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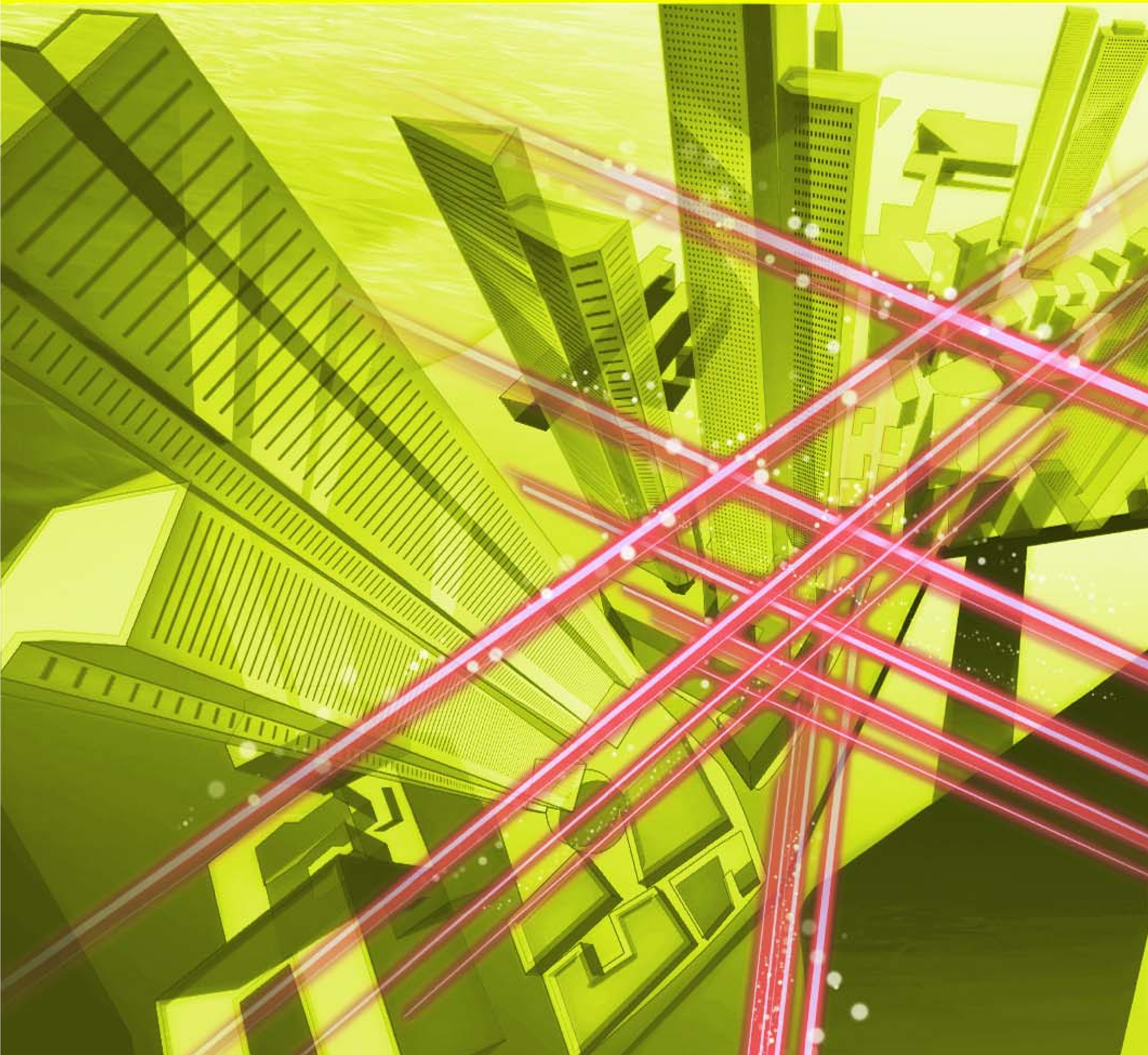

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Device Technology Development for Beyond 100G Optical Transport Network

Masahito Tomizawa, Akimasa Kaneko, and Shunji Kimura

Abstract

The capacity of the optical transport network has been expanding for over 30 years, which has enriched the communication environment of users. This expansion has also helped to reduce the cost of communication lines and facilitate the growth of the Internet and the widespread use of smartphones. In the near future, an optical transport network with a capacity beyond 100 Gbit/s per wavelength (beyond 100G optical transport network) and its device technology will be needed in order to provide more sophisticated communication services such as IoT (Internet of Things) and 5G (fifth-generation) mobile access. This article reviews NTT laboratories' development of device technology for the beyond 100G optical transport network.

Keywords: optical transport network, device technologies, beyond 100G

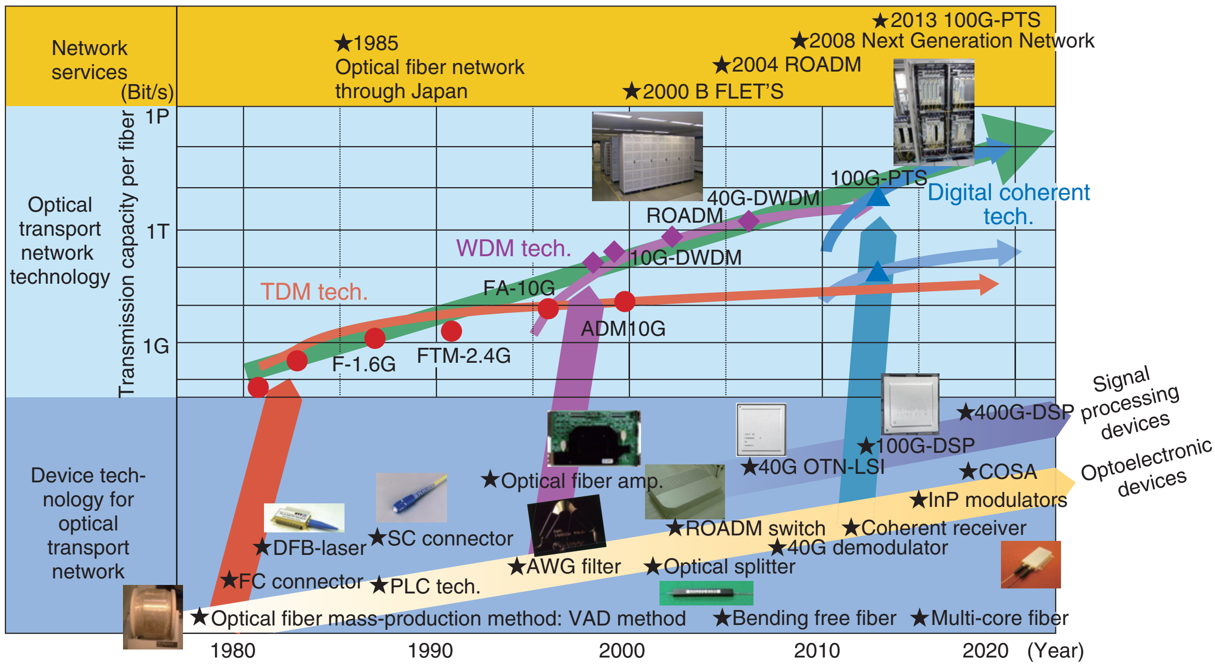
1. Introduction

Expectations for communication networks have been increasing more and more in recent years. The development of the Internet of Things (IoT) is one example of such an expectation. The IoT is expected to make people's lives richer by connecting and controlling all things via networks. The fifth-generation (5G) mobile access network, which smoothly bridges numerous users/things and core networks in the IoT world, is also attracting attention. It is an optical transport network whose device technology supports the realization of IoT from the viewpoint of long-haul data transmission.

The capacity of the optical network has been expanding for over 30 years, which has enriched people's communication environment (**Fig. 1**). From the 1980s to the early 1990s, time-division multiplexing (TDM) techniques were developed to reduce the cost of communication lines and to realize integrated services digital networks (ISDNs). With TDM techniques, the capacity of the optical transport network reached 10 Gbit/s per optical fiber. From the late 1990s through the 2000s, progress was made in wavelength-division multiplexing (WDM) techniques in order to cope with the rapid growth in Internet traffic. WDM techniques finally reached a capacity of 1 Tbit/s per fiber. Digital coherent technology has been applied since the 2010s, which has boosted the capacity to manage drastic increases in traffic caused by the widespread use of smartphones. At present, 8 Tbit/s per fiber capacity has already been realized and utilized in real systems.

Digital coherent technology is very different from conventional TDM and WDM techniques in terms of the light modulation scheme for carrying digital data. While conventional TDM and WDM techniques use only optical intensity for light modulation, digital coherent technologies modulate not only optical intensity but also the optical phase. Moreover, digital coherent devices can multiplex light polarization, whereas TDM and WDM devices cannot.

Because light parameters for carrying digital data are increased in digital coherent technology, the



ADM: add/drop multiplexer
AWG: arrayed waveguide grating
COSA: coherent optical subassembly
DFB: distributed feedback
DSP: digital signal processor
DWDM: dense wavelength division multiplexing
FC connector: fiber transmission system optical connector
FTM: fiber termination module
LSI: large-scale integrated circuit
OTN: optical transport network
PLC: planar lightwave circuit
PTS: packet transport system
ROADM: reconfigurable optical add/drop multiplexing
SC connector: single fiber coupling optical fiber connector
VAD: vapor-phase axial deposition

Fig. 1. Transition of optical transport network and device technologies.

capacity per one wavelength of light has reached 100 Gbit/s at present. (When WDM techniques were the prevailing technology, a few dozen wavelength signals were multiplexed in one optical fiber. At the end of the WDM era, 40-Gbit/s capacity per wavelength had been achieved due to steady progress in TDM techniques.) As mentioned so far, digital coherent technology adopts a more complex light modulation and multiplexing scheme than those of conventional TDM and WDM techniques, and it is the optoelectronic devices that physically realize the complex digital coherent technology. Communication traffic in the world of IoT with 5G mobile access is expected to continue to increase, so an optical transport network beyond 100 Gbit/s per wavelength (hereafter, 100 Gbit/s/λ; λ (lambda) = wavelength), referred to as a beyond 100G optical transport network is highly desirable by people all over the world.

2. Requirements for beyond 100G optical transport network and development strategy for associated devices

Three requirements for the beyond 100G optical transport network and the strategy of developing the optoelectronic devices used with it are summarized in **Table 1**. NTT laboratories established the development strategy in order to meet the requirements, and development of the optoelectronic devices is underway to achieve the beyond 100G optical transport network. The details of the development strategy are described below.

2.1 Expanded capacity

Communication traffic will continue to increase in the next generation, and it will be vital to expand the capacity in order to meet the increase. In particular, it is important to find a way to transport mobile traffic long distances at reasonable cost as soon as possible. Mobile traffic is currently growing at 1.4 times the current amount per year. Although 8-Tbit/s total capacity optical transport systems with 100 Gbit/s/λ were installed in 2013, 30-Tbit/s-class systems with 400 Gbit/s/λ are expected to be necessary by 2017 to support the growing mobile traffic. Optoelectronic devices used for such optical transport systems should be ready one year ahead of the time they are needed; therefore, research and development (R&D)

Table 1. Optical transport network requirements and device development strategy.

Requirements for optical transport network	Expanded capacity	Downsizing of optical transport equipment	Low latency
Device development strategy	• Multi-level coherence (xQAM) • Faster modulation (higher baud rate)	• Choosing appropriate materials for devices and optimizing device design	• Expansion of domain of optical technologies (ultralong-haul optical transmission, optical switches w/o EO/OE conversion)
Concrete development activities	• DSP implementing QPSK and 16QAM • Optical transmitter and receiver corresponding to QPSK and 16QAM	• Optical modulator and receiver using InP and Si • DSP using state-of-the-art miniaturized CMOS process (20 nm, 16 nm)	• DSP equipped with soft-decision forward error correction (SD-FEC) and frequency domain equalization

CMOS: complementary metal-oxide semiconductor
EO/OE: electrical-optical/optical-electrical
InP: indium phosphide
QAM: quadrature amplitude modulation
QPSK: quadrature phase-shift keying
Si: silicon

of optoelectronic devices must be done quickly and efficiently.

NTT laboratories have been focusing on digital coherent technology as a way to expand the capacity of the optical transport network. R&D is underway on more sophisticated modulation schemes such as 16-level quadrature amplitude modulation (16QAM), as well as conventional optical modulation schemes such as quadrature phase-shift keying (QPSK). We are also working to increase the speed of modulation (baud rate). By combining a more sophisticated modulation scheme and a faster baud rate, we will be able to achieve a much larger capacity of the optical transport network in the near future. One concrete example of this is that NTT laboratories are trying to implement a more sophisticated modulation scheme and a faster baud rate into a digital signal processor (DSP), which is the heart of the optical transport network utilizing digital coherent technology. As for the optical transmitter and receiver, we are focusing especially on the coexistence of highly linear input-output characteristics and faster performance, which are essential for implementing a more sophisticated modulation scheme and faster baud rate.

2.2 Downsizing of optical transport equipment

The volume of optical transport equipment affects the size of the facility of the communication carrier company, so compact assembly/packaging is essential. If the communication traffic is increased several times with the new equipment, the volume of the equipment will need to be equal in size or smaller than the previous equipment. In recent years, not only have the facilities of communication carrier companies been directly connected to the optical transport network in order to deliver information long distances, but so too have datacenters run by information technology companies. The allotted space for equipment in datacenters is very limited, so compact assembly/packaging is mandatory when installing optoelectronic devices in datacenters.

Two aspects in the R&D of optoelectronic devices that are important in order to achieve compact assembly/packaging are: 1) making each device smaller, and 2) reducing power consumption to prevent the inevitable problem of heat radiation in smaller size devices. For example, although a 100-Gbit/s/λ digital coherent optical transceiver (commercialized in 2013) has a footprint of 5 inches × 7 inches (12.70 cm × 17.78 cm), a 1.6 inch × 4.2 inch CFP2-ACO (centum (100) gigabit form-factor pluggable 2 - analogue coherent optics, 4.06 cm × 10.67 cm) optical transceiver has been developed and is being commercialized in 2016. From now on, making devices smaller and reducing power consumption will remain important tasks, and progress in these areas will continue rapidly.

To make devices smaller, NTT laboratories choose appropriate materials for optoelectronic devices and optimize the device design. Selecting high refractive index materials such as indium phosphide (InP) and silicon (Si) helps in reducing the sizes of optoelectronic devices, but we are also focusing on optimizing the device design so as not to degrade the optical transport performance. Also, to reduce power consumption, NTT laboratories have been researching and developing ways to reduce the driving voltage of optical modulators. Optical modulators using InP are a representative example of such development, and the details are described in the other Feature Articles

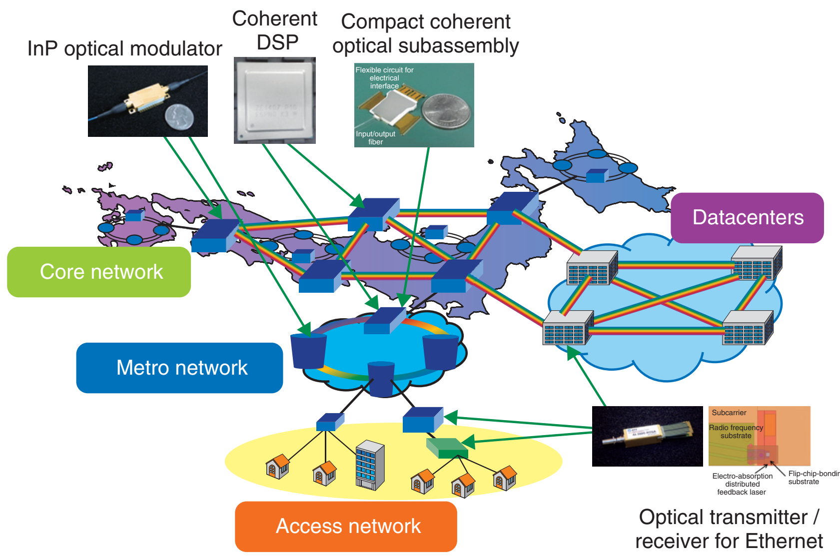


Fig. 2. Devices developed for optical transport network.

in this issue. As for DSP, the use of a state-of-the-art complementary metal-oxide semiconductor (CMOS) miniaturized process made it possible to achieve a drastic reduction in power consumption. While 40-nm and 20-nm CMOS miniaturized processes were used in developing the DSP, a 16-nm process—the first in the world—is being used in the most recent development to further reduce power consumption.

2.3 Low latency

In the near future, many applications using the communication network will be introduced. These applications include those for services that require real-time responses and that have low latency. Examples for such services include highly sophisticated financial services and smart cars connected to the communication network.

The total latency of network services mainly depends on the configuration of servers and the architecture of the network. However, in terms of the optical physical layer, reducing the latency inside the optical transport equipment is effective in reducing the overall latency. The most effective way to reduce latency is to reduce the number of times data packets are stored and forward-processed after optical-to-electrical (OE) conversion, or in other words, to reduce the number of core routers. Moreover, if OE and electrical-to-optical (EO) conversions were excluded as well as the decreased number of core routers, much lower latency would be obtained. These technical trends require expanding the domain of optical technologies, for example, extending the transmission distance of optical signals without OE/EO conversion relay and routing optical signals without the OE/EO process.

To contribute to the low latency of the communication network using optical technologies, NTT laboratories have been researching ways to extend the reach of optical signals in the optical transport network and investigating switching techniques that do not require OE/EO conversions. The following Feature Articles introduce NTT's development of a DSP implementing soft-decision forward error correction (SD-FEC) and frequency domain equalization to extend the optical transmission distance.

3. Future overview

The final goal of NTT laboratories, especially NTT Network Innovation Laboratories and NTT Device Innovation Center, is the widespread use of the beyond 100G optical transport network. To achieve this goal, we are continuing our R&D on state-of-the-art technologies and fabrication of easy-to-use devices in a timely manner based on the development strategy described earlier. The Feature Articles in this issue introduce the following devices, which have been developed according to this strategy (**Fig. 2**).

(1) Coherent DSPs: These are the heart of the optical transport network with digital coherent

technology [1]

(2) InP coherent optical modulators and compact coherent optical subassembly: These have the compact size needed for the next generation of optical transport equipment and achieve adequate performance by working in conjunction with coherent DSPs [2, 3]

(3) Optical transmitter and receiver for high-speed optical Ethernet: These are essential optical components for connection between routers/switches in client-side and coherent systems [4]

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He received an M.S. and Ph.D. in applied physics from Waseda University, Tokyo, in 1992 and 2000. From 2003 to 2004, he was a visiting scientist at Massachusetts Institute of Technology, USA. He has been engaged in R&D of high-speed optical transmission systems. Since 2009, he has been a project leader of the 100G Center-of-Excellence (CoE) Consortium consisting of several manufacturing companies and is responsible for the development and marketing strategies of 100G coherent DSPs. In 2013, he received the President's Award of the Ministry of Internal Affairs and Communications of Japan from the Telecommunication Technology Committee for his contributions and leadership of the consortium in the 100G digital coherent CoE project. In 2015 and 2016, he received Fellow-grade memberships from the Institute of Electronics, Information and Communication Engineers (IEICE) and the Optical Society of America, respectively.

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Digital Signal Processor (DSP) for Beyond 100G Optical Transport

Yoshiaki Kisaka, Masahito Tomizawa, and Yutaka Miyamoto

Abstract

As a foundation for the coming full-fledged big data society, optical communication networks must further advance in speed, capacity, and cost-effectiveness. This article introduces beyond 100G (beyond 100 Gbit/s per channel) digital coherent optical transmission technology, which is a key to developing high-capacity optical communication networks, and the digital signal processor (DSP) that provides core functions for this technology.

Keywords: digital coherent optical transmission, digital signal processing, multi-level modulation scheme

1. Introduction

Recent advances in telecommunications technology are expected to usher in a full-fledged big data society. These advances include the spread of FTTH (fiber to the home), the growing use of smartphones, the development of the 5G (fifth-generation) mobile communication system, which provides super-high-speed mobile access, and the introduction of the IoT (Internet of Things), in which everything is interconnected via the Internet. This trend demands that we achieve further advances in the speed, capacity, and cost-effectiveness of optical communication networks, as they are the foundation for many communication services.

One technology that is expected to satisfy this demand and that has been gaining attention in recent years is digital coherent optical transmission. This uses coherent detection to improve both receiving sensitivity and frequency utilization and employs digital signal processing to achieve compensation for waveform distortion, which accumulates in long-distance optical fiber transmission [1, 2]. Such waveform distortion compensation has so far been difficult to achieve. Digital coherent optical transmission technology is already used in high-capacity transmission systems that operate at a level of 100 Gbit/s per channel. With this technology, wavelength-division multiplexing (WDM) optical transmission systems with a total capacity of 8 Tbit/s have been introduced commercially.

Currently, the standardization of 400-Gbit/s Ethernet transmission is in progress. This provides the potential for commercial development of beyond 100-Gbit/s per channel (beyond 100G) optical transport technology. The trends in the development of digital signal processing technology for digital coherent optical transmission are shown in **Fig. 1**. There are two possible directions for improving the technology applied to the existing 100-Gbit/s transmission: enhancing performance and reducing power consumption. A high performance digital signal processor (DSP) needs to increase in both transmission capacity and distance with realistic power consumption to be implemented in transmission equipment. In contrast, a low-power DSP requires low-power consumption, a small package size, and low cost for implementation with metro-access and datacenter networks.

This article focuses on the former, in particular, on extending the distance of beyond 100G transmission. To increase the transmission capacity per fiber, it is necessary to enhance frequency utilization. An effective way to achieve this is to increase the number of

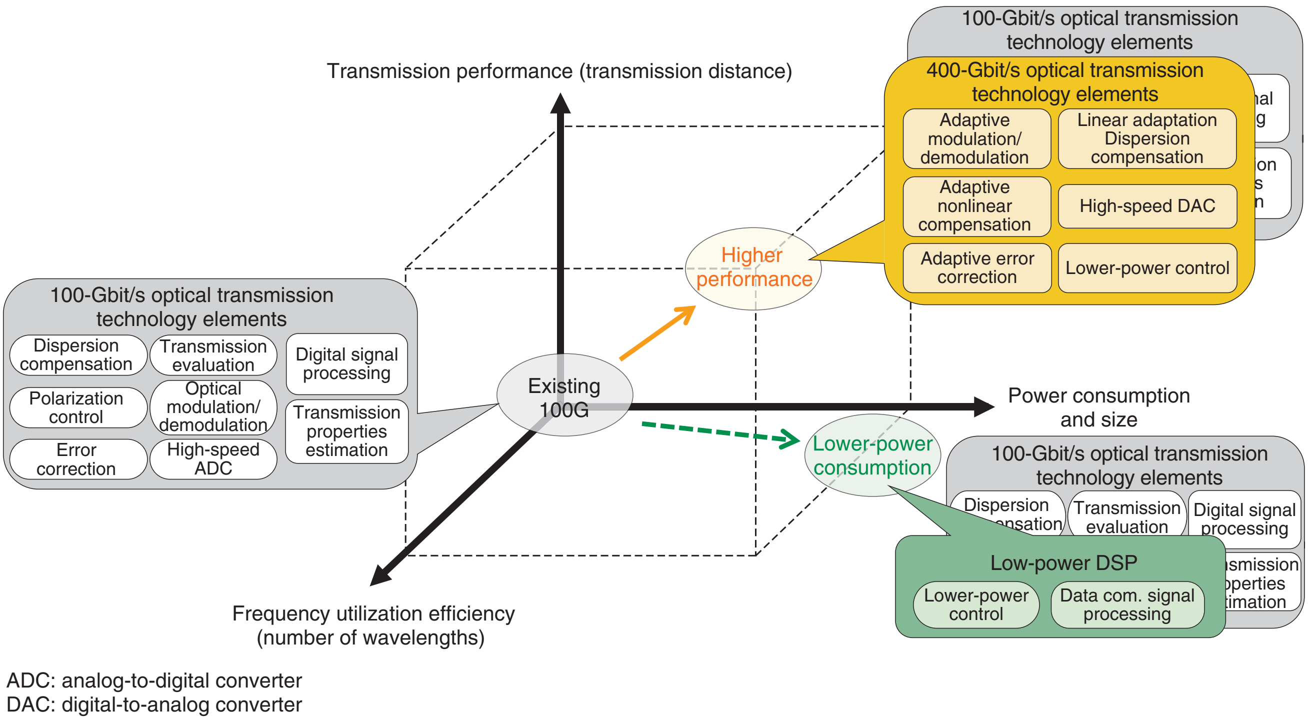

Fig. 1. Technical development of digital coherent signal processing.

modulation levels in the optical amplitude and/or phase. However, if the number of modulation levels is to be increased, the optical signal-to-noise ratio (OSNR) required to achieve the desired symbol error rate also needs to rise. If the transmission power is increased to raise the OSNR, inter-symbol interference caused by the nonlinear optical effects of the optical fiber increases, which in turn reduces the possible transmission distance. Therefore, if we are to implement a beyond 100G optical transport system, we need to combine a number of technologies, including nonlinear compensation technology, which compensates for nonlinear optical effects, and high coding gain FEC (forward error correction). In addition, we have to consider applying adaptive modulation/demodulation technology, which adaptively selects the modulation/demodulation method most suitable for the particular transmission performance margin in order to maximize the network transmission capacity.

Another effective way to increase frequency utilization is to reduce the frequency spacing between adjacent channels in WDM. This requires the frequency spectrum of the optical signal to be narrowed. Nyquist filtering is essential for this because it enables digital signal processing at the transmitter to narrow the optical signal spectrum with minimum degradation in signal quality. To develop a beyond 100G optical transport system, it is important to achieve these signal processing functions with a practical level of power consumption.

2. Digital coherent optical transmission technology

An overview of the digital coherent optical transmission technology is shown in **Fig. 2**. The modulation method most commonly used in conventional optical transmission systems has been on-off keying (OOK), in which 1 and 0 in the optical signal used are indicated by on and off states (intensity modulation), and the variation in optical intensity is detected by a photo detector. When OOK is applied to transmission at a rate of 100 Gbit/s, the degradation in transmission quality due to various waveform distortions of the optical signal during propagation through an optical fiber becomes significant. As a result, the transmission distance is limited to only a few kilometers.

To avoid this problem, digital coherent optical transmission has been developed and adopted in 100-Gbit/s optical transport systems. This achieves highly efficient and stable long-distance transmission

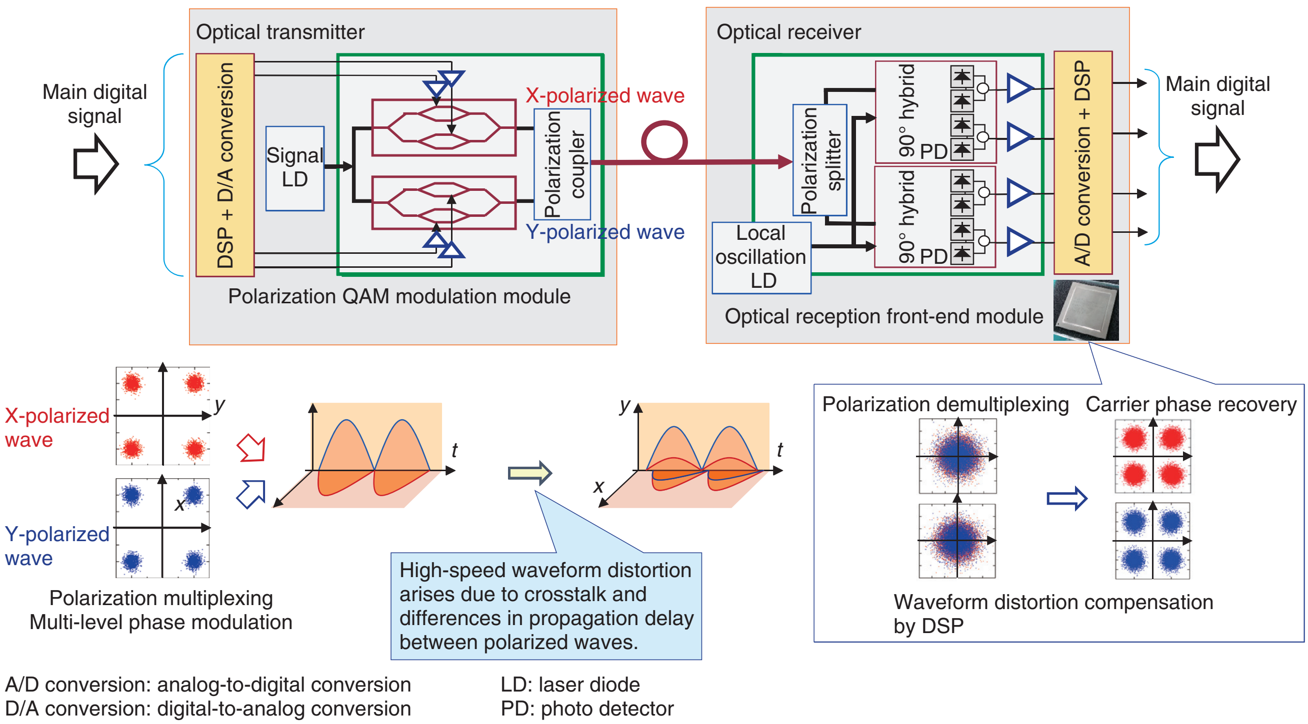

Fig. 2. Overview of digital coherent optical transmission.

by not relying only on optical intensity but also using digital signal processing to utilize the phase and polarization of light, which are both properties of a light wave.

The main modulation scheme applied to 100-Gbit/s optical transport is dual-polarization quadrature phase-shift keying (DP-QPSK). This modulates optical signals with four different phases and also uses the X-polarized wave and the Y-polarized wave to carry different signals. It achieves high receiving sensitivity by using coherent detection, in which a local oscillator light generates an interference signal with the received optical signal. From this interference signal, the intensity and phase information of the received optical signal is detected. The two polarization-multiplexed signals can be demultiplexed using digital signal processing. DP-QPSK achieves frequency utilization four times as high as that of OOK. Digital signal processing can also be used at the receiver to compensate for waveform distortions due to chromatic dispersion, polarization mode dispersion (PMD), and crosstalk between polarization signals on the optical fiber. Consequently, optical fiber transmission over more than 1000 km becomes possible without using optical compensation media such as dispersion compensating optical fiber.

If the capacity of beyond 100G optical transmission systems is to be further increased, it is necessary to use higher multi-level modulation of optical signals such as dual-polarization 16-level quadrature amplitude modulation (DP-16QAM), which uses both optical intensity and phase. Different types of modulation can be generated by changing modulation signals generated using digital-to-analog (D/A) conversion in the same hardware of the transmitter/receiver including the optical modulator, driver amplifier, and optical receiver. This makes it possible to select the optimal modulation scheme depending on the channel capacity or transmission distance required.

3. DSP for beyond 100G optical transmission

We have developed a real-time DSP for digital coherent optical transmission through an open innovation in which a number of organizations have participated [3, 4]. This work was supported by a research and development (R&D) project of the Ministry of Internal Affairs and Communications (MIC) of Japan and another project of the National Institute of Information and Communications Technology

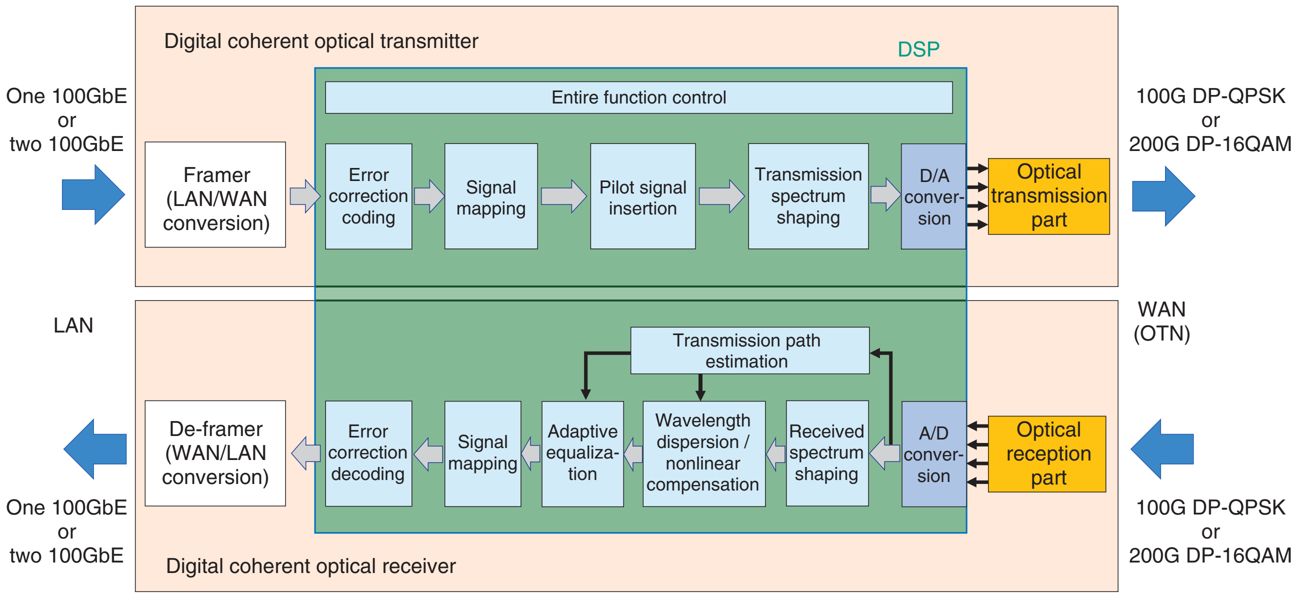

Fig. 3. Configuration of digital coherent optical transmitter/receiver.

(NICT).

In digital coherent optical transmission, the DSP performs modulation/demodulation and waveform distortion compensation. The functional configuration of the digital coherent optical transmitter/receiver used is shown in **Fig. 3**. We describe here an example of transmitting/receiving a 200-Gbit/s optical signal. In the transmitter, the framer converts the two 100-Gbit/s Ethernet (100GbE) signals input from the local area network (LAN) into two optical transport network (OTN) frame formats (optical-channel transport unit (OTU)4 signals) for the wide area network (WAN) and outputs them to the DSP. The DSP performs soft-decision error correction [5] with a redundancy of 20% or 25%, which provides strong error correction capability. The signals are then mapped onto four lanes (two orthogonal phases (phases I (in-phase) and Q (quadrature)) for each of the two orthogonal polarized waves (X- and Y-polarized waves)). After that, a pilot signal for estimating the status of the transmission path, for example, the OSNR, is added. Digital filtering for narrowing the optical signal spectrum is then applied. This is followed by D/A conversion. Finally, the optical transmission part converts the signals into 200-Gbit/s DP-16QAM signals and transmits them.

In the receiver, the optical receiver element mixes the received signal light with the local oscillation light to apply coherent detection and converts the light into four-lane analog signals as in the transmitter. The DSP converts the analog signals into digital signals and compensates for waveform distortion due to chromatic dispersion and optical nonlinear effects in the optical fibers [6, 7]. It then performs adaptive equalization, demodulation of the 16QAM signals, and error correction decoding. Thus, two OTU4 signals are obtained. The adaptive equalization element performs demultiplexing of the polarization-multiplexed signals and compensation for waveform distortion due to factors such as PMD. The transmission path estimation component rapidly estimates the in-band OSNR and the chromatic dispersion of the transmission path. With this information, it selects the optimal modulation method by using a pilot-aided bidirectional feedback channel between the transmitter and receiver [8] and performs rapid signal recovery [1, 2]. The entire function control element controls the coordinated operations of the different functional blocks within the DSP. The de-framer converts the two OTU4 signals into two 100GbE signals and outputs them to the LAN. If DP-QPSK is used for modulation, the transport rate becomes 100 Gbit/s, and only one 100GbE signal is handled.

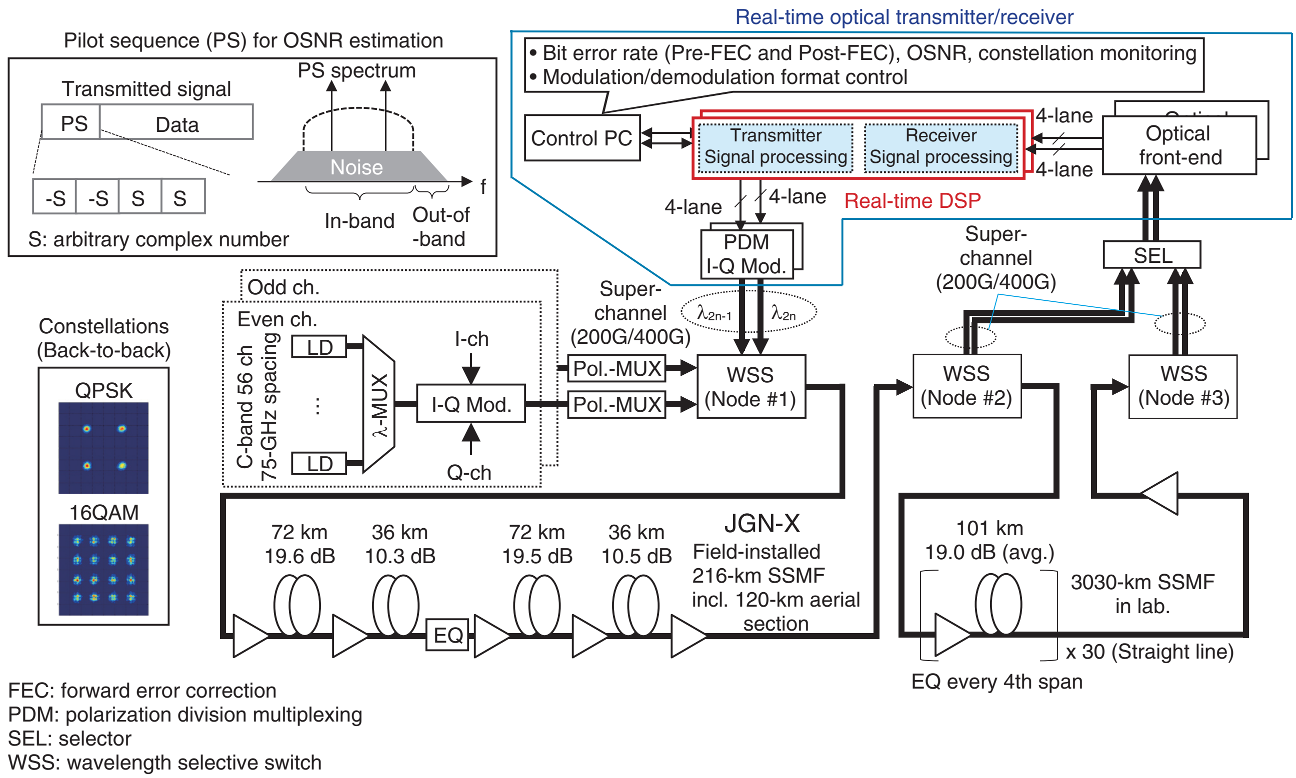

Fig. 4. 400-Gbit/s/ch real-time field trial setup.

4. 400-Gbit/s/ch real-time field transmission experiment

A 400-Gbit/s/ch real-time adaptive modulation/demodulation experiment [9, 10] conducted using a real-time DSP and the Japan Gigabit Network-eXtreme (JGN-X) testbed is described below. The configuration of the field experiment system used is shown in **Fig. 4**. The system consisted of three photonic nodes (#1, 2, and 3). The nodes were interconnected by two types of fiber cable: a JGN-X field-installed testbed fiber cable (216-km single-mode fiber (SMF)) and a laboratory fiber (3030-km SMF). The JGN-X field-installed fiber was made up of fibers that were looped between the NICT Koganei headquarters and the TOKAI Chofu Repeater Station. The cable length was 18 km including a 10-km aerial section. Twelve fiber cores were used for the 216-km transmission line, with a 120-km aerial section. A gain equalizer (EQ) was inserted mid-span of the 216-km field fiber.

The transmission fiber in the laboratory consisted of 30 spans of 101-km standard SMF (SSMF) on a bobbin. Gain EQs were inserted at every fourth span (404 km). The even and odd channels of a continuous oscillation light from a laser diode (LD) light source that had been wavelength-division multiplexed with C-band 75-GHz spacing were modulated separately, and polarization-multiplexed signals were generated by a self-delayed polarization multiplexer (Pol.-MUX). They were then optically multiplexed by Node #1 to generate either DP-16QAM signals or DP-QPSK signals with 112 wavelengths (ranging from 1529.114 nm to 1562.283 nm) at C-band 37.5-GHz spacing as background WDM signals.

Two real-time optical transmitters/receivers were prepared in order to generate super-channel signals, for example, 400-Gbit/s-2subcarrier (SC)-DP-16QAM and 200-Gbits/s-2SC-DP-QPSK signals. The real-time optical transmitter/receiver used Nyquist filtering to narrow the optical signal spectrum so that 400-Gbit/s or 200-Gbit/s super-channels with two wavelengths placed close to each other could be built. Node #1 replaced the two wavelengths (λ_{2n-1} and λ_{2n}) of the background WDM signal with two different wavelengths from two real-time DSP-based transmitters. The real-time transmitter/receiver had a function for estimating the OSNR using a pilot

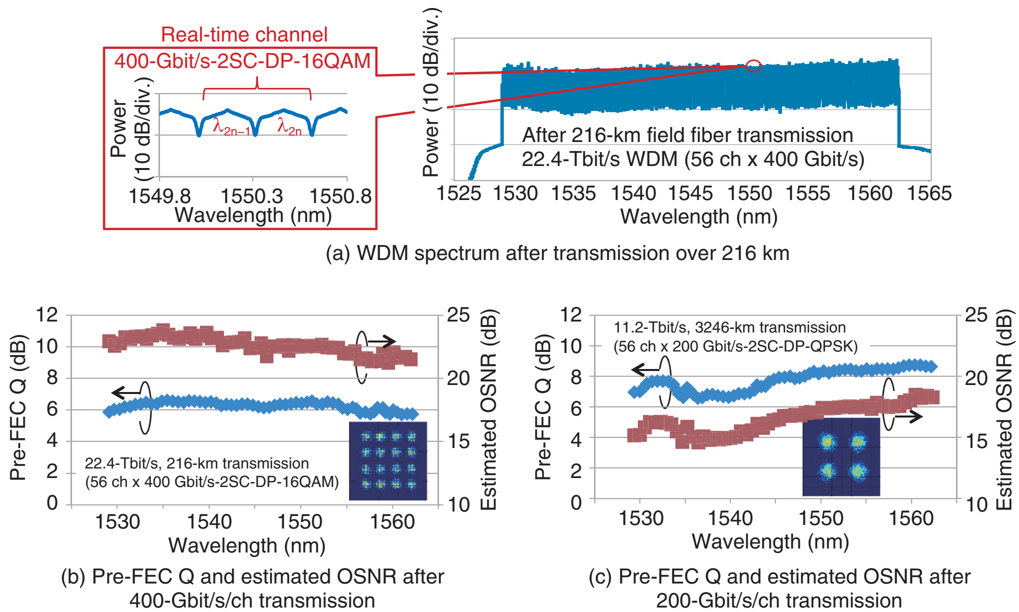

Fig. 5. Results of 400-Gbit/s/ch real-time field trial.

signal [8]. This allowed adaptive modulation/demodulation. Namely, the OSNR of the received optical signal, which varied depending on the transmission distance, was estimated and used to select the appropriate modulation/demodulation scheme. In this experiment, adaptive modulation/demodulation transmission was carried out using an optical switch within Node #2 to change the transmission distance.

Some results of an experiment with a 112-wavelength WDM signal having a total capacity of 22.4 Tbit/s are presented in **Fig. 5**. In this experiment, an OSNR of 20 dB was used as the threshold for determining whether DP-16QAM transmission was possible. After transmission over 216 km, the estimated OSNR was greater than the 20-dB threshold, indicating that DP-16QAM transmission was possible. The measured Q value before error correction of all the channels was about 6 dB, and we confirmed that the signals were free of errors after error correction. After transmission over 3246 km, the estimated OSNR was less than 20 dB. Therefore, DP-QPSK was selected instead. In this case, the Q value before error correction was also greater than 6 dB, and we also confirmed that the signals were error-free after error correction. This experiment verified that adaptive modulation/demodulation using an estimated OSNR is possible.

5. Conclusion

This article has described the latest trend in beyond 100G digital coherent optical transmission technology, which is the critical technology for building a high-capacity optical communication network that will provide a foundation for the coming full-fledged big data society. We will continue our R&D to enhance the performance and expand the application area of this technology.

Acknowledgments

This work is partly supported by the R&D project on “Research and Development of Ultra-high-speed and Low-power-consumption Optical Network Technologies” of the MIC of Japan and the R&D project on “Research and Development of Optical Transparent Transmission Technology (Lambda Reach)” of NICT. We sincerely thank all concerned parties involved in the projects.

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Compact Optical Modulator and Coherent Optical Subassemblies for Beyond 100G Transport Network

Norihide Kashio and Yusuke Nasu

Abstract

This article presents an indium-phosphide-based optical modulator and a silicon-photonics-based coherent optical subassembly. Both devices enable compact and low-power beyond 100G (beyond 100 Gbit/s per wavelength) digital coherent transceivers that are essential for constructing an optical transport network economically.

Keywords: coherent transceiver, InP, silicon photonics

1. Introduction

Steady progress has been made in the last few decades in expanding the transmission capacity of optical transport networks [1]. Recently, digital coherent technology with advanced modulation formats was proposed, which can significantly increase the transmission capacity of optical transport networks by incorporating ultrahigh-speed digital signal processing [2]. A commercial service employing 100-Gbit/s dual-polarization quadrature phase-shift keying (QPSK) systems is already in operation. Transceivers for the digital coherent technology need various components in order to support complicated modulation formats.

However, there is strong demand for small-form factor pluggable digital coherent transceivers in order to expand their application space from long-haul networks to cost-sensitive metro areas and datacenter interconnections. The specifications of digital coherent transceivers such as power consumption and size are standardized at the Optical Internetworking Forum (OIF), where service providers, equipment vendors, and component vendors cooperatively develop implementation agreements (IAs) for optical networking products.

The evolution of digital coherent transceivers, discussed at OIF, is shown in **Fig. 1**. The IA on the first-generation digital coherent transceivers, which were 5 × 7 inches (in) in size, was issued in 2011. Since then, the size and power consumption of these transceivers have been continuously reduced. At the second generation, the size was reduced to 4 × 5 in, and the latest IA at the OIF was for a centum (100) gigabit form-factor pluggable 2 - analogue coherent optics (CFP2-ACO) with a size of 1.6 × 4.2 in. Such compact transceivers facilitate high-density and low-power optical network equipment for metro networks and datacenter interconnects. Another aspect in regard to the evolution of the transceiver is the speed. If the transceiver can support beyond 100 Gbit/s per wavelength (beyond 100G) speed with the same form factor as 100 Gbit/s, the size required for a transmission capacity will be substantially reduced.

In this article, we present an indium-phosphide (InP)-based optical modulator and a silicon (Si)-photonics-based coherent optical subassembly (COSA). We first discuss the InP-based modulator, which was the key component to achieve the current generation CFP2-ACO transceiver. The InP-based modulator can achieve high speed with a compact size, and is promising for future very high-speed transceivers. Then, we discuss the Si-photonics-based COSA. The Si can integrate various kinds of optical devices on a single chip and will help to achieve an extremely compact transceiver.

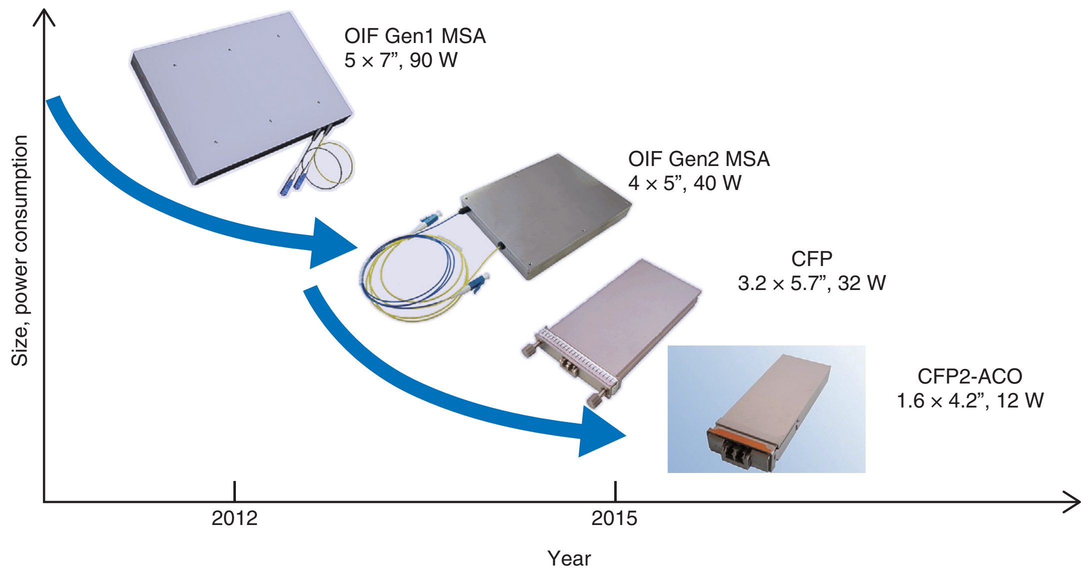


Fig. 1. Evolution of digital coherent transceivers.

Table 1. Features of InP and LN modulators.

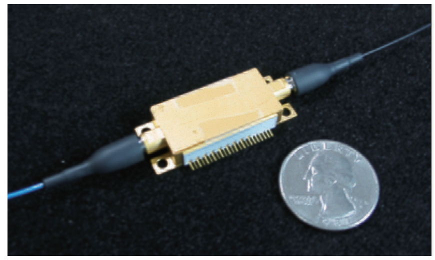
	InP	LN
Modulation length	Small (~3 mm)	Large (~3 cm)
Driving voltage	Small (1.5–2.5 V)	Large (~3 V)
Modulation speed	High speed (> 45 GHz)	High speed (> 35 GHz)
Thermal shift	Large	Very small
Optical loss	Moderate	Low
Stability	High	Low (bias shift)

2. InP-based optical modulator

NTT laboratories have developed a compact and high-speed InP optical modulator by making use of the superior optical properties of InP materials [3]. **Table 1** summarizes the features of an InP and lithium niobate ($LiNbO_3$: LN) modulator. Quantum confined stark effects in an InP-based multiple quantum well structure used in a waveguide core enable a large phase shift per unit length. Thus, the length of the phase modulation for an InP modulator can be reduced to as small as ~3 mm, which is one-tenth that for an LN modulator (~3 cm). In addition, the InP modulator can also provide low driving voltage (1.5–2.5 V). These features are beneficial for low-power operation.

Furthermore, the InP modulator is free in principle from direct current bias fluctuation under operation, which is observed in LN modulators. A photograph and the features of our InP modulator are shown in **Fig. 2**. The modulator provides a driving voltage of less than 2.5 V while significantly reducing the footprint to half that of the LN modulator. The compact and low-power InP modulator technology makes it possible to achieve CFP2-ACO transceivers.

Table 2 compares the size and power consumption of the first- and second-generation optical modulators. A large portion of the power consumption in an



• Differential operation
• Surface mount radio frequency interference
• Driving voltage (Vπ): < 2.5 V @32 Gbaud
• Extinction ratio: > 20 dB
• Size: 34 × 15.6 mm (less than half that of LN modulator)

Fig. 2. Photograph and features of the developed InP modulator.

Table 2. Size and power consumption of LN and InP modulators.

	Generation 1	Generation 2
Material	LN	InP
Size	13.2 × 90.5 × 7 mm	15.6 × 34 × 6.5 mm
Power consumption*	5.2 W	3.5 W

* Total power consumption for modulator and driver integrated circuits (ICs).
Power consumption values for each driver IC were obtained from OIF2013.239.00.

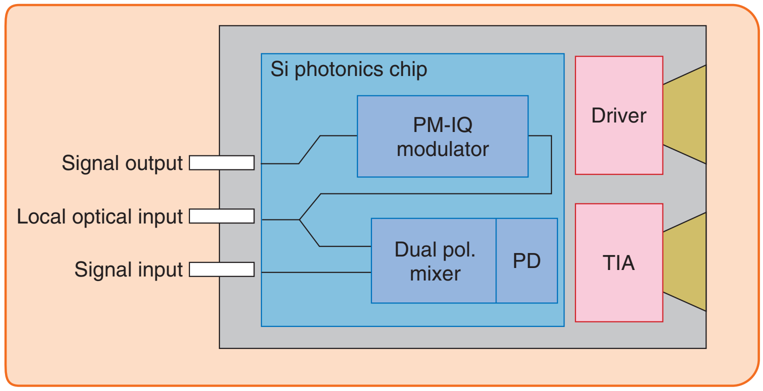
optical modulator is determined by drivers. The power consumption of drivers for the LN and InP modulators is 5.2 W and 2.5 W, respectively. Even when taking into account the power consumption of a thermoelectric cooler (1 W) to maintain the operating temperature of the InP modulator, the total power consumption of the InP modulator (3.5 W) is still 1.7 W lower than that of the LN modulator.

3. Si-photonics-based COSA

NTT laboratories have been developing a COSA based on Si photonics technology in order to further reduce the size of digital coherent transceivers. In digital coherent transport systems, the digital signal processor (DSP) not only demodulates signals but also compensates for signal distortion in the transmission line and analog devices. The powerful ability of DSP has opened up more choices in optical devices for the transceiver, including Si photonics, which uses microfabrication technology for LSIs (large-scale integrated circuits). Si substrates, which are transparent to 1.5-μm-wavelength light, are used as the platforms of photonic integration.

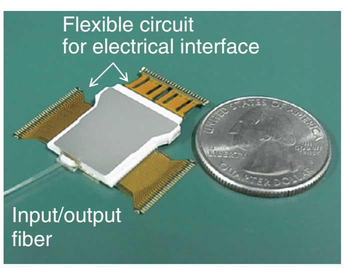
NTT laboratories started research and development on Si photonic devices in 2000, foreseeing the potential of Si photonics [4]. Now, in addition to simple passive devices, high-speed optical modulators and germanium (Ge) photo detectors (PDs) can be integrated in Si substrates.

The digital coherent transceiver has an optical modulator and drivers at the transmitter part and an integrated coherent receiver (ICR) at the receiver part. The ICR consists of 90° optical hybrids, high-speed PD arrays, a dual polarization mixer, and transimpedance amplifiers (TIAs) that convert the output current of PDs into a voltage signal. To date, these optical devices have been fabricated with different materials and connected with optical fibers. A function block for a COSA module is shown in **Fig. 3**. The key optical components are integrated in a single chip (Si photonics chip), and the drivers and TIAs are implemented in a package, as shown in **Fig. 4**. The subassembly eliminates the optical fibers and lenses that are conventionally used for connection between optical devices, resulting in an extremely small digital coherent transceiver.



IQ: in-phase and quadrature
PM: polarization multiplexed

Fig. 3. Function block of COSA module.



(Size: 19 × 17 × 2.1 mm)

Fig. 4. Photograph of COSA module.

4. Conclusion

An InP-based optical modulator and Si-photonics-based COSA are promising enablers for the future generation of digital coherent transceivers. The InP modulator is essential for future high-speed and long-distance transmission systems, and the COSA is essential for metro and datacenter interconnections. Both devices are key components for constructing cost-effective beyond 100G transport networks. NTT laboratories will continue to develop the key devices that contribute to the evolution of optical transmission networks.

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High-sensitivity 4-channel Receiver Module with Avalanche Photodiode for 400-Gbit/s Ethernet

Yasuhiko Nakanishi, Tetsuichiro Ohno, Toshihide Yoshimatsu, and Hiroaki Sanjoh

Abstract

We developed an integrated 4-channel receiver optical subassembly (ROSA) with high-sensitivity avalanche photodiode (APD) for 400-Gbit/s Ethernet. A minimum receiver sensitivity of –21.2 dBm with a 4-channel × 28-Gbaud PAM-4 (four-level pulse amplitude modulation) APD-ROSA was achieved, enabling us to achieve 30-km transmission.

Keywords: avalanche photodiode (APD), 400-Gbit/s Ethernet, receiver optical subassembly (ROSA)

1. Introduction

Data traffic both within and between datacenters is rapidly increasing as the demand for cloud computing, video streaming, and mobile services grows. To cope with this demand, the Institute of Electrical and Electronics Engineers (IEEE) is currently discussing the standardization of 400-Gbit/s Ethernet [1] as the next-generation standard following 100-Gbit/s Ethernet. The bit rate/lane and modulation format of each operating distance in 400-Gbit/s Ethernet using an optical fiber are listed in **Table 1**. The 400-Gbit/s Ethernet is the first to employ a higher-order modulation (HOM) format for the Ethernet optical data transmission. The optical modulation format currently employed is non return to zero (NRZ); however, 400-Gbit/s Ethernet employs a four-level pulse amplitude modulation (PAM-4) as a kind of HOM format. While an NRZ signal consists of two levels (0 and 1), PAM-4 consists of four levels (0, 1, 2, and 3), as shown in **Fig. 1**. Therefore, the transmission of a PAM-4 signal can achieve twice the bit rate of the NRZ signal under the same baud rate.

The standardization of 400-Gbit/s Ethernet is based on operating distances up to 10 km. However, the possibility of extending the operating distance has been discussed to cope with the increasing capacity of inter-building links and mobile backhaul [2]. Extending the operating distance will require enlarging the power budget from transmitter to receiver. One promising method to do this is to improve sensitivity using an avalanche photodiode (APD). Applying an APD to a receiver not only achieves a high-sensitivity receiver thanks to inner gain, but also a compact receiver thanks to its low power consumption [3].

2. Linearity of APD receiver optical subassembly (APD-ROSA)

In systems with the PAM-4 signal, photodiodes are required to achieve high linearity of an output photocurrent against the optical input power. While APDs can deliver high performance in terms of responsivity, they exhibit higher nonlinearity than p-i-n photodiodes (pin-PDs) in direct current (DC) input and output characteristics due to both the thermal effect and the space charge effect [4]. Consequently, in order to employ APDs in the PAM-4 system, it is necessary to measure the linearity of an APD receiver using a linear-type transimpedance amplifier (TIA) and confirm the degree of nonlinearity.

Table 1. Bit rate/lane and modulation format in 400-Gbit/s Ethernet using optical fiber.

	400GBASE-SR16	400GBASE-DR4	400GBASE-FR8	400GBASE-LR8
Operating distance	100 m	500 m	2 km	10 km
Bit rate/ lane	26.5625 Gbit/s	106.25 Gbit/s	53.125 Gbit/s	53.125 Gbit/s
Modulation format	NRZ	PAM-4	PAM-4	PAM-4
Media	Multi-mode fiber	Single-mode fiber	Single-mode fiber	Single-mode fiber
Number of lanes and multiplexing	16 lanes Parallel fibers	4 lanes Parallel fibers	8 lanes WDM	8 lanes WDM

WDM: wavelength division multiplexing

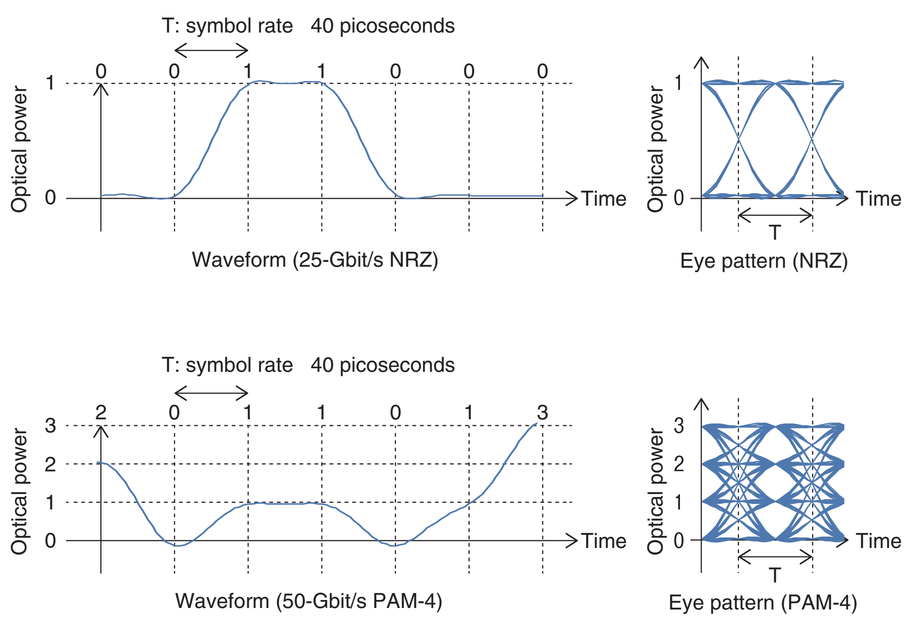

Fig. 1. Comparison of optical modulation formats.

The measured output photocurrents in a pin-PD and our APD and the calculated output photocurrent when the APD operates with the ideal linearity are plotted in **Fig. 2**. As indicated by the solid red curve and the dashed red line, the gap between the red curve and the line increases as the input optical power is increased. These results show that our APD has nonlinearity in DC input and output characteristics. If the waveform of the optical PAM-4 input is converted to an electrical signal in accordance with DC input and output characteristics of the APD, one concern is that the amplitude of the upper inner-eye would become smaller than that of the middle and lower inner-eyes, resulting in bit error rate (BER) degradation.

To evaluate the effect of DC nonlinearity on the optical-to-electrical (O/E) conversion of PAM-4 signals, we measured the ratio of each inner-eye amplitude to the outer-eye amplitude, as shown in **Fig. 3(a)**. To simplify the measurements, we used an experimental baud rate of 10 Gbaud and a PAM-4 modulation format. The measurement results are shown in **Fig. 3(b)**. The solid curves are the ratios calculated from the DC input and output characteristics of the APD. In the calculation, the extinction ratio (ER) of the outer-eye is assumed to be 4.8 dB. The calculated values deviate by 9% from 33% for the average

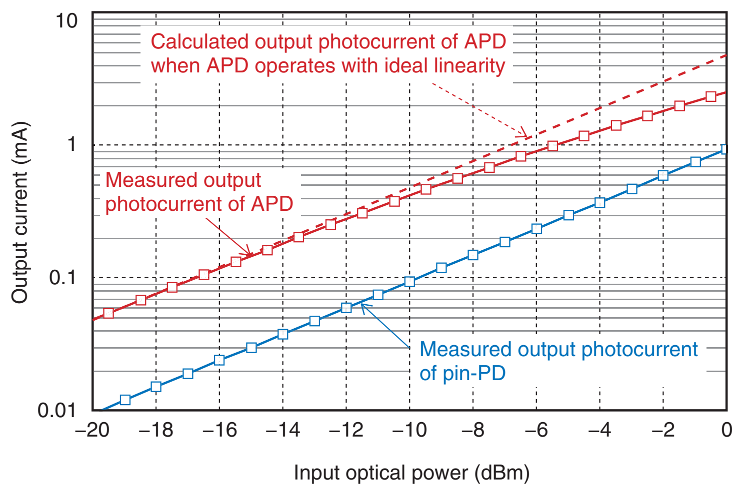

Fig. 2. DC input and output characteristics of pin-PD and APD.

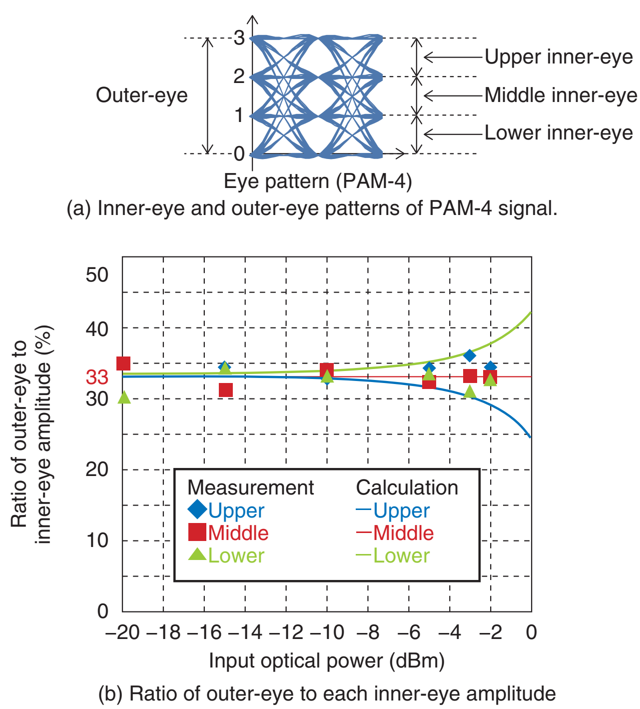

Fig. 3. Linearity of APD-ROSA.

received power of 0 dBm due to the DC nonlinearity. In contrast, the measured ratios stay at 33%, which is within the range of measurement error, regardless of the received optical power. These results indicate that the O/E conversion of PAM-4 signals does not seem to be affected by DC nonlinearity for average received powers up to –2 dBm.

3. APD-ROSA for 400-Gbit/s Ethernet systems

A photograph and schematic view of a 4-channel APD-ROSA, which can receive 200-Gbit/s (4-channel × 28 Gbaud × PAM-4) signals are shown in **Fig. 4**. The APD-ROSA consists of a planar lightwave circuit demultiplexer (PLC-demux), a quad-channel

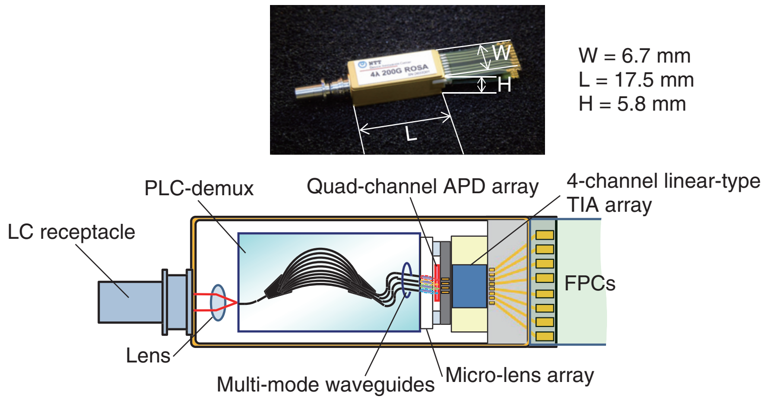

Fig. 4. Photograph and schematic view of 4-channel APD-ROSA.

APD array, and a linear-type TIA array. An LC receptacle and flexible printed circuits (FPCs) are respectively attached to the optical wavelength-division multiplexing (WDM) input and electronical output. The optical coupling between the PLC-demux and APD array employs a low-loss technique using both the multi-mode waveguide and micro-lens array developed for a 100-Gbit/s Ethernet ROSA [5]. The input 4-wavelength × 28-Gbaud PAM-4 optical signal is demultiplexed into four wavelengths in the PLC-demux. In the quad-channel APD array, the optical signals are converted to electrical signals and fed into the linear-type TIA array. Then, amplified 4 × 28-Gbaud PAM-4 signals are output from the linear-type TIA array. The package size is as small as 17.5 × 6.7 × 5.8 mm in order to install two modules in a CFP8 (centum (100) gigabit form-factor pluggable 8) [6] transceiver (107.5 × 40 × 9.5 mm) for 400-Gbit/s operation. The total power consumption of the APD-ROSA is as low as 860 mW at room temperature.

The performance of the 4-channel APD-ROSA in receiving PAM-4 signals was investigated in a back-to-back configuration. The experimental setup is shown in **Fig. 5**. The input optical signal from a tunable laser source was modulated using a lithium niobate Mach-Zehnder modulator with a 28-Gbaud PAM-4 signal of a 2^{15}-1 pseudo random bit sequence (PRBS). The wavelengths for lanes 0, 1, 2, and 3 were respectively set at 1295.56, 1300.05, 1304.58, and 1309.14 nm. The ER of the outer-eye for lanes 0, 1, 2, and 3 was 5.6, 6.4, 6.0, and 6.8 dB, respectively. The PAM-4 signal was received and converted to the electrical signal by the APD-ROSA and then input into a digital storage oscilloscope with 33-GHz analog bandwidth and a sample rate of 80 GSample/sec. We demodulated the stored signal by offline digital signal processing, in which we used a half-symbol-spaced adaptive equalizer with 17 taps. A variable optical attenuator was inserted before the APD-ROSA to change the input power.

The BER measurement results for single-channel operation of each lane are shown in **Fig. 6**. We observed a minimum receiver sensitivity better than –21.2 dBm in optical modulation amplitude (OMA) of the inner-eye for all channels at a BER of 2e-4, assuming the Reed-Solomon forward error correction (544, 514) defined in 100GBASE-KP4 (IEEE 802.3bj) [7]. The symbols plotted on 1e-6 show that no bit error is observed within the stored data length. This minimum receiver sensitivity has a margin of 9.3 dB for the sensitivity (–11.9 dBm) required in 400GBASE-LR8. This margin would enable 400-Gbit/s transmission with an extended operating distance up to 30 km, assuming a 0.4-dB/km loss of single-mode fiber.

4. Conclusion

We developed a 4-channel APD-ROSA as a key component to achieve 400-Gbit/s Ethernet. The APD-ROSA is integrated using a quad-channel APD array, PLC-demux, and linear-type TIA. We investigated the linearity of the APD-ROSA for PAM-4 signals and confirmed that three inner-eye amplitudes of the output waveform were kept equal up to –2 dBm. We also successfully demonstrated 28-Gbaud operation with a minimum receiver sensitivity of –21.2 dBm or below for PAM-4 signals. This result indicates that with an assumed 0.4-dB/km loss of a single-mode

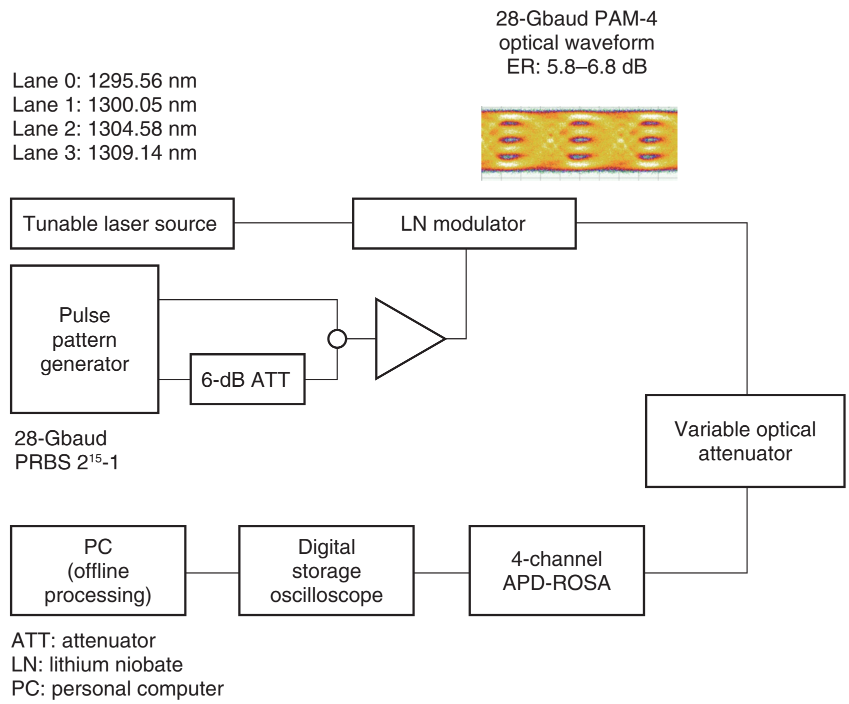

Fig. 5. Experimental setup.

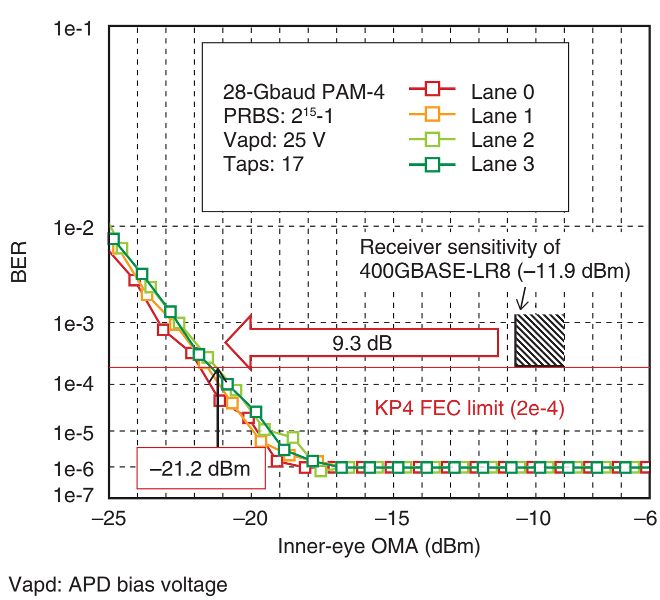

Fig. 6. BER of 4-channel APD-ROSA.

fiber, the APD-ROSA is a promising device to achieve 400-Gbit/s data transmission up to 30 km or longer.

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High Frequency Optical Module Assembly Technique Enabling High Modulation Speed over 100 Gbit/s/λ

Satoshi Tsunashima, Shigeru Kanazawa, and Hiromasa Tanobe

Abstract

A novel optical module assembly technique enabling high modulation bandwidth is described. This optical module features not only high modulation bandwidth but also a small footprint and low-power dissipation. These features help accelerate optical module development for 400-Gigabit Ethernet applications.

Keywords: 100 Gbit/s/λ, high modulation bandwidth, flip-chip interconnection

1. Introduction

In response to the urgent demand for expanded network bandwidth for mobile and cloud computing networks, the standardization of high transmission bandwidth is being actively discussed. In Ethernet standardization, the Institute of Electrical and Electronic Engineers (IEEE) standard 802.3ba [1] was adopted as the standard for 100-Gigabit Ethernet (100GbE) in 2010 (**Fig. 1**). The IEEE 802.3ba standards define that wavelength-division multiplexing (WDM) transmission technology be utilized to establish 100GbE optical links for 10-km and 40-km single-mode fiber (SMF) transmission. In WDM transmission, four 25-Gbit/s optical data signals with different wavelengths are launched on SMFs and travel along the SMFs. This transmission scheme is called multi-lane transmission.

In 2013, the IEEE 802.3bs [2] task force started discussions on 400-Gigabit Ethernet (400GbE) standards to cover the emerging shortage of bandwidth capacity in 100GbE based networks. The 400GbE transmission uses a multi-lane transmission scheme with a newly introduced signal modulation technology called four-level pulse amplitude modulation (PAM-4)*1. Eight 50-Gbit/s PAM-4 optical signals with different wavelengths establish a 400GbE fiber optic link with the multi-lane scheme.

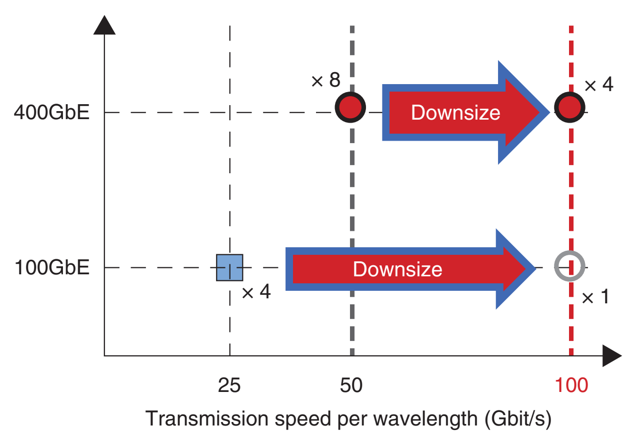

Fig. 1. Ethernet standardization trends.

In the optical transceiver marketplace, some manufacturers launched their 400GbE transceiver products,

*1 PAM: A form of pulse modulation. By making the amplitude direction multilevel, we can increase the amount of information per modulation. At level four modulation, it is PAM-4: $\log_2 4 = 2$bit.

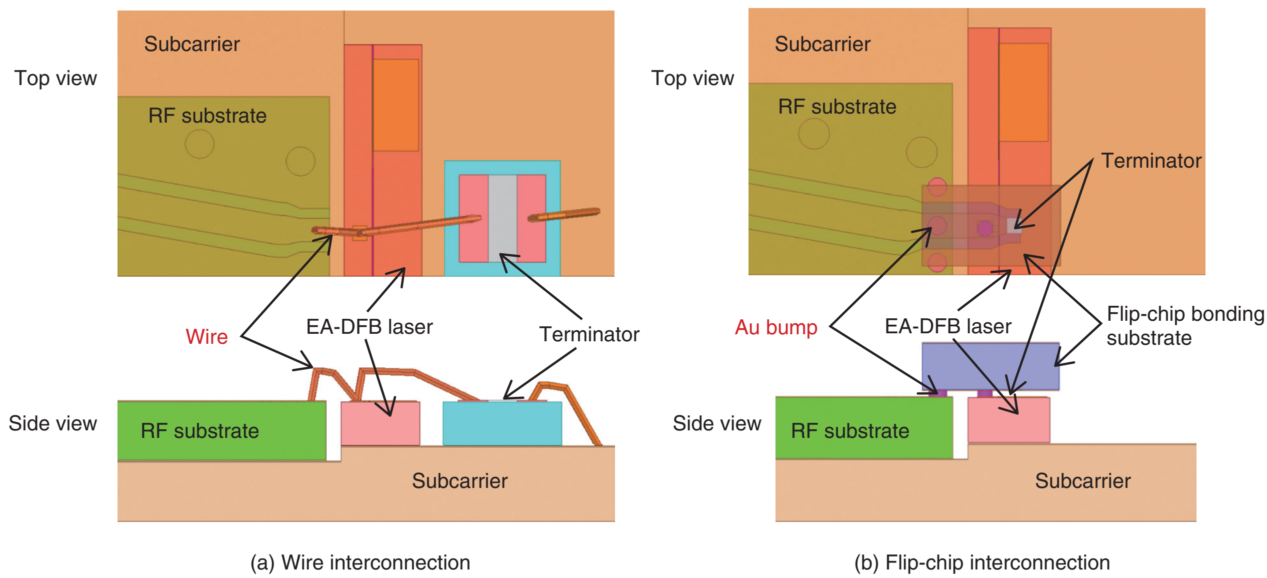

Fig. 2. Schematic structure of wire and flip-chip interconnections.

known as CFP8 (centum (100) gigabit form-factor pluggable 8) [3], before the IEEE 802.3bs task force had finalized the 400GbE standards. This CFP8 transceiver typically has four optical assemblies consisting of two transmitter optical subassemblies (TOSA) and two receiver optical subassemblies (ROSA). Each assembly of TOSA and ROSA runs at 200 Gbit/s with four wavelengths and transmits and receives 50-Gbit/s optical signals per wavelength. There are various requirements for cost reduction and downsizing of the CFP8 400GbE optical transceivers arising from an issue involving the use of four optical assemblies. This has made establishing optical assemblies based on serial 100-Gbit/s with one lambda (λ: wavelength) transmission an urgent priority for future 400GbE fiber optic networks.

A new assembly technique developed by the NTT Device Innovation Center can establish a high modulation bandwidth in each wavelength by improving the high-speed electromagnetic characteristics in an optical module with a novel flip-chip interconnection[*2] technique. With this new technique, each wavelength transmits an optical signal at 100 Gbit/s (100 Gbit/s/λ), thus enabling 400GbE to be attained. This new assembly technique is explained in detail in the following sections.

2. 100 Gbit/s/λ-high frequency assembly technique

The serial 100 Gbit/s optical signal transmission is a key technology for future Ethernet networks. By using four wavelengths at 100 Gbit/s, the 400GbE transmission can be established. A flat and wideband frequency response for the serial 100-Gbit/s optical module is essential in order to obtain multi-level modulation (PAM-4) and a high-speed symbol rate (50 Gbaud) in the serial 100-Gbit/s optical signal transmission. However, conventional optical transmitter modules cannot extend the modulation bandwidth beyond 50 Gbit/s at high-speed transmission such as 50-Gbit/s operation. The schematic structure of a wire interconnection in the conventional optical transmitter module is shown in **Fig. 2(a)**. The radio frequency (RF) signal is transmitted from an RF substrate through a wire to an electroabsorption modulator (EAM) integrated with a distributed feedback laser (EAM-DFB laser, or EA-DFB laser). Due to the nature of the characteristics in wire inductance, the modulation bandwidth degrades rapidly with a longer wire.

*2 Flip-chip interconnection: A chip interconnection technique. Generally, by forming small protruding metallic terminals as electrodes of chips, the chips can be placed and connected on to the face of the substrates. This helps to reduce the assembly footprint compared to conventional metal wire interconnection techniques.

To resolve this issue, we propose using a flip-chip interconnection technique as a wire-free interconnection. The schematic structure of the flip-chip interconnection is shown in **Fig. 2(b)**. A flip-chip bonding substrate is connected to an RF substrate and an EAM with gold (Au) bumps. The height of the Au bumps is as small as just a few micrometers (~10 μm). To eliminate wire connections between the EAM and a terminator, a terminator resistance thin film is integrated on the flip-chip bonding substrate. The flip-chip interconnection reduces the parasitic inductance since the wire is no longer necessary. Therefore, the flip-chip interconnection improves the frequency response of the module, as shown in **Fig. 3**.

Eye diagrams of 56-Gbaud PAM-4 (112 Gbit/s) signals obtained under the configuration of a back-to-back transmission and after 10-km SMF transmission using the flip-chip interconnection EA-DFB laser module are shown in **Fig. 4**. Clear eye opening characteristics with four levels (0, 1, 2, 3) are observed even after 10-km SMF transmission thanks to the high modulation bandwidth and the flat frequency response of the module.

Generally, the digital signal processing circuits are introduced to high-speed optical communication systems using a multi-level modulation format in order to compensate for the bandwidth degradation occurring in the optical modules. However, those digital signal processing circuits use a lot of electric power, which creates additional latency on the transmission link, so it is desirable to reduce the number of digital signal processing circuits for future Ethernet networks.

The bit error rate (BER) characteristics are shown in **Fig. 5** for back-to-back configuration and 10-km SMF transmission without any digital signal processing such as BCH (Bose-Chaudhuri-Hocquenghem) forward error correction (FEC). The BER of less than 1×10^{-3}, which is the error-free condition for the BCH FEC, was obtained even after 10-km SMF transmission. Our optical module has a sufficiently high modulation bandwidth and flat frequency response to make the digital signal processing unnecessary [4]. The module enables us to construct low-power consumption and low-latency networks thanks to the elimination of the digital signal processing circuits. Moreover, this optical module helps reduce the number of wavelengths from eight to four so that we can establish 400GbE transmission.

Moreover, if digital signal processing is utilized to compensate for the bandwidth degradation in an optical transmission link while using our optical module, dramatic improvements in transmission bandwidth can be expected. In our experimental work, we demonstrated 200-Gbit/s per wavelength operation [5]. By applying this technique in 100-Gbit/s per wavelength operation, the digital signal processing as a bandwidth degradation compensator becomes unnecessary, which thus reduces power consumption.

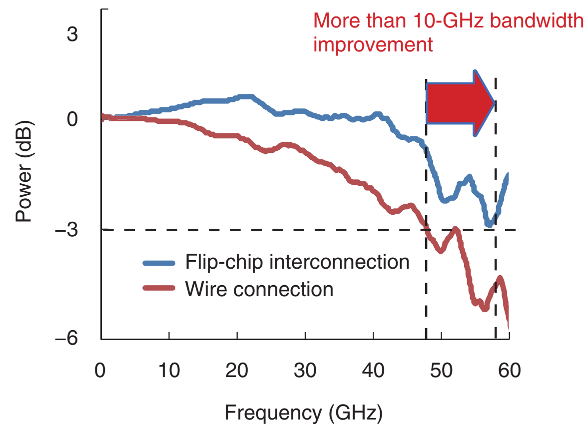

Fig. 3. Frequency response of wire and flip-chip interconnections.

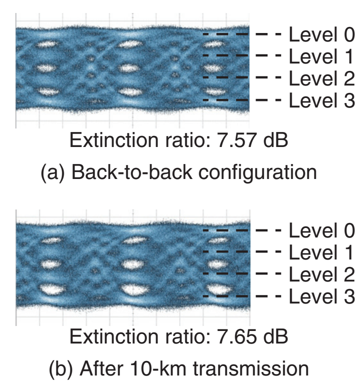

Fig. 4. Eye diagrams under 56-Gbaud PAM-4 operation.

3. Future plans

The proposed assembly technique makes it possible to achieve a smaller optical module with lower-power consumption. We plan to create a flip-chip interconnection 4ch optical transmitter module integrated with an optical multiplexer for 400GbE transmission.

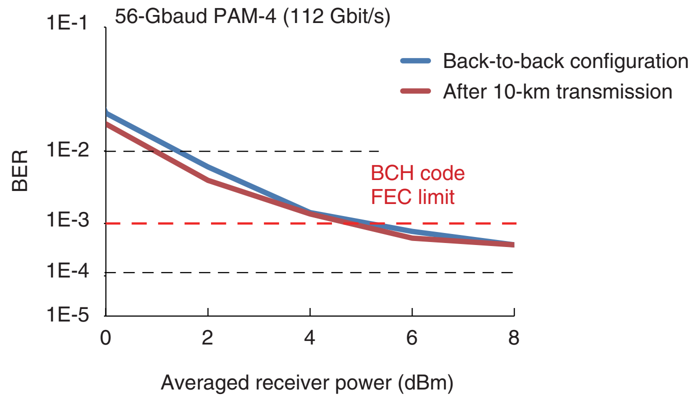

Fig. 5. BER characteristics under 56-Gbaud PAM-4 operation.

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Promotion of Environmental Management According to ITU-T L.1410 in NTT Group

Minako Hara and Xiaoxi Zhang

Abstract

The NTT Group is moving forward with environmental management practices conforming to ITU-T (International Telecommunication Union - Telecommunication Standardization Sector) Recommendation L.1410. Here, we describe the promotion of energy-saving technology for datacenters, the evaluation of environmental contributions of products and services developed by NTT laboratories, and the environmental solution label.

Keywords: environmental management, ICT, ITU-T L.1410

1. Introduction

THE GREEN VISION 2020 formulated by the NTT Group in November 2010 promoted three approaches for activities related to three environmental management themes (**Fig. 1**). The three themes focus on creating a low carbon society, implementing closed-loop recycling, and conserving biodiversity. The three action approaches are efforts to reduce the environmental impact of our own business activities (Green of ICT), the use of information and communication technology (ICT) services to contribute to reducing the environmental impact by society as a whole (Green by ICT), and contributions to various environmental protection activities together with Group employees, their families, and local communities (Green with Team NTT) [1].

More specifically, *Green of ICT* refers to the efforts by the NTT Group to reduce its own environmental impact by lowering CO_2 emissions through increased energy efficiency of ICT equipment and ICT facilities such as networks and datacenters. *Green by ICT* refers to efforts that contribute to reducing the environmental impact of society as a whole from a broad perspective that encompasses all fields. Those efforts include using ICT to reduce consumption and the need to transport people and goods, increase the efficiency of energy use in the supply chain, and increase the visible impact of ICT use on the environment. *Green with Team NTT* refers to participation in various activities aimed at protecting the environment by Team NTT, a group whose members support the corporate social responsibility of the NTT Group and employees of the NTT Group in general, together with local communities.

Worldwide attention is being placed on the use of ICT to increase energy efficiency and efficiency in the production and consumption of goods as well as the use of ICT to reduce the transportation of people and products. To promote the introduction of ICT, we need ways to quantitatively evaluate the effectiveness of its positive environmental contributions. NTT laboratories are developing methods for calculating the environmental impact of the Green of ICT and Green by ICT approaches.

One result of that research is the development of a method for calculating the amount of CO_2 emissions over the entire lifecycle of products, networks, and services, which has been adopted as Recommendation L.1410, "Methodology for Environmental Life Cycle Assessments of Information and Communication Technology Goods, Networks and Services" by the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T).

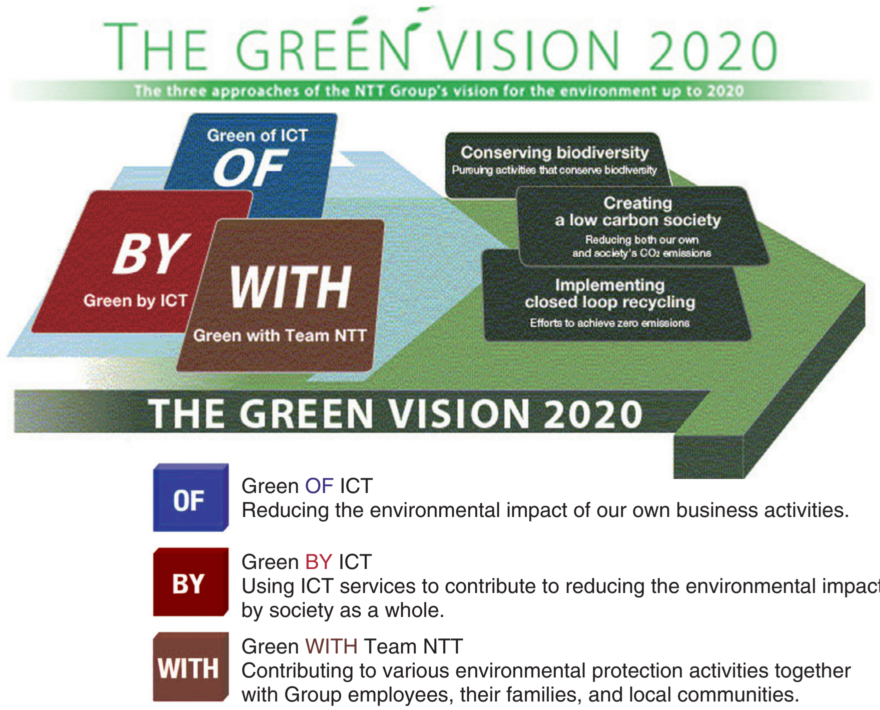


Fig. 1. THE GREEN VISION 2020.

Here, we describe efforts within the NTT Group to promote effective environmental management based on that Recommendation.

2. Case study of environmental assessment on energy-efficient technology for datacenters based on ITU-T L.1410

Datacenters generally consume about ten times as much power per unit floor area as offices, so a quantitative evaluation of the effect of introducing energy-saving technology can be expected to contribute to a reduction of CO_2 emissions as such technology is adopted. NTT laboratories have performed a lifecycle environmental impact assessment based on ITU-T L.1410 with the objective of evaluating the effect of energy-efficient datacenters on the environment. The subject of the study was a datacenter implementing a combination of NTT FACILITIES technology, including a highly efficient air-conditioning system, a high-voltage direct current (HVDC) power supply system, and technology for reusing the heat generated by equipment (**Table 1**) [2]. The results of the annual operation of servers, air conditioning, and the power supply for a datacenter with a total annual ICT equipment power consumption of 183,585 kWh revealed there was an annual reduction in CO_2 emissions of about 40%. This case study was published as a supplement to ITU-T L.1410 [3].

3. Assessment of the environmental contribution of research and development (R&D) products

The NTT Service Innovation Laboratory Group, NTT Information Network Laboratory Group, and NTT Science and Core Technology Laboratory Group have been engaged in various research projects related to ICT and are striving to reduce the environmental impact of ICT while contributing to ICT development on the basis of THE GREEN VISION 2020 [3]. Since the 2014 fiscal year, the three laboratory groups have been efficiently and effectively operating an integrated environmental management system designed to reduce the environmental impact of ICT use. The laboratory groups have moved forward with creating and providing R&D results that make positive contributions to the environment. The R&D results provided to NTT operating companies make large indirect contributions via customers and society as a whole to reducing the environmental

Table 1. Technology used in energy-efficient datacenter.

Type	Energy-saving technology	Description
Air conditioning	Highly efficient package air conditioners for datacenters	Designed to match the characteristics of datacenters, these air conditioners feature highly efficient operation using the latest fans and compressors.
	Package air conditioners featuring indirect outdoor air cooling	These air conditioners reduce power consumption by using outdoor air for cooling; the compressor is stopped in seasons when the outdoor air temperature is low.
	Rack-mounted air conditioners for local cooling	These air conditioners are mounted on racks near high-temperature servers to efficiently treat hot air from the servers and reduce the power needed by fans for air circulation.
	Use of ground heat	This technology provides cooling in the summer and other seasons by circulating water through pipes buried underground.
	Airflow control	This technology raises the operating efficiency of air conditioners by preventing the mixing of hot exhaust air from servers with the cool air supplied from the front of servers.
Power supply	High-voltage direct current (HVDC) power supply system	This technology decreases the number of power conversion steps to reduce power loss by supplying power to servers and other equipment with direct current at about 380 V instead of the conventional 100/200 V alternating current.
Heat reuse	Use of heat generated by servers	This technology reduces air-conditioning power consumption for both the datacenter and offices by using the hot air produced by the servers for office heating.

impact of ICT use, thus helping to prevent global warming. In partial accordance with the concept of ITU-T L.1410, we are making progress in clarifying NTT's contribution to the alleviation of global warming by evaluating the contribution of R&D results, publishing environmental reports, and providing feedback to the R&D process.

In the 2014 fiscal year, the results of ten research projects were evaluated, and two that were found to have made large contributions, "edge router systems for next-generation networks—high-capacity routing node for next-generation network transport systems" and "voice mining platform," were described in Environmental Report 2015 [4]. Here, we describe those results together with their contributions to the environment.

3.1 Edge router systems for next-generation networks

The high-capacity routing node is the core router of the transport system for the next-generation network and will be used in a redundant three-level star configuration. The area edge routers installed in edge node buildings have a higher accommodation ratio for subscriber service edges (SSEs)[*1] than previous routers, and the evaluation was performed for the case in which the core routers were equipped with newly developed interface modules. The conventional edge routers and the developed edge routers were compared for the same amount of information processing, and the increase in the SSE accommodation ratio was taken as a quantitative measure of the environmental contribution.

In the evaluation, there were 154 SSEs per conventional edge router and 240 SSEs for one developed edge router[*2]. The systems were set up for redundancy with active equipment (system 0) and backup equipment (system 1) as shown in **Fig. 2**.

The results show that the developed system accommodating 240 units contributed to a 37% decrease in annual CO_2 emissions (195 t CO_2/year) relative to the conventional case. The main factor in the decrease is that the increase in the number of SSEs accommodated per edge router reduces the number of required edge routers to one (or two, considering both the active and backup systems).

3.2 Voice mining platform

Problems encountered in conventional analysis of calls in call centers include the fact that only a small volume of calls can be analyzed because the calls must be transcribed manually and also that the analysis is subjective and time-consuming. Voice mining technology makes it possible to quickly and flexibly analyze a large volume of calls objectively and quantitatively, which has previously been difficult to

*1 SSEs: Routers that accommodate access lines on the lowest level.
*2 The maximum SSE accommodation for the developed interface module.

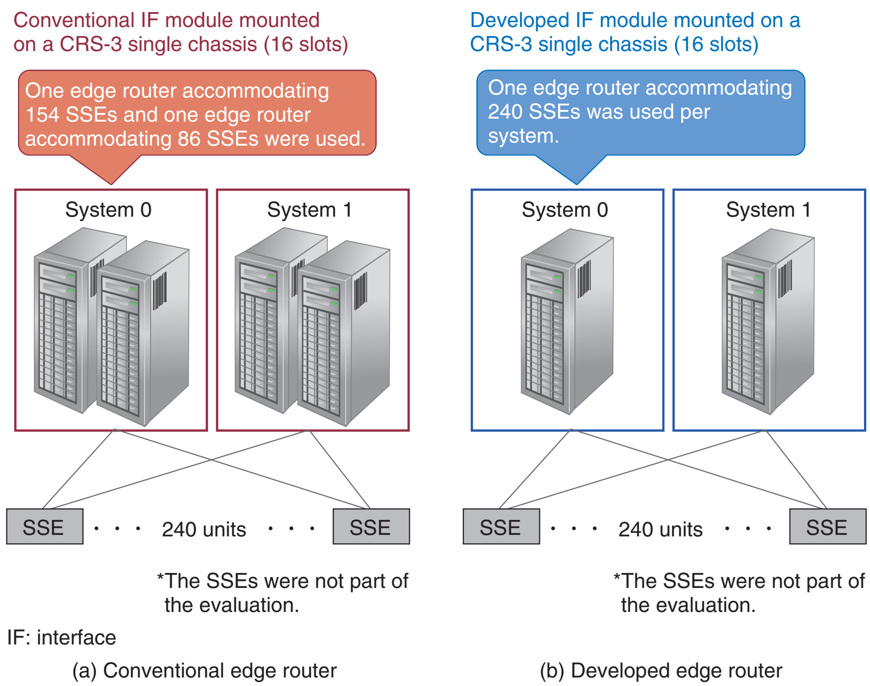


Fig. 2. Evaluation model for edge router systems for next-generation networks.

achieve. NTT's voice mining platform records the calls between operators and customers in call centers and uses speech recognition technology to convert the calls to text. Various call analysis techniques that use spoken language processing technology are then performed. This platform can be used to increase efficiency in the process of discovering problems in call center operations and in the products and services offered so that improvement policies can be set [5].

We evaluated the application of this platform in a call center. To quantify the environmental effect, we compared two cases for analysis (**Fig. 3**). In the first case, the analysis was performed manually after all calls had been obtained. In the second case, the analysis work was partially automated by using the voice mining platform. The call center used for this evaluation had 50 operators, and the analysis was done monthly on all calls, for a total of 12 times in one year. The evaluation conditions were manual transcription of recorded call speech for the conventional case and automatic conversion of the recorded call speech to text followed by partial automation of the analysis task for the case in which the voice mining platform was used.

The evaluation results show that using the voice mining platform for call analysis contributed to reducing CO_2 emissions by 98% (257 t CO_2/year) compared to the conventional process of analysis. The main factor in the emission reduction is the substantial decrease in manual work achieved through automation of call analysis.

4. NTT Group environmental solution label

The NTT Group environmental solution labeling system certifies ICT solutions provided by the NTT Group that exceed a specified criterion for reducing the environmental impact (reduction of CO_2 emissions) of ICT as environment-friendly solutions [6]. The use of some ICT services contributes to reducing the environmental impact of our society as a whole [7]. In the NTT Group, services that reduce CO_2 emissions by 15% or more are certified as environment-friendly solutions and are marked with a label in the service catalog and other places (**Fig. 4**). Our objective in providing such services is to reduce the environmental impact of the NTT Group, our customers, and society as a whole. We have been evaluating the effect of ICT services on reducing CO_2 emissions according to the Environmental Efficiency Assessment Guidelines for ICT Services issued by the Japan Forum on Environmental Efficiency (currently merged with the Life Cycle Assessment Society of Japan) [8]. The article "Assessment of ICT Effects in

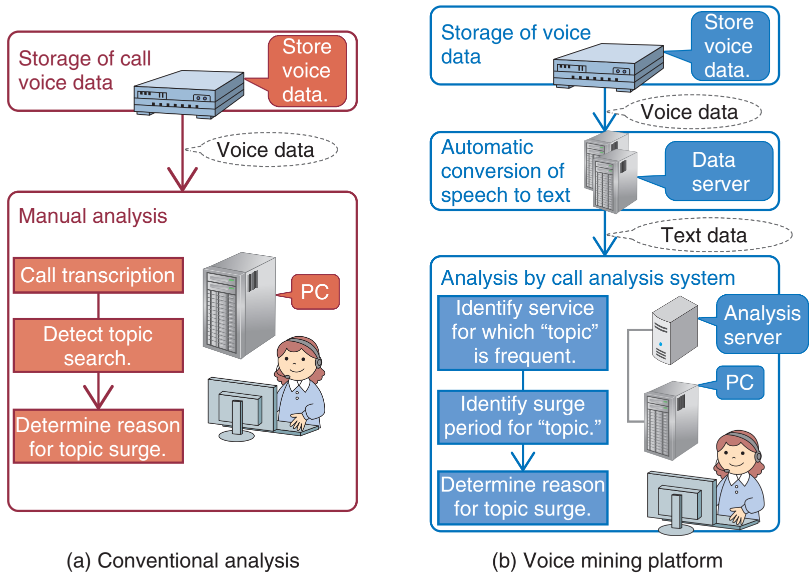


Fig. 3. Evaluation model for voice mining platform.

Fig. 4. NTT Group environmental solution label.

the Reduction of Environmental Impact,” which is based on those guidelines, appeared in the “Study Group on ICT Policy Concerning Global Warming” report issued by the Ministry of Internal Affairs and Communications of Japan in April 2008. The approach of the assessment methods described in the article were incorporated in ITU-T L.1410.

Here, we present and explain the assessment results for three solutions that are likely to have relatively high environmental impact reduction effects from among the solutions that were certified in 2015 and 2016.

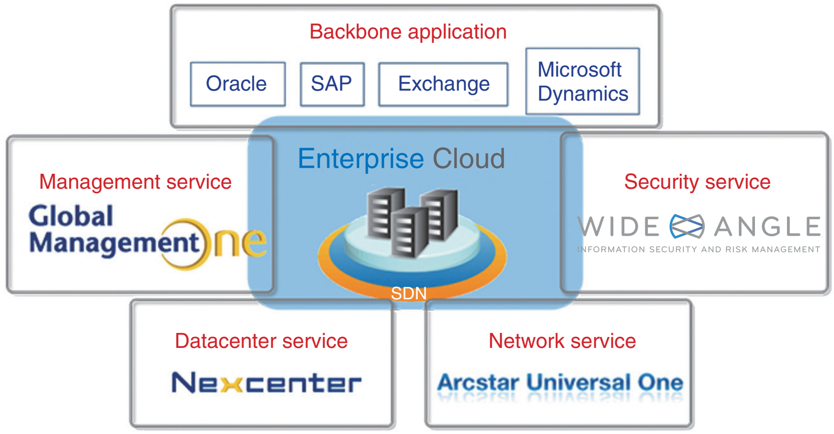
4.1 Enterprise Cloud from NTT Communications

Enterprise Cloud is a global cloud service that takes advantage of NTT Group’s strong technical capabilities and abundant expertise concerning networks, datacenters, applications, and security as a telecom carrier (**Fig. 5**). Enterprise Cloud makes it possible to reduce CO_2 emissions by providing for virtualization of servers and storage. The assessment conditions involved an enterprise with four offices and 300 employees that operates and manages ICT storage facilities with a capacity of 6900 GB over a period of one year. The assessment revealed that use of the system reduced CO_2 emissions by 74% relative to a conventional system.

4.2 TopicRoom from NTT Software

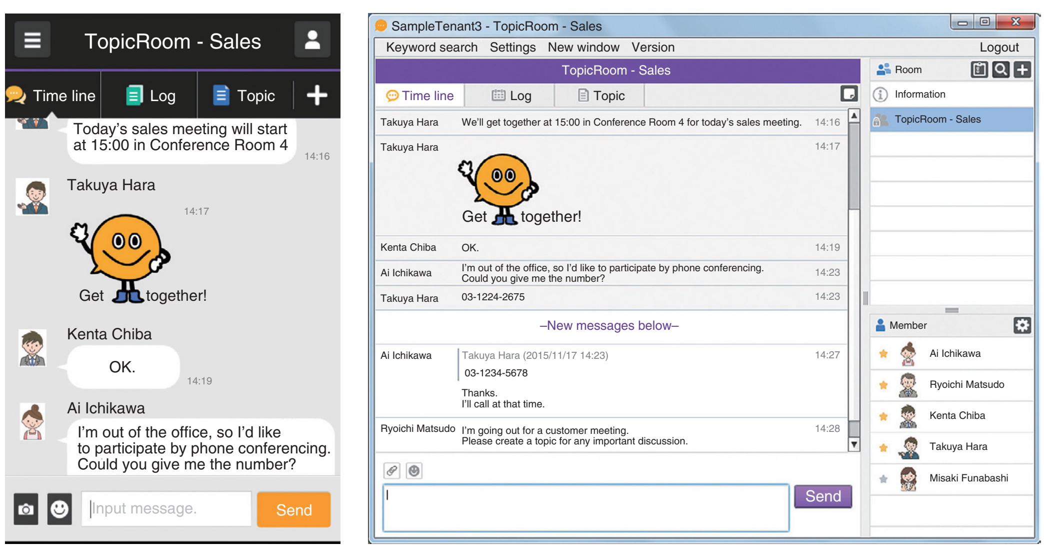
TopicRoom is a chat tool for fast, secure, and simple sharing of business information. It can be used on desktop computers, tablet devices, and smartphones, so work efficiency can be increased by sending a message on an issue to be discussed to TopicRoom from any device so that the issue can be resolved quickly (**Fig. 6**) [9]. Use of TopicRoom can be expected to reduce the time and movement of people to attend meetings as well as the use of paper.

Under the assessment conditions of 48 meetings involving a total of five people from five offices (Shinagawa, Ogikubo, Yokohama, Nagoya, and Osaka) over a period of one year, the use of TopicRoom reduced CO_2 emissions by 78% relative to the conventional process (where employees traveled to attend meetings).



SDN: software-defined network
*Oracle is a registered trademark of Oracle Corporation and/or its affiliates.
SAP is a registered trademark of SAP AG in Germany and in several other countries all over the world.
Microsoft Dynamics is a registered trademark of Microsoft Corporation in the United States and/or other countries.

Fig. 5. Overview of Enterprise Cloud.



(a) Android/iOS (b) Windows/Mac

Fig. 6. Images of TopicRoom discussion threads.

4.3 BizInspect® from NTT DATA Shikoku

BizInspect® is a solution in which a tablet device is used to check inspection items, enter results, and automatically generate and save reports during the inspection, testing, investigation, or repair of buildings and other facilities (**Fig. 7**). When performed in the conventional way, this task involves carrying a large amount of paper materials and requires a lot of time to compile reports with photographs of the inspection site. Using BizInspect reduces the amount of materials needed and makes the work more efficient. For periodic inspections and other such tasks that are performed repeatedly, inspectors can check the previous inspection results, so it is possible to perform the inspection efficiently while maintaining the inspection information obtained up to the

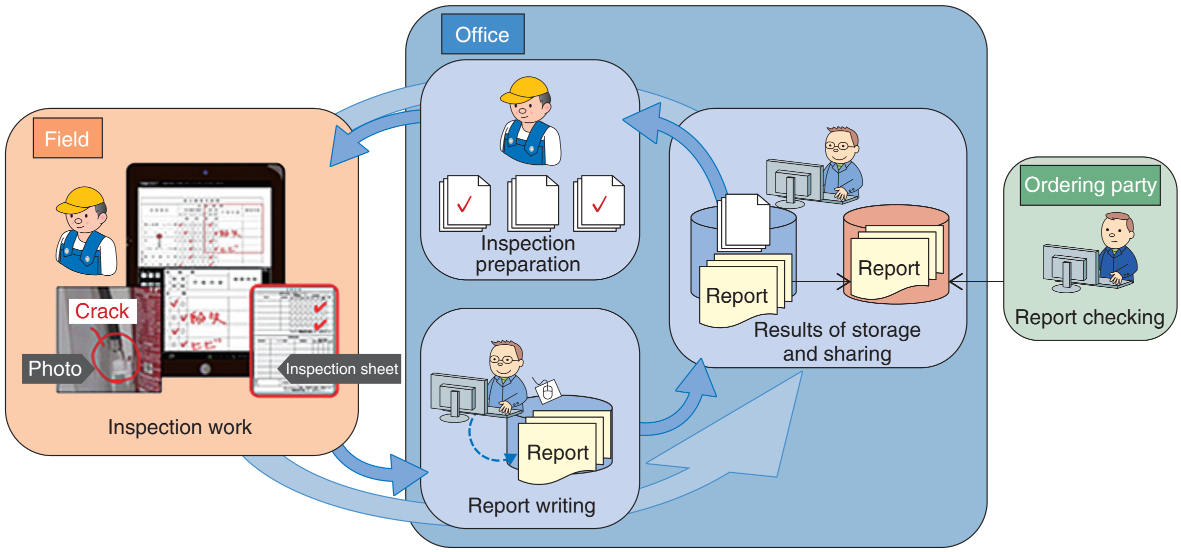


Fig. 7. Overview of BizInspect®.

previous inspection. With paperless inspection materials and reports, the natural resources consumed for paper can be reduced, and the storage space required for paper materials can also be eliminated. Another advantage is that the input of information is not duplicated in the on-site inspection work or in the report production work that is done in the office, so less time is required to complete the task.

BizInspect was assessed in conditions involving four inspections and the production of reports for them at 900 locations over a one-year period, and the results revealed that the use of BizInspect resulted in a 68% reduction in CO_2 emissions relative to the conventional process.

5. Future challenges

The NTT Group will continue to develop environment-friendly solutions and to promote the social contribution and environmental impact reduction effect of ICT in ITU-T well into the future.

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Minako Hara

Senior Manager, Environment Management Promotion Office, Technology Innovation Department, NTT WEST.

She received a B.S. in applied chemistry from Tokyo University of Science in 1998, and an M.E. and Ph.D. in applied chemistry from the University of Tokyo in 2000 and 2005. During 2004–2006, she was a post-doctoral researcher at the Japan Science and Technology Agency, where she developed a methodology of environmental impact assessment and an eco-efficiency index. She joined NTT Energy and Environment Systems Laboratories in 2006 and studied environmental assessment, including life cycle assessment and material flow analysis. She moved to NTT WEST in 2016. She is a member of the Society of Environmental Science, Japan and the Society for Environmental Economics and Policy Studies.

Xiaoxi Zhang

Research Engineer, Environmental Technology and Management Project, NTT Network Technology Laboratories.

She received a B.S. and M.S. in social engineering from Tokyo Institute of Technology in 2007 and 2009. Since joining NTT Energy and Environment Systems Laboratories in 2009, she has been engaged in research on risk-based management of telecommunication infrastructures. She moved to NTT Network Technology Laboratories in 2015. She is currently researching environmental assessment of ICT use. She is a member of the Institute of Electronics, Information and Communication Engineers.

Arkadin: Global Unified Communications & Collaboration Champion in a Dynamic Digital Workplace

Didier Jaubert

Chief Executive Officer, Arkadin SAS

Abstract

Arkadin is one of the largest and fastest growing communications and collaboration service providers in the world. With a vision rooted in the belief that progress emerges from people's desire to share, Arkadin offers a complete range of integrated audio, web, video, and unified communications solutions. This article introduces the company's operations, strategies, and potential future as an NTT Communications Group company.

Keywords: audio/web/video conferencing, cloud, digital workplace

1. Introduction

In a global workplace that is becoming increasingly digital and connected, enterprises must become more agile to compete and succeed. Rapid and seamless communications through any device is essential at every level of the organization, whether between departments, divisions, or countries, anywhere in the globe. The net result is a new importance on workforce engagement. Having the right mix of collaborative technologies is essential for driving productivity, improving employee wellbeing, and retaining top talent.

At Arkadin, we have a collection of market-leading audio/web/video conferencing and unified communications solutions that are essential for success in our digitally connected global workplace. All services are delivered in the cloud and are backed by a cutting-edge infrastructure for premium service quality.

Our business model is based on deploying services that are administered locally by highly trained Arkadin professionals who are geographically and culturally close to our clients. As entrepreneurs, we began with this innovative local approach to customer service from our start in 2001, and it remains a key pillar of our success.

Arkadin is one of the largest and fastest growing providers of unified communications and collaboration (UC&C) services in the world. We have operations in over 30 countries, with 56 offices spread throughout the Americas, EMEA (Europe, the Middle East, and Africa) and CEMEA (Central and Eastern Europe, the Middle East, and Africa), and in the Asia Pacific region, including China, which serve over 50,000 clients from a vast range of industries (**Fig. 1**).

Our mission is to lead companies to increased growth and success by delivering positive collaboration experiences. We are driven by the idea that progress emerges from people's desire to share and work together. As such, our vision is to be at the forefront in meeting growing demand for cloud-based UC&C services by providing organizations with the best

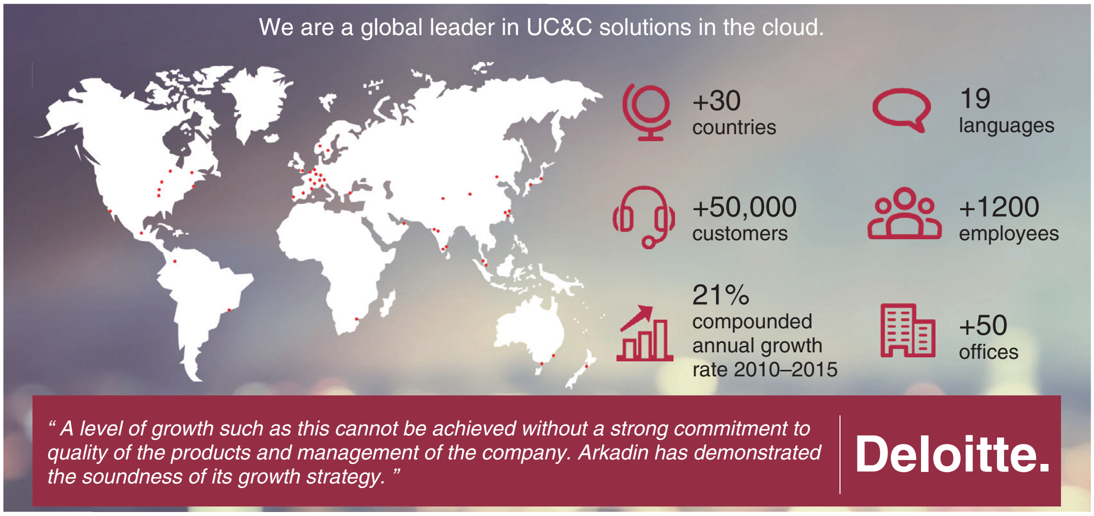


Fig. 1. Global service coverage.

Fig. 2. Expertise in collaboration technologies.

solutions for enhancing their business (**Fig. 2**).

2. Strong performance positions Arkadin as #1 cloud collaboration service provider

Arkadin is profitable and has gained a 21% compound annual growth rate over the past five years, which is very healthy. We hosted just over 30 million meetings in 2015, with 119 million participants clocking 82 million hours in total, as well as 40,000 events, of which 3000 were webcasts. Our strong performance has made us the fastest growing cloud collaboration provider in the industry (**Fig. 3**).

3. Arkadin values are significant competitive differentiators

Values run through everything we do, both from a cultural and business perspective, and we are convinced they set us apart in the marketplace. Our

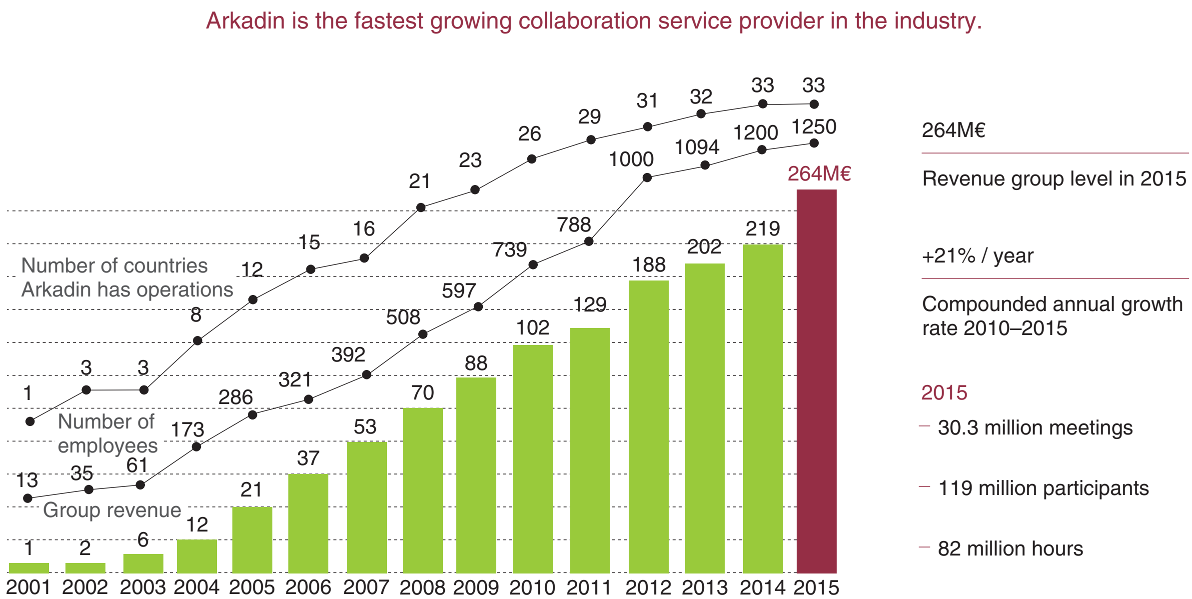


Fig. 3. Achieving strong growth.

cultural values are based on respect, working together, entrepreneurial spirit, and workplace enjoyment, while our business values are centered on creating and sustaining a premium customer experience. They are inextricably linked. A premium customer experience begins with a strong culture within Arkadin. We know that a happy workforce makes for happy customers. This idea is central to our business, and we believe it gives us a significant advantage. We are so passionate about our values that we recently launched a new website to showcase how they apply across all aspects of our organization [1].

4. Strategic acquisitions to propel agile global growth

Acquisitions of organizations with stellar track records, advanced technologies, and trusted reputations allow us to expand our global footprint and market share. Our most recent example is our purchase of T-Uno last year, which enabled us to enter Colombia with the market leader in the region. We also acquired AT Conference [2] in 2015, a New York-based audio and web conferencing provider, which is helping us to increase our customer base and market share in the North American collaboration market. Arkadin will be keeping the AT Conference brand and Information Systems to leverage their strength in the small- and medium-sized businesses (SMB) sector. Their service and support complement our existing capabilities, while our full suite of UC&C solutions are a great fit for their customers.

We also target potential technologies for acquisition that will enhance our customer value proposition and provide cutting-edge UC&C solutions for meeting all communications requirements.

Our 2014 acquisition of implement.com [3], a key Microsoft partner with a stellar track record in enabling service providers to leverage hosted voice and Microsoft technologies, has allowed us to extend our UC-as-a-Service (UCaaS) offerings so that businesses can harness the full power of UC for greater workplace productivity. Arkadin has benefited from their honed UC expertise and advanced collaboration service platform. The acquisition has been instrumental in giving us the most advanced business productivity tools, plus all telephony capabilities, in a convenient, cost-efficient cloud-based offer in Arkadin Total Connect.

In the video category, our acquisition of French video specialist Novasight [4] in 2012 gave us a leg up in video managed services, an important long-term growth market.

The synergies from these acquisitions are significant. Together with NTT Communications, we offer the complete package: the most advanced UC&C technologies and global infrastructure plus comprehensive, locally administered support services, resulting in a tremendous competitive advantage on a worldwide basis and a win-win for our customers.

5. Product and marketing strategies driven by a digitally transformed workplace

We are in a hyper-connected world where anytime, anywhere, any-device communication is the expectation. Trends driven by the cloud, social communities, and a mobile workforce are driving dramatic changes in global workplaces, and they will only intensify as millennials become more dominant and achieve leadership positions. Workers' expectations are changing fast, and collaboration technology is a vital enabler. There is a new importance placed on the engagement of people and a flatter work structure. Workers are expected to access their information from anywhere—even their corporate intranets. Teams need to collaborate virtually across geographical barriers and time zones to be effective and competitive. And flexible work policies are no longer just something nice to have, but are essential for driving productivity, retaining top talent, and reigning in costs for unnecessary business travel. In short, collaboration technologies are vital enablers.

All of these trends and developments translate to a very dynamic market for our services, and we are extremely well positioned to profit. We have the ambition and an aggressive plan to capture a sizable share of the market. Our strategy is centered on three strategic pillars, which are explained in the following subsections.

5.1 Best UC&C solutions in the cloud

There is no future without great products. Arkadin has a two-pronged product strategy that has fueled our strong growth. We have our own branded ArkadinAnytime audio conferencing and ArkadinAnywhere web conferencing, with the most digitally advanced cloud collaboration platform [5].

We also maintain partnerships with leading technology companies including Microsoft, ON24, Adobe, Vidyo, Cisco, Blue Jeans Network, and IBM for best-in-class cloud solutions that are rich in features, intuitive, and integrated with our premium audio conferencing for an exceptional user experience. Each of our partners has a different set of capabilities that enable us to be a true one-stop shop for UC&C services.

5.1.1 UC—a key enabler of digital workplace transformation

In the UC sector, Arkadin offers a suite of market-leading solutions from Microsoft Skype[*1] for Business and Cisco Jabber[*2] combined with WebEx[*2]. Delivered in the cloud for fast international deployment offering a high return on investment (ROI), the services are integrated with Arkadin's stable, crystal-clear audio conferencing and combined with our comprehensive support services.

The center of our UC strategy is Arkadin Total Connect, a Microsoft Skype for Business hosted service. Integrated into Arkadin 'as a Service,' Arkadin Total Connect offers voice, contact center, and conferencing services to Office 365[*3], all under a 'single pane of glass,' which frees up information technology (IT) teams to focus on other strategic projects. The voice-enabled Office 365 deployment seamlessly integrates with Exchange Online (within Office 365) for unified messaging that drives efficiencies while reducing costs associated with traditional PBX (private branch exchange) and third-party conferencing services.

Businesses benefit from the convenience of a single all-in-one solution, which offers substantial cost savings from on-premises UC deployment, coupled with Arkadin's premium quality integration, networking expertise, and customer support.

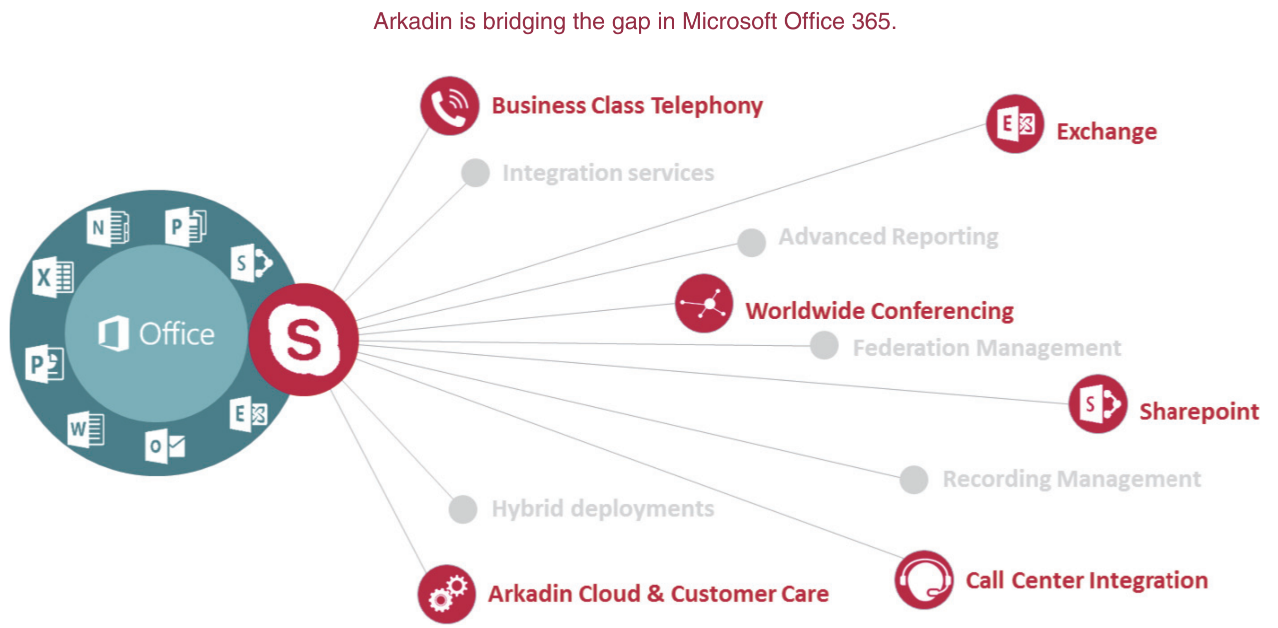
In December 2015, Arkadin was named a launch partner for the new Skype for Business meetings and voice services in Office 365. Arkadin will be a key resource for driving the rollout of the new services. We are one of only a few service providers operating on a global scale that meet Microsoft's requirements and enable it to offer a fully integrated platform for meeting and voice services (**Fig. 4**).

Being named a launch partner is a testament to our eight-year history of success in hosting voice in the cloud for Microsoft UC services. As an NTT Communications' subsidiary, we can leverage the company's sophisticated global voice architecture and integration capabilities and help customers reduce the costs and complexity associated with voice deployments. Our professional end-user support, training, migration, and change management capabilities guarantee efficient rollouts. The net result is a single source for deploying Office 365 as a business-class phone system, contact center, and conferencing platform delivered in the cloud.

*1 Microsoft and Skype are registered trademarks of Microsoft Corporation in the United States and/or other countries.

*2 Cisco Jabber and WebEx are registered trademarks of Cisco Systems, Inc. and/or its affiliates in the United States and certain other countries.

*3 Office 365 is a registered trademark of Microsoft Corporation in the United States and/or other countries.



*Excel Launch Icon 2012, Exchange Launch Icon 2013, Office with Office 2012 Design, OneNote Launch Icon 2012, Outlook Launch Icon 2012, PowerPoint Launch Icon 2012, Publisher Launch Icon 2012, Skype "S" Design, SharePoint, SharePoint Launch Icon 2012, and Word Launch Icon 2012 are registered trademarks or a trademark of Microsoft Corporation in the United States and/or other countries.

Fig. 4. A key provider of Microsoft Skype for Business services and voice services in Office 365.

A good example of how we are helping clients to succeed with Office 365 is with a Texas-based IT services firm. ENTRUST Technology Consulting Services required a hosted UC solution that would have all collaboration features and mobility in one product, plus voice and a call center solution. Arkadin Total Connect for Office 365, integrated with Clarity Connect, provided everything they needed in a simple-to-manage hosted solution. It has transformed the way they think about their operations. The ENTRUST workforce is now empowered to operate from wherever they are, and is thus able to better service their customer base and expand their footprint since they are no longer dependent on any single location.

"Arkadin Total Connect for Office 365 enables our workforce to operate from anywhere they are. Working at home is no different than working from our office. It has transformed the way we think about our operations."
Mitchell R. Sowards, President, ENTRUST

5.2 Premium customer experience

In this fast changing business environment that is driving tremendous change in global workplaces, it is more essential than ever to listen to customers and adapt strategies when necessary for delivering on their requirements.

A premium client experience is in our DNA, and it is a key competitive differentiator. Our local yet global approach to customer service sets us apart in the industry and delights our clients since they deal with local teams who speak their language and understand their culture. Regional customer success teams take the time to understand our clients' unique needs and challenges, whether they are a global conglomerate or an SMB, so that we can implement the tools that will deliver a high ROI. It is all about a complete 365-degree experience in the spirit of a true partnership for building customer loyalty.

Our service strategy is truly end-to-end and multilayered, encompassing live assistance 24/7 in 19 languages, and user training that is live, onsite, and virtual. We offer sophisticated reporting tools and professional services complete with project managers, and technical pre-sales and service relationship managers for more complex collaboration and UC deployments. Our value-added capabilities also include professional services for concierge and endpoint management, infrastructure monitoring, and billing services (**Fig. 5**).

Arkadin's customer Hatch, one of the world's

Fig. 5. Arkadin value proposition.

pre-eminent suppliers of technical and strategic services for the mining, metallurgical, and energy industries, with operations throughout North America, Europe, the Middle East, South America, Asia Pacific, and South Africa, relies on virtual meetings to communicate high level company information to its 10,000 global employees. Hatch recently experienced the value of our live, value-added global service strategy in conjunction with a large annual meeting in South Africa. We had the complete array of audio, video, and multimedia solutions, plus experienced engineers and support technicians in South Africa as well as their headquarters in Ontario, Canada, for pulling off the meeting. For the first time, Hatch had every aspect of the event covered by one provider. Following the success of the meeting, Arkadin now provides a cost-efficient, one-vendor approach for all of Hatch's large global meeting needs regardless of where their conferences are staged.

"Arkadin had the complete array of audio, video, and multimedia solutions, plus experienced engineers and support technicians in South Africa as well as Ontario, Canada, for pulling off our large general meeting. It was the complete package. For the first time we had every aspect of the event covered by one provider. The huge success of our meeting convinced us to use Arkadin for all of our large global meetings and webcasts regardless of where in the world they are located."
Stephen Goodger, ICT Lead – Operational Management, Hatch

To ensure we continue to deliver the best experience for our clients, we have instituted a three-pronged plan that addresses People Development, World Class Operations for delivering the most advanced infrastructure, and World Class Digital Customer Experiences. As an example of our commitment to customers, we implemented a new Customer Lifecycle Program for an improved, globally consistent onboarding process for all new ArkadinAnytime and ArkadinAnywhere users. It is part of a renewed focus on improving our customers' digital experience and reinforces our overall value proposition, while giving us a significant competitive advantage around the customer pain point of low new-user adoption.

We devised a personalized new-user nurture campaign to replace the original "one shot" welcome pack. It consists of three strong induction emails with reasons to activate the service and handy tools to make collaboration easier. The tools include: a Getting Started Guide, Mobility Apps, and a Productivity Toolbar. Taking advantage of Arkadin's newly refreshed brand, these communications are more visual and dynamic (**Fig. 6**). All new customers who still fail to activate after this first phase of induction are sent through a second 'adoption' nurture flow with additional motivational messages to encourage them to get started.

We rolled out the program in the second half of 2015, and it is now live in most Arkadin countries. To date, customer engagement has been extremely high, with adoption levels for new users averaging 59% compared to the previous global average of 43%. In addition to being added value for customers, it is also a high revenue generator for Arkadin, creating €2

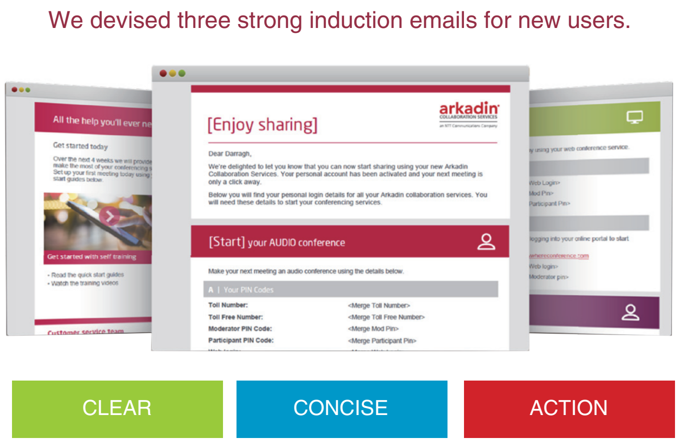


Fig. 6. New welcome emails.

million worth of net new revenue since its launch last year, and it will continue to build as new territories and products are added.

We have now made onboarding incredibly simple, and the results speak for themselves. In addition, we are proud to be a finalist in this year's Oracle Markie Awards for "Best International Campaign 2015" based on the global impact of this customer-led initiative.

5.3 Expansion and profitable long-term growth as a member of NTT Group

In addition to having the best technology partners, Arkadin will continue to align with strategically positioned telecommunications companies, agents, resellers, and systems integrators who share our philosophy about the value of cloud-based UC&C services. At the center of this dynamic ecosystem are NTT Communications and fellow NTT Group subsidiary Dimension Data. We have programs in place that leverage each of their strengths, resulting in powerful synergies for our customers. For example:

- Arkadin is collaborating on NTT Communications' Arcstar brand of collaboration services in Japan. We recently launched the Japan Platform in April 2015 as an Arcstar UCaaS Microsoft Type service utilizing Arkadin's international platform.
- Reselling agreements are in place in North America, Europe, and Asia. Each market has a distinct platform, which is a tremendous competitive advantage, especially in selling to large global companies.
- Our partnership is not all about business. The people side is equally important. Considering the very different cultural orientations and work styles between teams based in Japan and the West, we have instituted programs to accelerate mutual understanding and appreciation of our strengths and differences. One example is our employee exchange program that enables us to connect and share our knowledge, culture, and values. To date, approximately 10 employees from both companies have participated by leaving their home turf for offices in Paris and Montpelier, France, as well as in Hong Kong, Tokyo, and Singapore. We are confident programs like this will be enormously beneficial in building better teamwork and synergies between teams across the globe.

6. Bright and digital future with NTT Communications

Our opportunities for greater global growth and leadership are unlimited and are just beginning to be realized. Arkadin is well positioned within the larger NTT Group for enabling the organization and its subsidiary companies to achieve global leadership in cloud-based UC&C services. Together we offer customers the most sophisticated infrastructure, networking, and telecommunications capabilities. In the 30 months since NTT Communications acquired Arkadin, we have been working closely as a team to ensure we leverage our complementary strengths for providing the most comprehensive collection of the highest quality UC&C solutions available in the market.

Photo 1. Arkadin team.

Recently, NTT Communications launched *Vision 2020 – Transform. Transcend*, an innovative initiative that is perfectly placed to serve an ever-changing digital world [6]. Arkadin will work together with NTT Communications to continually assess market trends and provide customers with new state-of-the-art technologies that will not only bring business change, but will break boundaries and extend our imagination.

We believe our team of global entrepreneurs and our stellar portfolio of UC&C products, set within a high-growth market, give us all the components we need for a bright and digital future (**Photo 1**).

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Didier Jaubert

Chief Executive Officer, Arkadin SAS.

Didier Jaubert brought 30 years of commercial and general management experience with IT and telecommunications multinationals to Arkadin. He had senior roles at Orange Business Services, where he was recognized for his expertise in outsourcing and system integration, and at IBM, where he held various management positions in sales and global services in France and the U.S. He has a degree in engineering from the Ecole Centrale Paris and an economics degree from Paris University. He has been Chief Executive Officer of Arkadin since October 2015.

New NTT Colleagues

—We welcome our newcomers to the NTT Group

This is a corner of the NTT Technical Review where we introduce our new affiliate companies.

BIT.Group

SAP service provider; established in 2004; headquartered in Bautzen, Germany

Founded in 2004, BIT.Group GmbH stands out as a provider of innovative services for national and international customers. The multi-certified SAP* partner has about 380 employees and offers extensive SAP services focusing on SAP application management, technology services, application lifecycle management, and cloud services.

In June 2016, BIT.Group GmbH and itelligence AG, a Germany-based SAP consultancy firm and a subsidiary of NTT DATA Corporation, reached an agreement for itelligence AG to acquire 100% of outstanding shares in BIT.Group GmbH.

With this acquisition, itelligence AG is cementing its position as one of the leading information technology service providers in Germany with a strong focus on cloud and SAP managed services. For further information about the acquisition, please visit: http://itelligencegroup.com/us/crprtprsrlss/itelligence-acquires-application-management-and-cloud-specialist-bitgroup/

Contact:
Public Relations Department
NTT DATA Corporation
Tel: +81-3-5546-8051

VietUnion

Payment service provider; established in 2008; headquartered in Vietnam

Since 2011, NTT DATA Corporation has been investing in VietUnion Online Services Corporation (VietUnion), a group company of Saigon Construction Corp (SCC). VietUnion has been expanding its payment business primarily through "Payoo." Payoo enables users to make different sorts of bill payments for almost all the big chain retailers, nearly 4000 stores in total throughout Vietnam, such as convenience stores, ICT (information

* SAP is a registered trademark of SAP AG in Germany and in several other countries all over the world.

and communication technology) shops, shopping centers, and supermarkets. Payoo also has a mobile application for smartphones that enables customers to pay charges via Internet banking provided by over 20 local banks. VietUnion also provides various software solutions such as a mobile POS (point of sales) system, smart-card solutions for transportation, location-based solutions for billers, and platforms for tuition fee management and collection for 1700 schools in Ho Chi Minh City.

In June 2016, NTT DATA Corporation reached an agreement to purchase additional shares in VietUnion through its subsidiary NTT DATA Asia Pacific Pte. Ltd and to take on VietUnion as an NTT DATA Group company. Partnered with SCC, NTT DATA Corporation is committed to support VietUnion in strengthening its internal structure as well as establishing its position in the market in order to generalize non-cash payment in the country. For further information about the acquisition, please visit: http://www.nttdata.com/global/en/news-center/others/2016/062300.html

Contact:
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NTT DATA Corporation
Tel: +81-3-5546-8051

External Awards

Achievement Award

Winner: Naonori Ueda, NTT Communication Science Laboratories
Date: June 2, 2016
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE)

For his pioneering research on statistical learning theory.

Best Presentation at JPA Annual Convention

Winner: Ryunosuke Sudo, Kyushu University; Daisuke Satoh, NTT Network Technology Laboratories; Yuji Takano, Doshisha University; and Takemi Mochida, NTT Communication Science Laboratories
Date: June 16, 2016
Organization: The Japanese Psychological Association (JPA)

For "Examination of the Measures and Subjective Stress of Calling Party during Disaster."
Published as: R. Sudo, D. Satoh, Y. Takano, and T. Mochida, "Examination of the Measures and Subjective Stress of Calling Party during Disaster," Proc. of the 79th JPA Annual Convention, Nagoya City, Japan, Sept. 2015.

Best Paper Award 2015

Winner: Hiroaki Shiokawa, University of Tsukuba; Yasuhiro Fujiwara and Yasuhiro Iida, NTT Software Innovation Center; Makoto Onizuka, Osaka University
Date: June 18, 2016
Organization: The Database Society of Japan (DBSJ)

For "Density-based Clustering for Dynamic Graphs."
Published as: H. Shiokawa, Y. Fujiwara, Y. Iida, and M. Onizuka, "Density-based Clustering for Dynamic Graphs," DBSJ Japanese Journal, Vol. 14-J, 4, Mar. 2016.

TTC Chairman's Prize

Winner: Akira Takahashi, NTT Network Technology Laboratories
Date: June 21, 2016
Organization: Telecommunication Technology Committee (TTC)

For his contribution to the standardization of quality of service and quality of experience concerning audiovisual communication services and IP networks.

JSAI Best Paper Award 2015

Winner: Makoto Nakatsuji, NTT Service Evolution Laboratories; Yasuhiro Fujiwara, NTT Software Innovation Center; Hiroyuki Toda and Hiroshi Sawada, NTT Service Evolution Laboratories; Jin Zheng and James Hendler, Rensselaer Polytechnic Institute
Date: June 24, 2016
Organization: The Japanese Society for Artificial Intelligence (JSAI)

For "Tensor Factorization that Utilizes Semantics behind Objects."
Published as: M. Nakatsuji, Y. Fujiwara, H. Toda, H. Sawada, J. Zheng, and J. Hendler, "Tensor Factorization that Utilizes Semantics behind Objects," Trans. JSAI, Vol. 30, No. 3, pp. 510–525, May 2015 (in Japanese).

JSAI Incentive Award 2015

Winner: Koh Takeuchi, NTT Communication Science Laboratories; Yoshinobu Kawahara, ISIR, Osaka University; and Tomoharu Iwata, NTT Communication Science Laboratories
Date: June 24, 2016
Organization: JSAI Special Interest Group on Fundamental Problems in Artificial Intelligence (SIG-FPAI)

For "Structured Regularizer for Spatio-temporal Matrix Completion."
Published as: K. Takeuchi, Y. Kawahara, and T. Iwata, "Structured Regularizer for Spatio-temporal Matrix Completion," Proc. of the 100th SIG-FPAI, pp. 47–52, Kumamoto, Japan, Mar. 2016 (in Japanese).

The Meritorious Award on Radio

Winner: Yoshitaka Shimizu, NTT Network Innovation Laboratories; Nei Kato, Tohoku University; Kouji Eguchi, Fujitsu Limited; and Shinichi Yamaguchi, NTT Communications
Date: June 27, 2016
Organization: Association of Radio Industries and Businesses (ARIB)

For development of the movable and deployable ICT resource unit (MDRU).

OECC/PS 2016 Best Paper Award

Winner: Kazushige Yonenaga, Kengo Horikoshi, Seiji Okamoto, Mitsuteru Yoshida, Yutaka Miyamoto, and Masahito Tomizawa, NTT Network Innovation Laboratories; Takeshi Okamoto, Hidemi Noguchi, Jun-ichi Abe, and Junichiro Matsui, NEC Corporation; Hisao Nakashima, Yuichi Akiyama, Takeshi Hoshida, and Hiroshi Onaka, Fujitsu Limited; Kenya Sugihara, Soichiro Kametani, Kazuo Kubo, and Takashi Sugihara, Mitsubishi Electric Corporation
Date: July 6, 2016
Organization: The 21st Optoelectronics and Communications Conference/International Conference on Photonics in Switching 2016 (OECC/PS 2016) organizing committee

For "Field Demonstration of Modulation Format Adaptation Based on Pilot-aided OSNR Estimation Using 400Gbps/ch Real-time DSP."
Published as: K. Yonenaga, K. Horikoshi, S. Okamoto, M. Yoshida, Y. Miyamoto, M. Tomizawa, T. Okamoto, H. Noguchi, J. Abe, J. Matsui, H. Nakashima, Y. Akiyama, T. Hoshida, H. Onaka, K. Sugihara, S. Kametani, K. Kubo, and T. Sugihara, "Field Demonstration of Modulation Format Adaptation Based on Pilot-aided OSNR Estimation Using 400Gbps/ch Real-time DSP," OECC/PS 2016, TuB2-2, Niigata, Japan, July 2016.

OECC/PS 2016 Best Paper Award

Winner: Kengo Nozaki, Shinji Matsuo, Takuro Fujii, Koji Takeda, Masaaki Ono, Abdul Shakoor, Eiichi Kuramochi, and Masaya Notomi, NTT Basic Research Laboratories
Date: July 6, 2016
Organization: OECC/PS 2016 organizing committee

For "Sub-fF-capacitance Photonic-crystal Photodetector towards fJ/bit on-chip Receiver."
Published as: K. Nozaki, S. Matsuo, T. Fujii, K. Takeda, M. Ono, A. Shakoor, E. Kuramochi, and M. Notomi, "Sub-fF-capacitance Photonic-crystal Photodetector towards fJ/bit on-chip Receiver," OECC/PS 2016, TuE1-3, Niigata, Japan, July 2016.

OECC/PS 2016 Best Paper Award
Winner: Wataru Kobayashi, NTT Device Technology Laboratories; Naoki Fujiwara, NTT Device Innovation Center; Takahiko Shindo, NTT Device Technology Laboratories; Shigeru Kanazawa, NTT Device Innovation Center; Koichi Hasebe, Hiroyuki Ishii, and Mikitaka Itoh, NTT Device Technology Laboratories
Date: July 6, 2016
Organization: OECC/PS 2016 organizing committee

For "Ultra Low Power Consumption Operation of SOA Assisted Extended Reach EADFB Laser (AXEL)."
Published as: W. Kobayashi, N. Fujiwara, T. Shindo, S. Kanazawa, K. Hasebe, H. Ishii, and Mikitaka Itoh, "Ultra Low Power Consumption Operation of SOA Assisted Extended Reach EADFB Laser (AXEL)," OECC/PS 2016, WD3-2, Niigata, Japan, July 2016.

Technical Committee on Communication Quality Research Encouragement Award
Winner: Rie Tagyo, NTT Network Technology Laboratories; Hideaki Kinsho, Osaka University; Daisuke Ikegami, NTT Network Technology Laboratories; Takahiro Matsuda, Osaka University; Akira Takahashi, NTT Network Technology Laboratories; Tetsuya Takine, Osaka University
Date: July 26, 2016
Organization: Technical Committee on Communication Quality, IEICE Communications Society

For "Inference of QoS Degradation Based on Spatial Dependence in Mobile Networks."
Published as: R. Tagyo, H. Kinsho, D. Ikegami, T. Matsuda, A. Takahashi, and T. Takine, "Inference of QoS Degradation Based on Spatial Dependence in Mobile Networks," IEICE Tech. Rep., Vol. 116, No. 10, CQ2016-1, pp. 1–6, Apr. 2016.

Papers Published in Technical Journals and Conference Proceedings

Five Senses Theater: A Multisensory Display for the Bodily Ultra-reality

Y. Ikei, K. Hirota, T. Amemiya, and M. Kitazaki
Emotional Engineering, Vol. 4, pp. 145–164, June 2016.

The present paper describes a multisensory virtual reality (VR) system built for the exploration of the bodily ultra-reality.

Development of Embodied Sense of Self Scale (ESSS): Exploring Everyday Experiences Induced by Anomalous Self-representation

T. Asai, N. Kanayama, S. Imaizumi, S. Koyama, and S. Kaganoi
Frontiers in Psychology, Vol. 7, 1005, July 2016.

The scientific exploration of the self has progressed, with much attention focused on the Embodied Sense of Self (ESS). Empirical studies have suggested the mechanisms for self-representation. On the other hand, less attention has been paid to the subjectivity itself of the self. With reference to previous studies, the current study collected items that reflect the ESS and statistically extracted three factors for it: Ownership, Agency, and Narrative. The developed questionnaire [Embodied Sense of Self Scale (ESSS)] showed good enough validity and reliability for practical use. Furthermore, ESSS discriminated schizophrenia, a disorder of the ESS, from controls. We discuss the factorial structure of ESS and the relationship among factors on the basis of the current results.

Perceived Topographic Surface Modulated by Pitch Rotation of Motorized Motion Chair

T. Amemiya, K. Hirota, and Y. Ikei
Transactions of the Virtual Reality Society of Japan, Vol. 21, No. 2, pp. 359–362, July 2016 (in Japanese).

A great number of driving simulators with visual presentation have been developed. But little is known about the perception of a topographic surface induced by visual and vestibular stimuli when a user runs over a bump or hole. In this paper, we conducted a user study to assess how congruence or incongruence of visual and vestibular shape cues influence the perception of a topographic surface. Experimental result show that the vestibular shape cue contributed to making the shape perception more than the visual one. The result of a linear regression analysis showed that performance with visual unimodal and vestibular unimodal cues could account for that with visuo-vestibular multimodal cues.

Event-based Transient Visual and Tactile Feedback Produces a Sensation of Impact

T. Amemiya
Transactions of the Virtual Reality Society of Japan, Vol. 21, No. 2, pp. 381–384, July 2016 (in Japanese).

This paper reports a design of a new haptic feedback technique for desktop applications which creates a sensation of impact with modulated transient visual and tactile feedback. A transient vibration or impulse tactile stimulus was presented when a computer mouse cursor made contact with a virtual object on the screen, while changing the visual motion of the cursor. Two experiments were performed to compare the effect of stimulus combination and find an effective time lag of visuotactile stimuli to generate a clear sensation of impact. Experimental evaluations showed that a sensation of impact was successfully induced by tactile stimuli of either single pulse or damped oscillation, while a strong sensation of vibration was not induced, and the sensation of impact was induced when tactile stimuli were presented 30–120 ms after the cursor made contact.

On Maximizing a Monotone *k*-submodular Function Subject to a Matroid Constraint

S. Sakaue

arXiv:1607.07957, July 2016.

In this paper, we prove that a greedy algorithm outputs a 1/2-approximate solution for monotone k-submodular maximization with a matroid constraint. The algorithm runs in $O(M|E|(\mathrm{MO} + k\mathrm{EO}))$ time, where M is the size of an optimal solution, $|E|$ is the size of the ground set, and MO and EO represent the time for the membership oracle of the matroid and the evaluation oracle of the k-submodular function, respectively.

Topographic Surface Perception Modulated by Pitch Rotation of Motion Chair

T. Amemiya, K. Hirota, and Y. Ikei

Proc. of HCI International 2016, pp. 483–490, Toronto, Canada, July 2016.

The paper investigates multimodal perception of a topographic surface induced by visual and vestibular stimuli. Using an experimental system consisting of a motion chair and optic flow on a wide screen, we conducted a user study to assess how congruence or incongruence of visual and vestibular shape cues influence the perception of a topographic surface. Experimental results show that the vestibular shape cue contributed to making the shape perception larger than the visual one. Finally, the results of a linear regression analysis showed that performance with visual unimodal and vestibular unimodal cues could account for that with visuo-vestibular multimodal cues.
