 2027(in trillion U.S. dollars). From Statista 2024: https://www.statista.com/statistics/870924/worldwide-digital-transformation-market-size/

AI Market Prediction

According to Next Move Strategy Consulting, AI market, valued at nearly $100 billion as of 2022, is projected to expand significantly, reaching close to $2 trillion by 2030 (Fig. 5.4). This robust growth encompasses a broad spectrum of industries including supply chains, marketing, product development, and research. Emerging technologies such as chatbots, image-generating AI, and mobile applications are poised to drive innovation within this sector.

As one of the outstanding events, the introduction of Chat GPT 3.0 in 2022 marked a pivotal moment in the evolution of generative AI, reflecting a surge in public and academic interest. This trend is exemplified by a dramatic increase in Google searches for generative AI from 2022 to 2023. Anticipated updates to existing models and the development of new generative AI programs suggest that this interest will continue to grow. Asian countries, plus 1,000 companies in Latin America. In 2022, 35% of companies integrated AI into their operations, up 4% from 2021, driven by easier access and implementation, advancements in AI technologies, and a rise in AI-skilled professionals. AI tools and skills are increasingly business-focused, enhancing growth. There's a significant adoption gap between large corporations and SMBs. Large enterprises are 100% more likely to implement AI than SMBs, a notable rise from 69% in 2021. Large companies are actively integrating AI, while SMBs vary from considering to having no AI plans. China and India lead in AI usage with about 60% adoption among IT professionals, outpacing South Korea, Australia, the US, and the UK. Industries like automotive and financial services are particularly inclined towards AI.

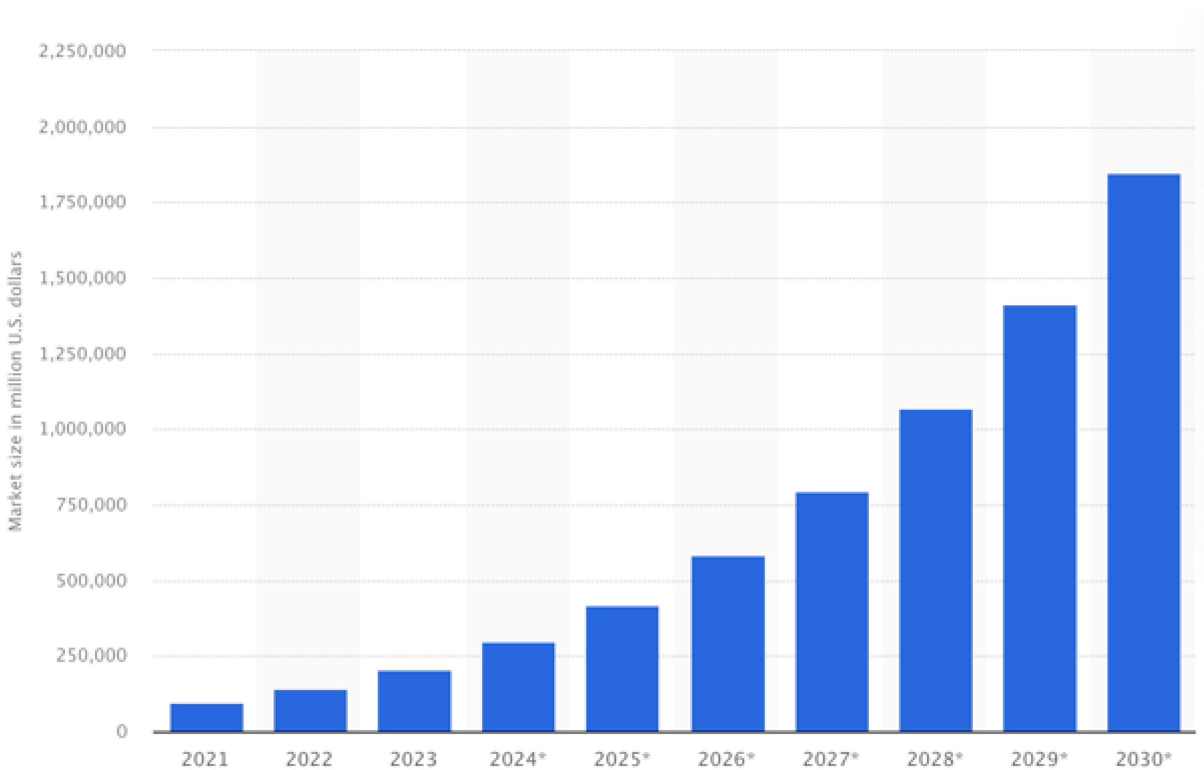

Fig. 5.4. AI market size worldwide in 2021 with a forecast until 2030(in million U.S. dollars).

From Statista 2024: https://www.statista.com/statistics/1365145/artificial-intelligence-market-size/

Large companies are expanding AI into their applications and processes over the next year, while smaller companies focus on R&D. Many companies recognize a deficiency in cloud and data infrastructure, which hinders AI adoption. While some companies prefer private cloud environments, current AI users often use hybrid and multi-cloud setups for better data access and model operation. There's a global preference for private clouds, with some regions favoring mixed environments. Korean companies prefer public clouds more than the average. In 2022, there's an 8% increase in IT professionals emphasizing the importance of running AI where the data resides, highlighting its significance for their companies.

Semiconductor Market Prediction

Also, semiconductors play a crucial role in various sectors, notably in smartphones, where advancements support technologies like extended reality (XR), 5G, and AI. The demand is also expanding in servers and data centers, where semiconductors enable cloud services and AI applications, including edge computing. In the industrial and automotive sectors, the increasing integration of smart technologies drives the need for sophisticated semiconductors. Technically, four markets can be differentiated within the semiconductors market, integrated circuits, optoelectronics, discrete semiconductors, and sensors & actuators (Table 5.2).

Table 5.2

Four markets within the semiconductors

Integrated Circuits	**Optoelectronics**	**Discrete Semiconductors**	**Sensors & Actuators**
Integrated circuits (ICs) are semiconductors that are manufactured using several interconnected devices. These devices are cost-	The Optoelectronics market includes semiconductor devices that are used for light-sensing and -emitting functionalities. This includes devices	Discrete semiconductors are the basic type of semiconductors, often built using a single semiconductor device. Unlike complex integrated	The Sensors & Actuators market includes semiconductor devices that are made for measuring physical, chemical, and biological properties such as temperature,

effective and efficient when compared to the number of discrete devices used to achieve the same functionality.	such as displays, light-emitting diodes (LED), optical switches, etc.	circuits, they are used in applications to perform an elementary electronic function. Semiconductors such as diodes, transistors, resistors, capacitors, and inductors can be classified as discrete semiconductors.	pressure, and acceleration, as well as gyroscope sensors and microelectromechanical (MEMS) devices that convert electrical signals into physical actions in devices such as relays, digital micromirrors, etc.

The revenue from Integrated Circuits, which NTT is trying to enter newly, in the semiconductor market, has experienced significant growth with notable fluctuations over the period from 2016 to 2027. After starting at $298.0 billion in 2016, it saw a peak at $493.0 billion in 2021, followed by a temporary decline, and is projected to surge to $736.0 billion by 2027 (Fig. 5.5) . This trajectory reflects an overall upward trend with periodic dips, driven by technological advancements, market demand, and economic factors impacting the semiconductor industry.

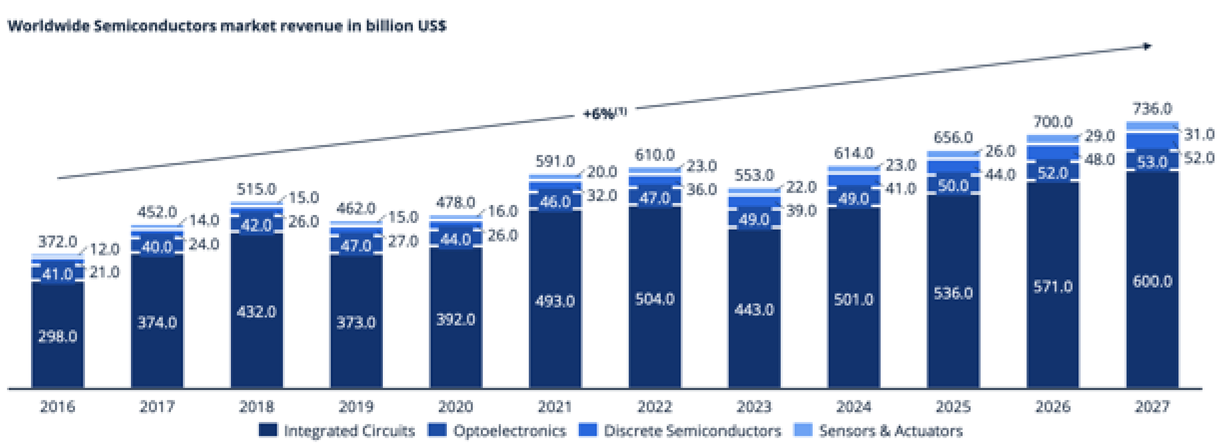

Fig. 5.5. Integrated Circuits revenues in billion USD are estimated to increase at a CAGR of 6.6% from 2016 to 2027. Semiconductors: market data & analysis, Statista Market Insights 2023 p51

In 2020, the global silicon photonics market was valued at $712.4 million, with Intel and Cisco among the major industry leaders. This market is projected to expand to $983.1 million by 2021. From 2019 to 2022 as an innovation in semiconductor products, the market is expected to remain dominated by optical transceiver components, which are forecasted to represent 47.5% of the market by 2021. Additionally, optical cables are anticipated to experience growth, increasing their market share from 25.1% in 2019 to 26.8% in 2021, reflecting the dynamic expansion within this sector (Fig 5.6).

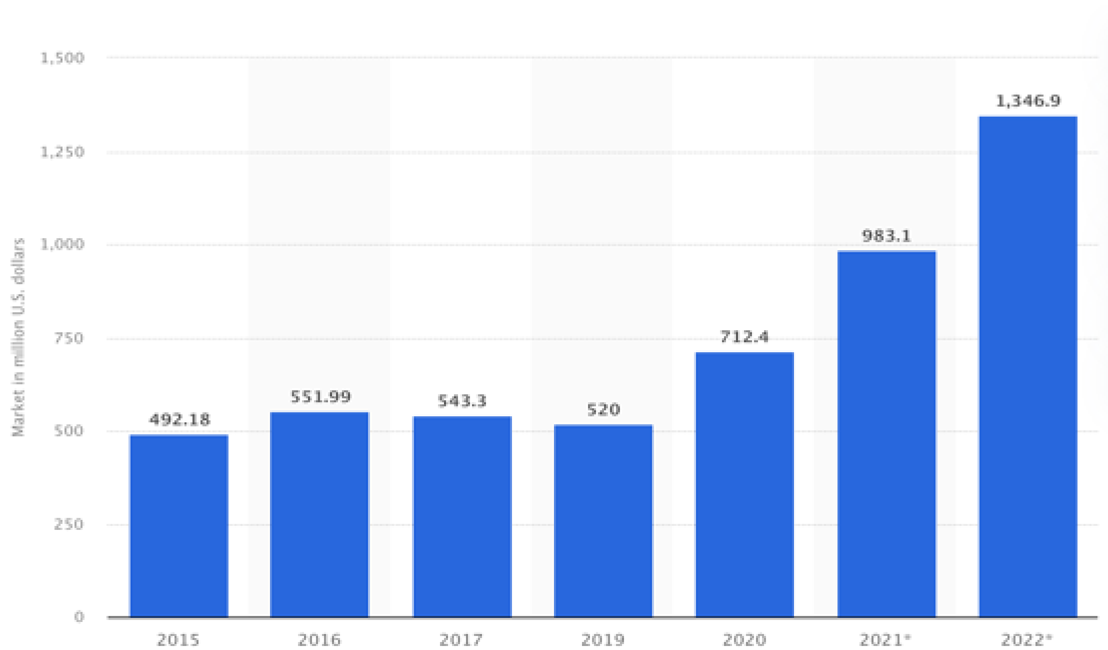

Fig. 5.6. Silicon photonics market revenues worldwide from 2015 to 2022(in million U.S. dollars). Retrieved from Statista 2024: https://www.statista.com/statistics/800526/worldwide-silicon-photonics-market-size/

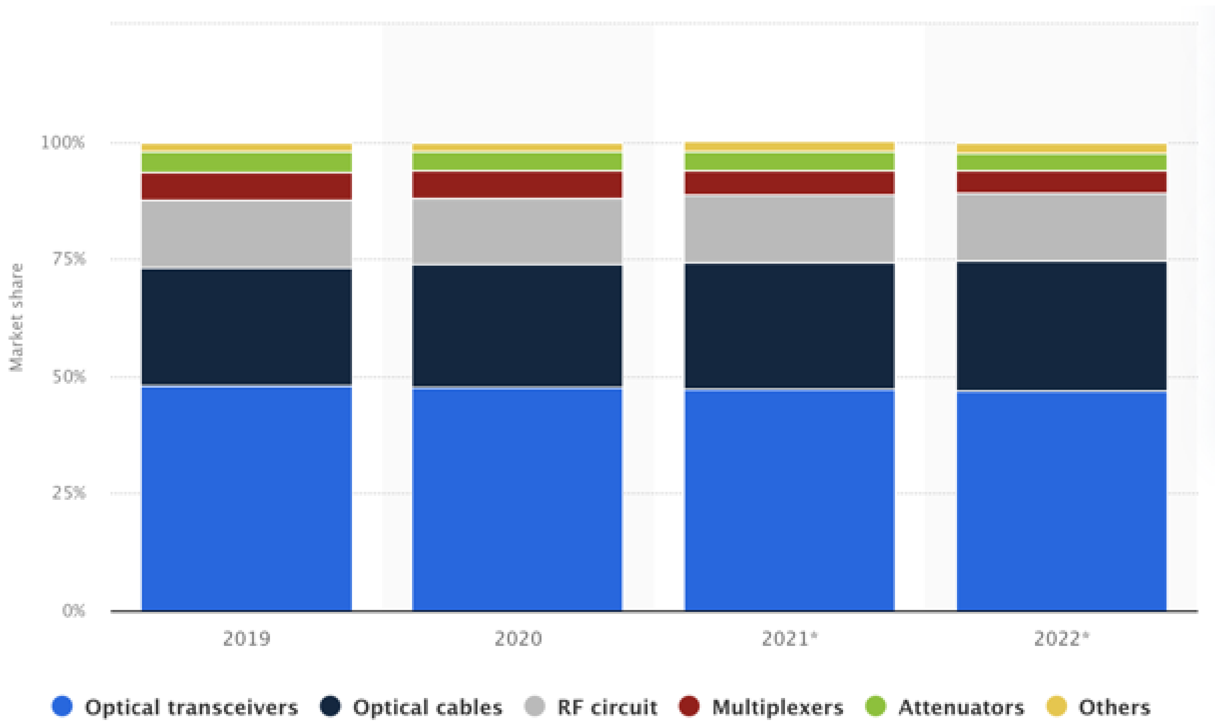

Fig. 5.7. Distribution of the silicon photonics market worldwide from 2019 to 2022, by component type.

From Statista 2024: https://www.statista.com/statistics/800556/worldwide-silicon-photonics-market-share-by-product/

The Intensity of Rivalry within Industry

For, the intensity of rivalry, the Herfindahl-Hirschman Index (HHI) is a common measure of market concentration and is used to determine the level of competition within an industry. The HHI is based on the work of economists Orris C. Herfindahl and Albert O. Hirschman. Herfindahl introduced the measure in his 1950 doctoral dissertation, which he later published, while Hirschman's work that contributed to the development of this index is often associated with his book "National Power and the Structure of Foreign Trade" (1945), although his direct contribution to the index is more general in terms of economic concentration.

It is calculated by squaring the market share of each firm competing in the market and then summing the resulting numbers. The value of the HHI can range from close to zero, indicating a highly competitive market with many small firms, to 10,000, indicating a monopoly where a single firm controls the entire market. Higher values of HHI suggest less competition and an increased likelihood of market power by leading firms. The HHI is currently used by antitrust agencies of each country to evaluate the potential impacts of mergers and acquisitions on market competition. Typically, markets are considered to be:

- Highly concentrated if the HHI is above 2,500 (High)
- Moderately concentrated if the HHI is between 1,500 and 2,500 (Mid)
- Not concentrated if the HHI is below 1,500 (Low)

To analyze the market conditions and the intensity of rivalry within the ICT solutions field, particularly in segments where the IOWN could be applied, we need a comprehensive evaluation. This includes examining market trends, technological advancements, barriers to entry, and the strategic behavior of industry players. These factors collectively shape the competitive landscape in the Network, Data Center (Colocation), and Cloud (IaaS) industries (Table 5.3).

Table 5.3

Intensity of Industry Rivalry within the Telecommunication, Data Center, Cloud (IaaS).

Segmentation	Top 5 Company	Share (%)	HHI
Network (2021)	AT&T (U.S.)	11.50%	**334.31 (Low)**
	Verizon (U.S.)	8.40%	
	China Mobile (China)	7.00%	
	Comcast (U.S.)	6.90%	
	NTT (Japan)	6.70%	
Data Center (Colocation) (2021)	Equinix (U.S.)	11.00%	**252.1 (Low)**
	Digital Realty (U.S.)	7.60%	
	China Telecom (China)	6.10%	
	NTT GDC (Japan)	4.30%	
	China Unicom (China)	4.20%	
Cloud (IaaS) (2022)	Amazon (U.S.)	40.00%	**2197.15 (Mid)**
	Microsoft (U.S.)	21.50%	
	Alibaba (China)	7.70%	
	Google (U.S.)	7.50%	
	Huawei (China)	4.40%	

Note: Share Data from Statista.

- Network: The Network sector is rapidly evolving due to the rollout of 5G technology, growing demand for mobile connectivity, and the expansion of Internet of Things (IoT) applications, and high-speed connectivity with data centers for enterprises driven by digital transformation and AI. These advancements are critical as they dictate the pace and direction of growth in this segment. However, entry barriers remain high due to the extensive infrastructure and regulatory approvals required, which in turn protect existing players but also curtail the intensity of rivalry by limiting new entrants. The competitive intensity is classified as low (HHI: 334.31) indicating a competitive market with multiple players having substantial market influence. This diversity in market share suggests that no single company can easily dominate the market dynamics, leading to competitive pricing, innovation, and service offerings. Also, the existing players need to upgrade infrastructure and offer differentiated services like faster data speeds and better coverage. On the other hand, barriers to entry into this industry could be high due to the need for extensive infrastructure and regulatory approvals in each country with market shares showing AT&T (US) at 11.5%, Verizon (US) at 8.4%, and others like Comcast (US) at 6.9%, NTT (Japan) indicating a competitive but not fragmented market, the dynamics here are conducive to sustained competitive engagement. These barriers protect existing players but also limit the intensity of rivalry by restricting new entrants. Companies in the industry need to continuously invest in technology and expand their service offerings to stay competitive as well as why NTT is moving forward with the IOWN concept. In the quest to standardize technology like TCP/IP for regulatory compliance and global interconnectivity, there exists the challenge of collaborating with competitors in a fiercely competitive market to establish new worldwide standards under the IOWN initiatives.

- Data Center (Colocation): In the Data Center sector, there is a significant demand driven by cloud computing, big data analytics, and an increase in digital content and services. Trends towards the development of green data centers could serve as a key differentiator. The barriers to entry are notably high, necessitating substantial capital investment for building secure and reliable facilities. The strategic locations of these data centers are essential for minimizing data latency and ensuring connectivity. The intensity of rivalry is moderate, focused on technological efficiency, location advantages, and value-added services such as disaster recovery and network security. Equinix (US) leads with a market share of 11.0%, followed by other major players like Digital Reality (US) at 7.8%, and the HHI is estimated to be moderate, suggesting a balance between competition and concentration. Operators can differentiate themselves by focusing on energy efficiency, better scalability options, and higher security measures. Strategic locations near major connectivity hubs can also provide a competitive edge.

- Cloud (IaaS): The Cloud (IaaS) market is characterized by a pressing need for scalable computing resources, with a significant shift towards multi-cloud and hybrid cloud environments. This segment is dominated by giants such as Amazon (US) with a market share of 40.0%, Microsoft (US) at 21.5%, and Google (US) at 7.5%. The barriers to entry are extremely high, as it requires extensive capital to establish and maintain scalable, secure, and reliable infrastructures. The market knowledge intensity also necessitates significant expertise in cloud architecture. Although the rivalry among the top players is relatively low, smaller players or new entrants could inject more competitive dynamics if they carve out niche services or focus on regional prominence. The HHI is quite high, indicating a highly concentrated market where the top players wield substantial market power.

To analyze the market conditions and the intensity of rivalry within the semiconductor industry, we need a comprehensive evaluation of the whole industry (Table 5.4). This includes examining market trends, technological advancements, barriers to entry, and the strategic behavior of industry players. These factors collectively shape the competitive landscape, particularly in segments where the IOWN could be directly applied including integrated circuit (IC) design services in silicon photonics, and IT devices (optical transceiver modules as an embedded component.

For overall market dynamics, the semiconductor industry, marked by high barriers to entry and varied intensity of rivalry across segments, is driven by a continuous push for technological advancements and market share expansion. The competitive dynamics within each segment are shaped by global economic conditions, technological disruptions, and regulatory environments, necessitating strategic planning and forecasting that are complex but crucial for long-term success.

For the technological shifts, markets undergoing rapid technological transformations, like semiconductors and image sensors, are likely to experience swift shifts in market shares, impacting the HHI dynamically. This factor is crucial in sectors critical to the deployment of IOWN technologies, as rapid innovation can alter competitive landscapes swiftly. On the other hand, the global nature of semiconductor supply chains means that geopolitical factors and logistical disruptions can significantly affect market shares and competitive dynamics as well since the structure of the semiconductor industry is complex and relies on collaboration with a diverse range of suppliers from numerous countries to produce a final product. This impact is particularly pronounced in segments reliant on sophisticated manufacturing processes, such as foundries and DRAM memory, where supply chain robustness is critical.

Table 5.4

Intensity of Industry Rivalry within Semiconductor Industry by Segmentations.

Segmentation	Top 5 Company	Share %	HHI
Whole Market (2023)	Intel (U.S.)	9.1%	**211.51(Low)**
	Samsung (Korea)	7.5%	
	Qualcomm (U.S.)	5.4%	
	Broadcom (U.S.)	4.8%	
	Nvidia (U.S.)	4.5%	
Fabless (2021)	Qualcomm (U.S.)	17.3%	**795.8 (Low)**
	Broadcom (U.S.)	12.4%	
	NVIDIA (U.S.)	12.1%	
	MediaTek Inc (Taiwan)	10.3%	
	AMD (U.S.)	9.5%	
Foundry (2021)	TSMC (Taiwan)	50.6%	**2985.19 (High)**
	Samsung (Korea)	17.6%	
	UMC (Taiwan)	7.5%	
	GlobalFoundries (U.S.)	5.9%	
	SMIC (China)	4.9%	
MCU (2021)	NXP (Neth.)	17.1%	**1134.42 (Low)**
	Renesas Electronics (Japan)	16.5%	
	STMicroelectronics (Switz.)	15.2%	
	Infineon Technologies (Germany)	13.6%	
	Microchip Technology (U.S.)	12.4%	
NAND Memory (2021)	Samsung (Korea)	33.9%	**1986.23 (Mid)**
	KIOXIA (Japan)	18.9%	
	Western Digital (U.S.)	13.9%	
	SK Hynix (Korea)	13.2%	
	Micron Technology (U.S.)	10.6%	
DRAM Memory (2021)	Samsung (Korea)	42.7%	**3172.33 (High)**
	SK Hynix (Korea)	28.6%	
	Micron Technology (U.S.)	22.8%	
	Nanya (Taiwan)	3.2%	
	Winbond (Taiwan)	1.0%	
Power Semiconductor (2021)	Infineon Technologies (Germany)	25.2%	**878.87 (Low)**
	Onsemi (U.S.)	9.3%	
	STMicroelectronics (Switz.)	7.8%	
	Mitsubishi Electric (Japan)	7.7%	
	Fuji Electric (Japan)	6.1%	
Image Sensor (2021)	Sony Semiconductor Solutions (Japan)	44.0%	**2555.67 (High)**
	Samsung (Korea)	18.5%	
	OMNIVISION (U.S.)	15.1%	
	GalaxyCore (China)	5.4%	
	Onsemi (U.S.)	4.5%	

Note: Source Data from Semiconductor & Digital Industry Strategy p. 20 by Ministry of Economy, Trade and Industry of Japan (2023, June) and Statista.

- Fabless: The Fabless segment, characterized by a low HHI 211.5, indicates a highly competitive market with numerous players. Prominent companies like Qualcomm (17.3%), Broadcom (12.4%), and NVIDIA (12.1%) lead with active innovation and diverse product offerings, fostering a dynamic competitive environment.
- Foundry: Despite the low HHI (795.8), the foundry sector exhibits a unique concentration, predominantly influenced by TSMC's significant market share (60.6%). This scenario suggests a limited competitive scope for smaller foundries, potentially steering the market towards a monopolistic competition structure.
- NAND Memory: The high HHI (2085.19) reflects a concentrated market dominated by a few key players, notably Samsung and SK Hynix. This concentration tends to stabilize pricing and moderate marketing strategies, which diminishes the intensity of rivalry among the incumbents.
- DRAM Memory: Contrary to its low HHI(1134.420) designation, this sector displays a moderate concentration level with significant influence from major firms such as Samsung, SK Hynix, and Micron. The rivalry remains robust but balanced, driven by competitive and collaborative dynamics that enhance technological advancements.
- Power Semiconductor: Exhibiting a medium concentration(HHI: 1986.23), this sector suggests moderate rivalry. The market is notably shaped by Samsung's extensive influence, tempered by other significant players like Marvell and Onsemi, which catalyze both competition and innovation, particularly in rapidly evolving areas like IoT and automotive technologies.
- Image Sensor (HHI: 3172.33 - High): With a very high HHI (3172.33): the image sensor market shows strong dominance by leading firms such as Sony and Samsung. The substantial market control exerted by these companies lessens the competitive intensity, reducing the opportunities for new entrants and curtailing aggressive market behaviors among established players.

Product Differentiation and Switching Cost

Effective product differentiation and the creation of products with high intrinsic value, such as semiconductors, can result in higher switching cost for consumers. Consequently, this heightened level of switching costs contributes to greater competitiveness within the industry. The examination of technological assessments in Chapter 3 reveals that while transistor size and density have continued to decrease, industry leaders are adhering to Moore's Law and Denard Scaling to enhance computing performance and energy efficiency. However, escalating the complexity and transistor count per unit presents significant technical challenges in both design and manufacturing, particularly amid surging demands from 5G and AI technologies.

Consequently, major IC design firms such as Qualcomm, Huawei, Nvidia, and AMD have increasingly relied on specialized foundries, including TSMC and Samsung (Table 5.5). This dependency creates a high switching cost, as altering this integrated supply chain can disrupt production and affect competitive positioning in the market. The sheer investment in tailored manufacturing processes and advanced design capabilities binds these companies to their foundry partners, enhancing the foundries' competitive advantage through entrenched customer relationships and specialized expertise.

This dynamic underscores why companies like Intel are pivoting towards silicon photonics research and development. Despite lagging in traditional communication and computing domains against rivals such as Qualcomm, Nvidia, and AMD, Intel and Broadcom's strategic shift aims to differentiate its offerings by leveraging advanced photonics to meet future computing demands, rather than merely increasing transistor counts. This approach not only addresses the diminishing returns of traditional scaling laws but also positions Intel and Broadcom distinctively in the evolving semiconductor landscape, potentially reducing its dependence on conventional foundry models and fostering a unique competitive edge.

Table 5.5

Transistor count by each company product

Product	Transistor count	Year	Designer(s)	Fab(s)	MOS process	Area	Transistor Density (tr./mm2)
			Microprocessors				
AMD Instinct MI300A	146,000,000,000	2023	AMD	TSMC	5 nm	1,017 mm2	144,000,000
Apple M2 Ultra	134,000,000,000	2023	Apple	TSMC	5 nm	NA	NA
Sapphire Rapids quad-chip module	44,000,000,000–48000000000	2023	Intel	Intel	10 nm	1,600 mm2	27,500,000–30000000
HiSilicon Kirin 9000s	9,510,000,000	2023	Huawei	TSMC	7 nm	107 mm2	107,690,000
Qualcomm Snapdragon 8 Gen 2	16,000,000,000	2022	Qualcomm	TSMC, Samsung	4 nm	268 mm2	59,701,492
Dimensity 9200 (ARM64 SoC)	17,000,000,000	2022	Mediatek	TSMC	4 nm	NA	NA
IBM Telum dual-chip module	45,000,000,000	2022	IBM	Samsung	7 nm	1,060 mm2	42,450,000
			GPUs				
GB200 Grace Blackwell	208,000,000,000	2024	Nvidia	TSMC	4 nm	NA	NA
Navi 33 RDNA3	13,300,000,000	2023	AMD	TSMC	6 nm	204 mm2	65,200,000
AD107 Ada Lovelace	NA	2023	Nvidia	TSMC	4 nm	146 mm2	NA
GA107 Ampere	8,700,000,000	2021	Nvidia	Samsung	8 nm	200 mm2	43,500,000

Note: Data from company reports.

As a next step, we will delve into an analysis of NTT IOWN's competitive landscape, alongside an examination of the current patent advancements in optical communications and optical processing technologies (Table 5.6) . The analysis of the patent acquisition status in the silicon photonics sector reveals a diverse range of industry entrants. This includes semiconductor companies like Intel, equipment manufacturers such as Cisco, and ICT solution providers including Oracle. Among these, Intel is notably ahead in research and development across all areas. From these results (Table 5.7), both Intel and NTT are prominent in integrating silicon photonics into broader technological solutions. Intel focuses on computational applications, while NTT targets communications infrastructure. Other equipment companies, such as Fujitsu and Cisco, also demonstrate specialized capabilities, making them competitive in particular niches of the photonics market.

Table 5.6

Patent Field Related to Silicon Photonics within Optical communications and Optical processing Technologies.

Technology Field	Description
Control of Light Beams	Relates to managing the direction, intensity, and properties of optical beams, critical in applications like optical switching and data transmission using light.
Semiconductor Photodetectors	Covers devices that convert light into electrical signals, essential for receiving data in optical communication systems.
Computer Details	Might refer to specific computational hardware that uses or processes optical signals, potentially including optical computing elements.
Transmission General	Includes general technologies and methods for transmitting data through optical means, likely encompassing various forms of optical data transport.
Communication Networks	Focuses on the infrastructure and technologies used to establish and maintain optical communication networks.
Telephone Systems, Switching, Remote Control	Covers the optical technologies used in the control and operation of telephone systems, including optical switches and remote management of these systems.
Digital Transmission	Deals with the methods and technologies for transmitting digital data over optical systems, crucial for modern telecommunications and data center operations.
Devices Using Stimulated Emission	Involves technologies like lasers and amplifiers that operate based on stimulated emission, where controlled light is used to boost or generate other light beams, crucial in many optical devices.
Optical Fibers, Optical Waveguides	Encompasses technologies related to optical fibers and waveguides, which guide light from one point to another and are fundamental components of all optical communication systems.

Table 5.7

The Number of Patent Acquisitions by Major Companies in Each Field.

Company Name	Patent Fields (Technologies)								
	Control of Light Beams	Semiconductor Photodetectors	Computer Details	Transmission General	Communication Networks	Telephone Systems, Switching, Remote Control	Digital Transmission	Devices Using Stimulated Emission	Optical Fibers, Optical Waveguides
Rockley Photonics (U.S.)	18	5	6	10	1	5	3	10	31
Iphit (U.S.)	11	2	6	39	2	4	21	10	37
Hewlett Packard Enterprise (U.S.)	10	6	5	23	2	8	17	8	39
Cisco Systems (U.S.)	12	4	1	15	5	4	9	16	55
Fujitsu (Japan)	35	7	1	22	-	-	17	23	42
Oracle (U.S.)	21	4	4	20	1	2	14	32	54
Huawei Technologies (China)	16	3	-	29	14	28	20	7	37
IBM (U.S.)	15	6	15	13	3	6	7	20	48
NTT (Japan)	35	30	-	12	1	1	5	20	96
Intel (U.S.)	25	47	88	28	5	19	21	21	93

Note: Data from Aotani, Y. , Nikkei xTECH / Electronics. (2024, March 13)

The competitive landscape is defined by the strategic focus of each company as reflected in their patent activities, which direct their technological progress and market positioning. Though the timing of each research result (Table 5.8) is not unified and they cannot be simply compared, these companies have published their developments in performance, particularly in the 200-400G range, and have achieved some degree of success in reducing power consumption. As of March 2024, NTT can be considered to be leading as it has achieved success with 400G and 800G (NTT, 2024).

Moreover, it seems that global leaders in network and data center operator segmentations like AT&T and Equinix have not entered this R&D competition from this patent status. Verizon, the No.2 global network operator successfully completed a 400Gbit/s ZR trial using Inphi's Colorz II technology, which transitioned seamlessly from 100Gb Ethernet QSFP28 to 400GbE QSFP-DD optics (Optics.org, 2020). Also, Digital Realty, the No2. data center operator in the world, conducted a field trial in Madrid using hollow core fiber technology with partners lyntia, Nokia, OFS, and Furukawa Solutions. This trial confirmed a latency reduction of over 30% and enhanced transmission rates, showcasing the technology's ability to travel nearly 46% faster than traditional fibers and potentially exceed the non-linear Shannon capacity limit (LIGHTWAVE + BTR, 2024). However, in both cases, the emphasis is more on validating the use of other companies products in their own production rather than advancing independent research and development, which does not appear to be a move towards entering the field of research and development like NTT, which has explicitly announced entry into the silicon photonics market, thus competition remains primarily among downstream side relatively. Considering regulatory variances across different regions, cooperation rather than competition with NTT might be advantageous for these companies.

From an R&D perspective, the NTT IOWN initiative is publicly aiming for an electrical efficiency improvement of 100 times, a transmission capacity increase of 125 times (100 Tbs per fiber), and an end-to-end latency reduction by 200 times. Whether NTT can achieve the target figures would be one of the critical factors in acquiring these players. Although comparisons on the performance and progress with other companies are challenging due to differing benchmark metrics, we can anticipate that the achievements by NTT could potentially be caught up by other players. Therefore, the challenge is not only boosting the R&D domain but also creating unique products and services and quickly capturing the market as industry standards to make a product difference and secure the higher switching cost. In this context, NTT's IOWN is not limited to the networking domain but extends to computing (encompassing servers, PCs, smartphones, vehicles, etc.), where all information processing is conducted through optical signals—a concept unique to the market.

Table 5.8

Product Comparison within the Silicon Photonics Lineup

Company	Technology Advantage	Achievement	Market Impact
Intel (U.S.)	Intel's substantial patents in computer details, semiconductor photodetectors, and optical fibers suggest a leading edge in integrating photonics into high-performance computing systems. This integration can lead to significant improvements in data center operations, including increased speed, reduced energy consumption, and greater bandwidth capabilities.	Intel has made significant advancements with its 100Gbps CWDM4 optical transceivers and is progressing towards 400Gbps solutions. These technologies are designed to support high data rates and are integral in reducing power consumption in data center environments. Specific numerical details on power savings were not detailed in the recent search	By advancing these technologies, Intel is not only enhancing its product offerings but is also likely influencing standards and practices across the computing industry, positioning itself as a critical player in future developments in cloud computing and AI technologies.

NTT (Japan)	NTT's focus on optical fibers and control of light beams positions it as a leader in the development of next-generation telecom infrastructure. Their work in semiconductor photodetectors also enhances capabilities in network reliability and data transmission efficiency.	Under the IOWN initiative, efforts are underway to convert all signals from electrical to optical, from networks to the internals of computers. Collaborative efforts between the IOWN Global Forum and Open ROADM MSA have demonstrated multi-vendor 400Gbps/800Gbps interoperability to enable innovative Data Center Exchange services. Photonics-electronics convergence technology, coupled with advanced monitoring, facilitates the provisioning of high-capacity services with low latency and low power consumption, significantly enhancing service delivery efficiency to remote data centers. Additionally, the demonstration has achieved a 40-60% reduction in electricity consumption at a commercial scale. (2024)	NTT's advancements are pivotal in telecommunications, potentially lowering the cost of data transmission and improving the accessibility of high-speed internet globally. Their technologies can lead to more robust and scalable communication networks, influencing market trends in 5G and beyond.
Fujitsu (Japan)	Fujitsu's strong patent presence in control of light beams and devices using stimulated emission indicates their proficiency in light manipulation technologies and laser systems, critical for both telecommunications and advanced sensing applications.	The Photonic-Electronic Technology Research Association (PETRA) and Fujitsu Ltd. have developed a silicon photonics transceiver that transmits data at the world's highest transmission density of approximately 400Gbps/cm^2, about twice that of conventional technology, using small, high-capacity optical transmission technology. Additionally, they have developed an optical modulation transmission technology that generates high-speed optical signals with four-level pulse control, enabling high-speed data transmission of 56Gbps per channel with 40% less power consumption than before.	Fujitsu's innovations may drive new applications in IoT and smart devices, impacting various sectors including healthcare, automotive, and manufacturing through enhanced sensors and communication systems.

Cisco Systems (U.S.)	With a solid foundation in optical fibers and waveguides, Cisco is well-equipped to enhance data transmission capabilities in network systems. Their balanced approach in photonic devices suggests versatility in offering comprehensive network solutions.	Cisco's Co-Packaged Optics (CPO) system, demonstrated at OFC 2023, shows a reduction in system power consumption by 25-30% for their routing solutions. This innovation integrates silicon photonics-based optical tiles driving 64x400G FR4, showcasing substantial power efficiency improvements in high-performance networking equipment	Cisco's advancements in photonics likely contribute to the evolution of global data networks, enhancing the efficiency and capacity of internet infrastructure, which is crucial as the demand for data and connectivity continues to grow.
Iphri (U.S.)	Iphri's focus on digital transmission and optical waveguides shows their commitment to enhancing data transfer technologies, crucial for reducing latency and increasing bandwidth in communications.	Iphri's involvement in silicon photonics is not well-documented, requiring further investigation. Inphi Corporation launched its 400G DR4 silicon photonics platform on December 3, 2020, which includes a PIC, TIA, and analog controller combined with its Porrima PAM4 DSP. This platform enables efficient, cost-effective production by offering PICs on 200-mm wafers for high-volume manufacturing.	These technological advances by Iphri could significantly influence the telecom sector by enabling faster and more reliable services, impacting consumer and business communications markets.
Rockley Photonics (U.S.)	Rockley Photonics' investments in optical waveguides indicate their capability to improve photonic communication systems, essential for efficient light-based data transmission.	Rockley's biosensing chips are optimized for low-power operation in wearables, allowing continuous health monitoring with minimal battery impact. Their 400G DR4 transceiver uses a four-channel silicon PIC chipset. The transmit PIC features 1310nm DFB lasers and electro-absorption modulators for output fiber coupling. The receive PIC includes integrated photodetectors and converters for input fiber coupling.	Their technologies may enable more scalable and less costly photonic solutions, potentially altering the competitive landscape in industries reliant on high-speed data transfer.
Huawei Technologies (China)	Huawei's diverse patent portfolio across telecommunications systems and photonics elements positions it to integrate advanced photonics into consumer and commercial network equipment.	Huawei's development in silicon photonics includes 200G and 400G optical transceivers. Although specific figures on power reduction were not available, these advancements aim to enhance data communication networks by improving transmission efficiency and reducing power consumption	As a major player in global telecommunications, Huawei's advancements in photonics can drive the adoption of more advanced network technologies in emerging markets, influencing worldwide connectivity standards.

Hewlett Packard Enterprise (U.S.)	HPE has a diverse patent portfolio in silicon photonics, indicating robust capabilities in photonic integration across various platforms. Strong focus on enhancing data center functionalities through photonics, particularly in improving bandwidth and reducing latency.	Ayar Labs is revolutionizing the semiconductor and computing industries by driving a 1000x improvement in interconnect bandwidth density with 10x lower power consumption. Using industry-standard, cost-effective silicon processing techniques, Ayar Labs develops high-speed, high-density optical-based interconnect "chiplets" and lasers to replace traditional electrical I/O. However, specific performance data on their silicon photonics is not publicly available.	HPE's photonics advancements contribute to more efficient data centers, essential for cloud and big data applications. Their innovations in photonics are likely to set new trends in IT infrastructure, especially in hybrid IT and network security environments
IBM (U.S.)	IBM's focus on integrating photonics with computing aligns with its leadership in cognitive computing and quantum computing, where photonics can play a crucial role in enhancing processing speeds and computational capabilities.	IBM has developed optical transceivers that integrate silicon photonics technology, achieving data transfer rates of up to 100 Gbps. Specific power consumption figures were not available, but these developments are part of IBM's broader efforts to enhance performance and efficiency in computing systems	IBM's photonics innovations are likely to have a transformative impact on the computing industry, particularly in areas requiring high-speed data processing and advanced algorithm computations, like AI and big data analytics.

Note: Source Data from company reports.

Competition and Cooperation Landscape within the Silicon Photonics Market

To achieve these goals, NTT will need to determine whether to compete or collaborate with key players among upstream competition, in the long and short term, respectively. Specifically, long-term, relationships with Intel (whether as competitors or partners) and short-term strategies with Cisco are crucial.

On October 30, 2023, Intel announced the divestment of its pluggable optical transceiver business to Jabil, a U.S. company (CRN, 2023). This decision aligns with Intel's strategy to concentrate on higher-value components and photonic I/O solutions for AI infrastructure instead of data transmission fields like network infrastructure. The sale includes the manufacturing and sales of current products as well as the development of future products, including the existing optics division. This move, announced by Intel's CEO Pat Gelsinger, is part of a broader strategy to optimize Intel's portfolio and drive long-term value creation. The activity allows Intel to better meet the evolving needs of data center customers, particularly in areas like hyperscale cloud services and AI data centers. As Intel moves away from communication areas where it could potentially compete with NTT in the short term, it also raises strategic questions about long-term collaboration or competition in computing areas, given NTT's vision of expanding its IOWN concept to encompass computing domains. As a result, while it seems unlikely that Intel will compete directly with NTT in the networking area shortly, the expansive vision of IOWN suggests that future collaborations or competition in the computing domain could be significant.

As a founder of the IOWN Global Forum consortium, NTT, along with Intel and Sony, is committed to broadening the IOWN concept, including joint R&D on optoelectronic fusion devices. Meanwhile, NTT plans to commercialize technology that replaces electrical signal exchanges between chips with optical signals by 2030, a significant undertaking given the dual importance of communication and computing in the IOWN vision.

For the short-term, decisions regarding Cisco's relationship, particularly as initial market shares in the communication domain are critical. Cisco dominates the enterprise network market, holding over 56.4% market share in 2019, making it challenging to simply replace existing equipment with optical technology. As Cisco advances its new Co-Packaged Optics (CPO) system, demonstrating potential power reductions of up to 50% for connections between the switch ASIC and optics, it could remain a significant presence in the industry standardization and new architectural designs because of the existing market influence power (Cisco Blogs, 2023). Therefore, the IOWN initiative considers creating a vendor-free system that does not use traditional IP traffic architectures, collaborating with other equipment manufacturers besides Cisco develop standard yet cost-effective configurations for data centers and telecommunication operators. Details of this initiative will be discussed later. NTT's strength against Cisco lies in its global market share in both wireless and fixed networks and data centers, facilitating the implementation of technical and commercial experimentation and reaching end-users quickly.

Additionally, NTT maintains cooperative relationships with many network vendors, making it easier to form alliances. Originally, NTT has been a leader in service validation speeds in the optical domain, a competitive advantage over companies like AT&T and Verizon. For example, NTT achieved the world's fastest optical transmission of over 2 Tbits/s per wavelength, a large-capacity communication network technology to support IOWN & 6G. This is a groundbreaking milestone in optical communications by transmitting digital coherent optical signals at a record speed. This development was demonstrated over a 240 km transmission line using advanced ultra-wideband baseband amplifier IC modules and high-precision digital signal processing. This achievement not only doubles the conventional capacity per wavelength but also significantly extends the possible transmission distance. This positions NTT as a potential leader in the commercialization of silicon photonics, crucial for future large-capacity networks supporting the IOWN and 6G initiatives.

Additionally, at OFC2024, held in California, NTT showcased a multi-vendor Data Center Exchange (DCX) utilizing its IOWN All-Photonics Network (APN) technology (Fig. 5.8). This demonstration highlighted high-capacity optical connections at speeds of 400Gbps and 800Gbps. While the specific number of vendors involved wasn't detailed, the key achievements of the demonstration included maintaining low latency and low power consumption across all-optical connections. These features are critical for linking distributed data centers effectively. The demonstration underscored the interoperability of different vendors' products through open standards, as well as the practical efficiency of photonics-electronics convergence devices in operational settings. This event marked a significant step forward in demonstrating the real-world capabilities and future potential of integrated photonic technologies in large-scale data infrastructure.

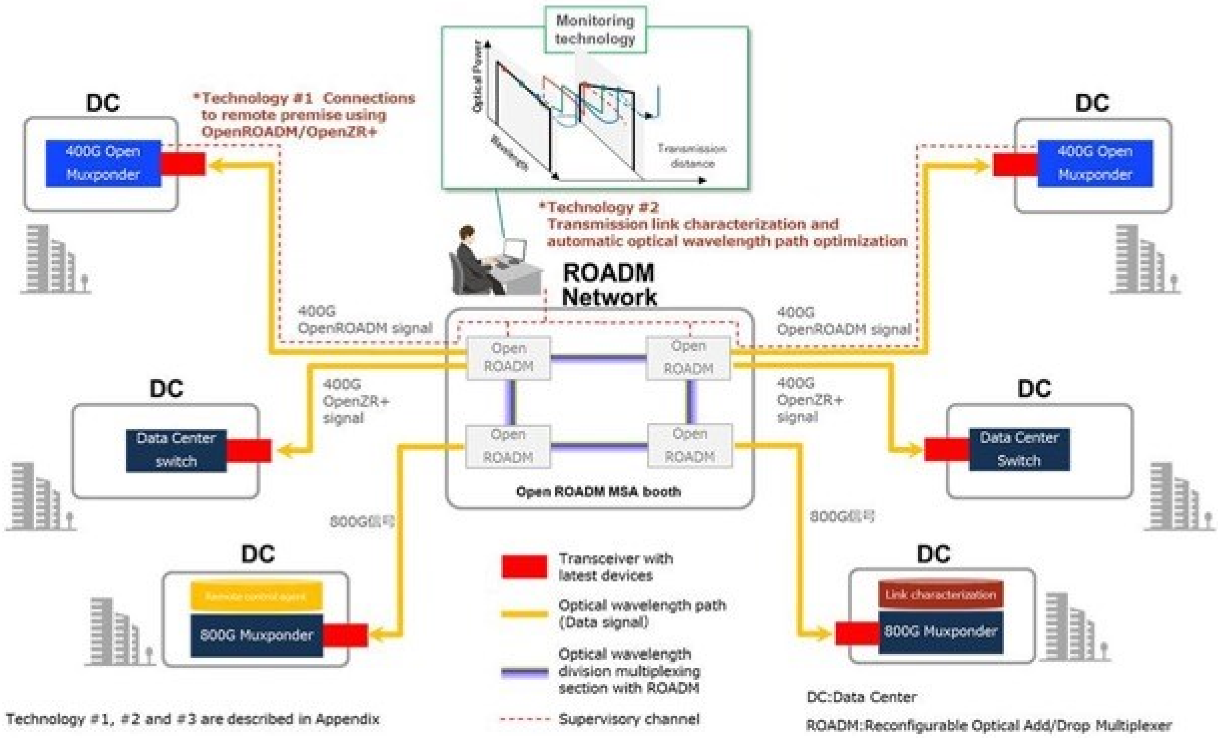

Fig. 5.8. 400Gbps/800Gbps IOWN APN demonstration at OFC2024 by multi-vendor products leveraging photonics-electronics convergence device and open standards. From Statista 2024: https://www.statista.com/statistics/800556/worldwide-silicon-photonics-market-share-by-product/

The IOWN Global Forum, established in January 2020 by Intel, Sony, and NTT, has experienced rapid membership growth. Initially launched with three founding companies, the forum expanded to 39 organizations by January 2021, grew to 88 by January 2022, and exceeded 130 members by September 2023, with new members joining nearly every month. The forum attracts a diverse array of participants including enterprises, research institutes, universities, academic institutions, and municipalities, reflecting its dual focus on use-case and technical studies. Recent activities include hybrid online and offline meetings, with significant events held in New York City, Osaka, and Munich, featuring lively discussions and technical evaluations of emerging technologies.

These meetings highlight the forum's expanding global footprint and its emphasis on implementing and evaluating new technologies through proofs of concept and technical roadmaps. Collaborating with members of the IOWN Forum can enable us to quickly establish industry standards and secure a competitive advantage over companies like Cisco. By uniting our efforts, we can leverage collective expertise and resources to accelerate the development and adoption of innovative technologies. This strategic alliance can help shape future industry norms in our favor, ensuring our position at the forefront of technological advances.

5-2-2. Bargaining Power of Suppliers

This force addresses how much power an industry’s suppliers have and how much control they can exert on the contributing inputs in terms of quality, price, and volume. Industries in which producers rely on a few key suppliers will experience stronger bargaining forces from these suppliers. Conversely, if there are many suppliers or low switching costs, the supplier power is reduced.

Integrated Device Manufacturer (IDM) Business Model Case

In the realm of upstream business operations, companies face a critical decision regarding their business model: whether to adopt the IDM model, encompassing semiconductor design through to manufacturing or opt for the fabless model, focusing solely on design and outsourcing manufacturing to foundries. These decisions wield significant influence over a company's Return on Invested Capital (ROIC), with careful consideration of power dynamics with suppliers being particularly paramount.

An IDM is a company that designs, manufactures, and sells its own semiconductor chips. Unlike fabless semiconductor companies, which outsource manufacturing to third-party foundries, IDMs handle both design and fabrication in-house. The strategic driver behind IDM status often lies in control and vertical integration. By having control over both design and manufacturing processes, IDMs can potentially achieve greater efficiency, tighter integration of components, and better quality control. This integration can lead to faster time-to-market, enhanced product customization, and greater competitiveness in the semiconductor market.

Additionally, IDMs may benefit from economies of scale by having all processes under one roof, potentially reducing costs and improving profit margins. However, maintaining IDM status requires significant investment in both research and development and manufacturing capabilities, which can be a strategic challenge in a rapidly evolving industry. As NTT is currently emphasizing research and development in PIC design, there will be a requisite shift towards investing in manufacturing capabilities as well if should the IDM business model be adopted. Specifically, strategic investments will be necessary to secure control over suppliers through the procurement of semiconductor materials and cutting-edge equipment that align with NTT's exacting standards and technological needs.

Degree of Supplier's Monopoly in Upstream Business

The following Table 5.9 provides an overview of key semiconductor material domains and their market shares. Mask blanks, essential for photomask formation, are dominated by HOYA and AGC for EUV applications, while HOYA and Shin-Etsu Chemical lead for other light sources. Photomasks, crucial for circuit pattern formation during the exposure process, are primarily self-manufactured by semiconductor giants like TSMC and Samsung. However, Toppan Photomasks, Photronics, and Dai Nippon Printing are prominent external suppliers. Polysilicon, vital for silicon wafer production, is led by Tokuyama in Japan, capturing a 20% global share as of 2022. Silicon wafer manufacturing is monopolized by Shin-Etsu Chemical, SUMCO, GlobalWafers, Siltronic, and SK Siltron. Sputtering targets, crucial for thin film formation, are dominated by JX Metals, Toho, Honeywell Electronic Materials, and Praxair. Photoresists, integral for semiconductor patterning, witness Japanese dominance, with JSR, Tokyo Ohka Kogyo, Shin-Etsu Chemical, Sumitomo Chemical, and FujiFilm commanding over 90% of the market. JSR's acquisition by the Japan Industrial Innovation Corporation (JIC) signifies industry consolidation. Chemical Mechanical Polishing (CMP) slurries, used for wafer polishing, see Cabot as a major player, along with FujiFilm, Resona, and Fujimi among Japanese manufacturers. High-purity gases, crucial for semiconductor processes, see strong Japanese representation, including ADEKA, SK Materials, Air Water, Air Products and Chemicals, Air Liquide, Kanto Denka Kogyo, Sumitomo Seika, Central Glass, Daikin, Nippon Oxygen, Toray Chemical Research Institute, Zeon Corporation, Forsang, Mitsui Chemicals, and Resona.

These high supplier power in essential materials like silicon wafers or photomasks can squeeze the IDM's margins, potentially lowering their ROIC. For example, Shin-Etsu and SUMCO's dominant position in the silicon wafer market might lead to higher prices or stringent terms, impacting the cost structure and hence the ROIC of IDMs who depend on these materials for their core operations. A new IDM entering the market would need to navigate the concentrated supply markets, such as those controlled by these dominant players. Building relationships with these dominant suppliers or finding alternatives could significantly impact their startup phase, affecting both initial costs and long-term sustainability.

Table 5.9

Degree of Monopoly in the Semiconductor Materials Market

Segmentation	Company	Share (%)	HHI
EUV Mask Blanks (2021	HOYA (Japan)	80%	6800 (High)
	AGC (Japan)	20%	
	NA	NA	
	NA	NA	
	NA	NA	
Other Mask Blanks (2021)	HOYA (Japan)	60%	4825(High)
	Shin-Etsu (Japan)	35%	
	Others	5%	
	NA	NA	
	NA	NA	
Photomasks (2023)	Toppan Photomasks (Japan)	39%	3094(High)
	Photronics (USA)	33%	
	DNP (Japan)	22%	
	NA	NA	
	NA	NA	
Polycrystalline Silicon(2023)	Hemlock (USA)	24%	1478 (low)
	Wacker (Germany)	18%	
	REC (Norway)	17%	
	Toyo Tanso (Japan)	17%	
	NA	NA	
Silicon Wafers (2019)	Shin-Etsu (Japan)	29%	2071 (Mid)
	SUMCO (Japan)	22%	
	GlobalWafers (Taiwan)	20%	
	Siltronic (Germany)	15%	
	SK Siltron (South Korea)	11%	
Sputter Target (2019)	JX METALS (Japan)	32%	2265 (Mid)
	TOSOH (Japan)	20%	
	Honeywell Electronic Materials (US)	21%	
	Linde (Germany)	20%	
	NA	NA	
Photoresists (2019)	JSR (Japan)	27%	1915 (Mid)
	Tokyo Ohka Kogyo (Japan)	26%	
	Shin-Etsun (Japan)	17%	
	Sumitomo (Japan)	11%	
	Fujifilm (Japan)	10%	
CMP (2019)	CMC Materials (Japan)	32%	1441 (High)
	Shin-Etsu (Japan)	14%	
	Resonac (Japan)	11%	
	Fujimi (Japan)	10%	
	NA	NA	

Note: Data from each company press release and articles.

In addition, the semiconductor equipment industry exhibits varying degrees of market concentration across different segments, as reflected by the calculated HHI values (Table 5.10). For example, in segments like lithography and coater/developer, where a single company dominates, IDMs face significant challenges in negotiating favorable terms, potentially leading to higher costs and less flexibility in their manufacturing operations. A leading but unnamed company in the Netherlands controls 92.8% of the market, with minor shares held by Canon and Nikon for I-line lithography. The market's HHI would be extremely high, approaching 8,639, reflecting a highly concentrated market. Tokyo Electron holds an 84.1% share, with Screen capturing 3.4% with it's dominance, the estimated HHI is 7,084, indicating a highly concentrated. For CVD, shares are not specified but include AMAT (USA), Lam (USA), and Tokyo Electron (Japan). Although specific HHI cannot be calculated without exact shares, the presence of major industry players suggests a competitive yet tight market. This concentration suggests near-monopoly conditions, potentially restricting IDM negotiation power substantially.

Conversely, in segments with lower concentration, such as ion implantation and wafer appearance inspection, IDMs might experience slightly more negotiation leverage. This analysis underscores the critical impact of supplier concentration on the strategic decisions of IDMs within the semiconductor industry. Each segment's dominance by a few companies likely results in a higher HHI, suggesting less competition and greater market control by leading suppliers. This situation would generally allow suppliers to exert significant influence over pricing, availability, and terms, potentially impacting the operational flexibility and cost structure of IDMs.

Table 5.10

Degree of Monopoly in the Semiconductor Equipment Market

Segmentation	Top 5 Company	Share (%)	HHI
Drawing (2021)	IMS Nano fabrication (Austria)	53.4%	3755.42 (High)
	NuFlare Technology (Japan)	26.3%	
	Vistec (Germany)	11.9%	
	JEOL (Japan)	8.4%	
	NA	NA	
Lithography (2021)	ASML (Netherlands)	92.80%	8639.76 (High)
	CANNON (Japan)	4.60%	
	Nikon (Japan)	2.60%	
	NA	NA	
	NA	NA	
Lithography I-line (2021)	Canon (Japan)	37.00%	2738 (High)
	Nikon (Japan)	37.00%	
	NA	NA	
	NA	NA	
	NA	NA	
Coater/Develop (2021)	Tokyo Electron (Japan)	84.10%	7084.37 (High)
	Screen	3.40%	
	NA	NA	
	NA	NA	
	NA	NA	
CVD (Film Deposition) (2021)	AMAT (USA)	35.8%	1965.58 (High)
	Lam (USA)	17.2%	
	Tokyo Electron (Japan)	14.0%	
	ASM (Netherlands)	11.1%	
	Kokusai Electric (Japan)	8.3%	
Spatter (Film Deposition) (2021)	AMAT (USA)	86.4%	7568.84 (High)
	Ulvac (Japan)	9.8%	
	Cannon Anelva (Japan)	2.8%	
	NA	NA	
	NA	NA	
LPE (Film Deposition) (2021)	ASML (Netherlands)	44.90%	2734.25 (High)
	AMAT (USA)	26.80%	
	NA	NA	
	NA	NA	
	NA	NA	
Etching (2021)	Lam (USA)	37.7%	2646.12 (High)
	Tokyo Electron (Japan)	25.3%	
	AMAT (USA)	23.5%	
	Hitachi High-Technologies	5.7%	
	NA	NA	
Single Wafer Processing Cleaner (2021)	Screen (Japan)	34.70%	2442.21 (High)
	SEMES (South Korea)	24.40%	
	Tokyo Electron (Japan)	22.00%	
	Lam (USA)	12.60%	
	NA	NA	
Single Wafer Processing Cleaner (2021)	AMAT (USA)	52.6%	4159.77 (High)
	Ebara (Japan)	37.0%	
	KC (South Korea)	4.9%	
	NA	NA	
	NA	NA	
Heat Treatment (2021)	AMAT (USA)	52.60%	3697.04 (High)
	Tokyo Electron (Japan)	23.2%	
	KOKUSAI ELECTRIC (Japan)	19.8%	
	NA	NA	
	NA	NA	
Ion Implanter (2021)	Axcelis (USA)	39.6%	3085.54 (High)
	AMAT (USA)	34.7%	
	Sumitomo Heavy Industries	17.7%	
	NA	NA	
	NA	NA	
Wafer Surface Inspection (2021)	KLA (USA)	66.0%	4576.2 (High)
	ASML (Netherlands)	12.8%	
	Hitachi High-Technologies	5.60%	
	AMAT (USA)	5.0%	
	NA	NA	
Wafer Appearance Inspection (2021)	KLA (USA)	31.7%	1687.39(Mid)
	AMAT (USA)	21.0%	
	Evident (Japan)	10.10%	
	Bruker (USA)	8.5%	
	Hitachi High-Technologies	8.2%	
Conveyance (2021)	Daifuku (Japan)	52.00%	5008 (High)
	Murata (Japan)	48.00%	
	NA	NA	
	NA	NA	
	NA	NA	

Note: Data from Semiconductor & Digital Industry Strategy p. 20 by Ministry of Economy, Trade and Industry of Japan (2023, June).

On the other hand, for the fabless business model, TSMC holds 50.6% and Samsung 17.6% of the market share, with an industry concentration measure, HHI, standing at a significantly high 2985.19. This can be attributed not only to the substantial annual capital investments required but also to the fact that only companies with the technological prowess of TSMC and Samsung can produce cutting-edge chips, such as those in the 3-5nm range (Fig. 5.9). Procurement from such uniquely skilled companies carries weight due to the competitiveness they offer. Even if NTT adopts a fabless business model, there remains the potential for suppliers to wield negotiating power. Moreover, if there are advantages over Integrated Device Manufacturers (IDMs), initial entry might be promising, as it eliminates the need for extensive annual capital expenditures to control multiple suppliers, such as material and equipment manufacturers (Fig. 5.10).

Regarding advancements in silicon photonics technology from the supplier side, initiatives such as aligning with NTT IOWN, evaluating technology leakage and future competitiveness, and scrutinizing pricing negotiation leverage are imperative for cultivating supplier relationships. For example, TSMC is developing its Compact Universal Photonic Engine (COUPE) , which integrates electronics and photonic circuits via SoIC-X packaging, enabling high-speed optical connectivity (TSMC, 2024). COUPE surpasses current copper Ethernet standards, promising data rates exceeding 1.6 Tbps. TSMC plans to integrate COUPE into motherboard-level packaging, reducing latency and enhancing performance. Also, it is collaborating with industry giants like Broadcom and Nvidia (technote, 2024)

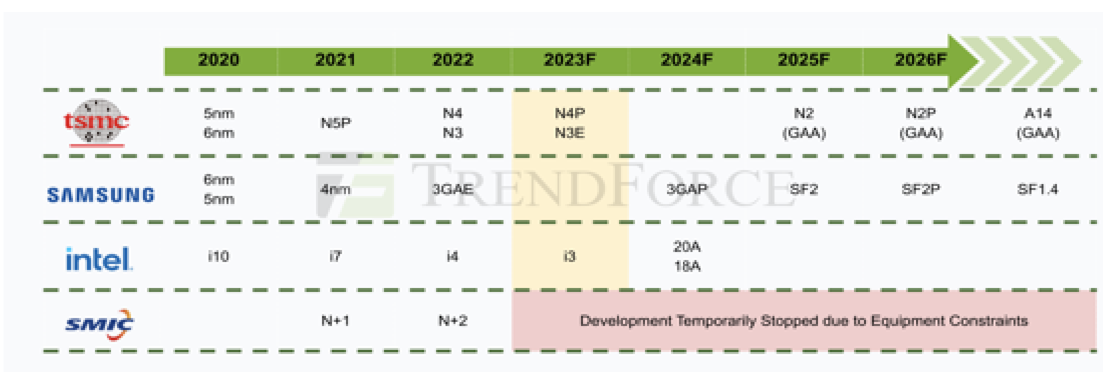

Fig. 5.9. Advanced Process Roadmap of Major Foundries. From TrendForce (Sep. 2023)

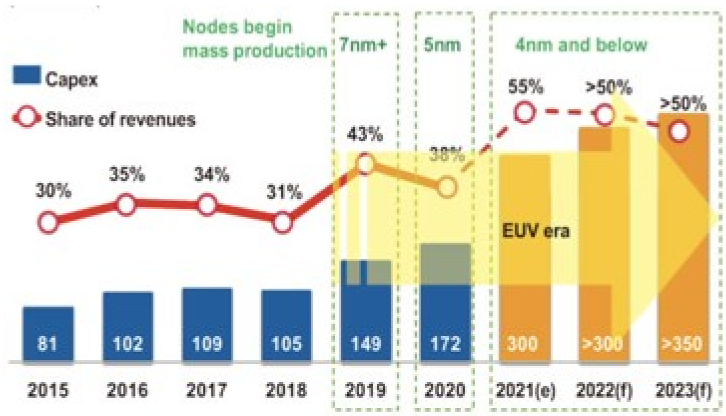

Fig. 5.10. Changes and estimation in TSMC's Capex each year (US$ 100m).

From DIGITIMES (July 14, 2021).

Option of Upstream Business Strategy & Operation (in the semiconductor market)

NTT is trying to implement three strategies in its efforts to penetrate the upstream business in the semiconductor sector, aiming to address the challenges of the manufacturing phase.

Firstly, a collaborative research agreement between NTT and Intel for the development of the IOWN communication Infrastructure was launched in 2020. NTT and Intel have entered into a joint research agreement to co-create the future communication infrastructure IOWN, which aims to significantly reduce power consumption and surpass the limitations of current technologies (NTT, 2020). This collaboration leverages NTT's leading-edge photonics, digital signal processing (DSP), computing, and network infrastructure management technologies alongside Intel's extensive technical portfolio, support structure, and expertise in hardware and software.

Through this partnership, NTT and Intel are committed to developing technologies capable of handling the explosive amounts of data required for a smart and connected world. The mission is to integrate optical technologies not only for long-distance signal transmission but also within processor chips in conjunction with electronic circuits, aiming to create a new computing base through electro-optical integration, develop a computing infrastructure that utilizes future communication infrastructures to the fullest, connecting ground, edge, and cloud environments to efficiently process massive amounts of real-time data from the real world, and design a software framework to enable the use of increasingly diverse and evolving AI computation devices within the high-speed distributed computing infrastructure. This project indicates the possibility of NTT outsourcing manufacturing to Intel and collaborating on sales. By establishing win-win relationships with other Integrated Device Manufacturers (IDMs) like Intel, NTT could potentially alleviate supplier power imbalances that exist with contractors such as TSMC, leading to lower costs and expanded distribution channels. However, this strategy raises concerns about potential technology leakage to Intel, which could unintentionally supply NTT's competitors with finished products or, in the future, sell similar products independently to other companies. Thus, measures to prevent such outcomes will be necessary.

The second strategy involves investing in the newly established foundry Rapidus, establishing a capital relationship, outsourcing manufacturing, and securing distribution channels. Rapidus is a foundry established by a group of semiconductor experts, funded by major Japanese corporations including Sony, Toyota Motor, Denso, Kioxia, NTT, NEC, SoftBank, and MUFG Bank. The Japanese government has also contributed 70 billion yen in development funds (Reuters, 2022). The aim is to develop and manufacture cutting-edge logic semiconductors. The establishment of Rapidus was motivated by concerns about Japan's lagging semiconductor industry and its diminishing prominence. Foundries are predominantly located in

Taiwan and China, posing economic security risks. The initiative to establish a next-generation semiconductor factory in Japan emerged during a Japan-US summit, recognizing the increasing demand in the automotive and AI sectors expected in the 2030s. This project involves collaboration between Japan, the US, and Europe, and with domestic and international materials and equipment industries. With licensing support from IBM, the initiative aims to realize a 2nm advanced LSI foundry in Japan (IBM, 2022). Outsourcing manufacturing to Rapidus could be a cost-effective alternative to relying on major foundries like TSMC and Samsung. Moreover, the devices produced could indirectly support other network operators like SoftBank and autonomous driving companies such as Denso and Toyota through the IOWN initiative. However, compared to larger foundries, Rapidus could face challenges related to production capacity, scalability, and achieving economies of scale.

Finally, the third strategy is to cooperate with the technology suppliers. Consequently, the optoelectronics fusion technology division of NTT research was spun off to establish a company named NTT Innovative Devices, which commenced operations as a specialized manufacturer with functions encompassing the design, development, manufacturing, and sales of optoelectronic fusion devices (Nikkei xTECH, 2023). The achievement of such precise design and manufacturing also requires high levels of technical expertise in both software and hardware, with a particular emphasis on the dependency relationship involving the hardware sector within the value chain. Furthermore, Japan's Ministry of Economy, Trade and Industry is funding the advancement of three cutting-edge technologies with 45.2 billion yen for the IOWN open innovation (Nikkei XTECH, 2023). The technologies include:

- Optical Chiplet Implementation Technology: NTT collaborates with Furukawa Electric, NTT Innovative Devices, NTT Device Cross Technology, and Shinko Electric Industries to develop in-package optical wiring technology through optoelectronic fusion. This aims to reduce resource consumption and lower power usage in devices by integrating Hybrid Photonical Integrated Circuits (PIC) and Electronic Integrated Circuits (EIC) using high-density packaging.
- Optoelectronic Fusion Interface Memory Module Technology: NTT and Kioxia are developing a broadband memory module directly connectable to optical interconnects. This Photonic Fabric Attached Memory Module (PFAM) will enable fixed-latency access for multiple computational resources and is partially developed in collaboration with Tohoku University. It addresses the challenges posed when light transmission speeds exceed memory write speeds, requiring specialized memory control mechanisms.
- Fixed Latency Computing Infrastructure Technology: Led by NTT, NEC, and Fujitsu, this project focuses on creating a computing infrastructure that ensures fixed-latency from data transfer to analysis. It aims to minimize latency impacts significantly and

reduce power consumption by using optoelectronic fusion technology and optical networking, enabling more efficient and predictable computing processes.

Downstream Business Model

In the realm of downstream business operations, including data center colocation, network businesses, and cloud services, the competitive dynamics of vendors in the optical transceiver, network equipment, storage, and server markets significantly influence not only pricing and availability but also the pace and direction of technological innovation. This analysis, leveraging the Herfindahl-Hirschman Index (HHI) and market share data (Table 5.11), aims to assess these dynamics within each segment and their implications on various business operations. The focus is on understanding supplier power, market impact, and technological innovations, providing insights into strategic procurement and partnership strategies.

Degree of Supplier's Monopoly in Downstream Business

For the server equipment market, characterized by a competitive market structure and a low HHI of 652.21, the scenario benefits purchasers by offering a variety of server solutions tailored to diverse operational demands from performance to energy efficiency. This low market concentration limits the power of individual vendors, fostering a competitive environment that ensures affordability and a range of technological options for data centers and cloud providers. Server vendors prioritize advancements in processing power and energy efficiency, which are crucial for supporting the increasing demands of cloud computing and data center services.

In the storage market, with a moderate HHI of 1038.28, top vendors like Dell and HPE wield significant influence over pricing and technological standards in data storage. This is critical for large-scale data center operations. The balanced power dynamics in this segment compel vendors to continuously innovate to maintain their market positions, which in turn influences cost and the adoption of new technologies in storage solutions. Innovations in cloud storage and data security are paramount, with significant collaborations between storage vendors and cloud providers shaping the service offerings. Advances include developments in solid-state drives (SSDs), hyper-converged infrastructure (HCI), and cloud storage services that provide scalable and flexible storage solutions.

The network equipment market exhibits a moderate HHI of 1208.55, where leading companies like Huawei and Cisco exert considerable influence. This influence can impact the cost structures and market conditions for services dependent on network infrastructure and data center operations. These vendors play a pivotal role in strategic partnerships that define the backbone technologies for cloud and data center operations, especially critical in the development of 5G and advanced networking technologies.

Finally, the highly competitive nature of the optical transceiver market, with an HHI of 605, provides data center operators and cloud service providers with substantial flexibility in sourcing components.

The diversity of suppliers ensures competitive pricing and fosters a rich environment for technological advancements. This segment's competitive stance encourages a multitude of partnerships, driving advancements in rapid data transmission technologies that are vital for modern data infrastructures. Collaborating with vendors under the IOWN concept and pursuing product development targeted at data centers might be a strategic approach, though considering further cost reductions by internalizing manufacturing processes could also be advantageous given the low barriers to entry in this market.

Table 5.11

Intensity of Industry Rivalry within the ICT Hardware Equipment Industry

Segmentation	Top 5 Company	Market Share (%)	HHI
Server Equipment (2021)	Dell Inc.	15.60%	625.21(Low)
	HPE / New H3C Group	15.70%	
	Inspur/Inspur Power Systems	8.40%	
	Lenovo	7.00%	
	IBM	5.00%	
Storage (2021)	Dell	26.80%	1038.28 (Low)
	HPE/New H3C Group	10.90%	
	NetApp	9.80%	
	Huawei	8.90%	
	Hitachi	4.90%	
Network Equipment (2020)	Huawei	28.90%	1208.55 (Low)
	Cisco	15.10%	
	Nokia	11.40%	
	Ericsson	9.60%	
	ZTE	5.90%	
Optical Transceiver (2020)	Lumentum	11.00%	605 (Low)
	II-VI	16.90%	
	InnoLight	10.00%	
	Hisense Broadband	8.00%	
	AcceLink	8.00%	

Note: Source Data from Statista and Semiconductor Today.

Cooperation with the Suppliers in Downstream Business (in the IT Device Market)

As part of the collaborative efforts under the IOWN initiative with network equipment vendors, NTT DOCOMO, Inc. and NTT have broadened their collaborative endeavors under the IOWN initiative for 6G technology development by incorporating new partners, SK Telecom Co., Ltd. and the high-performance measurement equipment manufacturer Rohde & Schwarz GmbH & Co. KG (Fig. 5.11). This expansion increases the total number of collaborating companies to seven, which also includes Fujitsu Ltd., NEC Corporation, Nokia, Ericsson, and Keysight Technologies, Inc. The partnerships are focused on conducting experimental tests across various frequency bands to expedite the development and standardization of 6G technology (NTT, 2024). Key achievements from these collaborations include:

- Nokia: Conducted successful trials in Japan using a prototype unit and a 128-element phased array antenna in the 140GHz band, demonstrating effective beamforming capabilities and maintaining strong reception despite receiver movement.
- Fujitsu: Experimented with a 100GHz band-phased array antenna and radio circuits, successfully gathering propagation path information comparable to distributed MIMO systems.
- Keysight Technologies: Specialized in sub-terahertz band propagation measurements and channel modeling, developing equipment that enables real-time, visual observation of radio wave directions and ultra-high resolution timing analysis with an ultra-wideband signal above 10GHz.

These initiatives are integral to DOCOMO and NTT's broader strategy to leverage diverse mobile communications technologies and partnerships, both domestic and international, to advance 6G research and development, and contribute to its global standardization and implementation. The progress and future plans of these collaborative efforts will be highlighted at MWC Barcelona 2024, which begins on February 26.

Additionally, within the scope of the IOWN Proof of Concept (POC), Nokia and NTT have showcased significant advancements with the application of APN technology in mobile fronthaul, enhancing power efficiency, transmission capacity, and reducing latency. The ongoing challenge is to engage major network vendors like CISCO and server and storage vendors such as Dell and HP, to transition from electrical to optical signaling in computing. This collaboration aims to establish an international standards framework encompassing both networking and computing technologies.

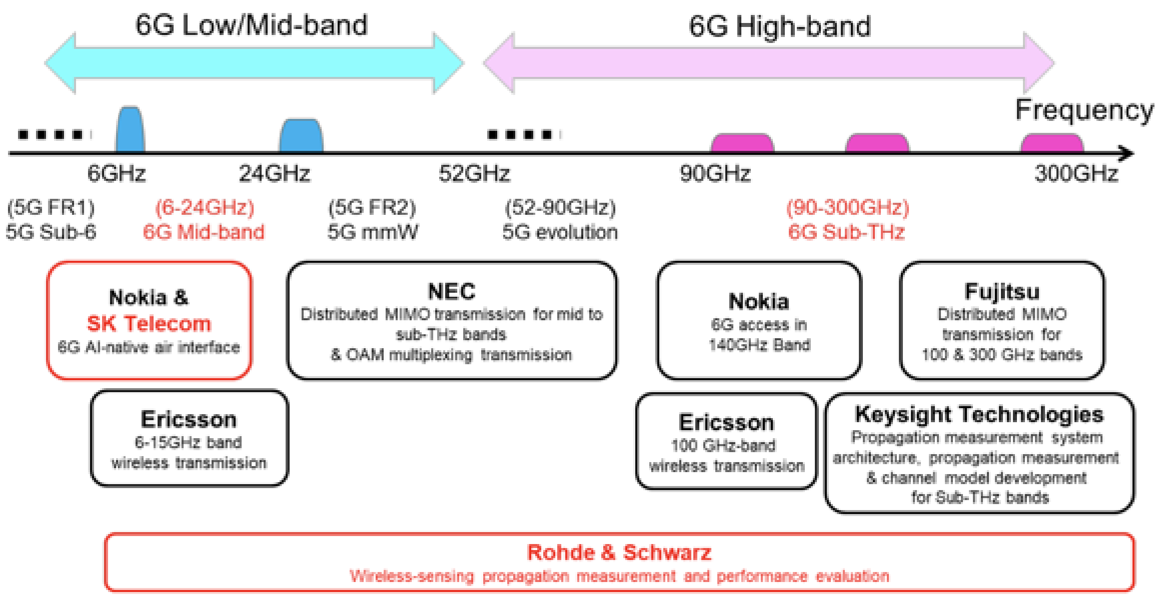

Fig. 5.11. Trials with seven collaborators, including two new companies under the IOWN initiative for 6G technology development. DOCOMO and NTT expand 6G collaborations with SK Telecom and Rohde & Schwarz - Highlighting trial progress with Nokia, Fujitsu, and Keysight Technologies (2024).

5-2-3. Bargaining Power of Buyers

This force looks at the power of customers to drive prices down. It is affected by the number of buyers, the importance of each buyer to the industry, and the cost to the buyer of switching from one product to another. If a small number of buyers purchase large volumes of industry output, they can negotiate for lower pricing or additional services.

Customer Segmentation Insight from Downstream Business

As the IOWN initiative is poised to transform various sectors including networks, data centers, and the servers within these centers used by cloud operators, the one of key focuses is on how to implement this technology within and between data centers and for cloud operators managing these servers.

For customer segmentation analysis, cloud operators wield significant buying power over their suppliers in the network, data center collocation, and IT equipment sectors as we saw in Chapter 3 of the section on dependency structure matrix (DSM). This power stems from their massive market share, the essential nature of their business to suppliers, the ability to switch suppliers relatively easily, and their strategic investments in vertical integration. As these cloud providers continue to grow and expand their infrastructure, their influence as major buyers in these markets is likely to increase further, shaping the dynamics of the supply chain in the telecommunications and IT industries.

In 2021, non-cloud and dedicated infrastructure spending constituted over half of enterprise infrastructure expenditures but is projected to be surpassed by shared and dedicated cloud spending by 2025. By 2026, spending on cloud and shared infrastructure is expected to represent almost half of all enterprise infrastructure spending (Fig. 5.12). With this market growth, cloud operators, who make critical decisions about network hardware, data center locations, and servers for computing purposes to provide services to cloud users, hold significant decision-making power. Thus, understanding the benefits IOWN offers to these operators is crucial. If cloud operators (one of the downstream customers) adopt the IOWN-compliant architectures, it naturally leads to the adoption of this architecture by network hardware, data center providers, and server vendors (down and upstream potential customers).

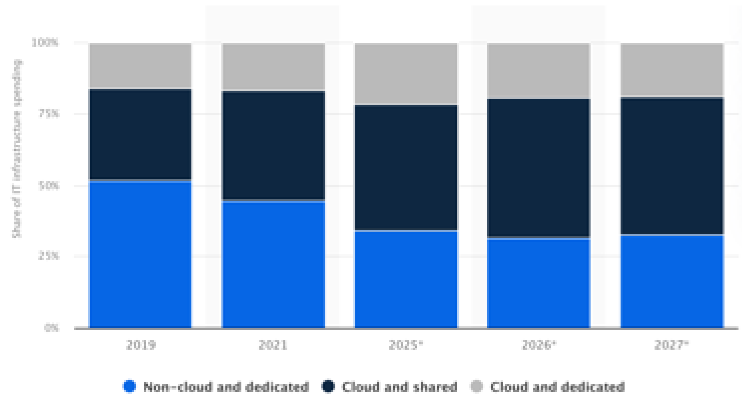

Fig. 5.12. Worldwide enterprise (IT) infrastructure buyer and cloud spending breakdown (by value) from 2019 to 2027, by deployment type. From IDC and Statista 2024

Degree of Buyer's Monopoly in Downstream Business

As we explored Table 5.3, the cloud market, particularly Infrastructure as a Service (IaaS), is characterized by a high concentration as indicated by the HHI 2,190. This suggests a dominant position by a few large players.

Amazon (AWS) holds a substantial market share of 40%, making it the leader in the cloud IaaS sector. Amazon's position allows it to shape market trends, influence pricing structures, and drive innovation, often setting standards that others follow. Also, Microsoft (Azure) is another significant player with 21.5% of the market. Its integration with other Microsoft products and services provides a strong value proposition for enterprises embedded in the Microsoft ecosystem. Google Cloud with 7.5% and Alibaba Cloud with 7.1% are also key players, though they hold smaller portions of the market compared to Amazon and Microsoft. Alibaba Cloud leads in China and is expanding globally, while Google Cloud is known for its data analytics and machine learning services. Huawei Cloud, with 4.8%, shows significant growth potential, particularly in China and regions where Huawei's telecommunications equipment is widely used. Their substantial revenues from cloud services translate into significant capital expenditures on data centers, networking, and equipment, enhancing their bargaining power.

We can anticipate that network and data center vendors such as AT&T, Verizon, Equinix, and NTT rely heavily on large cloud providers. Given the concentrated market power in cloud services, losing a client like Amazon or Microsoft could significantly impact their revenues, which in turn increases the cloud providers' buying power. While switching costs for cloud providers regarding networking and data center services are non-trivial, they are manageable due to the standardized nature of many of these services. This allows cloud providers to negotiate favorable terms due to their ability to switch suppliers without prohibitive costs. The competitive nature of the network market and IT equipment provides cloud providers with multiple sourcing options. The availability of various manufacturers and service providers allows cloud providers to strengthen their negotiating position, as they can choose different vendors if existing terms are not favorable. Companies like Equinix and NTT are enhancing their offerings to cater specifically to cloud giants, emphasizing the strategic importance of maintaining robust relationships with these customers. Cloud providers typically engage in long-term contracts with suppliers, providing stability but usually negotiated under terms favorable to the cloud providers due to their size and influence. The relationships are generally collaborative, aiming to ensure service continuity and scalability.

In the data center business, revenue distribution highlights the critical importance of network services, which account for about 58% of total revenues (Fig. 5.13). This indicates that network infrastructure not only plays a pivotal role in data center operations but also drives the majority of financial returns. Servers, storage, and other equipment contribute approximately 28% of revenues, underscoring the significant but lesser financial impact compared to network services.

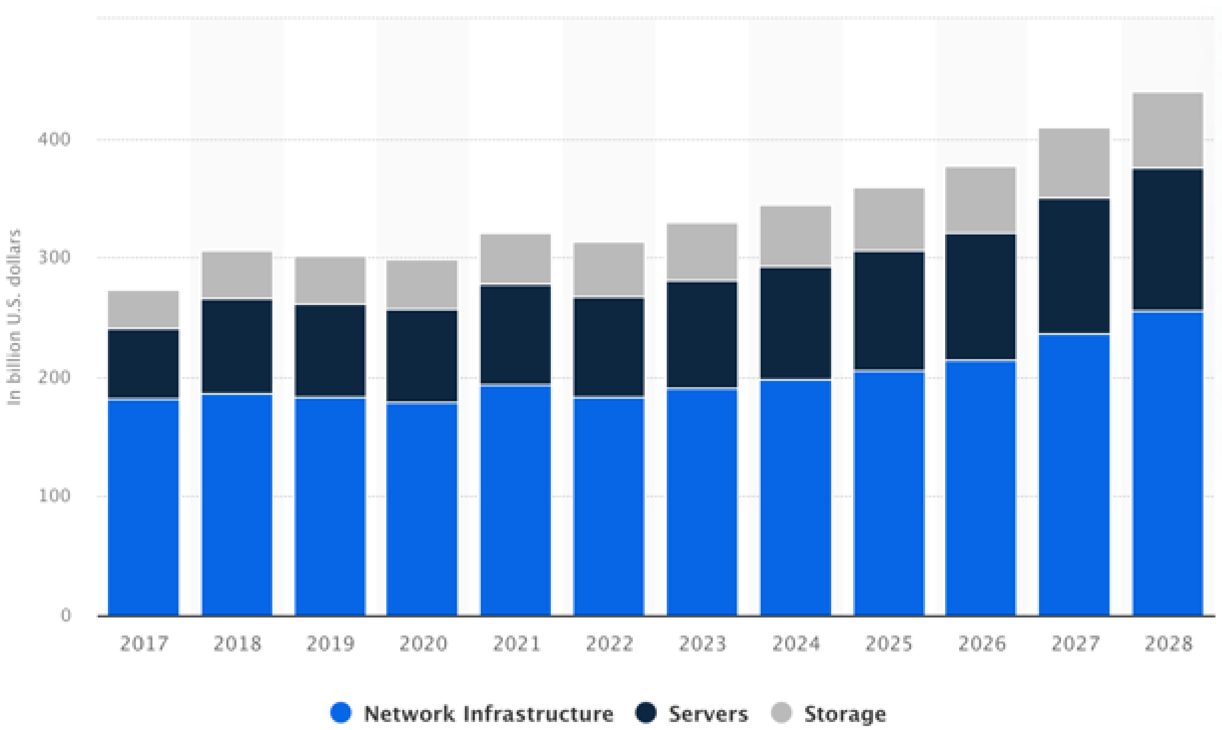

Fig. 5.13. Revenue in the Data Center market for different segments Worldwide from 2017 to 2028 (in billion U.S. dollars). From Statista 2024.

To maintain competitiveness in the data center market, companies need to focus on enhancing their network services. This could include investing in advanced networking technologies, improving bandwidth capacities, reducing latency, and ensuring high reliability and security. Effective network services attract more customers by enabling superior performance and scalability, which are crucial for businesses relying on cloud computing and large-scale data processing.

Given the revenue implications, companies should prioritize network improvements and strategic investments in network technologies to capitalize on their substantial revenue-generating potential within the data center business. Customers within this market are increasingly seeking faster, more reliable network connectivity. Driven by the expansion of cloud computing, streaming services, and the IoT, there is a heightened demand for networks that can manage large data volumes with low latency. According to Worldwide (2018), the global data center IP traffic was expected to increase to 19,509 exabytes per year by 2021. And it can be seen that approximately 95% of that traffic is from cloud providers (Fig.5.14).

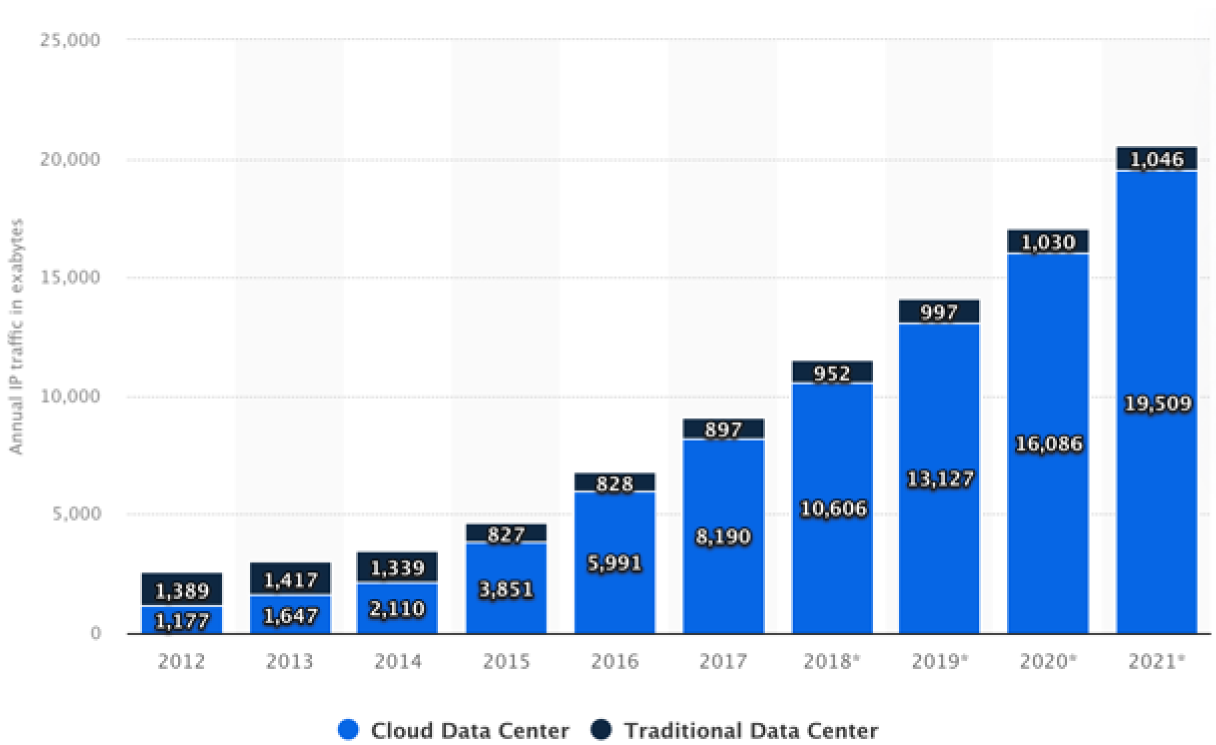

Fig. 5.14. Global data center IP traffic from 2012 to 2021, by data center type (in exabytes per year). Retrieved From Statista 2024.

NTT and NTT Data Group have conducted a demonstration connecting data centers owned by the NTT Group in the United Kingdom and the United States using the IOWN's All-Photonics Network (APN). This demonstration linked data centers approximately 100 kilometers apart and achieved communication with less than 1 millisecond of latency using IOWN APN technology.

This achievement signifies the potential for these data centers to function as a unified IT infrastructure, comparable to a single data center, facilitating distributed real-time AI analytics and applications in finance. In the UK, the Hemel Hempstead HH2 and Dagenham LON1 data centers were connected, while in the US, the Ashburn VA1 and VA3 data centers were linked using NEC-manufactured APN equipment. The tests measured round-trip delays and jitter between these data centers. The connection supported 400Gbps communication with sub-millisecond latency and microsecond-level jitter variation. Specifically, in the UK, the latency was recorded at 0.893 milliseconds with a jitter of 0.035 microseconds. Also, in the US, the latency was even lower at 0.062 milliseconds with a jitter of 0.045 microseconds.

These results significantly surpass typical cloud applications' latency requirements, where major cloud providers consider data centers with latencies under 2 milliseconds as equivalent. Traditional networks composed of Layer 2 switches generally experience several microseconds to tens of microseconds of jitter (NTT, 2024).

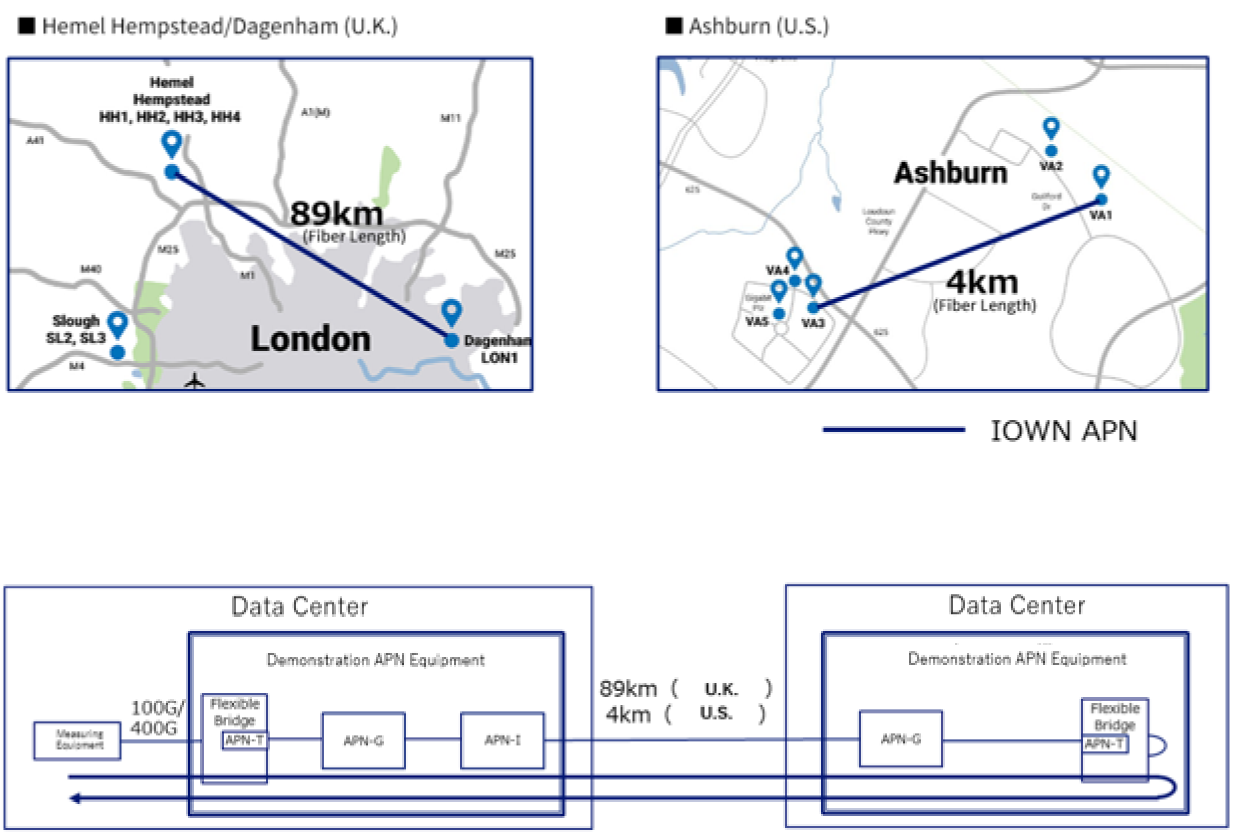

Fig. 5.14. Overview of the demonstration experiment on long-distance data center connections in the United Kingdom and the United States. From NTT Web Site: https://group.ntt/en/newsrelease/2024/04/12/240412a.html

Amazon (AWS) provides latency information between data center regions called AWS Latency Monitoring. The comparison between the result of the IOWN's latency performance and Amazon Web Services (AWS) latency monitoring between UK and US data center regions over the past year presents a compelling case for the IOWN technology (Table 5.12). The results indicate that IOWN offers significantly faster communication speeds, highlighting its potential to substantially enhance network services for cloud vendors, 3 times faster than AWS in the UK path, and 3.14 times faster than AWS in the US path. This superior performance of IOWN not only contributes to improving the efficiency and responsiveness of cloud services but also positions it as a valuable innovation for cloud vendors looking to optimize their network infrastructure. Faster latency directly impacts cloud service quality, affecting everything from real-time data processing and cloud computing to user experience and service reliability.

Table 5.12

IOWN APN Experimentation Region	NTT IOWN APN Latency per km (ms/km)	AWS Data Center Region	AWS Latency per km (ms/km)	Speed Improvement Factor
Inter UK (89km)	0.01003	Ireland to London (~464 km)	0.03011	**3.0000**
Inter US (4km)	0.0155	Virginia to Oregon (~3,900 km)	0.04867	**3.1400**

Note: *Comparison of the speed between IOWN APN and the current AWS Data Center Interconnection. This is based on the results of the IOWN APN latency measurements for long-distance data center connections between the United Kingdom and the United States conducted by NTT on April 12, 2024, and the average results from a year of AWS latency monitoring between data centers in the UK and US.*

Also, NTT and Sony Group Corporation, which is the highest image processing manufacturer, have successfully demonstrated precision remote operation using IOWN APN, enabling tactile feedback over long distances that mimics direct interaction. The joint demonstration (Fig 5.15) showcased the capability of providing real-time, stable operation feedback with high precision to a remote operator using low-latency communication technology. Uncompressed video transmission technology directly maps video data from SDI signal to the SMPTE ST 2110 stream, achieving a transmission delay of less than 1 millisecond from input to output. Also, utilizing RDMA's ability to transfer data directly from memory to the network without CPU intervention, the technology adapted to long-distance communication by generating a pseudo loopback signal, enabling reliable data transfers over extended distances without changing the application's usage of RDMA. Sony provided its advanced bilateral control system which accurately synchronizes the operator's movements with the robot arm's motions.

The system supports highly detailed tasks required in fields like medicine and scientific research, delivering force feedback with a precision of 1gf and sub-millimeter positional accuracy. The demonstration effectively utilized APN's low latency transport capabilities, confirming stable end-to-end operations with less than 1 millisecond of latency over approximately 120 kilometers. Additionally, the application-level communication via RDMA achieved extremely low jitter under 10 microseconds, demonstrating that APN can significantly reduce transmission delays and fluctuations.

These results indicate that APN's advanced network solutions can effectively extend precise control capabilities over larger distances, promising significant advancements in remote operations for various high-precision industries. This reliable network technology can enable cloud providers to pursue new connectivity businesses like the IoT and autonomous vehicle systems.

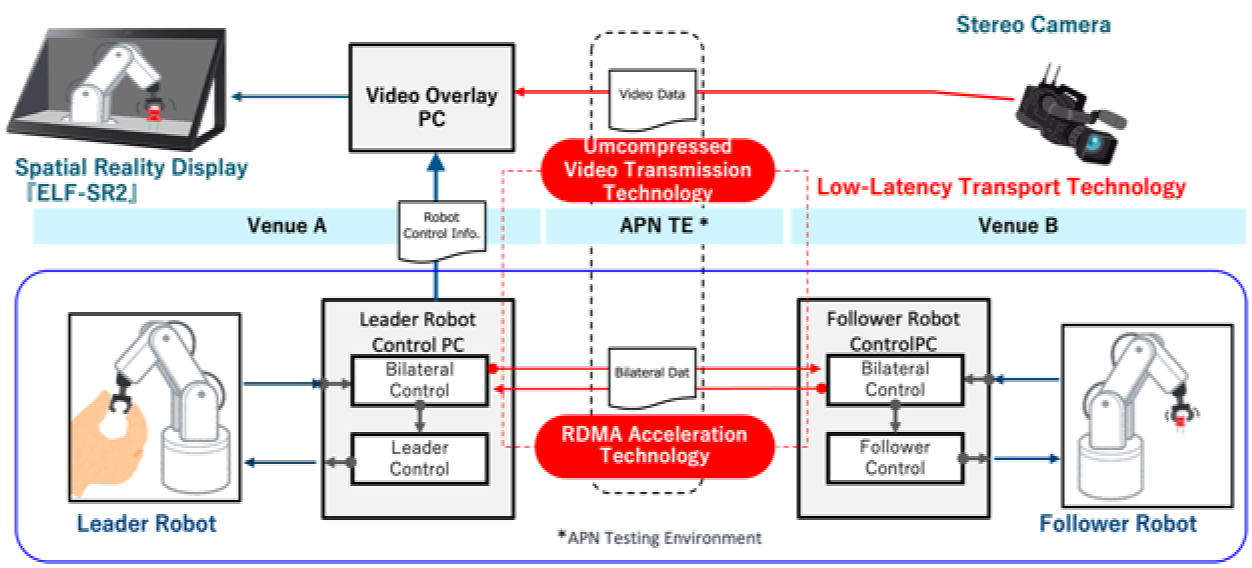

Fig. 5.15. Demonstration Image of remote operation with tactile sensation using low-latency transport technology and precise bilateral control technology in IOWN APN. Retrieved from NTT Web Site: *https://group.ntt/en/newsrelease/2023/11/10/231110b.html*

Customer (Buyer)'s Pain Point

Charles Fitzgerald's analysis (2024) highlights the CAPEX trends of major hypercloud providers—Amazon, Google, and Microsoft—to remain competitive, especially in the context of advancements in generative AI. In 2023, these companies collectively spent over $127 billion on CAPEX, maintaining the previous year's level. Microsoft saw a significant 45% increase in

CAPEX to $41.2 billion, driven by investments in AI and GPUs through its partnership with OpenAI, emphasizing its strategic focus on AI technologies to boost Azure's computational capabilities. Google's CAPEX rose modestly by 2% to $32.3 billion, with a delayed major server refresh suggesting a cautious approach. In contrast, Amazon reduced its CAPEX by 20% to $53.7 billion, the first cut in AWS's infrastructure investments, indicating a shift towards optimization over expansion.

He also discusses the impact of these trends on the cloud industry, highlighting the strategic shifts towards AI. Microsoft's investment in AI-specific capabilities like GPUs positions it to lead in AI-enhanced services. The report notes changing dynamics with hardware suppliers, especially NVIDIA, affecting the cloud providers' ability to compete in AI. For instance, tensions between Amazon and NVIDIA over GPU supplies could influence AWS's competitive edge. Fitzgerald suggests that the evolving strategies and investments in AI and cloud infrastructure by these companies will be pivotal in maintaining a competitive advantage in an AI-dominated landscape.

For example, large-scale language models like ChatGPT, which operate on GPT-3.5 and GPT-4, heavily rely on Graphics Processing Units (GPUs) for their development and operation. GPUs, known for their strength in parallel processing, are crucial for handling the massive data sets involved in machine learning and are indispensable in the development of these large-scale models. NVIDIA almost monopolizes the market for AI-development-suited GPUs, holding an estimated 80-95% market share. Particularly in generative AI development, their 2022 model, the "H100," has seen remarkable sales. Targeted for data centers, these GPUs are typically sold in clusters, with prices ranging from $20,000 to $30,000 each. Despite their high cost, the demand for these powerful GPUs has surged, leading to intense competition among major tech companies.

Over the past year, industry giants like Meta, Microsoft, Google, Amazon, and Oracle have reportedly ordered tens of thousands of H100 units. According to Omdia(2023), Meta and Microsoft each ordered 150,000 units, leading the demand. They are followed by Google, Amazon, Oracle, Tencent with 50,000 each, and startup CoreWeave with 40,000 units. Combined annual sales of the H100 and its predecessor, the "A100," were expected to exceed 500,000 units (Table 5.13). The lead time for H100-based servers was projected to stretch between 36 to 52 weeks, implying a wait of nine months to over a year from order to delivery. The significant market dominance of Nvidia, particularly in the GPU sector for AI development, does indeed provide them with substantial bargaining power. This dominance allows Nvidia to influence pricing and supply conditions significantly, potentially leading to increased costs for cloud providers who rely on their technology.

As these providers are under pressure to manage costs while staying competitive in the rapidly evolving AI market, they might actively seek alternative technologies or suppliers to mitigate dependency on Nvidia and enhance their bargaining position. This situation illustrates a typical challenge in tech industries where rapid innovation cycles and high competition can shift market dynamics and influence strategic decisions.

Table 5.13

Estimation of the investment amount of NVIDIA Chips

by major hypercloud providers and AI-enhanced service providers.

Company	Units Ordered	Estimated Investment (USD)
Meta	150,000	$3 billion - $4.5 billion
Microsoft	150,000	$3 billion - $4.5 billion
Google	50,000	$1 billion - $1.5 billion
Amazon	50,000	$1 billion - $1.5 billion
Oracle	50,000	$1 billion - $1.5 billion
Tencent	50,000	$1 billion - $1.5 billion
CoreWeave	40,000	$800 million - $1.2 billion

Note: Calculated based on Omdia's research results (2023).

Additionally, the trend over the past decade has seen a shift from traditional data centers to more efficient large-scale cloud-based and hyperscale data centers. According to the IEA International Energy Agency (2020), from 2010 to 2018, global data center energy consumption only slightly increased from around 194 TWh to 205 TWh, representing about 1% of global electricity use (Fig. 5.16). It also estimated that around 80% of energy would be consumed by cloud within data centers (Traditional: 39Twh, Non-Hyperscale: 69Twh, Hyperscale: 93Twh). Moreover, with the burgeoning impact of AI and digitization, a rapid increase in the number of large-scale data centers is expected, which could lead to a significant rise in overall data center power consumption.

Also, their latest report explores the significant impact of rapid AI integration into software programming across multiple sectors on the electricity demand of data centers. It highlights that search tools like Google could experience a tenfold increase in electricity consumption if AI is fully implemented. Notably, while a typical Google search requires 0.3 Wh of electricity, OpenAI's ChatGPT demands approximately 2.9 Wh per request. With an average of 9 billion searches daily, this translates to an additional annual electricity requirement of almost 10 TWh. The document also details forecasts for the AI server market, currently dominated by NVIDIA, which held a 95% market share in 2023. NVIDIA's AI servers, totaling 100,000 units shipped in 2023, consumed an average of 7.3 TWh of electricity annually. By 2026, the electricity demand for the AI industry is projected to increase at least tenfold from the 2023 levels.

Furthermore, in the 2024 Artificial Intelligence Index Report, Stanford University's Human-Centered Artificial Intelligence highlighted the escalating training costs of cutting-edge AI models, which have reached unprecedented levels. For instance, OpenAI's GPT-4 model incurred an estimated $78 million in computing costs, while Google's Gemini Ultra amounted to $191 million. These expenses, along with the substantial electricity usage required for AI training, pose significant economic and social challenges for data centers, cloud providers, and AI enterprises moving forward.

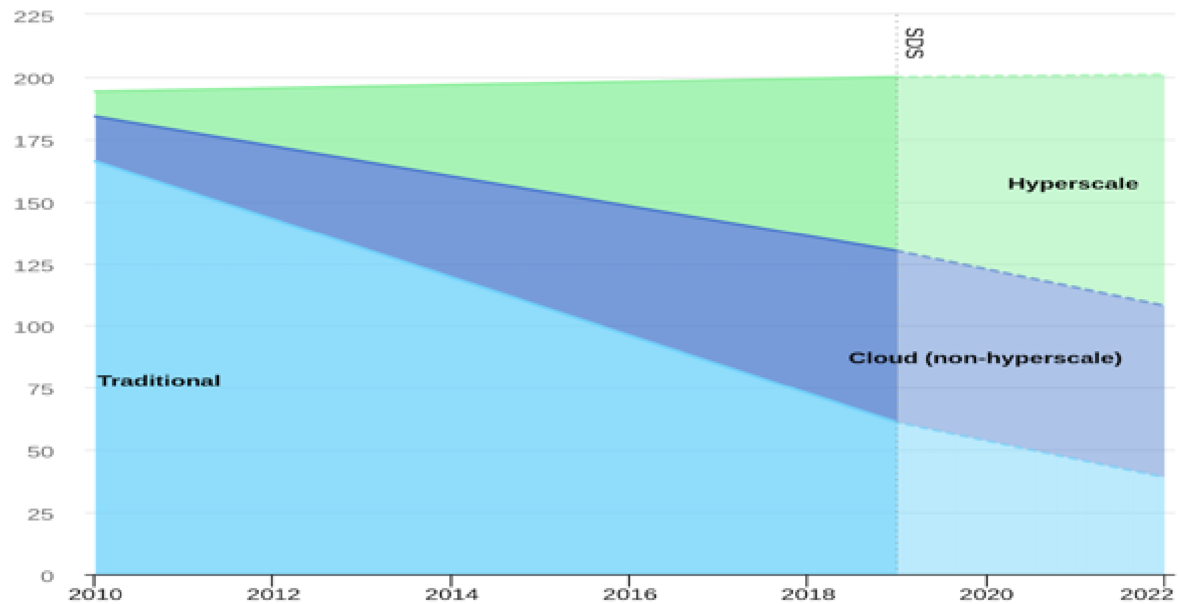

Fig. 5.16. Global data centre energy demand by data centre type, 2010-2022.

Retrieved from IEA Web Site: https://www.iea.org/data-and-statistics/charts/global-data-centre-energy-demand-by-data-centre-type-2010-2022

NTT's Value Proposition

NTT is proposing and developing the Super White Box as a strategy to address the increasing cost of equipment and the rising electricity consumption in data centers.

The traditional approach to building information and communication systems involves assembling a combination of servers, storage, and switches, and routers. Each component, or "box," is evaluated based on its performance and functionality. As technology evolves, these components are frequently replaced and reconnected to upgrade the ICT infrastructure. The concept of "disaggregation" is transforming this traditional approach. It separates hardware from software, leading to the advent of reconfigurable "white-box" hardware. With the advancement of virtualization technology, the use of white-box switches is becoming prevalent in networking, where virtual switches and routers operate within servers. This approach under the IOWN breaks down and reconfigures the physical and logical components within computers, establishing new control methods. By doing so, resources traditionally confined within servers, such as CPUs and memory, are liberated. These resources can then be managed at the rack or data center level as a single computer unit. This paradigm shift aims to dramatically enhance processing performance and power efficiency, making the system not only higher in performance but also more cost-effective by optimizing resource utilization across a broader scale.

The approach is outlined as a four-story structure, emphasizing the progressive development of optoelectronic fusion devices. The first floor focuses on creating these devices for infrastructure hardware. The second floor integrates these devices within the Super White Box (SWB) framework, paired with memory and GPU cards, to enhance computational performance and reduce power consumption through disaggregated computing. The third floor transitions into software-defined photonics and wireless technologies, incorporating Beluganos network OS and acting as orchestrators to deliver applications. The fourth floor is dedicated to developing industry-specific solutions and services.

Significant advancements in device packaging have been made, from the initial COSA format to the compact CoPKG configuration, which integrates optical circuits and DSPs, facilitating easier adoption due to simpler design requirements. The forthcoming Photon Engine, a larger, third-generation device set for a 2025 commercial release, will incorporate a Fiber Array Unit to boost power efficiency and processing speed, aimed at data center applications and showcased at the 2025 Osaka-Kansai Expo. Future generations aim for further miniaturization and efficiency, with the fourth generation scheduled for 2028, and a highly compact fifth generation expected by 2032, featuring Heterogeneous System MCM for cost-effective optoelectronic chipsets.

NTT is focusing on internal production technologies for up to the third generation, with planned investments below 10 billion yen. For the fourth generation and beyond, investments are expected to exceed 100 billion yen as the focus shifts from set manufacturers to semiconductor producers, exploring external production capabilities to meet demand. These technological strides also align with the Japanese Ministry of Economy, Trade, and Industry's predictions that such devices could lead to a 40% reduction in power consumption in data centers (METI, 2023).

PoC Results Achieved by IOWN in Meeting AI Demand

In a collaborative proof of concept (PoC) between Red Hat and NTT Software Innovation Center, the IOWN was utilized to dramatically reduce power consumption and latency in real-time AI analytics (5.17). Leveraging the APN and a Data Centric Infrastructure (DCI) compatible with Red Hat OpenShift, this solution optimizes AI inference at the edge, achieving up to a 60% reduction in latency and 40-60% in energy use.

The core innovation utilizes disaggregated computing, allowing computational resources like CPUs and memory, traditionally confined within servers, to be managed collectively across the data center, enhancing performance and energy efficiency. Specifically, the Red Hat OpenShift platform employs GPUdirect RDMA for high-speed data processing, efficiently transferring image data from local aggregation nodes directly to GPU memory via IOWN APN. This facilitates the rapid execution of NTT's AI inference engine, enabling substantial improvements in processing speed and power efficiency.

This system has demonstrated the potential to reduce energy consumption by up to 60% in setups managing 1,000 cameras, showcasing significant environmental benefits. This approach, highlighted in the IOWN Global Forum, represents a major advance in cloud computing and AI-driven analytics, setting a new benchmark for network and data center technologies towards more sustainable and efficient computing solutions.

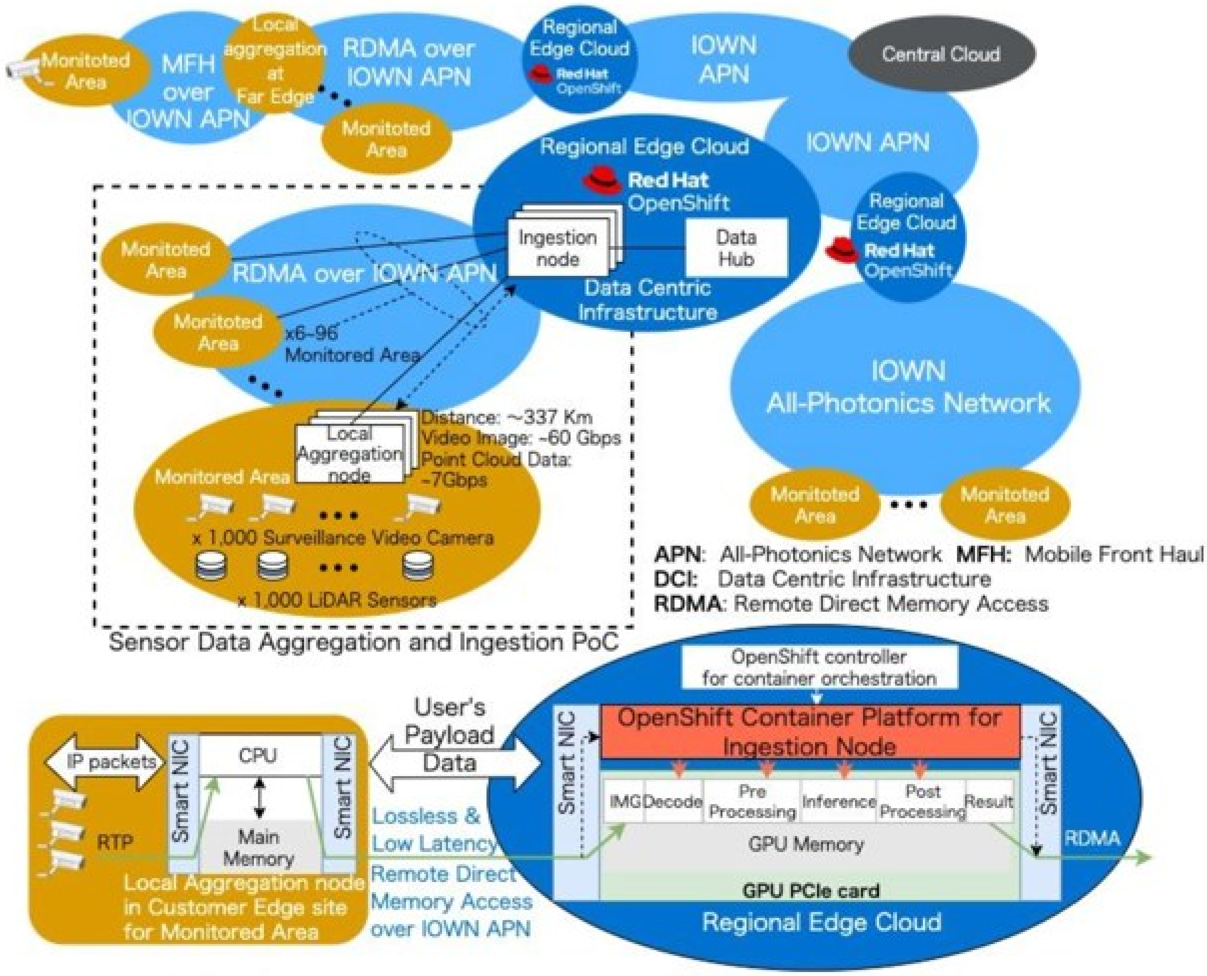

Fig. 5.17. IOWN GF reference implementation model for CPS Area Management use case.

From Red Hat Web Site: https://www.redhat.com/en/blog/ntts-accelerated-data-pipeline-red-hat-openshift-and-iown-all-photonics-network

5-2-4. Threat of New Entrants

The threat of new entrants refers to the risk that new competitors pose to existing players within an industry. A high threat of new entrants can depress profits for all players within the industry if they bring additional capacity and desire to gain market share. Factors that can lower this threat include high entry barriers due to economies of scale, high capital requirements, access to distribution channels, and regulatory policies.

Penetration from the Proximity Value Chain (Telecommunication Case)

The threat of new entrants is exemplified by players from adjacent value chains in chapter 3 of the DSM analysis entering NTT's development areas. Notably, areas with downstream end-users, such as the cloud, AI, and digital sectors, warrant close attention. For instance, major telecom companies and data center providers like AT&T, Equinix, and NTT, which hold shares in international communications—particularly in submarine cables and self-operated data centers—are of interest.

Submarine cables, the arterial highways carrying 99% of international internet traffic, have evolved significantly over their approximately 150-year history (KDDI, 2022). Originally developed for international telephony and internet relays, recent transformations have occurred as submarine cables now primarily connect data centers across the globe for giants like Google and Meta Platforms (formerly Facebook). These tech behemoths have not only transformed the role of submarine cables into intranet links but have also taken the lead in their construction.

This shift in the principal actors of submarine communication infrastructure is shaking up the traditional modalities of global communication (Table 5.14). Constructing a submarine cable, especially one crossing the Pacific over about 10,000 km, involves substantial investment, often amounting to billions of yen, and negotiations with national governments for landing rights. Traditionally, these cables were built by consortia of national telecom operators pooling their resources. However, a shift occurred in 2010 when Google joined the consortium for the 'Unity/EAC-Pacific' trans-Pacific cable project alongside various national telecom operators. Subsequently, other tech giants like Meta, Amazon, and Microsoft began participating in these consortia. This trend reflects a significant shift from renting cable capacity from traditional carriers to owning cables outright, driven by the cost benefits of eliminating middleman margins as data demands surge.

Table 5.14

History of Submarine Cables and the Owners

Cable Name	Owner	Main Landing Sites	Length (km)	Service Start Year
Unity/EAC-Pacific	Airtel, Google, KDDI, Singtel, TIME dotCom, Telstra	Japan, USA	9,620.00	2010
Southeast Asia Japan Cable (SJC)	China Mobile, China Telecom, Chunghwa Telecom, Globe Telecom, Google, KDDI, National Telecom, Singtel, Telkom Indonesia, Unified National Networks	Japan, China, Brunei, Philippines, Singapore	8,900.00	2013
FASTER	China Mobile, China Telecom, Google, KDDI, Singtel, TIME dotCom	USA, Japan, Taiwan	11,629.00	2016
Monet	Algar Telecom, Angola Cables, Antel Uruguay, Google	USA, Brazil	10,556.00	2017
Junior	Google	Brazil	390.00	2018
Tannat	Antel Uruguay, Google	Brazil, Argentina, Uruguay	2,000.00	2018
INDIGO-Central	Australia's Academic and Research Network, Google, Indosat Ooredoo, Singtel Optus, Superloop	Australia	4,850.00	2019
INDIGO-West	Australia's Academic and Research Network, Google, Indosat Ooredoo, Singtel, Superloop, Telstra	Australia, Indonesia, Singapore	4,600.00	2019
Curie	Google	USA, Chile, Panama	10,476.00	2020
Havfrue/AEC-2	Aqua Comms, Bulk, Meta (Facebook), Google	USA, Denmark, Ireland, Norway	7,650.00	2020
Japan-Guam-Australia South (JGA-S)	Australia's Academic and Research Network, Google, RTI	Guam, Australia	7,081.00	2020
Pacific Light Cable Network (PLCN)	Meta (Facebook), Google	USA, Taiwan, Philippines	11,806.00	2020
Dunant	Google	USA, France	6,400.00	2021
Grace Hopper	Google	USA, UK, Spain	7,191.00	2022
Equiano	Google	Portugal, Nigeria, Namibia, South Africa	Undetermined	2023
Echo	Meta (Facebook), Google	USA, Guam, Indonesia, Singapore	17,184.00	2023
Firmina	Google	USA, Brazil, Uruguay, Argentina	Undetermined	2023
Apricot	Chunghwa Telecom, Meta (Facebook), Google, NTT, PLDT	Japan, Indonesia, Taiwan, Philippines, Singapore	12,000.00	2024
Blue	Google, Omantel, Telecom Italia Sparkle	France, Greece, Italy, Cyprus, Jordan, Israel	Undetermined	2024
Raman	Google, Omantel, Telecom Italia Sparkle	Jordan, Saudi Arabia, Djibouti, Oman, India	Undetermined	2024

Note: Data from TeleGeography (2023): https://submarine-cable-map-2023.telegeography.com/

According to TeleGeography (2023), around 20 new submarine cables are laid each year, with these tech giants involved in approximately 20% of these projects. These companies tend to participate in long-distance projects like trans-Pacific or trans-Atlantic crossings. Remarkably, projects involving these large IT companies now constitute nearly 50% of the annual global length of submarine cables laid. The 'PLCN' cable, funded by Google and Facebook (at the time) and operational since 2022, is notable not only for its design capacity of 120 Tbps but also for its adjusted landing points from Hong Kong to Taiwan and the Philippines due to US-China tensions.

Currently, traditional carriers still have an edge in network speed, as seen in the comparison with Google, Meta, and Amazon. However, the ease of catching up with existing technology poses a challenge to NTT in maintaining its unique position and potential revenue from international lines provided to cloud and AI enterprises. For instance, NTT is collaborating with Mitsui & Co., and JA Mitsui Leasing on the JUNO project, which can transmit at 350 Tbps across approximately 10,000 km in Japan (Chiba and Mie prefectures) and the U.S. (California) (NTT, 2022). Meanwhile, Google is planning a submarine cable named Topaz to connect Japan with Canada, designed to handle transmissions up to 240 Tbps (Submarine Networks, 2022).

Countermeasures Against New Entry

One proposed way to frustrate their ambitions is the utilization of IOWN. If the initiative can provide a service that is cheaper and far better performing than their own submarine cable facilities, they may begin to use IOWN as a network between their data centers. For its implementation, NTT, which is the third major shareholder of NEC (4.88%), is collaborating with other leading stakeholders in submarine cable facilities—like US-based SubCom (approximately 40% share), NEC (about 30%), and France's Alcatel Submarine Networks (around 20%)—to jointly develop and conduct pilot experiments.

NTT and NEC have achieved a world-first by successfully transmitting data over 7,000 km using a 12-core optical fiber, a crucial technology for NTT's IOWN initiative (5.18). This breakthrough could significantly enhance the capacity of both submarine and terrestrial optical networks. Globally, about 450 submarine cables are covering 1.4 million km, capable of transmitting the equivalent of 10,000 two-hour movies per second across continents. These cables, designed for long distances up to 16,000 km and deep-sea pressures, offer petabit-level capacities and a 25-year service life with minimal maintenance (NTT & NEC, 2024). Over the past 60 years, NEC has installed roughly 400,000 km of these cables. The core technology, known as spatial division multiplexing (SDM) via multi-core fiber transmission, increases transmission lanes within the same cable without notably increasing its size or weight. This allows for more straightforward handling and deployment.

Additionally, crosstalk issues at connection points are addressed with MIMO signal processing, which restores signal integrity over long distances. The recent experiment simulated maintaining data quality over a 52 km loop of 12-core fiber, showing promise for trans-Atlantic distances with potential future applications for trans-Pacific crossings. While a 12-core cable doesn't linearly increase speed twelvefold, it significantly boosts communication speeds, with ongoing research focused on maximizing this potential.

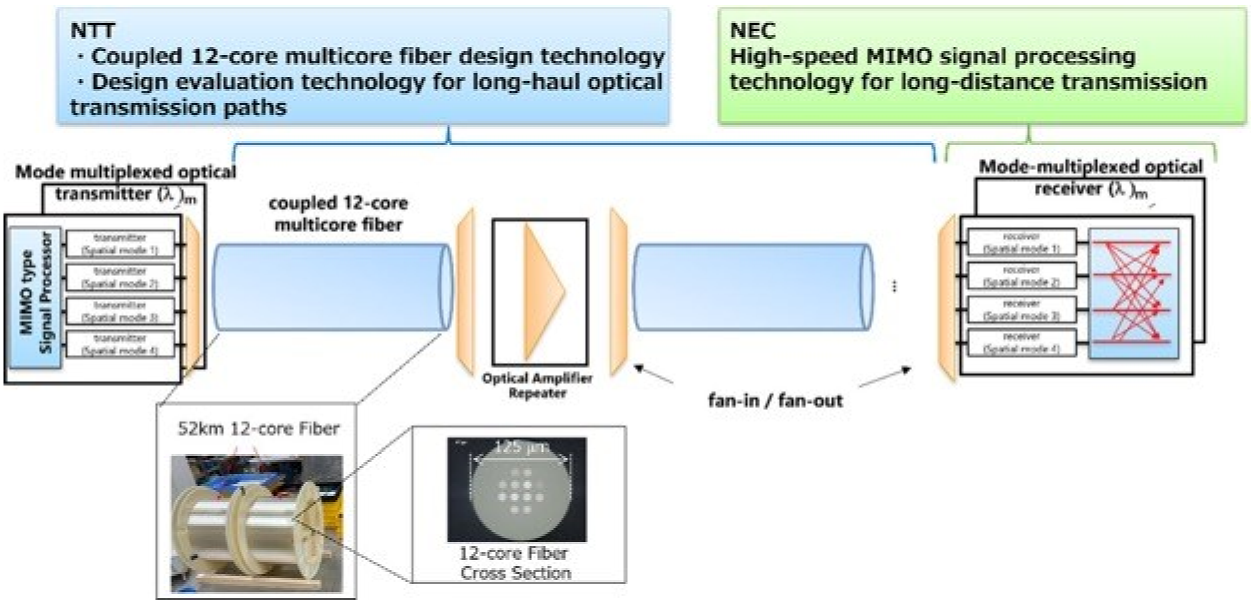

Fig. 5.18. Schematic diagram of the technologies developed.

From NTT Web Site: https://group.ntt/en/newsrelease/2024/03/21/240321a.html

Penetration from the Proximity Value Chain (Semiconductor Chip Case)

In the upstream business domain, cloud providers and AI developers might gain influence and venture into semiconductor design, challenging established players like Intel. Historically, Intel supplied chips for Apple's iPhones but faced revenue declines when Apple began manufacturing its own semiconductors. Apple introduced its in-house M1 chip in late 2020, marking the start of a transition across its Mac lineup to Apple silicon, which offers better integration of hardware and software, significantly boosting performance and efficiency. Although Intel components, such as USB chips, may still be used in some devices due to ongoing partnerships, Apple's primary Mac models now exclusively use Apple silicon. Apple's strategic shift to develop its own semiconductors primarily enhances performance and energy efficiency across its devices. This integration allows Apple to deliver precise functionalities that complement its software, improving the user experience and device performance. Furthermore, by designing its own chips, Apple reduces dependency on external suppliers, enabling quicker adaptation to market changes and more customized products (Tarasov, 2023). This move also secures Apple's supply chain and mitigates costs, positioning the company advantageously in a competitive market where efficiency drives success.

Additionally, major tech firms like Google, Apple, Facebook, and Amazon are developing or have announced the development of AI-specific chips, initially for server use in cloud environments, with potential expansion to autonomous vehicles and robots (Metz, C., et al. , 2024). These companies are entering a competitive arena that includes traditional semiconductor manufacturers, auto parts suppliers, and major electronics firms, underscoring the significance of AI chips in shaping the future of manufacturing. Google has been at the forefront with its Cloud TPUs, introduced in 2016, designed to accelerate machine learning tasks across services like Translate and Photos (Metz, C., 2016). Similarly, AWS has developed its own Tranium and Inferentia chips to maintain its lead in the public cloud sector and respond to competitive pressures from companies like Google (Hills, C., 2023).

The question to prevent these players from entering the IOWN’s main business domain is whether NTT can secure IP, design, or manufacturing contracts for this technology depending on their developmental progress and their ability to demonstrate clear advantages over existing technologies. As they explore extending the APN concept, there's a real possibility that this technology could be integrated not only in data processing environments like computers but also in the telecommunications sector. This integration would offer ultra-high-speed data transmission capabilities that could revolutionize how providers manage data flows, especially in areas where hyperscalers are not yet established. If NTT can prove that their optical signaling solutions offer superior speed and efficiency, they may well find opportunities to introduce these solutions to providers, promoting it as a next-generation technology that enhances both computer and telecommunications networks.

Threat of Startups

The market is growing rapidly, attracting a high likelihood of new entrants. Unlike manufacturing sectors such as foundries, the semiconductor design industry requires less capital and fixed costs, making it more accessible for startups. According to Trancxn (2024), there are currently 470 photonics startups in the American market alone (Table 5.11).

Additionally, equipment manufacturers like Cisco are enhancing their market presence by acquiring promising startups within the value chain. Cisco's strategy in silicon photonics is heavily oriented towards strengthening its hardware capabilities to meet growing demands for bandwidth and network efficiency in the multi-cloud era.

This approach was notably advanced through the acquisition of Acacia Communications in March 2021. Acacia, a leader in the development of high-speed optical interconnect technologies, has been pivotal in advancing coherent optical solutions, which are essential for handling increased internet traffic and the transition to higher network speeds. The acquisition is a core component of Cisco's broader "Internet for the Future" strategy, which prioritizes software, silicon, and optics as key areas for innovation.

This strategy aims to revolutionize networking across various domains by integrating Acacia's coherent optics technology into Cisco's offerings. This integration enables Cisco to provide versatile solutions ranging from discrete components to fully integrated systems tailored to the needs of webscale, service providers, enterprises, and public sector clients. Through continuous investments in foundational technologies and strategic partnerships, Cisco is enhancing its portfolio to support network transitions as port speeds escalate from 100G to 400G and beyond, reinforcing its commitment to delivering cutting-edge optical and coherent technology solutions to its customers (Cisco, 2021).

NTT, to stay ahead of competitors, will likely need to proactively acquire promising startups to both safeguard its position and advance technological innovation.

Table 5.11.

Major Silicon Photonics Startup List

Company	Founded Year	Location	Funding (USD)	Stage	Key Investors	Business Overview
Inphi	2000	San Jose	78.5M	Acquired (by Marvell)	Mayfield, Herald Investment Management, +14 others	High-speed analog semiconductor solutions for communications and computing markets.
Acacia	2009	Maynard	20M	Acquired (by Cisco)	Summit Partners, Commonwealth Capital Ventures, +4 others	High-speed coherent optical interconnect products for communication markets.
Nanotronics	2009	Brooklyn	136M	Series E	Founders Fund, Gaingels, +11 others	Automated vision-based inspection systems for semiconductors and aerospace.
PsiQuantum	2015	Palo Alto	680M	Series D	Redpoint Ventures, Temasek, +22 others	Photon-based universal quantum computers for AI and drug discovery.
Nicslab Inc.	2020	Palo Alto	373.2K	NA	Techstars Allied Space Accelerator and 2 more	Electronic and photonic integrated circuits for optical solutions in data centers, AI, and quantum computing.
AEye	2013	Pleasanton	61.8M	Series B	Kleiner Perkins, Intel Capital, +21 others	AI and cloud-enabled LiDAR sensor solutions for automotive and other sectors.
Lightmatter	2017	Boston	422M	Series C	Google Ventures, Fidelity Investments, +12 others	AI-based photonic microprocessors for supercomputers.
Zayo	2007	Boulder	825M	IPO	Morgan Stanley, Battery Ventures, +23 others	Fibre communication infrastructure, bandwidth connectivity, and networking services.
FiberSight	2021	Coimbra	200K	NA	Tiago Neves	Sustainable water sensing solutions using optics.
Lidwave LTD.	2021	Jerusalem	3.8M	NA	Jumpspeed Ventures and 2 more	Coherent perception sensor-on-a-chip for AI, automotive, and smart cities.

Note: Created from "Photonics startups in the United States" by Trancxn, March 11, 2024.

5-2-5. Threat of Substitute Products or Services

The threat of substitutes refers to the risk posed by alternative products. A high threat of substitutes can make an industry more competitive and decrease profit potential for the existing firms. This force is particularly strong if the substitute product offers a price advantage or superior performance. We will explore packaging, quantum, and space communication technologies as substitute products against the IOWN.

Packaging Technologies

For semiconductor segmentation, the technical advancements in 2.5D and 3D packaging technologies represent critical steps forward in the semiconductor industry's quest to bypass the diminishing returns of Moore's Law scaling, meaning that the technologies are critical in overcoming the challenges posed by traditional transistor scaling like silicon photonics. These packaging solutions leverage cutting-edge material science and microfabrication techniques to enhance interconnect density, reduce power consumption, and improve overall system performance, thereby enabling the next generation of electronic devices to meet the ever-growing demands for speed and efficiency (5.19).

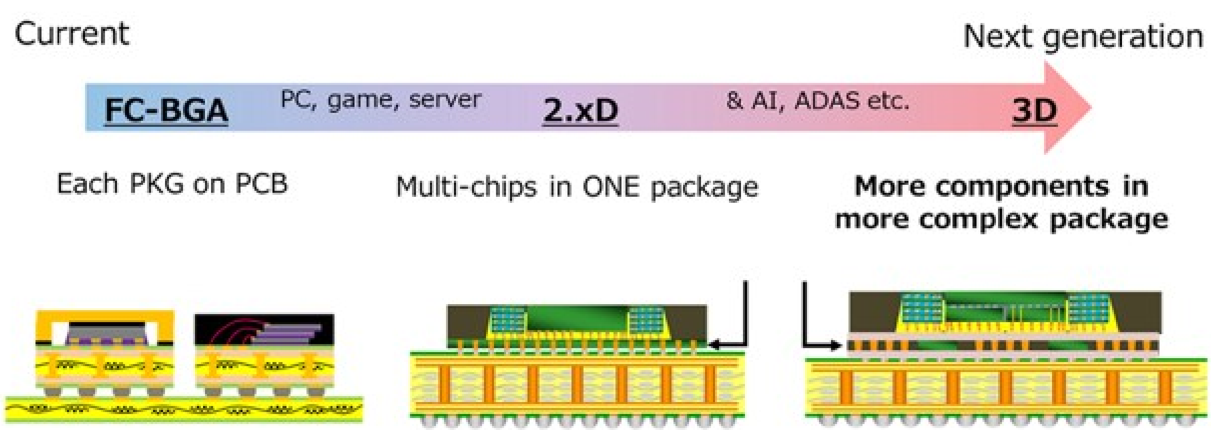

Fig.5.19. Flow from FC-BGA to next generation 2.xD and 3D packages.
https://www.resonac.com/jp/solution/tech/next-gen-semiconductor-packages.html

2.5D packaging employs an interposer, typically made of silicon or glass, which serves as an electrical interface routing connections between multiple chips housed within the same package. This interposer enables shorter and more numerous connections between chips than traditional wire-bonding methods, significantly reducing the propagation delay and power consumption. The use of interposers can reduce cross-talk and electromagnetic interference, which enhances signal integrity and leads to improvements in overall system reliability and power efficiency. The integration of high-density interconnects (HDIs) on interposers also supports greater bandwidth capabilities, essential for high-performance computing applications.

3D packaging involves the vertical stacking of semiconductor dies, connected using through-silicon vias (TSVs) or micro-bumps. These vertical interconnect accesses (VIAs) allow for much shorter inter-die connections compared to horizontal configurations. 3D packaging typically employs techniques such as wafer bonding and die-to-wafer bonding, which are crucial for achieving the mechanical and thermal stability required for reliable operation. The vertical integration in 3D packaging reduces interconnect lengths dramatically, thus minimizing both the latency and the power required for data transfer between stacked chips. The thermal aspect of 3D packaging also benefits from the vertical arrangement, as heat dissipation can be more effectively managed through improved thermal interfaces and the use of advanced materials like high thermal conductivity adhesives.

In the advanced semiconductor packaging market, competition is notably fierce among the top industry players, as illustrated by the 2021 financial overview (Fig. 5.20). ASE Technology Holding, leading the market with $11.638 billion in revenue, significantly outpaces its competitors, establishing a dominant market presence that underscores its extensive capabilities and broad reach.

Following ASE, Amkor Technology and Intel represent substantial market forces with revenues of $6.061 million and $5.300 million, respectively, reflecting their strong operational bases and strategic investments in packaging technologies. The significant revenue gap between ASE and its closest competitors not only highlights ASE's market dominance but also the competitive gradient that other major players like JCET Group and TSMC face, with revenues of $4.841 million and $4.100 million. This tiered financial landscape reveals a market characterized by a high concentration at the top, diminishing gradually among smaller players like Samsung, Powertech, and Tongfu Microelectronics, each trying to carve out substantial shares by leveraging technological advancements and strategic market positioning.

The presence of these players across different revenue scales indicates varied strategies and market focuses, contributing to a dynamic competitive environment where technological innovation and strategic partnerships are crucial for gaining and maintaining market share.

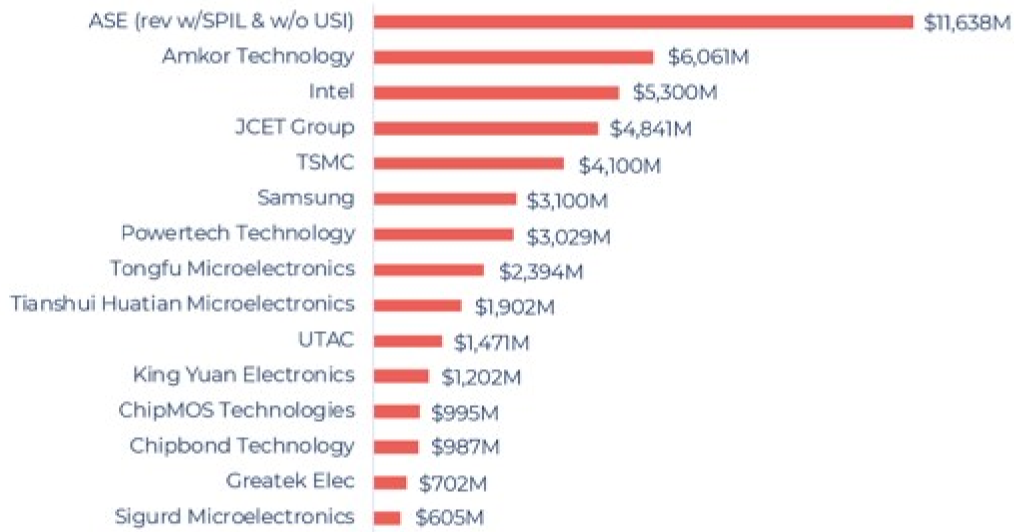

Fig. 5.20. 2021 TOP 15 PLAYERS INVOLVED IN ADVANCED PACKAGING - FINANCIAL OVERVIEW. Adopted from Status of the Advanced Packaging Industry 2022 report, Yole Intelligence, 2022

Within this market competition, some makers are trying to acquire market share by leveraging 2.5 D and 3D packaging technologies. For example, AMD offers the Instinct MI200 series GPUs for data centers, featuring a mechanism called the 2.5D Elevated Fanout Bridge (EFB). This design efficiently packages multiple dies into a single unit. The series achieves a double-precision floating-point (FP64) throughput of 47.9 TFLOPS, which is approximately 4.9 times greater than NVIDIA's A100, which offers 9.7 TFLOPS (Kasahara, K. , 2021).

Additionally, AMD unveiled the Instinct MI300 AI accelerator chip, designed to power the El Capitan supercomputer. This chip features a three-layer silicon stack comprising computing, memory, and communication components. It can transfer up to 17 terabytes of data vertically between these layers, enhancing machine-learning calculations by up to 3.4 times. The MI300 integrates three CPUs and six accelerator chiplets using 3D integration technology (Moore, S. K. , 2023).

For this packaging technology, it seems that TSMC is supporting the AMD's integration work. TSMC has introduced several next-generation advanced packaging technologies, such as Chip on Wafer on Substrate (CoWoS-R) and System-on-Wafer (SoW), which improve chip performance by increasing I/O density through stacking. These innovations are crucial for advancing chip technology and meeting the growing demands of large-scale data centers.

For instance, TSMC's system-level wafer technology enables accommodating more chips on 12-inch wafers, enhancing computational power and reducing space in data centers (TSMC, 2024). TSMC's SoIC has become a leading technology for 3D chip stacking. Some reports state that AMD is the first customer to adopt SoIC, using it in conjunction with CoWoS for its MI300 chips. Also, Apple is also entering the generative AI market, planning to debut its ARM-based CPU for AI servers, potentially in the next year, and extending 3D SoIC technology to its consumer MacBook processors by 2026.

Meanwhile, NVIDIA is set to launch its R100 using CoWoS-L packaging next year, with a new model anticipated in 2026 (Trendforce, 2024). The use of 2.5D and 3D packaging technologies represents breakthrough innovations that go beyond the limits of Moore's Law.

Currently, these technologies still rely on the existing electrical signal systems, which differs from the strategies pursued by Intel and NTT Innovative Device, where there is an emphasis on enhancing performance through the conversion of inter-chiplet signals to optical signals. However, these innovations are not necessarily contradictory. Therefore, it appears necessary to pursue a fusion of packaging technologies with optical signaling between chiplets in future IOWN technological developments.

Quantum Technologies

New technologies leveraging quantum science could be one of the disruptive innovations for the existing ICT architecture. Quantum computing utilizes principles of quantum mechanics such as superposition, entanglement, and quantum interference. Unlike classical computers that use bits as the basic unit of data (either 0 or 1), quantum computers use quantum bits, or qubits, which can represent and store information in both 0 and 1 simultaneously thanks to superposition. This capability allows quantum computers to process complex calculations at speeds unachievable by classical counterparts.

The computers can theoretically solve problems such as integer factorization (via Shor's Algorithm) exponentially faster than classical computers (Shor, P. W. , 1994). This capability could disrupt industries reliant on current cryptographic techniques, fundamentally changing cybersecurity.

Also, quantum networks involve transmitting quantum information, expressed through qubits, across nodes using quantum states. This network structure supports the development of quantum internet, which promises to enhance security through quantum key distribution (QKD) methods that are immune to conventional eavesdropping techniques (H. J. Kimble., 2002). The networks can significantly disrupt traditional data transmission methods by providing a platform for unconditionally secure communications, changing how sensitive data is transmitted across industries like finance, healthcare, and government (S. Wehner. et al, 2018).

Ultimately, quantum machine learning (QML) integrates quantum algorithms to enhance machine learning tasks (Biamonte et al, 2017). QML could potentially accelerate complex computations such as database searches and optimization problems by exploiting quantum parallelism where multiple computations are performed simultaneously. QML promises to significantly improve the speed and efficiency of data analysis, potentially disrupting sectors like pharmaceuticals through faster drug discovery processes and finance through quicker optimization of portfolios (Mensa, S., et al, 2023).

Technical Benchmark in Quantum Computer

The burgeoning field of quantum computing has primarily focused on the "qubit count" as a benchmark of computational capability, similar to how the number of transistors in traditional microprocessors (from early models like the 6502 to the latest Intel Pentium) has historically indicated their power. While not a comprehensive measure, it provides a straightforward and accessible metric. Other indices like "quantum volume," introduced by IBM and subsequently adopted by companies like Honeywell and Quantinuum, also contribute valuable insights into quantum processing capabilities (Cross, A. et et al, 2019).

An analysis below shows the historical increase in qubit counts, illustrating the progression over time across various qubit technologies. The data reveals a clear trend towards higher qubit counts. By plotting different technologies against one another, it highlights significant advancements and the current state of the field. The comparative analysis shows that superconducting technologies are at the forefront, with IBM currently leading with a processor of 433 qubits (Etim, I., 2022). Although our focus here is primarily on quantifying qubit counts, it's important to note that this comparison does not account for factors like qubit fidelity.

Nonetheless, tracking the qubit count offers a straightforward and insightful way to compare the evolution of different quantum technologies. It also presents trend lines representing the average qubit count over time, which indicate a general upward trajectory across all technologies.

Additionally, we plot specific trend lines for each technology, which demonstrate their respective rates of growth in qubit numbers. Notably, we can observe a "hockey stick" growth pattern, characterized by a sharp rise in the maximum number of qubits achieved each year—an "expanding" maximum that consistently records the highest observed qubit count in superconducting technology which is used by major developers like Google and IBM. Photonics technology which is used by NTT is a little bit behind them in Jan 2022 (Fig. 5.21).

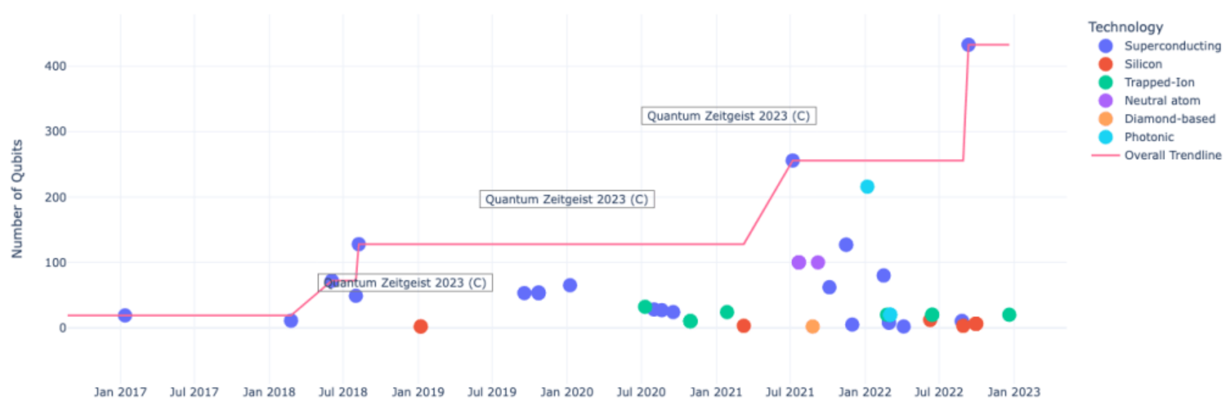

Fig. 5.21. Historical Trend Line of The Number of Qubits by Technologies. Brett. (2023, July 19). Retrieved from https://quantumzeitgeist.com/a-brief-look-at-qubit-growth-and-the-rise-of-quantum-computing/

Additionally, the development of quantum computing performance metrics such as CLOPS allows for a nuanced comparison of computational technologies, highlighting differences in performance, energy efficiency, and operational costs.

This evolving landscape challenges the conventional benchmarks set by supercomputers and paves the way for innovative approaches to computing. The introduction of CLOPS (Circuit Layer Operations Per Second) by IBM marks a significant development in quantum computing performance measurement. CLOPS quantifies the speed at which a quantum processor can execute quantum circuits, analogous to logic circuits in classical computing. This metric is part of a trio of benchmarks essential for assessing quantum computing capabilities, complementing the existing metrics of Scale (number of qubits) and Quality (Quantum Volume).

Together, these benchmarks enable a comprehensive evaluation of quantum computers, allowing for comparisons both between different systems and over time as technology progresses (Gambetta, J. et al, 2021). Quantum circuits represent the fundamental computation unit in quantum computing, much like logic circuits in classical systems. IBM's leading quantum systems. Traditionally, the performance of supercomputers has been measured by FLOPS (Floating Point Operations Per Second), a metric that has facilitated the comparison and benchmarking of these powerful systems over decades.

The evolution of supercomputing speeds, documented in the attached figure, illustrates significant technological advances. While classical computing performance has adhered to Moore's Law, doubling approximately every two years, quantum computing introduces a new paradigm. Quantum volume, a measure of the number of qubits and the depth of circuits that can be reliably executed, has been doubling annually (Fig. 5.22). This trend suggests a potential "Quantum Moore's Law," indicating rapid progress in quantum computing capabilities (Nicholas, 2021).

Table 5.12

Comparison between FLOPS and CFLOPS

Metric	FLOPS (Floating Point Operations per Second)	CLOPS (Circuit Layer Operations per Second)
Definition	Measure of supercomputer performance	Measure of quantum computer performance
Speed	Supercomputer Fugaku 415.5 petaFLOPS	IBM Bogota 1419 CLOPS
Cost	$1,881.79 trillion for 1 GFLOP in 1945	$xxx for 1 GCLOPS
	$0.04 for 1 GFLOP in 2020	On AWS it costs $0.3 per task and $0.00019 per shot; how do we translate that into CLOPS?

Note. Result from A new metric to measure quantum computing speed. From (Qkrishi, 2021).< https://qkrishi.com/blog/f/clops-a-new-metric-to-measure-quantum-computing-speed

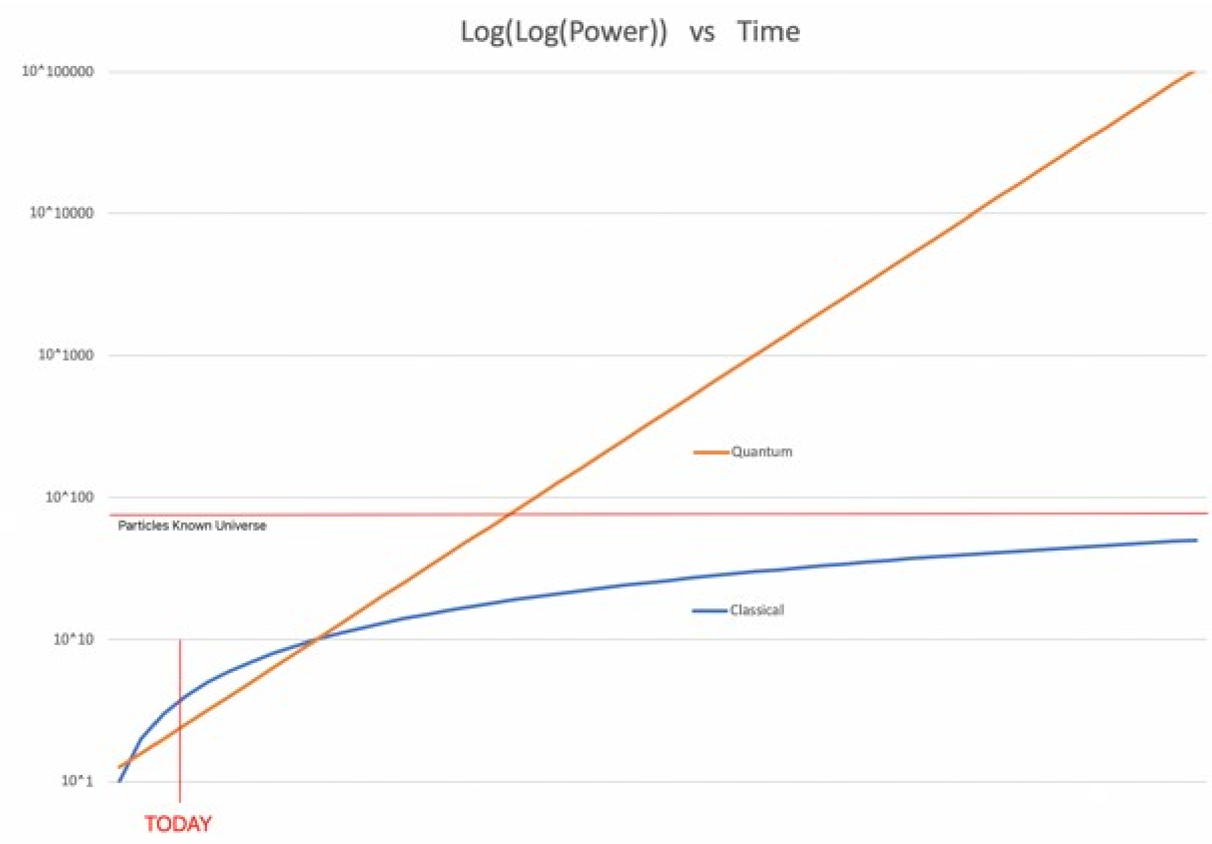

Fig. 5.22 Performance of Classical computers vs Quantum computers by time with Log-Scale.

Yoder, N. (2021, June 1). Moore's Law of Moore's Law of Quantum Computing: Retrieved from https://nickyoder.com/moores-law-quantum-computer/

The transition from FLOPS to CLOPS not only signifies a shift in computing paradigms but also implies a change in energy consumption profiles (Table 5.13). Whereas supercomputers like the Frontier demand upwards of 30 megawatts of power, leading to high operational costs, quantum computers operate on a much smaller scale, significantly reducing both energy usage and costs (Oak Ridge National Laboratory, 2023).

For instance, A hypothetical quantum computer with 10,000 qubits may require just 10 kW(Swinhoe, D., 2024), far less than 0.05% of Frontier's consumption. Recent data highlights a significant uptrend in the energy consumption of supercomputers, with some nearing a staggering 30 megawatts of power usage (Johnson-Groh, M, 2023). This immense consumption not only pertains to computational processes but also to the heat generated by these systems, which subsequently requires considerable energy for cooling, thus further increasing their environmental and energy footprint. Based on data from the U.S. Energy Information Administration, the average electricity cost for commercial entities in February 2023 was $0.1277 per kilowatt-hour. To estimate Frontier's annual electricity expenses, we first convert its power usage from kilowatts to kilowatt-hours. Frontier operates continuously at 21,100 kW, leading to an annual consumption of:

- 21,100 kW * 24 hours/day * 365 days/year = 184,716,000 kWh/year

*Multiplying the annual consumption by the cost per kilowatt-hour gives:

- 184,716,000 kWh/year * $0.1277/kWh = approximately $23,589,392.20 per year

In stark contrast, quantum computing presents a radically different energy profile. Consider a publicly accessible quantum computer with over 250 qubits that consumes under 10 kW. This is less than 0.05% of Frontier's power usage. Despite the nascent nature of quantum technology, its energy consumption does not directly correlate with the number of qubits. Extending this to a hypothetical scenario where a quantum computer is equipped with 10,000 qubits, we estimate it would still require just around 10 kW. This figure represents far less than 0.05% of the energy consumption of Frontier, offering a substantial reduction in both energy use and associated costs.

This comparative analysis underscores the potential of quantum computing to achieve significant energy savings. However, it also highlights the need to consider other factors such as performance capabilities and practical applications, where supercomputers currently hold a substantial lead. As quantum technology evolves, it may offer more viable and cost-effective alternatives, especially in operations where energy efficiency is crucial.

Table 5.13

Major Supercomputer & the Power Consumption (KW)

Year	Computer	Power Consumption (KW)
2022	Frontier – Oak Ridge National Lab, USA	21,100
2020-2021	Fugaku – RIKEN Center for Computational Science, Japan	29,889
2018-2019	Summit – Oak Ridge National Lab, USA	10,096
2016-2017	Sunway TaihuLight – National Supercomputing Center in Wuxi, China	15,371
2013-2015	Tianhe-2A - National Supercomputer Center in Guangzhou, China	17,808
2012	Titan – Oak Ridge National Lab, USA	8,209
2011	K computer, RIKEN Advanced Institute for Computational Science, Japan	12,660
2010	Tianhe-1A - National Supercomputing Center in Tianjin, China	4,040
2009	Jaguar - Oak Ridge National Lab, USA	6,950
2008	Road Runner – Los Alamos National Lab, USA	2,483
2004	BlueGene/L - DOE/NNSA/LLNL, USA	2,329
2003	Earth-Simulator, Japan Agency for Marine-Earth Science	3,200

Note: Created based on the latest TOP500 rankings in the supercomputer: https://www.top500.org/

Quantum Market Analysis

The International Data Corporation (IDC) has released its latest forecast for the global quantum computing market, projecting a growth from $1.1 billion in 2022 to $7.6 billion by 2027, a compound annual growth rate (CAGR) of 48.1%. This growth encompasses both base quantum computing as a service and adjacent services. However, this projection marks a decrease from IDC's earlier forecasts due to several setbacks, including slower advancements in quantum hardware, competition from emerging technologies like generative AI, and macroeconomic challenges like increased interest and inflation rates.

Despite these challenges, IDC (2023) anticipates that quantum computing market growth will primarily be driven by the development of quantum computing as a service infrastructure and the increasing demand for performance-intensive computing tasks. Additionally, investment in the sector is expected to grow at a CAGR of 11.5% during the same period, totaling nearly $16.4 billion by 2027. Significant funding from both public and private sources, including 14 global government agencies, is fueling research and advancements in quantum computing technologies.

Table 5.14 below illustrates the diversity in quantum computing methods and the lack of international standardization akin to traditional computer and network architectures. Quantum computers operate on principles of quantum mechanics, such as superposition and interference, to perform calculations.

Currently, four primary architectures are recognized for potentially practical quantum computers: superconducting circuits, ion traps, semiconductor-based, and optical methods. Superconducting qubits, utilized by major companies like IBM, Intel, Google, and D-Wave, operate at extremely low temperatures of a few millikelvin. Despite widespread use, these systems face challenges in scaling due to increasing error rates with more qubits, which compromise overall performance. For instance, IBM aims to scale up to 4,000 qubits, but must address these error rate challenges. The ion trap method, used by companies such as Quantinuum and IonQ, leverages ions held in a vacuum and manipulated by lasers to perform computations (Gent, E., 2022). This method offers longer coherence times due to its resistance to electromagnetic interference and does not require extreme cooling. However, the precise operation and integration of the qubits remain complex and time-consuming. Silicon spin qubits which NTT is exploring, represent an emerging technology with the potential for higher operating temperatures (1 to 3 Kelvin) and smaller cooling systems compared to superconducting qubits. This method uses the spin states of electrons confined in silicon as qubits (Hashimoto, T., et al., 2023)

Table 5.14

Quantum Methods and Representative Organizations

Quantum Method	Quantum Bit Representation	Advantages	Disadvantages	Representative Adopting Organizations
Superconducting Circuit	Two possible states of electrical circuits in superconducting state	Error rate below 1%, Integrable	Quantum bits are unstable, Cryogenic cooling required	IBM Google D-Wave
Ion	Two possible ways for an electron to orbit a single ion	Error rate below 1%, Quantum bits are stable	Some operations are slow, Vacuum container required	IonQ Quantinuum
Semiconductor	Two possible orientations of a magnet carried by a single electron trapped in a semiconductor substrate	High-density integration possible	Error rate is still high, Cryogenic cooling required	RIKEN Intel
Optical (Photonics)	Two possible directions of oscillation of a single photon	Operates at room temperature and in the air, Fast operations	Error rate is still high, Some operations are probabilistic	University of Science and Technology of China Xanadu Quantum Technologies NTT

Note: Created based on the information by A frontline report on quantum machine learning based on a correct understanding of quantum computers (AINOW, 2022), Quantum computing companies (Dargan, J., 2023), 10 companies building quantum computers (Round, J. 2023), and each company's web site.

The bar chart (Fig. 5.23) shows the number of quantum computing invention patent applications filed by leading companies worldwide in 2020. This data is a useful indicator of the R&D capabilities and competitive positioning of these companies in the quantum computing sector. I

BM tops the chart with 554 patent applications, indicating a strong focus on innovation and a substantial investment in quantum computing research and development. Also, D-Wave with 430 and Google with 372 patent applications show strong competitive stances. D-Wave is known for its focus on quantum annealing technology, which is a specialized approach to quantum computing. Google's high number of applications likely reflects its broad research agenda, including advancements in quantum algorithms and hardware. Since these 3 top employed the Superconducting Circuit method, the technology could be currently ahead of the others.

For NTT, it has filed 57 patent applications, which places it significantly lower than the top contenders but still notable within the broader landscape. Although not at the forefront in terms of the quantity of patents, the quality and specificity of patents could be more indicative of NTT's strategic focus areas. NTT's involvement in quantum computing, complemented by its strong position in telecommunications and network services, might also suggest a strategic integration of quantum technologies with these sectors.

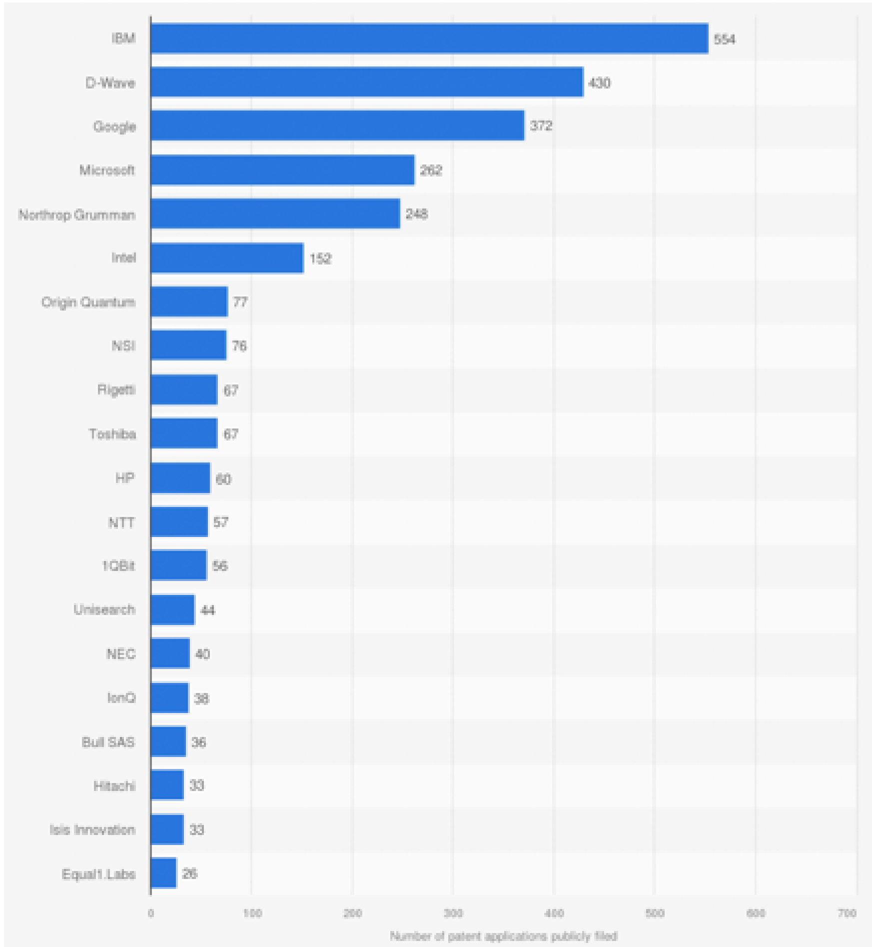

Fig. 5.23 Number of quantum computing invention patent applications filed publicly worldwide in 2020, by leading company. From Statista: https://www.statista.com/statistics/1191138/global-number-of-quantum-computing-patent-applications-publicly-filed-by-leading-company/

Though promising, the development of silicon spin qubits is still in its early stages, with RIKEN and Delft University of Technology leading research efforts in collaboration with Intel (Swayne, M., 2023 & Intel, 2022). Quantum computers, particularly those utilizing silicon photonics where photons serve as qubits, heavily rely on semiconductor manufacturing processes. While companies like IBM and Intel possess the capability to produce quantum chips in their fabrication plants, many smaller quantum ventures are likely to partner with or outsource to semiconductor foundries for mass production (Table 5.15). Currently, GlobalFoundries is notably active in engaging with the quantum industry, alongside companies such as PsiQuantum, Equal1, Xanadu, and Archer Materials, which specialize in silicon-based quantum technologies (GlobalFoundries, 2021).

Table 5.15

Major Quantum Supplier List

Category	Equipment/Technology	Representative Adopting Organizations
Quantum Chip Manufacturing	Electron Beam Lithography Device	Zyvex, etc.
Quantum Computing Cooling Systems	Cryogenic Refrigerators	Bluefors, Oxford Instruments, Sumitomo Heavy Industries, etc.
Quantum Bit Control	Microwave Signal Generators	Keysight Technologies, Zurich Instruments, etc.
Low-Temperature Specialized Evaluation	Auto Probers	Bluefors, FormFactor, etc.
Quantum Device Simulation	Quantum Device Simulators	imec, AIST/Q-LEAP, Nano Academic Technologies/STMicroelectronics, etc.
Quantum Chip Control Circuits in Low-Temperature Environments	Cryogenic CMOS (CryoCMOS) Devices	AIST/Q-LEAP/NEDO, Intel, etc.

Note: Created based on Quantum computers: A new market in the semiconductor supply chain (Ando, Y., 2022Creating new markets through cutting-edge technology: Roadmap to 2030 (Nomura Research Institute, 2023).

Space Communication Technologies

As Fig. 5.24 shows, currently, over 99% of the Internet's international communications are transmitted via fiber-optic submarine cables (KDDI, 2022). Nevertheless, the burgeoning advancements in space communication technology could potentially disrupt the existing telecommunications framework, which currently extends access to the last mile of international communications.

SpaceX, under the leadership of Elon Musk, is at the forefront of the private sector's developments in rocket technology. A Starlink satellite has a lifespan of approximately five years and he hopes to have as many as 42,000 satellites in this so-called megaconstellation, a group of many satellites that work together to deliver broadband Internet access like global Internet connectivity (Space.com, 2024).

Notably, according to the latest International Telecommunication Union (ITU) data, about one-third of the global population, or 2.6 billion people, remains offline in 2023. In response, numerous companies worldwide are investing in satellite broadband projects, aiming to capture this vast, untapped market through space-based communications.

Additionally, the strategic military applications of such technologies have come to the fore, highlighted by their use in the Ukraine-Russia conflict (CNN, 2024). Furthermore, the practical benefits of this technology were underscored by its effectiveness during the Noto earthquake disaster in Japan in 2024 (KYODO NEWS, 2024).

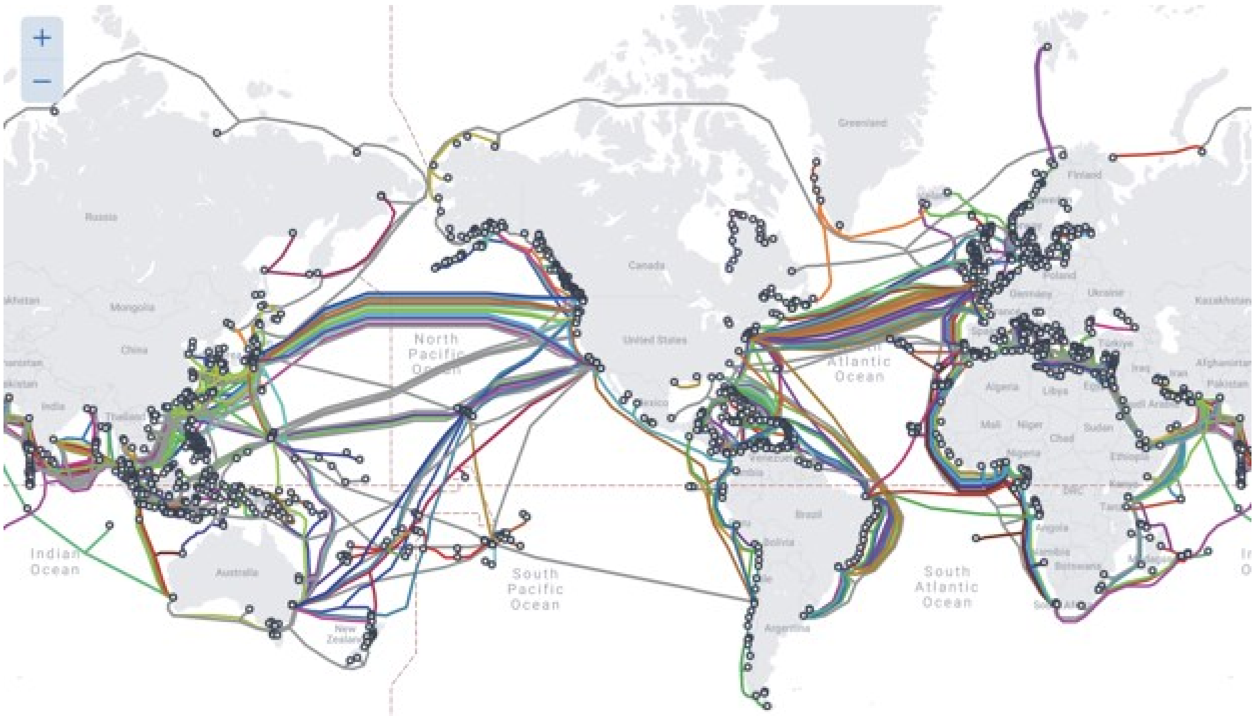

Fig. 5.24 Submarine Cable Map from https://www.submarinecablemap.com/

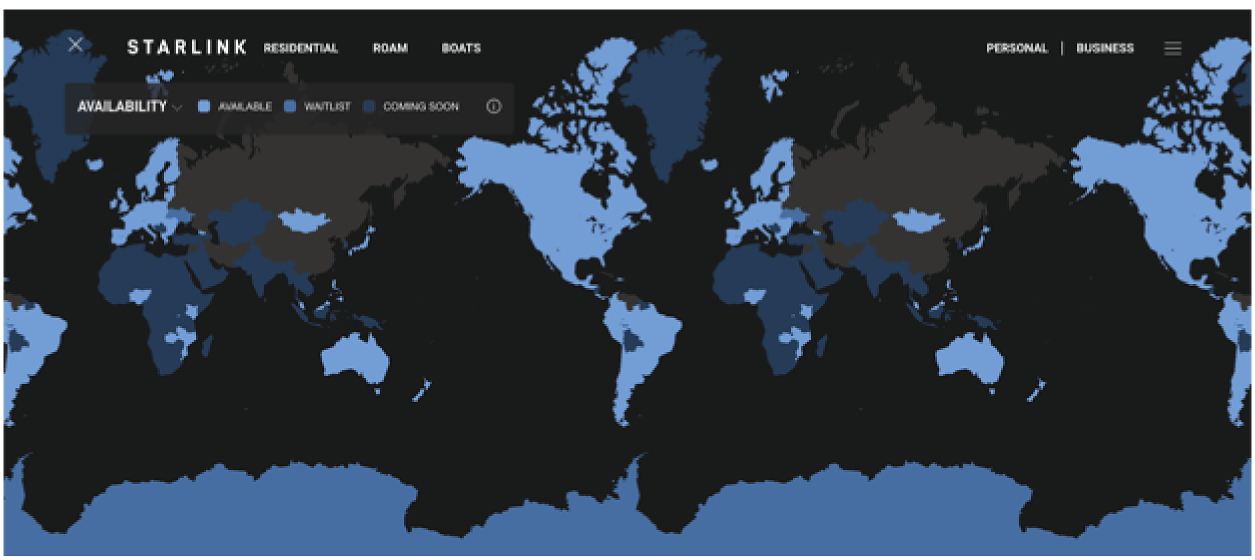

Fig. 5.25 Starlink Availability Map from https://www.starlink.com/map

This research focuses on the deployment of data relay satellites designed to enhance communication capabilities. These satellites are instrumental in providing data transmission and communication services between terrestrial ground stations and satellites, as well as inter-satellite communications. The satellites are strategically placed in various orbital regimes including Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Orbit (GEO), each chosen based on the specific communication needs and mission objectives (Fig. 5.26, Table 5.16). This infrastructure plays a critical role in the global communication network, enabling efficient and reliable space-based communication systems.

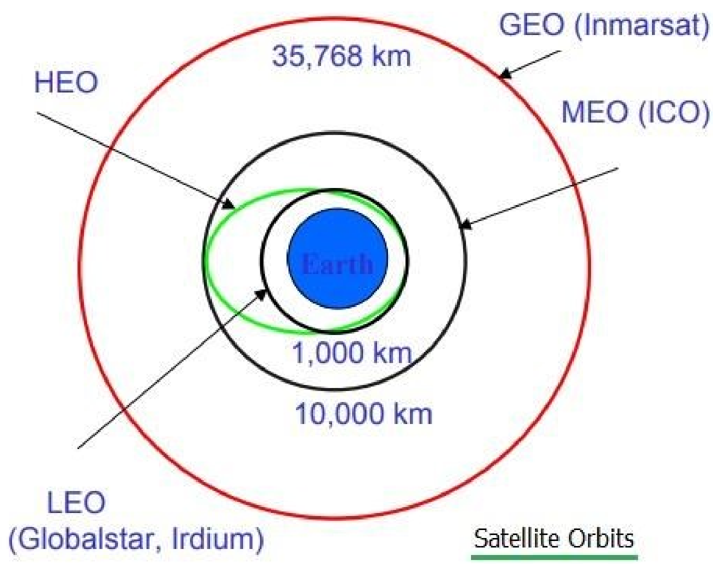

Fig. 5.26 Satellite Orbits.

From West East Space: https://westeastspace.com/encyclopedia/medium-earth-orbit/

Table 5.16

Characteristics and Typical Services in Each Orbit

Orbit Type	Characteristics	Representative Services and Examples
LEO (Low Earth Orbit)	・Close to Earth (approx. 160 to 2,000 km) ・Requires many satellites for global coverage ・Lower power requirement for communication ・Faster orbital speed, leading to frequent handovers in communication networks	・Earth Observation: Planet Labs (satellite imagery for environmental monitoring) ・Telecommunications: Starlink (broadband internet services by SpaceX) ・Scientific Research: CubeSats (various universities and research institutions for space studies)
MEO (Medium Earth Orbit)	・Altitude range between 2,000 km and 35,786 km ・Fewer satellites needed compared to LEO for global coverage ・Suffers from higher radiation levels ・Used for applications requiring broader coverage than LEO but more frequent visibility than GEO	・Navigation and Positioning:GPS (U.S. Global Positioning System), Galileo (European navigation system) ・Medium-Distance Communications: Thuraya (satellite phones and internet services for maritime and aeronautical sectors)
GEO (Geostationary Orbit)	・Fixed position at 35,786 km directly above the equator ・Visible continuously from the same ground area ・Larger and more power-intensive satellite terminals required due to distance	・Broadcast Services: DirecTV (satellite television), Intelsat (global broadcast and communication services) ・Weather Forecasting: GOES (Geostationary Operational Environmental Satellites by NOAA for weather updates) ・Long-Distance Telecommunications: HughesNet (broadband satellite services for remote areas)

Note: Created based on Space technology strategy: Market strategies and development technologies in communications (Advanced Satellite Systems Technology Center, 2023), Trends in space business and satellite communications (the Japanese Ministry of Internal Affairs and Communications, 2024),). LEO vs. MEO vs. GEO satellites: What's the difference? (Heukelman, C., 2018), and How do LEO, GEO, and MEO satellites differ (IP Access International, 2023)

Starlink Case

As an industrial benchmark, the Starlink leverages a constellation of the LEO satellites positioned between 340 kilometers and 1,150 kilometers above Earth to deliver broadband services with substantial advantages over conventional geostationary satellite systems.

By deploying satellites at altitudes as low as 340 kilometers, Starlink offers markedly reduced latencies ranging from 20-40 milliseconds, in contrast to the typical 200 milliseconds experienced with geostationary satellites at about 36,000 kilometers (IP Access, 2023). This reduction in latency is crucial for supporting real-time applications like video conferencing and online gaming, which require quick data response times.

Also, according to the speedcast, its satellites provide higher bandwidth, facilitating download speeds up to 350 Mbps, which is critical for delivering high-speed internet to underserved remote and rural regions where traditional broadband infrastructure is not feasible. The strategic deployment of approximately 1,600 satellites at 550 kilometers, 2,800 at 1,150 kilometers, and 7,500 at 340 kilometers ensures extensive and reliable coverage. Cost efficiency is another pivotal aspect of Starlink's strategy. SpaceX has achieved significant cost reductions by reusing rockets and launching multiple satellites simultaneously. As of August 2022, the constellation comprised 2,388 satellites, demonstrating the scalability of SpaceX's launch operations.

The company's innovative approach includes miniaturizing satellites and employing single-panel solar arrays to increase launch capacity by up to 60 satellites per mission, further driving down costs. In managing its satellite constellation, SpaceX has implemented dynamic satellite coordination to maintain continuous coverage as the satellites traverse the globe.

This network-like operation differs from traditional stationary satellite setups, allowing for adaptive repositioning and better service connectivity. Environmental considerations are integral to SpaceX's operations, with proactive measures to mitigate space debris. This includes placing satellites in a lower "parking orbit" for initial testing, ensuring only fully operational satellites are moved to their final orbits. Non-functional satellites are intentionally lowered to decay in Earth's atmosphere, and similar measures are taken to deorbit operational satellites at the end of their life cycle to prevent space clutter. This comprehensive approach highlights

SpaceX's commitment to sustainable space operations while maximizing the efficiency and reach of its Starlink service.

Space Communication from Technical advancement

The analysis of space network communication speeds, particularly through the lens of the NASA Deep Space Network (DSN), offers a fascinating glimpse into the technological advancements over decades. The DSN's data rates have shown significant improvements as outlined in the historical data from 1958 to 2015, depicting an S-curve pattern of technological growth (NASA, 2015). This pattern indicates a lifecycle starting with a slow initial growth (proof of concept), accelerating during the takeoff and rapid progress stages, and eventually slowing down as the technology matures (Fig. 5.27).

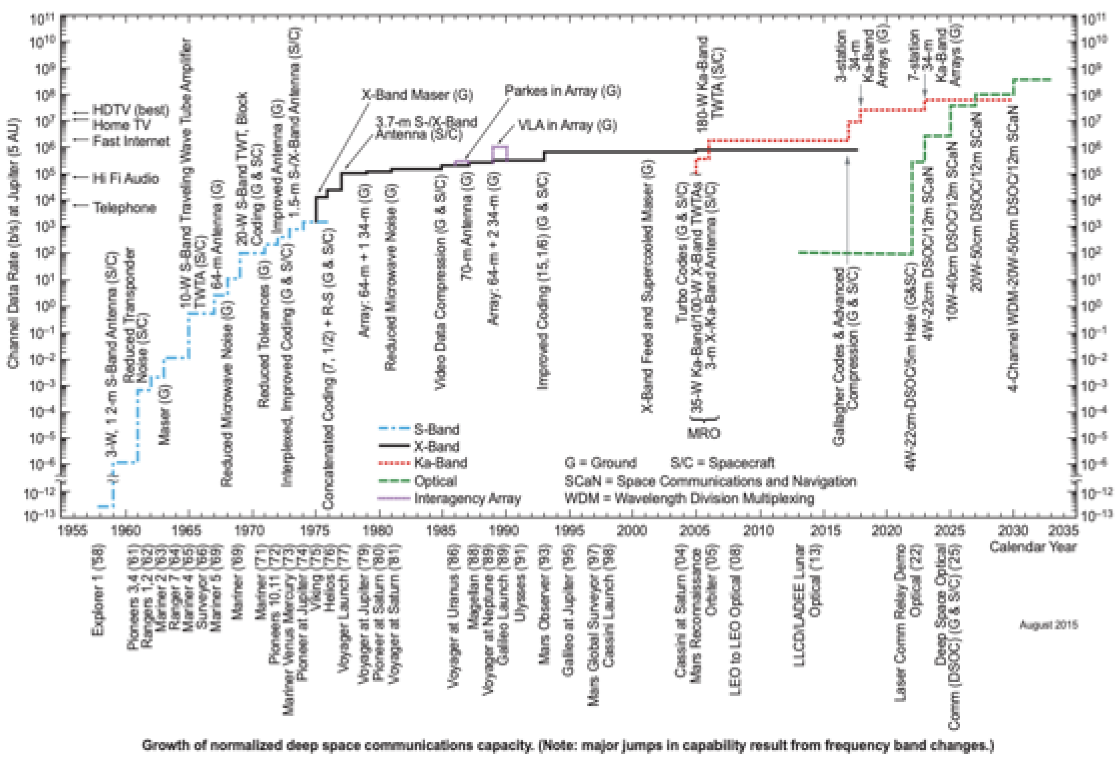

Fig. 5.27 DESCANSO performance metrics: Profile of deep space communications capability.

From NASA Web site: *https://descanso.jpl.nasa.gov/performmetrics/stairstep.pdf*

Their predictions show that while RF (represented by Ka-Band) communications have experienced consistent growth, the advent of optical communications is projected to surpass RF in terms of data rate capabilities by 2027, reflecting a significant shift in the technology used for space communication networks. This transition from RF to optical technologies illustrates a typical scenario described by the Interlocking S-Curves Hypothesis and the Disruptive Innovation Theory.

Optical communications, emerging at the saturation point of RF technologies' S-curve, are anticipated to experience rapid growth, disrupting the existing standard and setting a new trajectory for future developments. This not only demonstrates the potential for optical technologies to reshape the landscape of space communications but also highlights the dynamic nature of technological advancement where newer technologies can leapfrog established ones, leading to shifts in industry standards and practices.

Furthermore, as the latest technical development, NASA achieved a new milestone in space communications by establishing a 200 gigabits per second (Gbps) data transmission rate using an optical link between an orbiting satellite and Earth—setting a record for the highest data rate in optical communications on April 28, 2023. This advancement was enabled by laser communications, which encode data onto light waves, a shift from traditional radio wave-based systems. According to the announcement by NASA (2023), the TBIRD system, part of NASA's Pathfinder Technology Demonstrator 3 (PTD-3) satellite, recently doubled its previous data transmission record to 200 Gbps.

This system can send multiple terabytes of data—equivalent to approximately 500 hours of high-definition video—in just six minutes over a ground station. Beth Keer, the mission manager at NASA’s Goddard Space Flight Center, highlighted the significance for future space missions, noting that such advancements in space communications are crucial for extended explorations on the Moon and Mars. The PTD-3 CubeSat, roughly the size of two cereal boxes, is designed for cost-effective and efficient laser communications tests. Developed by Terran Orbital and launched from Kennedy Space Center, PTD-3 benefits from a synchronized orbit that supports consistent testing.

The initiative involves collaboration with partners like MIT’s Lincoln Laboratory and utilizes a modified ground station at NASA’s Jet Propulsion Laboratory in California. This breakthrough in laser communications, part of NASA's SCaN and Small Spacecraft Technology programs, aims to significantly improve data transfer capabilities for future missions.

Submarine Communication from Technical Advancement against Space Communication

On the other hand, in the evolution of submarine cable technologies, remarkable advancements in data transmission rates have been achieved through successive generations of technology, marked by the deployment of increasingly complex technologies and higher capacities. Papapavlou, C. et al (2022) explored this advancement well (Fig. 5.28).

Initially, first-generation submarine cables employed Quadrature Phase Shift Keying (QPSK) modulation with coherent detection and Polarization Mode Dispersion (PMD) compensation, achieving data rates up to 40 Gbps. This era focused on stabilizing foundational technologies for long-distance optical transmission.

By the second generation, which spanned from 2012 to 2015, data rates increased significantly to 200 Gbps. This leap was facilitated by the adoption of 16-QAM modulation formats, Soft Decision Forward Error Correction (SD FEC), and Chromatic Dispersion (CD) pre-dispersion techniques. These enhancements improved signal integrity and increased transmission distances without a substantial increase in signal noise or loss.

The third generation, extending from 2016 to 2019, pushed data rates to 400 Gbps using 32 QAM modulation. Key advancements during this period included Nyquist shaping, which maximizes the use of available bandwidth, and further improvements in FEC technologies. These developments allowed for more data to be transmitted over the same optical infrastructure, optimizing existing assets while improving cost efficiency.

The latest, fourth generation, has seen submarine cables reach speeds up to 800 Gbps through the use of 64 QAM modulation. Innovations such as probabilistic constellation shaping (PCS), enhanced FEC, and nonlinear compensation have been pivotal. PCS, for example, optimizes the power and phase of the signal constellation points to maximize the communication rate under nonlinear channel conditions prevalent in submarine environments. Most recently, cutting-edge developments like the "Confluence-1" system have utilized Spatial Division Multiplexing (SDM) with 24 fiber pairs, surpassing 500 Tbps capacity.

This system represents a significant leap in efficiency and capacity, designed to meet the burgeoning global demand for high-speed, high-capacity, and reliable long-distance data transmission across oceans. The continuous push for higher data rates is driven by the global explosion in data traffic and the need for robust, low-latency communications infrastructure. These technological milestones not only highlight the technical innovations but also underscore the strategic importance of submarine cables in global connectivity and communication networks compared with a space network system from a data transmission speed perspective.

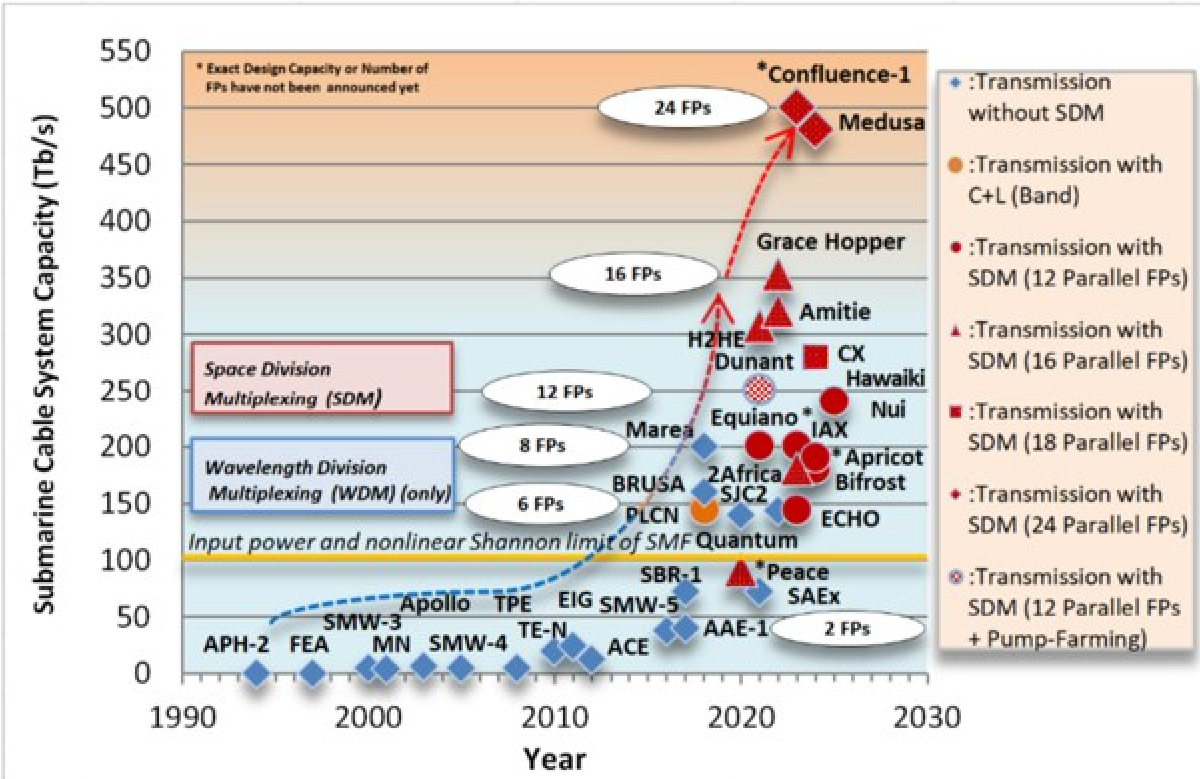

Fig. 5.28 Submarine cable system capacity × cable length through time for 70 different cable systems. From Toward SDM-based submarine optical networks: A review of their evolution and upcoming trends (Papapavlou, C. et al, 2022)

In the Table 5.17, from cost perspective, submarine cable systems require a significant upfront investment for installation, with costs ranging from USD 2.0 million to 6.8 million per kilometer, and face high maintenance challenges due to vulnerability to physical damage. In contrast, space communication systems like Starlink have potentially lower initial launch costs per unit, estimated at around $5 million or below for deploying multiple satellites, and benefit from lower maintenance costs in space, though they require regular satellite replacements due to their shorter lifespan.

While submarine cables have limited scalability post-installation, space systems offer high scalability through additional satellite launches, making them potentially more cost-effective in the long run due to the reusable nature of launch technology and modular satellite design. The economic efficiency of space systems may surpass that of submarine cables as technological advancements continue to reduce costs associated with launches and satellite production.

Table 5.17

Comparison between Submarine Cable and Space Communication Systems from Business Points

Cost Category	Submarine Cable Systems	Space Communication Systems (e.g., Starlink)
Initial Installation	USD 2.0 million to 6.8 million per kilometer.	Estimated $5 million or below per Starship launch for deploying satellites.
Maintenance	High due to vulnerability to physical damage and the technical challenges of undersea repairs.	Lower for satellites; periodic replacement required. No physical repairs in orbit, but ground station maintenance needed.
Operational Costs	Costs associated with power for repeaters, regulatory compliance, and securing permits.	Operational costs of ground stations and satellite network management.
R&D Costs	Lower relative to space systems; mainly focused on improving cable durability and data capacity.	High, due to continuous development in satellite technology and launch capabilities.
Replacement Costs	Infrequent but potentially extensive due to cable damage or technology upgrades.	Regular satellite replacement required due to limited lifespan.
Scalability	Limited post-installation; expansion requires laying new cables.	High scalability; additional satellites can be launched to expand capacity.
Economic Efficiency	Economies of scale primarily during deployment. Subsequent modifications or expansions can be costly.	Higher initial costs, but potentially lower incremental costs with scale due to reusable launch technology and modular satellite design.
Lifespan	Typically designed for 25 years of service.	Satellites have a shorter operational lifespan, usually around 5-15 years.

Note: Created based on Market Size, Share & Industry Growth Analysis Report by Application (Communication Cable and Power Cable), Component (Dry Plant Products and Wet Plant Products), Offering, Voltage, Type (Single Core and Multicore), Insulation, End User, and Geography (Submarine Cable Systems, 2022), and Starship, Starlink, and some SpaceX-economics (Rao,A.,2023)

Space Communication Market Trend

From market perspectives, the telecommunications sector, particularly within the realm of space-based services, is poised for substantial growth, projected to reach approximately 1.58 trillion USD by 2028. Analysis of global revenue data from 2017 to 2028 reveals a consistent upward trajectory in the communication services market. Initiating at about 1.32 trillion USD in 2017, the revenue has shown a steady increase each year, influenced by the expansion of global connectivity and advancements in communication technologies (Fig. 5.29). This trend underscores a dynamic and robust market environment with escalating demand for innovative communication solutions.

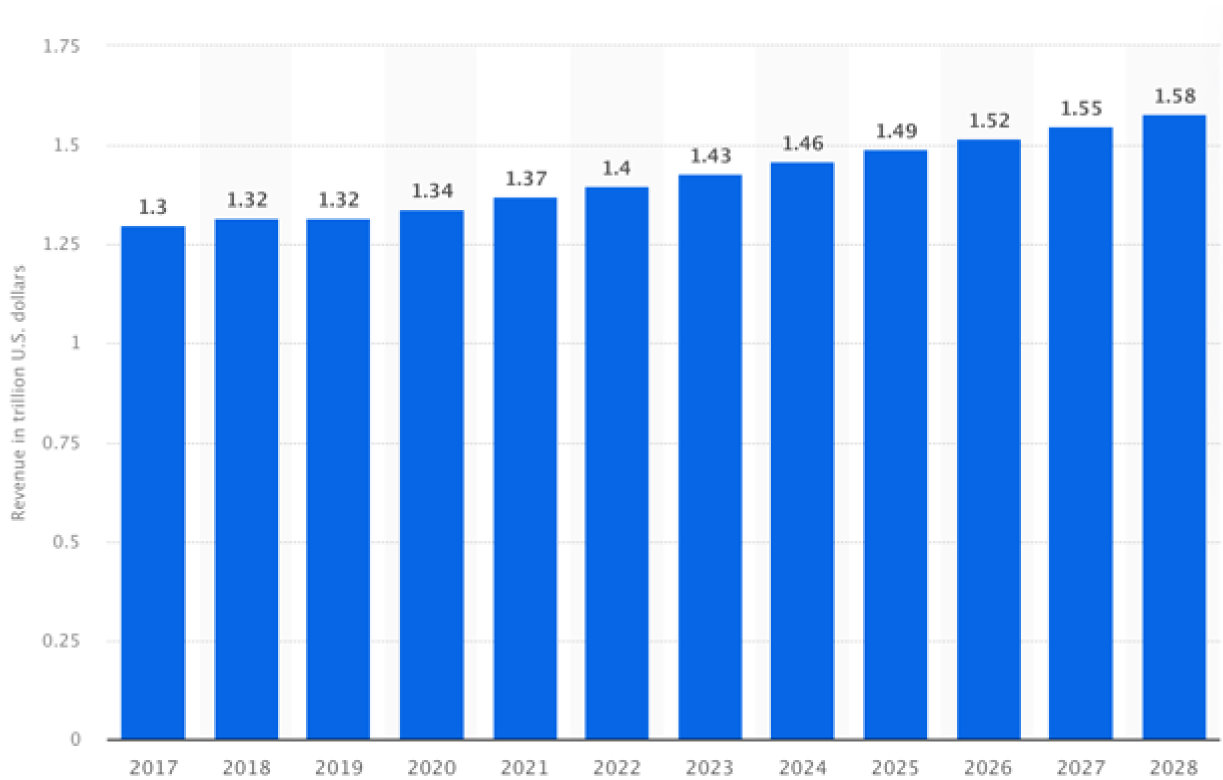

Fig. 5.29 Revenue of the communication services market worldwide from 2017 to 2028(in trillion U.S. dollars). From Statista: https://www.statista.com/forecasts/1253394/communication-services-revenue-worldwide

Simultaneously, the emerging 5G telecommunications sector, while starting from a smaller base, is expected to experience exponential growth (Fig. 5.30). As of 2022, the 5G satellite communication market, which spans commercial, consumer, defense, and government sectors, indicates significant economic activity. The commercial sector, leading with a revenue of approximately 13,896 million USD, highlights the crucial role of business applications in driving the adoption of 5G technologies. Following closely, the consumer sector accounted for about 11,386 million USD, with the government and defense sectors also making notable contributions. Forecasts for 2032 suggest a near doubling in commercial revenue, emphasizing the expected expansive growth of 5G applications across various domains, which underscores its potential to revolutionize communication landscapes significantly.

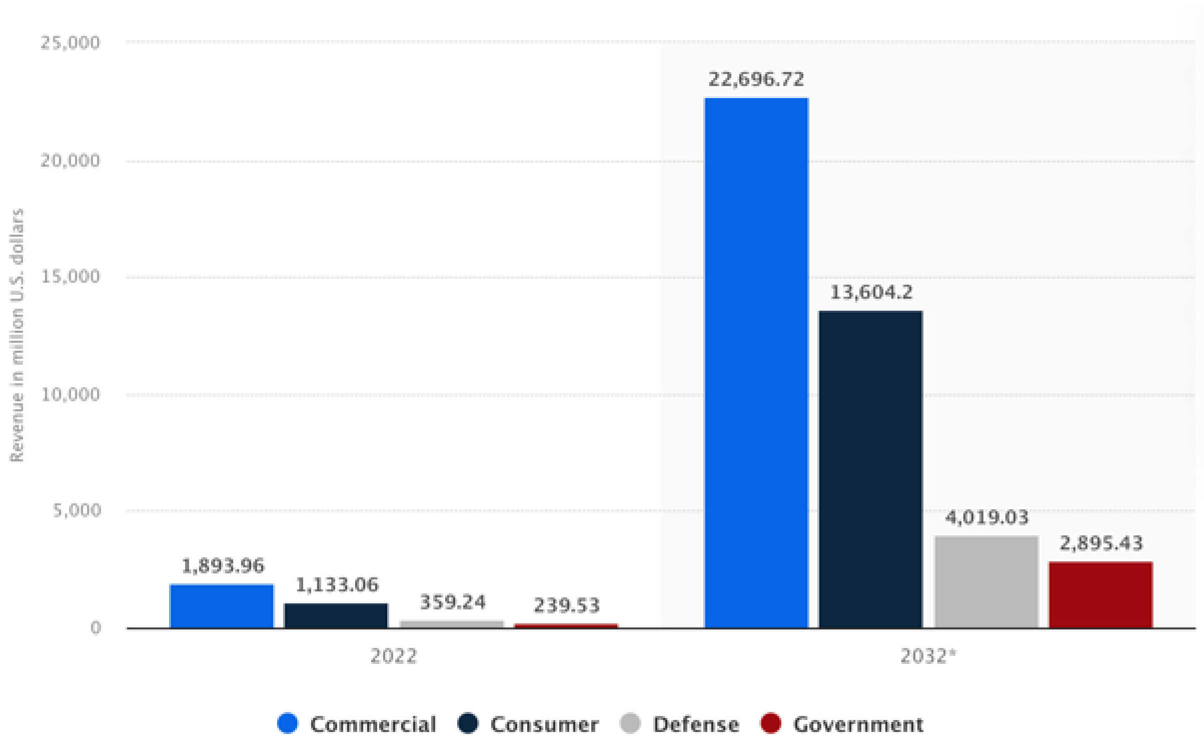

Fig. 5.30. 5G satellite communication market worldwide in 2022 with a forecast for 2032, by end user (in million U.S. dollars). From Statista: https://www.statista.com/statistics/1384234/global-5g-satellite-communication-market/

In terms of competitive positioning within the satellite industry, the number of satellites a company operates can be a significant indicator of market dominance (Fig. 5.31). As of October 2023, Starlink leads this metric, managing a fleet of 4,874 satellites, which constitutes more than 40% of all active satellites. This substantial presence primarily supports broadband internet services and is followed by 1,005 geostationary satellites, vital for a range of applications including telecommunications, broadcasting, and weather forecasting.

The comprehensive deployment of satellites across various functions, including scientific research, national defense, and amateur radio, not only reflects the strategic importance and diverse applications of satellite technology but also highlights the growing dependency on such technologies for global communications and other critical activities. This extensive utilization underscores satellite technology as a pivotal area of study and technological advancement, with significant implications for global connectivity and information dissemination.

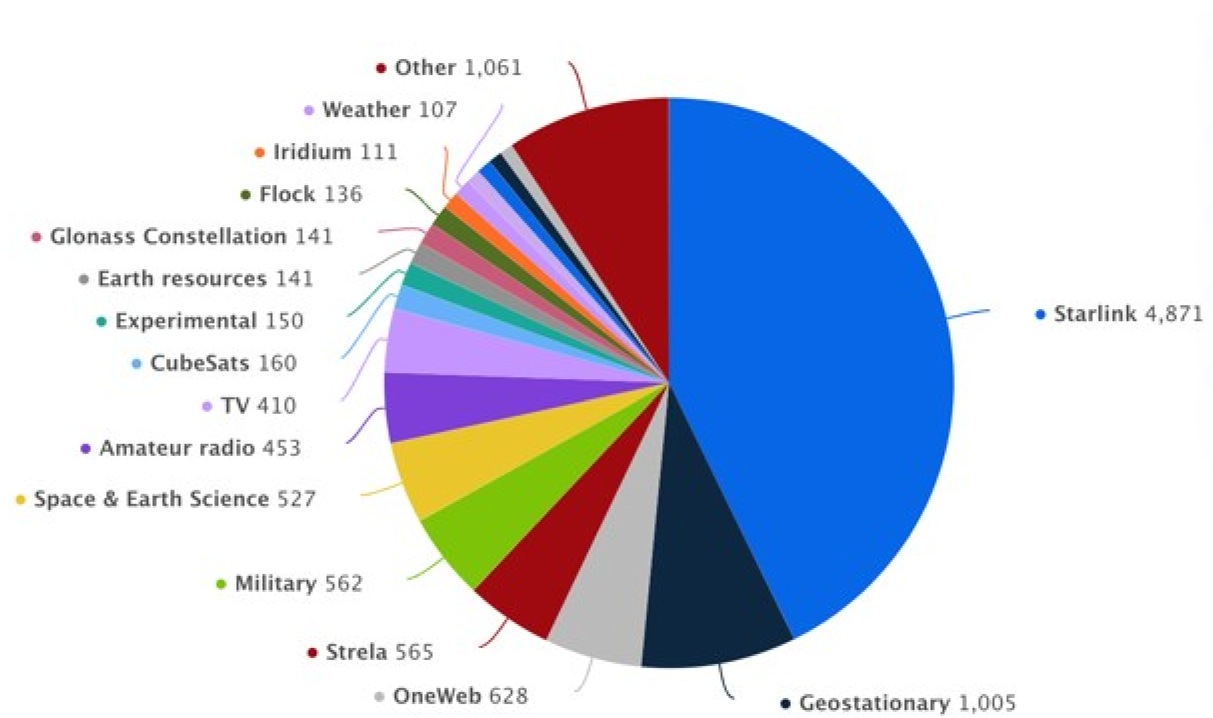

Fig. 5.31. Number of satellites in orbit as of October 2023, by category or major operator.

From https://www.statista.com/statistics/1224643/active-satellite-by-operator/

Space Communication with the IOWN

As for NTT's space communication activities, NTT introduced the concept of the "Space Integrated Computing Network," under the IOWN initiative, which aims to eliminate communication constraints between space and Earth in 2021 (2022, NTT). This innovative network structure involves deploying relay satellites in low Earth orbit (LEO) to geostationary orbit (GEO) and creating a multi-layered optical network in space that can also facilitate optical communication from geostationary orbit to the Earth.

One of the main advantages of this network is the integration of data collection and analysis from a space-based data center positioned in geostationary orbit, which would allow for the provision of timely and efficient space services. Currently, satellites in low Earth orbit predominantly use conventional radio waves for communication with Earth, which only allows for a few minutes of connection every 90 minutes due to their high-speed orbital movement. The Space Integrated Computing Network proposes using optical communications to overcome these limitations, enabling faster and more extensive communication capabilities in space.

This network will be multi-layered, with different segments of communication infrastructure:

- High Altitude: Near the stratosphere, High Altitude Pseudo Satellites (HAPS) serve as airborne base stations, interconnected through an optical network to expand mobile communication coverage.
- Low Earth Orbit: Satellites in lower orbits collect various data from Earth, which are then communicated through a network of higher altitude relay satellites connected by optical fibers.
- Geostationary Orbit: The space data center processes and analyzes data received from LEO relay satellites and can transmit information and analysis results back to Earth using optical or radio waves.

Also, this project includes developing a space-based data center to address the limitations of computational capabilities on current satellites, which struggle with restricted space and power. While space data centers can't compete with terrestrial ones in cost-effectiveness, they are crucial for minimizing Earth's environmental burden. NTT is investing significantly in this project, focusing initially on enhancing the immediacy of data acquisition from Earth observation satellites. Current satellites experience delays of 1-2 days in transmitting data to ground stations due to limited communication opportunities. NTT plans to overcome this by processing data directly in space, allowing for real-time data acquisition and reducing communication load and delays. The proposed space data center will comprise a constellation of dozens to hundreds of satellites in low Earth orbit, capable of distributed processing and transmitting data from the nearest satellite to Earth stations, ensuring minimal delay.

The overarching vision of the Space Integrated Computing Network is to create a sustainable, autonomous infrastructure in space that can process and analyze data generated in space, without being affected by terrestrial disasters (Fig. 5.32). This integrated infrastructure connects through RF and optical wireless technologies and aims for distributed computing across a constellation, allowing real-time data processing in space. This network is designed to support space sensing, space data centers, and a Space Radio Access Network (RAN) for the Beyond 5G/6G era, integrating terrestrial and non-terrestrial networks (NTN) to provide ultra-coverage and disaster-resistant communications.

In May 2021, NTT and SKY Perfect JSAT announced their cooperation on integrating Earth and space sensing data platforms, and in November 2019, NTT collaborated with JAXA to use satellites for technology demonstrations scheduled for launch in 2022, with plans to launch a space data center by 2025. Further, NTT DOCOMO and Airbus are conducting experiments on radio wave propagation from HAPS in the stratosphere to ground antennas, the results of which will integrate with the Space Integrated Computing Network (Docomo, 2022).

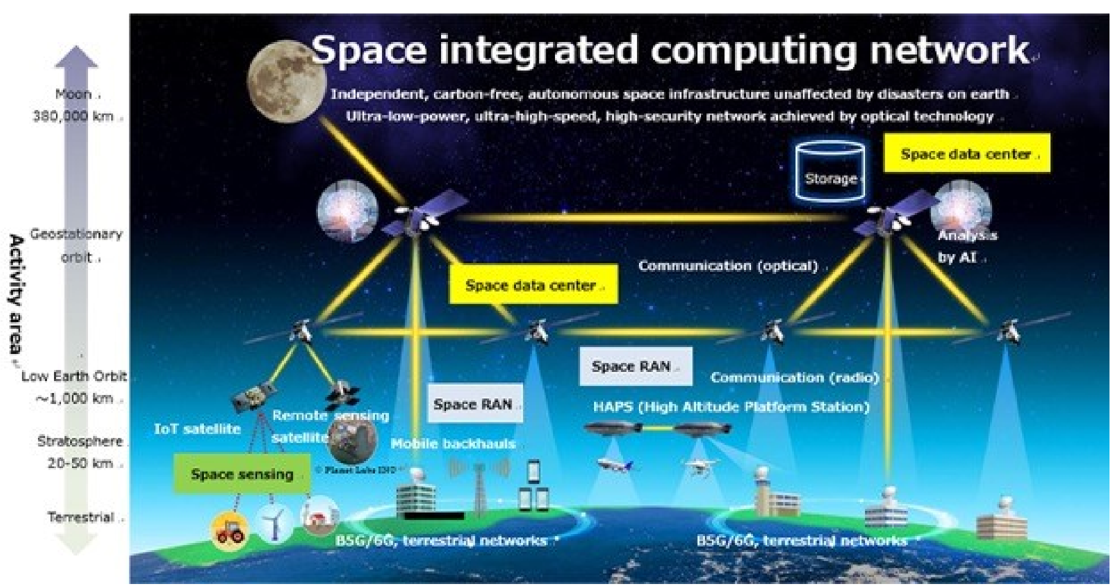

Fig.5.32 Space Integrated Computing Network concept. Retrieved from Docomo Web Site: https://www.free6gtraining.com/2021/05/ntt-and-sky-perfect-jsat-to-build-space.html

Chapter Conclusion

Chapter 5 provides an in-depth analysis of the competitive environment surrounding NTT's IOWN initiative using Porter's Five Forces framework.

NTT has committed to investing approximately 8 trillion yen over five years in areas including IOWN. However, segments like semiconductors, telecom equipment, and computers/peripherals have low average ROIC globally and high capital costs (WACC). In Japan, where funding is raised, ROIC minus WACC is negative for these segments, potentially resulting in lower returns on investments. On the other hand, the barriers to entry in the US and Europe might be high. The traditional model of creating products in Japan and expanding them overseas might be difficult to implement. Therefore, collaborating with existing players in manufacturing and sales while implementing the IOWN system could result in better investment performance.

Also, NTT faces significant competition from companies like Cisco, which has advanced its Co-Packaged Optics (CPO) system to convert electrical signals into optical signals in networking equipment. Cisco's rapid implementation of 400Gbps technology challenges NTT, which has achieved 800Gbps by 2024. To maintain its competitive edge, NTT needs to expand its optical signal conversion to end-to-end systems, including servers, PCs, smartphones, and other devices, which could establish a faster, more energy-efficient system, with the IOWN Frum partners actively. Also, it is better decision to consider partnering with Intel, which has a strong capability in the computing processing technologies for the short-term, but, NTT, which has a strangeness in communication processing technologies should prepare a management plan for potential competition with them in the long term.

The semiconductor and telecom equipment industries exhibit high industry concentration, with significant entry barriers due to the advanced nature of the products. This gives suppliers considerable bargaining power. NTT's adoption of an Integrated Device Manufacturer (IDM) model, similar to Intel, could expose it to financial pressures from suppliers, particularly in regions like the EU and Japan where expected returns are negative. Also, focus on extending optical signal conversion to end-to-end systems and developing open specifications to allow multi-vendor control. Also, it is important to make a plan about partnering with Intel and Rapidus for short-term collaboration for efficient operation system potential within the semiconductor industry competition.

Additionally, the high capital investment and advanced technological requirements in the semiconductor and photonics industries create significant entry barriers for new competitors.

Established players like TSMC, Intel, and Rapidus, with substantial manufacturing expertise and sales networks, pose a continuous threat to new entrants. Therefore, it is critical to establish a manufacturing outsourcing and joint sales scheme with partners like Intel and Rapidus to lower capital costs, and monitor advancements by TSMC, Broadcom, and Nvidia in the silicon photonics area.

Furthermore, cloud providers and telecom operators are key buyers in the market. They face challenges in managing massive data processing capacities required for AI and IoT advancements. NTT's IOWN platform offers potential solutions for these buyers by providing high-speed, energy-efficient computing technologies, which could reduce their operational costs and enhance performance, , and these are business opportunities.

Chapter 6: Conclusion

Throughout Chapters 3 and 4, we have analyzed both the macro-environmental factors (political, economic, social, technological) and micro-environmental factors (value chain, and Porter's competitive forces) surrounding NTT's IOWN initiative. In this chapter, we conclude the strategic direction of NTT's IOWN based on these analyses. We will consider short-term and long-term strategies for R&D, operations (manufacturing and sales), and market engagement.

R&D

In the short term, NTT needs to respond to competition from Cisco, which has also entered the downstream value chain and is closely positioned in the current market. Cisco is advancing its Co-Packaged Optics (CPO) system, utilizing silicon photonics technology like NTT to convert electrical signals in the networking area into optical signals. Although Cisco has achieved 400Gbps, NTT has progressed to 800Gbps by 2024. Despite NTT's lead in research and development, Cisco's quicker implementation speed, especially in data center networking equipment—which constitutes 90% of their installations—poses a threat. NTT's countermeasures should include not only converting network devices into optical signal transmitters like Cisco but extending the conversion to end-to-end systems (encompassing servers, PCs, smartphones, machines, automobiles, and electronic computing devices). This approach, not yet pursued by other companies, could establish a faster, more energy-efficient system that is socially recognized. Additionally, NTT should develop open specifications that allow multi-vendor control, adding value beyond the dependence on a single provider like Cisco. Currently, NTT is ahead with about 130 companies in the IOWN Global Forum, working on specifications and PoCs, gaining a competitive edge in industry standard specifications.

In the long term, the decision whether to compete with or partner with Intel will be critical. Short-term, Intel has decided to divest its silicon photonics network application division, indicating a move towards commercializing computer processing optical signals. As NTT and Intel are founders of the IOWN Global Forum, collaboration could be facilitated. However, with the potential rise in AI demand, the need for high-speed data processing and energy-efficient solutions within data centers could increase, positioning NTT and Intel in complementary development segments. By 2030, NTT aims to commercialize optical signal computer chips independently, which may lead to competition with Intel. The future could involve fierce competition, market segmentation, or joint ventures.

Furthermore, these R&D initiatives are expected to be costly. NTT has committed to investing approximately 8 trillion yen over five years in areas including IOWN, but segments like semiconductors, telecom equipment, and computers/peripherals have low average ROIC globally and high capital costs (WACC). Particularly in Japan, where funding is raised, ROIC minus WACC is negative for these segments, which could mean lower returns on investments. It would be beneficial for NTT to highlight the energy efficiency of their R&D projects and consider funding through low-interest green bonds or from sources outside Japan.

Additionally, long-term considerations must include new technologies and alternatives. For instance, while leveraging current semiconductor manufacturing setups, the application of 3D packaging technology, actively pursued by companies like TSMC, should be integrated into photonic-electronic convergence designs. Quantum computing, where companies like Google and IBM are leading with superconductive quantum technologies, presents a challenge for NTT's optical-based quantum computer and network initiatives. The compatibility of semiconductor types used in current architectures with optical signals must be assessed. NTT must decide whether to focus solely on optical-based quantum architectures, develop compatible architectures with superconductivity, or continue evolving traditional computing under the IOWN framework if quantum solutions are over-spec and cost-inefficient.

Regarding space communication, the field lacks standardization and various specifications exist. Introducing NTT's optical communication approach could be understood as expanding service value, but international standardization efforts will be necessary moving forward.

Operation

In terms of operations for manufacturing and sales, NTT must consider the structure for semiconductors and IT devices that implement these components upstream. While advancing R&D in semiconductor design, NTT is now transitioning to a phase where it must select a manufacturing and sales structure for products that incorporate silicon photonics. Similar to an Integrated Device Manufacturer (IDM) model like Intel, NTT may need to manage multiple vendors, including semiconductor material and equipment manufacturers. The Herfindahl-Hirschman Index (HHI) indicates high industry concentration with values such as EUV Mask Blanks (6800), Other Mask Blanks (4825), Photomasks (3094), and semiconductor equipment like Drawing (3755.42) and Lithography (8839.76), which signifies high entry barriers due to the advanced nature of these products. An ROIC-WACC analysis shows that the semiconductor industry has expected returns of 6.12% in the US, -0.92% in the EU, and -1.37% in Japan, whereas the semiconductor equipment industry exceeds expectations with 13.29% in the US, 6.45% in the EU, and 4.29% in Japan, aligning with higher profitability for suppliers. Therefore, if NTT adopts an IDM model, it may face financial pressures from suppliers during the initial low-volume production phase, especially in regions like the EU and Japan where expected returns are negative, making it a challenging business area.

NTT Innovative Devices, while contracting for PIC design, might also consider incorporating foundry functions similar to TSMC and Samsung if transitioning to an IDM model. As seen from TSMC's capital expenditure plans, substantial annual investments in semiconductor equipment are required. This parallels NTT's core businesses—telecommunications and data centers—which are also capital-intensive. Given the uncertainties in early-stage product-market fit, adopting a robust manufacturing and sales framework from the outset may not be prudent. Initially, it may be more advantageous to establish a manufacturing outsourcing and joint sales scheme with already disclosed partners like Intel and Rapidus. This approach would offer flexibility and lower capital costs. Semiconductor manufacturers like Intel and Rapidus, with their established manufacturing expertise and sales networks, could potentially enhance sales promotion for NTT's entry into the market, aligning with the cooperative short-term R&D strategy with Intel. However, as discussed in the R&D session, NTT may eventually compete with Intel in fields outside of networking, specifically in optical circuit design and manufacturing for computers. The extent of technology disclosure, patent usage, and fees need careful consideration, as well as safeguarding against technological leaks to contracted companies.

Additionally, with TSMC announcing the Compact Universal Photonic Engine (COUPE) and companies like Broadcom and Nvidia entering photonic-electronic manufacturing, it's crucial to monitor how these firms, with significant market shares in fab-less manufacturing and specific sectors, will advance in the silicon photonics area. Their involvement in the IOWN Global Forum could also be pivotal in standardizing architectural designs.

Lastly, as analyzed in the macro environment, the long-term implications of US-China trade regulations must be considered when selecting manufacturing and sales locations. Japan, being geographically close to China's large semiconductor market, offers logistical advantages but must navigate US trade restrictions. The US is actively encouraging semiconductor manufacturers to establish production within its borders. Given these conditions, designing in

Japan and initially manufacturing and selling for the US, Japan, and Europe would serve as a risk hedge. Long-term decisions should be responsive to the evolving US-China relations.

Market

Currently, numerous players across various segments are conducting pilot projects with NTT's IOWN initiative. As analyzed in Chapter 5, there is a need to explore how telecommunication and cloud service providers within data centers can offer added value through the IOWN platform, encouraging major players to deliver services based on its specifications to end-users, thus creating additional value.

In the short term, as per IDC's report, it is expected that by 2027, about 70% of infrastructure spending will transition to cloud or hybrid environments, indicating that initially, providing value to hyperscale cloud operators should be a priority. As seen in Chapter 5's analysis of Supplier Power, the market environment for equipment used by telecommunication and cloud operators shows a relatively low industry concentration, with HHI scores of 652.21 for server equipment, 1038.28 for storage, 1208.55 for network equipment, and 605 for optical transceivers. This suggests that differentiation in technology is becoming challenging due to lower supplier bargaining power. Incorporating IOWN into their products could offer these providers a competitive advantage, potentially leading to more enthusiastic participation in the initiative. However, their product development strategies are focused on further enhancing performance, security, and quality (error rates), and they do not face immediate managerial challenges. For instance, in the U.S. market, which holds a significant industry share, the ROIC-WACC values for Computer/Peripherals and Telecom Equipment are 19.61% and 8.61% respectively, suggesting high expected returns on investment. However, the high volatility in ROIC indicates that major players apart from Japan might not risk their R&D investments in adopting the photonic-electronic convergence architecture of IOWN without a compelling business need. In this context, there is also a potential risk of incremental innovation leading to a 'innovation dilemma,' whereas IOWN could offer a disruptive innovation that could potentially change existing market dynamics for them.

Furthermore, as discussed in Chapter 5's Power of Buyer analysis, cloud providers face technological and managerial challenges in handling massive data processing capacities required for AI, digital, and IoT advancements. This responsibility includes managing significant energy consumption and ethical obligations towards reducing it. The benefits of joining the IOWN platform could be particularly appealing to cloud providers as they develop services capable of handling immense data loads. Considering the future needs for data processing and transmission, primarily led by cloud providers, these operators are likely to invest and cooperate actively in initiatives like IOWN, especially if their needs become more apparent. For instance, in the early market phases, as indicated by 2022 data, about 60% of data center revenue derived from networking, and nearly 95% of this network traffic originated from cloud-based infrastructures (2021). Particularly, as the demand from cloud providers becomes more defined, manufacturers of existing infrastructure such as routers and servers may find it necessary to commit to the new architecture proposed by the IOWN initiative. Specifically, with the Cloud industry's Herfindahl-Hirschman Index (HHI) at 2197.15, indicating relatively high market concentration, the potential for IOWN to provide significant added value to top players like AWS (Amazon) with a 40% market share, and Azure (Microsoft) with 21.5%, is substantial. By standardizing high-speed communications and computing services under IOWN, its widespread adoption could be rapidly accelerated. As previously mentioned, looking at the Return on Invested Capital minus Weighted Average Cost of Capital (ROIC-WACC) in the Computer Service Industry, with figures of 18.20% in the US and 32.08% in the EU, integrating IOWN as a standard component could result in significant revenue gains. Therefore, it would be strategic to prioritize replacing traditional networking solutions with IOWN for cloud providers first. The performance comparison data we implemented between AWS and IOWN 1.0 indicates that the IOWN could offer more than three times the speed currently available in U.S. and EU data centers, which significantly enhances the value proposition for cloud operators to adopt this technology. Additionally, the increase in traffic between North America and Asia has led to active developments in submarine cables by cloud companies like Microsoft, Google, and Meta. NTT's unveiling of the JUNO project, a U.S.-Japan submarine cable capable of 350 Tbps, although still outpaced by Google's Topaz Project at 240 Tbps, suggests that owning dedicated lines still offers significant benefits for cloud providers. However, if collaborative development with NEC results in a 5-10 fold improvement in performance, cloud service providers would find this technology indispensable. Dominating this business area would not only enhance NTT's network presence in Asia and North America but also significantly elevate its data center service offerings.

In the medium term, as explored in Chapter 3's Technical Assessments and Chapter 5's Buyer Power analysis, cloud operators need to provide high-speed, energy-efficient computing technologies to manage the projected data processing requirements of 180 zettabytes by 2025. The rapid advancements in AI and digital technologies are expected to further accelerate this need. According to the IEA, data centers are forecasted to consume about 80% of their energy from cloud operations, with projections reaching up to 3,000 TWh by 2030 and potentially as high as 500,000 TWh by 2050 in a low-carbon society scenario. As transistor miniaturization becomes increasingly challenging and each transistor unit's contribution to computing performance and energy efficiency diminishes, the industry may face the limits of Moore's and Denard's Laws. In this context, the shift from electrical to optical signaling, especially between chips as envisioned by NTT and Intel in the IOWN Global Forum (targeting 2030), represents a revolutionary approach that could potentially achieve 100 times the energy efficiency while enhancing performance by 125 times. The adoption of such photonics-electronic convergence devices could signal a breakthrough innovation and possibly establish a new industry standard. The key here lies in how extensively current computing infrastructure, such as servers and storage, can integrate IOWN's technologies. The concept of 'White Box' devices proposed by NTT Innovative Device offers a cost-effective, vendor-neutral, and energy-efficient solution that could disrupt the market, particularly as cloud operators and AI service providers currently struggle with Nvidia's vendor lock-in and high chip costs with high data center energy consumption. This makes the latter mechanism more beneficial, although the existing sales channels of the former must also be considered for widespread industry deployment. These assessments will be crucial in deciding the strategic direction for implementing IOWN technologies in the network area.

Moreover, in the medium term, the implementation of next-generation technologies, particularly in the 6G standard, must be considered. This is crucial for telecom equipment manufacturers, especially those in the EU and Japan, who have shown less profitable returns in recent analyses and may have been slow in adopting 5G technologies. The adoption of IOWN's architecture for 6G could offer these manufacturers a chance to regain their footing in the next-gen communications sector. As explored in Chapter 5's Supplier Power analysis, companies like Nokia, Ericsson, NEC, and Fujitsu are already participating in trials for 6G standards under IOWN, which could help mitigate the competitive disadvantages faced by local telecom operators due to varying regulations and licensing requirements across countries. Therefore, incentivizing equipment manufacturers to incorporate IOWN specifications and sell them internationally could be a strategic move. The analysis of telecom markets in the U.S. and EU shows that fixed-line services (Telecom Service) are expected to yield higher returns compared to wireless services, which suggests a need for targeted strategies to appeal to telecom operators and equipment manufacturers to adopt IOWN standards. These considerations will be crucial for future challenges in the industry.

Finally, in the long term, the technological integration of IOWN into devices for the vast number of PC and smart phone users in populous regions like Asia will be important. As these areas face challenges such as aging populations and labor shortages, there is an increasing demand for AI, autonomous driving, and robotics, which could also benefit from the adoption of IOWN technologies. Additionally, with still 2.6 billion people offline and potential difficulties in deploying new fixed lines due to labor shortages, attention must also be directed towards space communications. This could become increasingly important in preparing for future infrastructural needs and operational challenges in the telecommunications sector.

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