What’s Hot in R&D
H-AP-1

Dig-A-Map: Web Search that Projects Documents onto Time and Space
Overview

This is a Web page retrieval service that can find desired documents at high speed by manipulating ‘place’, ‘time’ and ‘keywords’. After determining the place and time of interest, ‘keywords’ and the geographical distribution of information relevant to those keywords can be determined. The function can also be combined with a Web search engine to retrieve Web pages that contain information relevant to a ‘place’ and ‘time’ range.

Features

- Web search service in which a range of ‘place’ and ‘time’ of interest can be specified in addition to ‘keywords’.
- Keywords that are relevant to a particular time and place can be discovered.
- Keywords can be used to find places that are high in interest.
- Information specific to a region can be found as well as information on a particular place.
- Can handle vague search requests such as “Is there anything of interest near this place?”

Application scenarios

- Travel planning
  - The next travel destination is the Miura peninsula in April. What’s going on there?
  - This summer, I want to see fireflies! When and where can I find them?
- Web browsing by place and time
  - When I search for Ryoma Sakamoto, these places turn red. Why?
  - How was the cherry blossom viewing season last year?
- Retrieval of information on a place
  - Is there anything of popular interest near this place on this topic?
What’s Hot in R&D

Information Sharing Platform Technologies

Technologies for achieving common functions essential to content sharing business and electronic commerce such as copyright management, electronic settlement, and information delivery.

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Sheepdog: Distributed Storage System for Virtual Machines

**Overview**
Sheepdog is a distributed storage system for virtual machines based on Linux*¹ QEMU/KVM*². It runs on multiple commodity servers and provides highly available and variously sized volumes to virtual machines. Sheepdog is an autonomous system; new servers join automatically, and failed nodes are automatically removed. In addition, Sheepdog scales to hundreds of servers and has linear scalability.

**Features**
- Reliable system with no single point of failure
- Autonomous and easily manageable system
- Scalable to hundreds of servers in performance and capacity
- Developed as open source software and merged into QEMU/KVM
- Supported by many other management systems (e.g. OpenStack, libvirt)

**Application scenarios**
- Infrastructure as a Service
- Hosting service based on virtualization
- Server consolidation of many servers
- Online storage service

---

*¹ Linux is a registered trademark of Linus Torvalds in the U.S. and other countries.
*² KVM: Kernel-based Virtual Machine
Intelligent Cryptosystems

Overview

Intelligent Cryptosystems have advanced logic in their encryption/decryption mechanisms and provide more sophisticated control of data communications. For example, each document can be encrypted with a decryption condition such as “only division directors or personnel division managers can decrypt it”. Through such advanced encryption/decryption mechanisms, Intelligent Cryptosystems will promote broader usage of cloud computing.

Features

- Users can share data securely in a cloud computing environment, because the data encryption and access control mechanisms are integrated.
- A user can encrypt data by specifying only a decryption condition, without specifying who can decrypt it.
- The decryption keys can be independently generated after the encryption process.
- Intelligent Cryptosystems are constructed efficiently and securely by using a new advanced mathematical methodology called “dual pairing vector spaces”.

Application scenarios

- Confidential data sharing in a company’s systems
- Content delivery that has flexible access conditions

- Intelligent Cryptosystems were developed by NTT and Mitsubishi Electric Corporation and announced in a news release in July 2010.
Overview
As the adoption of smartphones accelerates rapidly, more and more people use smartphones as a replacement for laptops. There are commercial solutions that bring the conventional thin-client (remote desktop sharing) technology to smartphone users as a way to prevent data leakage. However, since controlling a PC desktop through a small touch screen of a smartphone presents a number of usability issues, mobile thin-client technology tailored for smartphones is in demand.

Our approach adopts Android OS (instead of a PC OS) as a thin-client server. This not only allows smartphone users to access a remote Android desktop optimized for small screens, but also utilize the rich devices such as touch panel, camera, GPS, accelerometer and SD card embedded in a smartphone. As a result, users can enjoy greater usability and productivity, while maintaining the same security level of conventional thin-client solutions.

Features
- Supports Android, iPad/iPhone, Windows Mobile, etc.
- Mobile applications installed on a thin client server can support gesture control and access sensor readings, camera and microphone on the client device. These features create new user experience different from that of conventional desktop sharing for PC users.
- Bulk data (sensor log, photos, etc.) stored on a thin-client server can be processed at high-speed through large-scale distributed computing resources in the cloud.
- By mounting an NFS\(^1\) remote storage to a smartphone as a virtual SD card, all applications on the smartphone can read/write data directly from/to the remote storage (without any dedicated API\(^2\)).

Application scenarios
- Store confidential location information on a corporate map server, receive GPS signals from a smartphone and prevent data leakage by transmitting only the graphic pixels of map images back to the smartphone.
- Decode a QR code on the server, extract additional corporate information and transmit the graphical image of the result back to the smartphone.
- Make phone calls by looking up a remote client telephone directory without importing it to the smartphone.
- Take confidential photos and save them directly to the remote storage without leaving any local copy.

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\(^1\) NFS: Network File System
\(^2\) API: Application Programming Interface
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End-user QoE Monitoring Agent for IPTV Services

Overview
We have developed a QoE*1 monitoring agent, which is software that is embedded in the STB*2 or other user terminal to estimate the quality of service as experienced by customer (QoE) for IPTV*3. Remote monitoring of QoE data for individual customers from an operation center or other facility allows rapid confirmation of the situation when a customer inquires the audiovisual quality or performance of quality management before a customer complains.

Features
- Represent qualitative customer opinion such as ‘distorted image’ as an objective numerical index
- Because quality is estimated using only packet header information, there is very little computational load and the function can be embedded in the customer terminal
- Highly accurate quality estimation compared to MDI*4 or other existing techniques is achieved by estimating the number of frames over which packet loss errors extend for different types of video frames
- Planned as a proposal for international standardization in 2011

Application scenarios
- Efficient service operation and management through quality monitoring for individual IPTV users without installation of special quality measuring devices
- Specifically, (1) rapid confirmation of the situation when a customer inquires the audiovisual quality, (2) determining the cause of failures, and (3) improved customer satisfaction through averting silent dissatisfaction

*1 QoE: Quality of Experience
*2 STB: Set-Top Box
*3 IPTV: Internet Protocol TeleVision
*4 MDI: Media Delivery Index (a measure of quality specified in RFC4445)
Standardization of the Vision and Design Goals of Future Networks

Overview
Research institutions around the world are carrying out search projects on future networks that will appear in 2020 and beyond. Rather than taking an approach of incremental improvements from existing networks and its technologies, the studies on future networks focus on more fundamental issues that impact various parts of the network. ITU-T launched a new body named FG-FN, Focus Group on Future Network, in 2009, and FG-FN produced its basic concept. This effort results in ITU-T Recommendation Y.3001, Future Networks: Objectives and Design Goals. NTT, with its wide range of experts working in various technical fields, promotes studies on future networks and has made significant contributions to FG-FN.

Features
- Virtualization that enables enabling performance optimization
- Energy reductions from the device level to the network level
- Data/content centric network architecture
- Effective and scalable IDs, ID separation with respect to roles
- Reliability and security

Application scenarios
- Service awareness: Anticipating new services without additional costs
- Data awareness: Handling enormous amounts of data securely and accurately
- Environmental awareness: Less consumption of materials and energy
- Social and economic awareness: Inviting new actors into the network ecosystem

Four objectives and twelve design goals of Future Networks (Quoted from ITU-T Recommendation Y.3001)
Virtual Network Architecture Over IP-optical Network

Overview
Recent trends in telecommunication have focused on service convergence in a shared IP (Internet protocol) network. However, innovative applications in the future are expected to have such diverse requirements that they cannot be easily accommodated in a common IP network. With our technology, we aim to create multiple virtual networks upon a common physical network infrastructure through integrated control of optical and IP networks. This will enable services to be launched quickly and operated independently.

Features
- Resource isolation in the physical layer avoids traffic conflicts between virtual networks.
- Dedicated use of dynamic optical paths supports on-demand use of gigabit-per-second-class communication.
- Resource allocation amounts and virtual network topology can be dynamically re-optimized in response to changes in traffic patterns.
- The architecture can be deployed without requiring any modification to existing routers and optical cross-connects that support the standard protocol GMPLS (generalized multi protocol label switching).

Application scenarios
- Carrier backbone networks
- Large-scale datacenter networks
- Ultrawideband services in the future such as uncompressed three-dimensional (3D) and high-definition (HD) video transmission
- On-demand wide-area virtual private network
**Transport Network Technology**

**Overview**
To meet the demand for high-volume communication traffic, we are working on high-speed transmission technology for 100 Gbit/s data transfer and new signal processing technology that integrates optical wavelength cross-connection (OXC) and packet switching. By implementing a 100 Gbit/s integrated transport system that applies the technology, we target the construction of a transport network that is economical, simple and energy-efficient through (1) high-speed and large-capacity traffic transport, (2) reduction of IP routing load on IP core routers, (3) improved operability from hardware integration, and (4) reduction of the NE Operations systems (NE-OpS).

**Features**
- Increase capacity, improve economy, simplify, and reduce power consumption for the backbone network through R&D on an new integrated transport system
- Ultra-fast 100 Gbit/s optical transmission by applying digital coherent technology
- Optical wavelength mesh network by applying OXC technology
- Packet transport network applies MPLS-TP*, which guarantees communication line quality and has maintenance and management mechanisms against failures

**Application scenarios**
- Backbone network of NTT Communications
- Metro network of NTT East Corporation and NTT West Corporation

---

* MPLS-TP: Multi Protocol Label Switching-Transport Profile
Drop Optical Fiber with Cicada Resistance

Overview

As a countermeasure against disconnection due to a species of cicada called the “bear cicada” (which occur on optical-fiber input (“drop”) cables to houses, particularly those in western Japan), a “drop optical fiber with cicada resistance” has been developed. This is an optical drop fiber that maintains the workability of a conventional optical drop fiber with non-cicada resistance as a result of optimization of the structure and sheath material of the fiber cable.

Features

- Optical-fiber core is protected from the ovipositor of a cicada by hard sheath.
- Cicada resistance is achieved without impairing fiber workability by optimizing material hardness and cross-sectional structure.
- Compatibility with related products is assured by utilizing the same structure and dimensions as conventional drop cable.

Application scenarios

- Drop cable to houses, apartment blocks, and office buildings

Features of the drop optical fiber with cicada resistance:

- Drop cable to houses, apartment blocks, and office buildings
- Optical-fiber core is protected from the ovipositor of a cicada by hard sheath.
- Cicada resistance is achieved without impairing fiber workability by optimizing material hardness and cross-sectional structure.
- Compatibility with related products is assured by utilizing the same structure and dimensions as conventional drop cable.

Comparison with non-cicada resistant drop cable

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<tr>
<th></th>
<th>Drop cable with non-cicada resistance</th>
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<tr>
<td>Cross section</td>
<td>Sheath with non-cicada resistance</td>
<td>Hard sheath</td>
</tr>
<tr>
<td>Cicada resistance</td>
<td>×</td>
<td>○</td>
</tr>
<tr>
<td>Sheath hardness¹</td>
<td>1</td>
<td>1.2</td>
</tr>
<tr>
<td>Sheath thickness²</td>
<td>Not specified</td>
<td>About 0.4 mm</td>
</tr>
</tbody>
</table>

*¹: Relative value *²: Thinnest part of sheath surface and core fiber

Verification of cicada measure by developed product

- Examination (cage examination): Actual performance value of cicada resistance is ascertained in examination that involve capturing cicadas each morning and piecing a drop cable with the ovipositor of a cicada close to laying eggs.

- Analysis: Correlation between parameters related to stab depth (such as casing hardness, tensile strength, coefficient of friction, modulus of elasticity, and elongation ratio) is analyzed.

Investigation on material that combines workability and cicada resistance

- Optimum sheath hardness is determined by examination and analysis.
Higher-voltage DC Power-supply System

Overview
As ICT services continue to grow in popularity, the power consumption of ICT equipment continues to rise. This rise in power consumption is linked, in turn, to increased operational costs and environmental damage due to CO₂ emission. The developed high-voltage DC power-supply system supplies electricity (at DC 380V) to ICT equipment housed in data centers. Implementing this system makes it possible to construct an “Earth friendly” power-supply system that is more efficient, more reliable, and more economical than conventional AC power supplies.

Features
- Thanks to the few steps involved in AC-to-DC (and vice versa) power conversion, the DC power supply
  - cuts power-conversion loss and reduces power consumption by about 15% in comparison to AC power supplies.
  - has low fault probability and high reliability.
- Since the high-voltage DC power supply can supply power at lower current than that of a DC-48V power supply, it is possible to scale down cables, cut installation costs, and improve latitude in equipment placement.
- Voltage-fluctuation suppression technology accumulated in developing DC-48V power supplies is utilized, and a stable power-supply system is created.
- In consideration of safety regarding the human body, a configuration with no exposed live-parts is adopted.

Application scenarios
- As a result of installing the system in data centers, telecommunications buildings, and so on,
  - it is possible to offer “green data centers”—which have a low environmental impact.
  - it is anticipated that power consumption concerning ICT will be cut.

- This work was performed in collaboration with NTT Facilities.

- Higher efficiency
- Higher reliability
- Lower installation cost
- Flexible installation

Merits of Higher-voltage DC Power-supply System
- Higher efficiency
- Higher reliability

Main Technical Developments
- Development of rectifiers for HVDC
- Development of power distribution cabinet for HVDC
- Optimizing power distribution conditions

AC system
1. UPS
2. Battery
3. AC/DC
4. DC/DC
5. AC/DC
6. DC/DC
7. AC/DC
8. DC/DC
9. AC/DC
10. DC/DC

-48V DC system
1. Rectifier
2. DC/DC
3. AC/DC
4. DC/DC
5. AC/DC
6. DC/DC
7. AC/DC

380V DC system
1. Rectifier
2. DC/DC
3. AC/DC
4. DC/DC
5. AC/DC
6. DC/DC
7. AC/DC

NTT Energy and Environment Systems Laboratories
World’s First 1-Gbit/s Multi-user MIMO Transmission

Overview

The wireless home network is desirable as a means of connecting various individual terminals to an optical fiber that run into the subscriber’s home. Home networks require stable transmission of high-volume video traffic, etc. To meet this requirement, NTT Laboratories developed a multi-user MIMO transmission prototype that enable simultaneous transmission of data to multiple destination terminals at the same time and on the same radio frequency without cross-interference (SDMA) for the next-generation high-speed wireless LAN (IEEE 802.11ac). The prototype employs a recursive weight calculation algorithm and a compressed CSI feedback technique. Thus we achieved real-time multi-user MIMO transmission at over 1 Gbit/s for the first time in the world.

Features

- A maximum total of 1.62 Gbit/s real-time wireless transmission to 6 terminals multiplexed by SDMA with multi-user MIMO technique.
- Recursive weight calculation algorithm that reduces circuit scale to about 1/6 in order to implement beam-forming control that has the accuracy needed for multi-user MIMO in an FPGA.
- Compressed CSI feedback technique capable of reducing CSI data volume to about 2/3 when a terminal sends the CSI to an access point for beam-forming control, thus shortening the overhead time.

Application scenarios

- Simultaneously video viewing of high-definition contents of IPTV distributed over the optical fiber network and for HD video players by family members in different rooms on wireless TV sets and computers.
- Networking by wireless connection of diverse types of terminals in the home, ranging from high-speed high-volume communication devices such as high-definition TVs to relatively low-speed devices such as sensors.

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*1 MU-MIMO: Multi-user, Multiple Input, Multiple Output
*2 SDMA: Space Division Multiple Access
*3 CSI: Channel State Information
*4 FPGA: Field Programmable Gate Array

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Spectrally Efficient Elastic Optical Path Network (SLICE)

Overview
Sustaining the growth of data traffic will require a more efficient and scalable optical transport platform for links of 100 Gbit/s and beyond. We devised a novel, spectrum-efficient and scalable optical transport network architecture, called the spectrum-sliced “elastic optical path” network (SLICE), and demonstrated its feasibility. Conventional optical networks allocate fixed bandwidth to every optical path regardless of its actual traffic volume and path length on the basis of the worst-case design policy. In contrast, SLICE applies adaptive spectrum allocation to an optical path according to the traffic volume and path length. Together with adaptive modulation format selection and elastic channel spacing, SLICE provides significant spectral resource savings; it would be a cost-effective means of optical transport in the coming 100 Tbit/s/fiber era.

Features
- Adaptive spectral resource allocation to an optical path according to traffic demand and path length to achieve significant savings of network resources
- Multi-rate, multi-reach (modulation format) optical transponders that generate the necessary minimum spectral width
- Bandwidth-variable ROADM*1s and WXC*2s that establish end-to-end elastic optical paths
- Elastic channel spacing by using the frequency slot concept instead of the current ITU-T fixed frequency grid
- A routing and spectrum assignment (RSA) algorithm that accommodates various traffic demands in a spectrally efficient manner

Application scenarios
- Metro transport networks that support a per-channel capacity of 100 Gbit/s and beyond in a highly economical manner
- Core transport networks that support a per-channel capacity of 100 Gbit/s and beyond in a highly economical manner
- Optical virtual private line service with a wide variety line rates

*1 ROADM: Reconfigurable Optical Add/Drop Multiplexer
*2 WXC: Wavelength Cross-Connect

Fig. 1. Concept of SLICE
Fig. 2. Spectral resource savings achieved by squeezing out stranded spectral resources that have not been fully utilized
10 G-EPON OLT and ONU LSIs

Overview
We have developed a system LSI that integrates the main functions of the 10 G-EPON (10-Gigabit Ethernet Passive Optical Network) on a single chip. It enables construction of an IEEE standard next-generation optical access network to which migration from the current GE PON using the current optical distribution network is easy. It is a chipset whose main components are a compact and inexpensive OLT*1 and ONU*2, which enable 10 Gbit/s communication, 10 times as fast as even the FLET’S optical system that is currently in service.

Features
- The OLT-LSI can accommodate both GE-PON ONU and 10 G-EPON ONU in the same system (handles dual rates)
- The ONU-LSI provides two modes, 10 G symmetrical upward and downward, and asymmetrical 10 G down with 1 G up
- Fast and efficient dynamic allocation of upward bandwidth by hardware and software combination
- Software sleep control reduces power consumption when the equipment is not being used
- VLAN*3 function allows flexible handling of diverse services

Application scenarios
- Increased speed and capacity of Internet services (for houses and condominium buildings)
- Network services for corporations
- Mobile backhaul network

*1 OLT: Optical Line Terminal
*2 ONU: Optical Network Unit
*3 VLAN: Virtual Local Area Network
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A Rich Communication Environment Using Home Electronics

Overview
As use of NGN becomes widespread, phone numbers will be used for rich communication that includes video and data as well as voice calls. The interworking of handy and familiar home electronics and other such devices provides a simple environment for achieving such rich communication. Our research is based on actual lifestyle scenarios and involves first establishing a signaling system, followed by specification of a Teleservice*1 for securing mutual connections between terminals for media (voice, video and data), and device interworking technology for easy provision of rich communication through the interworking of devices in the home.

Features
- Voice, video and data communication is possible with multiple interworking devices
- Voice, video and data can be transferred between interworking devices
- Digital content can be sent and received using phone numbers
- TTC*2 specifies the Teleservice, which enables file transfer and video communication between terminals on NGN
- Specification of a method for achieving communication through interworking of devices using UPnP*3 implemented with home electronics (UPnP FORUM: Telephony:1)

Application scenarios
- Communicate with relatives far away while sharing video and pictures, etc. via phone numbers
- Send and receive voice, video or data freely from the living room, study or other places in the home
- Describe products while viewing catalogs during a call
- Advising while looking at test papers such as giving corrections for distance learning, etc.
- Send color documents or materials via phone numbers, like FAX

*1 Teleservice: Decision on interchanging terminals within the communication path for media communication after the start of communication
*2 TTC: Telecommunication Technology Committee
*3 UPnP: Universal Plug and Play
Techniques for PWR (Personal Wireless Router)

Overview
PWR is a portable wireless cognitive router produced by NTT Broadband Platform, Inc. The unit has a compact chassis and is battery driven. PWR provides Internet access via 3G, WLAN, etc., and it automatically selects the most suitable wireless medium to connect WLAN terminals, such as laptop PCs and gaming devices, to the IP network. NTT Laboratories helped in the development of PWR by investigating how to make automatic selection of the most suitable network interface for maintaining communication quality and by conducting evaluations and field tests of the unit.

Features
- **Techniques of interface selection**
  - Suitable interface selection from various available network-side interfaces
  - Suitable radio channel selection of the terminal-side wireless LAN
- **Techniques for lengthening operation time**
  - Standby function when there are no active WLAN terminals
  - Interface control (Intermittent access points scan, inactive interface sleep, etc.)

Application scenarios
- **General users**
  - Music downloads, podcasts, etc., while on the move
  - Web browsing, network gaming, etc., in a café
- **Business users**
  - Access to a company’s network at a hotel without LAN equipment
  - Temporary wireless LAN environment at a construction site, etc.
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Zoom Microphone for Picking Up Distant Sounds

Overview
The zoom microphone can pick up distant sounds in analogy to a camera lens that can zoom in on distant targets. By locating a three-dimensional reflector near multiple microphones to collect spatially scattered sound energy, it is possible to pick up sounds from a specific distant target. This microphone will enable telecommunication services in which users can zoom in to video and pick up sounds at user-selected positions. It would also be useful for productions of highly realistic 3D video presentations and other high-resolution services that will become popular in the future.

Features
- The microphone can pick up distant sounds many meters away.
- Users can select any listening direction even though the equipment remains fixed.
- Multiple users can listen to sounds from different directions at the same time.
- It can “re-pick up” target sounds when multiple observed sounds have been recorded.

Application scenarios
- Content delivery: Live broadcasts of sports such as soccer, American football and figure skating
- Free-viewpoint TV: TV Programs in which users select the viewing position and angle
- Hall acoustics: Enabling Q&A sessions without hand-held microphones
- Telepresence systems: Clearly capturing the speech of a specific speaker in a large conference room
Fuel cells efficiently convert energy stored in fuel into electricity. Based on NTT's own technology, cells (i.e., power-generation elements) and a laminated “stack” for housing them were developed. Moreover, in cooperation with the outside world, a fuel-cell system featuring the world's highest power-generation efficiency and lifetime was developed. These technologies contribute to reduction of CO₂ emission.

### Overview
Fuel cells efficiently convert energy stored in fuel into electricity. Based on NTT’s own technology, cells (i.e., power-generation elements) and a laminated “stack” for housing them were developed. Moreover, in cooperation with the outside world, a fuel-cell system featuring the world’s highest power-generation efficiency and lifetime was developed. These technologies contribute to reduction of CO₂ emission.

### Features
- Ceramic cells that enable high-efficient power generation
- Original electrode material that realizes longer lifetime
- Original stack configuration that draws out best cell performance
- Even higher efficiency by utilizing high-temperature exhaust heat

### Application scenarios
- Power can be supplied to telecommunications buildings and offices at high efficiency (low CO₂-emission output level)
- Simultaneous supply of heat and power to schools and restaurants

### Specification of fuel-cell system

<table>
<thead>
<tr>
<th>Items</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>1,500 (W) x 900 (D) x 1,800 (H) mm</td>
</tr>
<tr>
<td>Weight</td>
<td>1,330 kg</td>
</tr>
<tr>
<td>Output</td>
<td>0 kW - 5 kW</td>
</tr>
<tr>
<td>Load following</td>
<td>50 - 100%</td>
</tr>
<tr>
<td>Generation efficiency</td>
<td>AC 45% (DC 54%)</td>
</tr>
<tr>
<td>Fuel</td>
<td>Town gas</td>
</tr>
</tbody>
</table>
Compact and Functional Photonic Device Integration based on Silicon Photonics

Overview
Silicon photonics technology enables high-productivity fabrication of ultra-compact photonic devices. We have used it to monolithically integrate various functional photonic devices on a silicon substrate. This technology can reduce the size and power consumption of photonic devices for telecommunications applications, and moreover, it can be applied to optical interconnections of LSI electronic circuits. Thus, it can help to reduce the costs and environmental loads in both future telecommunication networks and data centers that have to deal with huge amounts of data traffic.

Features
- Ultra-fine silicon fabrication technology for making compact and low-loss wavelength filters
- Compact silicon semiconductor waveguide for dynamic photonic functions such as fast optical intensity adjustment and modulation
- Photo-detectors based on high-purity germanium grown on a silicon substrate (developed in collaboration with the University of Tokyo)
- Monolithic hetero-function integration on a silicon substrate
- Low power consumption through compact device integration

Application scenarios
- Fast signal equalization of photonic nodes using multi-channel integrated VOA-PD*1 devices
- Low-power network operation with bandwidth control using compact WDM*2 receivers
- Large-capacity access networks using compact multi-channel transceivers with multi-level modulation formats
- Low-power LSI electronic circuits with on-chip optical interconnections

*1 VOA-PD: Variable Optical Attenuator-Photodiode
*2 WDM: Wavelength Division Multiplexing

* Ge-PD: Germanium Photodiode
Ultrahigh-speed DAC for Optical Communications Systems

Overview

Digital coherent optical transmission schemes with advanced modulation formats, such as M-QAM*1 and OFDM*2, are promising techniques for constructing future beyond-100-Gbit/s/ch optical communications systems. In the transmitter for such systems, ultrahigh-speed DACs*3 are key components for generating complex modulated signals. NTT Laboratories have sophisticated ultrahigh-speed transistor, InP HBT*4, technology and circuit design techniques, and have succeeded in developing ultrahigh-speed 6-bit DACs for such systems of the future.

Features

- The first 6-bit DAC that can operate at a sampling rate above 30 GS/s
- Provides various modulated signals, such as M-QAM and OFDM
- Uses our in-house ultrahigh-speed transistor, InP HBT, technology
- Novel circuit design techniques for ultrahigh-speed and low-power operation
- Uses broadband packaging technique

Application scenarios

- Future ultrahigh-speed and large-capacity optical communications systems (e.g. beyond-100-Gbit/s/ch optical communications systems)
- Future ultrahigh-speed optical access systems
- Measurement tools (e.g. ultrahigh-speed arbitrary waveform generator)

*1 M-QAM: M-ary Quadrature Amplitude Modulation
*2 OFDM: Orthogonal Frequency Division Multiplexing
*3 DAC: Digital-to-Analog Converter
*4 InP HBT: Indium Phosphide Heterojunction Bipolar Transistor
Photonic Crystal Laser with Ultra-low Power-energy Cost

Overview
Photonic crystal technologies enable us to make ultra-compact cavities with volumes less than 1 μm$^3$. A laser with an ultra-low threshold can be made by decreasing the cavity volume. Moreover, a photonic network chip, which is a hybrid integration with silicon CMOS*, must have appropriate output power for detecting the light at the photodetector and a high-speed direct modulation capability with very low power consumption. We have developed ultracompact buried heterostructure photonic crystal laser for such a purpose by employing the technologies of InP-based photonic integrated circuits.

Features
- World’s smallest buried heterostructure (5.0 x 0.3 x 0.15 μm$^3$) laser
- Ultralow threshold power (6.8 μW) and high output power (100 μW) achieved by optical pumping
- Extremely low energy consumption of direct modulated laser: 8.76 fJ/bit for 20-Gbit/s direct modulation with clear eye-opening
- Next step in development: PhC laser using electrical pumping.

Application scenarios
- High-density photonic integrated circuit
- Photonic network on chip: high-bandwidth density and reconfigurable photonic network on silicon CMOS
- CPU: continuous CMOS processor advances supported by energy-efficient optical system
- Green ICT: power efficient ICT equipment in data centers
- Other applications: ex. Ultra-small sensors requiring nano-scale light sources

* CMOS: Complementary Metal Oxide Semiconductor
Fast, Compact Random Number Generator Using Semiconductor Lasers

Overview
Random number sequences that are absolutely unpredictable are essential for data security, so there is a demand for a compact device that rapidly generates random numbers on the basis of a physical phenomenon. Our work focused on the phenomenon in which the intensity of light from a laser varies randomly over time at high speed. We used the most advanced integrated optical circuit technology and high-frequency packaging technology to achieve a fast and compact random signal generator module. Digitizing the random output signal of the module can produce an unpredictable sequence of random numbers at high speed.

Features
- Compact, integrated system by using integrated optical circuit technology
- Random number generation at 2.08 Gbit/s
- Physical guarantee that generated random number sequence cannot be predicted

Application scenarios
- Password generation, encryption key generation
- Generation of random numbers required for the segmentation processing of secret data in secret sharing schemes
- Generation of key sequences in quantum cryptography
- Can also be used in numerical computation in science and engineering that uses random numbers

Mechanism of random signal generation
The origin of randomness is quantum noise, which is unpredictable in principle. The quantum noise is rapidly amplified within a short time less than 0.5 ns due to instability nature of the optical feedback laser. Then it causes unpredictable and macroscopic random fluctuations in the laser output light, which is easily observable.
Human Activity Recognition with Wrist-worn Sensor Device

Overview
Activity recognition technology is one of the most important technologies for lifelogging and the care of elderly persons. The recognition method proposed in this study recognizes 'what a user is doing' by simply using a single wrist-worn sensor device. The device is equipped with a camera, a three-axis accelerometer, a microphone, a digital compass, and an illuminometer. The method recognizes the user's activities by employing objects the user is using, hand movements of the user, and sounds emitted in the activities.

Features
- We sense user's daily activities by focusing on his/her hand, which is the part of the body most often involved in daily activities.
- We can recognize various activities with a single device.
- A camera on the wrist captures images of objects held in the hand. This permits us to recognize activities by using visual information of objects being held.
- We can preserve the user's privacy because our method recognizes activities by using abstracted image and sound information.

Application scenarios
- Healthcare and care of elderly persons: Watch over elderly persons at a remote location
- Lifelogging: Making a continuous record of activities in daily life
- Context-aware services: Switch services automatically according to the user's activities
- Context-aware advertising: Recommend ads according to trends in daily activities
Atto-joule All-optical Switch ~Putting a Photonic Network into a Chip

Overview
Energy consumption and heat generation are becoming problematic issues in ICT, and it is expected that the introduction of photonic network technology into an information processing chip will help to alleviate them. Conventional photonic devices are too large and consume too much energy, and thus it is difficult to integrate many photonic devices in a chip at present. NTT Laboratories have built ultra-small all-optical switches that consumes an extremely small amount of energy, by employing a photonic crystal, which is an artificial dielectric structure with a periodic refractive index made by state-of-the-art nano-fabrication technology. We have demonstrated all-optical switching with a consumption energy of only 440 atto\(^3\) joule, a record-low value.

Features
- Photonic crystal that strongly confine light within a wavelength-sized volume.
- The all-optical switch with an ultrasmall photonic crystal nanocavity (0.02 \(\mu\)m\(^3\)).
- Highly integratable and ultrasmall device with ultralow energy consumption.
- All-optical switching of light signals by using a 440-atto joule control light pulse (less than 1/100th the energy of the previous record, Fig. 1).
- Alleviates trade-off between processing speed and energy consumption (Fig. 2).
- Capable of extracting pulse from a 40-Gbit/s pulse stream.

Application scenarios
- Key device for large-scale photonic integration technology. Promising for large-scale photonic integrated circuit.
- High-speed information processing chips with ultralow energy consumption
- Useful for implementing large-scale photonic network technology in MPU\(^2\) chips to drastically reduce the energy cost of information processing
- Integrated chips for routers, datacenters, and mobile terminals

\(^{1}\) atto: 1/10\(^{18}\)
\(^{2}\) MPU: Micro Processing Unit
New Digital Processing Scheme Using Micromachine Technology

Overview

We developed a novel digital processing method that involves vibrating a tiny doubly clumped beam oscillator fabricated with micromachine\(^1\) technology. This method allows not only the fundamental logic operations of AND, OR, and XOR, but also multiple operations in parallel. To our knowledge, this is the first proposal for constructing a logic circuit from a single electromechanical device. The technique is potentially the key to constructing nanomachine computers that may lead to highly energy efficient and robust signal processing systems.

Features

- The active element is a 250 \(\mu\)m-long, 85 \(\mu\)m-wide, and 1.4 \(\mu\)m-thick beam oscillator.
- The binary information is encoded as an oscillation with an amplitude of \(10^{-8}\) m.
- Multiple channels of binary information are encoded as the oscillations at different frequencies.
- The function of parametric frequency conversion\(^2\) can mix the input binary channels to construct all the primary logic gates.
- The multiple and parallel logic operations with multiple inputs and outputs are also possible.

Application scenarios

- Highly energy-efficient and robust computer systems
- Ubiquitous systems requiring low power consumption
- Integration with highly sensitive MEMS sensors and optical devices

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\(^1\) Micromachine (MEMS): Technologies to integrate micron-size mechanical devices on a chip using semiconductor microfabrication methods.

\(^2\) Parametric frequency conversion: A technique to generate difference or sum frequencies by mixing two oscillations with different frequencies.

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(A): Schematic drawing of parametric frequency conversion
(B): Example of logic operations