R&D Project Report

Overview of SINET3 –Next-generation Science Information Network

Shigeo URUSHIDANI[1], Shunji ABE[2], Jun MATSUKATA[3], Yusheng JI[4], Kensuke FUKUDA[5], Michihiro KOIBUCHI[6] and Shigeki YAMADA[7]

[1,2,3,4,5,6,7]*National Institute of informatics*

[1,2,4,5,7]*The Graduate University for Advanced Studies (SOKENDAI)*

ABSTRACT

This paper outlines the next-generation science information network, called SINET3, which will be launched in April 2007 as the integrated successor network to SINET and Super-SINET. Using leading-edge networking technologies, SINET3 will provide a rich variety of network services and will adapt flexibly to the needs of the research and education community. The network services include multi-layer services such as IP, Ethernet, and lambda services, well-prepared virtual private network services for collaborative research among related organizations, and layer-1 bandwidth on demand services for emerging high-performance applications. Introducing layer-1 switches as core network components, the network will be structurally changed into an advanced hybrid optical and IP/MPLS network and will form a nationwide innovative network infrastructure for the research and education community. This paper gives an overview of SINET3 from the viewpoints of network services, network architecture, and networking technologies.

KEYWORDS

Cyber Science Infrastructure, SINET3, hybrid network, multi-layer network, bandwidth on demand, L1VPN, next-generation SDH/SONET, GMPLS, MPLS, logical router, performance monitoring

1 Introduction

Through close collaboration and cooperation with leading universities and research institutions in Japan, NII is diligently promoting the construction of the Cyber Science Infrastructure (CSI), [1] which is a new comprehensive framework for IT-based environments to boost scientific research and education activities, and to further strengthen their international competitiveness. CSI's various initiatives include the national research grid initiative, [2] the university PKI and authentication system initiative, [3] and the academic digital contents projects, [4] as well as the project for a next-generation research and education network. [5] As preparation for the next-generation network to serve as the core of CSI, fruitful discussions among universities, research institutes, and NII have refined the network concept through careful analyses of the current situation and future possibilities.

NII currently operates two academic infrastructures, the Science Information Network (SINET) and the Super SINET. [5] SINET is a nationwide academic Internet backbone designed to promote research and education and to provide a high-speed communication environment for more than 700 universities and research institutions, as shown in Fig. 1. It also provides great connectivity to other domestic networks through private peering at its nodes and public peering at JPIX and JPNAP, and to foreign networks [6]–[11] through its international lines to the U.S.A. (New York and Los Angeles) and Asia (Singapore and Hong Kong). Super SINET provides an ultra-high-speed network environment to academic institutions concentrating on such re-

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1) *urushi@nii.ac.jp*, 2) *abe@nii.ac.jp*, 3) *jm@nii.ac.jp*, 4) *kei@nii.ac.jp*, 5) *kensuke@nii.ac.jp*, 6) *koibuchi@nii.ac.jp*, 7) *shigeki@nii.ac.jp*

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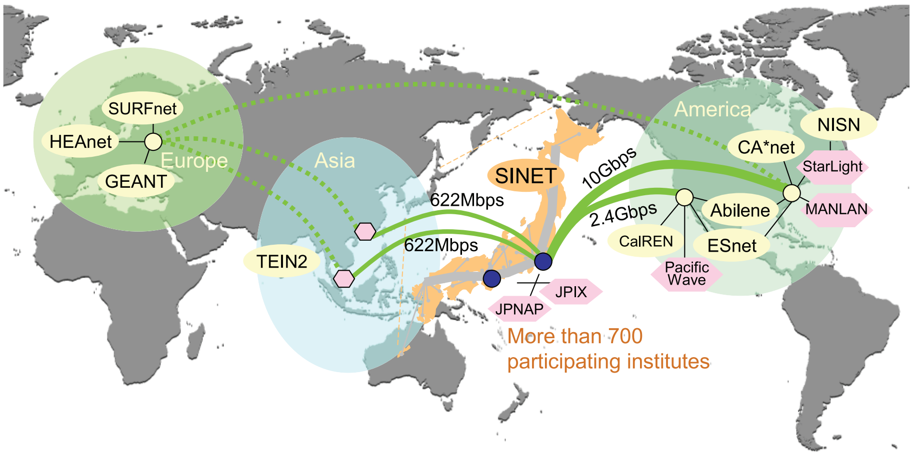


Fig. 1 Broad range of connectivity in SINET.

Table 1 Main features of SINET3.

Items	Features	Notes
Network services	Multiple layer	Accommodation of all layers
	Enriched VPN	Strong support of collaborative research
	Enhanced QoS	Strong support of high-performance applications
	Value-added	Provision of performance monitoring data
Network architecture	New architecture	Hybrid optical and IP/MPLS network
	High flexibility	Flexible resource assignment to layers 1-3
	High reliability	Fast service recovery owing to multiple loops
	Large capacity	Maximum of 40-Gbps lines

search areas as high-energy physics, nuclear fusion science, space and astronomical science, genome analysis, nanotechnology research, simulation sciences, and grid computing. Super SINET has contributed to a significant number of outstanding research findings.

As SINET and Super SINET have served admirably as the Japanese academic infrastructure, their traffic volume has steadily grown requiring more link bandwidth, and their users' requirements for network service capabilities have become increasingly diverse. However, current equipment, typically the IP routers, limits the capabilities for providing various network services as well as economizing the network for attaining higher-speed communication environments. Therefore, new technologies must be introduced in order to overcome these limitations. Meanwhile, new movements that aim to provide end-to-end circuit connections for high-performance applications based on hybrid network architectures have emerged in several academic fields, [8], [12] providing new opportunities to create innovative global research and education environments. After taking into account the above-mentioned situations, NII has decided to construct a next-generation academic infrastructure that integrates SINET and Super SINET, called SINET3.

The main features of SINET3 are shown in Table 1. It will provide multi-layer transfer services including end-to-end circuit services, enriched virtual private network services strengthening collaborative research among related organizations, enhanced qualities of service including bandwidth on-demand services for high-performance applications, and other value-added services, such as network performance monitoring. The network will be an advanced hybrid optical and IP/MPLS network and accommodate all of the network services into a single network, flexibly allocating network resources to each service in response to user demands. The network will also be highly robust against network failures and natural disasters owing to its multi-loop topology. The backbone capacity will be a maximum of 40 Gbps. As a whole, SINET3 will be a prolific, flexible and reliable infrastructure for the research and education community.

The following sections describe in detail the network service features, the network designs, the node systems capabilities, and applicable networking technologies.

2 Network service features

SINET3 provides a much broader range of network services than the currently provided services (Fig. 2). The network service menu is enriched with four main capabilities: multi-layer service capabilities, multiple virtual private network (VPN) service capabilities, multiple quality of service (QoS) capabilities, and network performance monitoring capabilities. The following subsections describe typical services and SINET3's new capabilities.

2.1 Multi-layer network services

SINET3 supports multi-layer network services, that is, IP (layer-3) services, Ethernet (layer-2) services, and lambda/dedicated line (layer-1) services.

The IP traffic has been steadily increasing; in addition, IPv6-based applications have a large potential to boost the total IP traffic. SINET3 therefore transfers both IPv4 and IPv6 traffic in a dual stack environment without degrading the network performance even for any mixture ratio between IPv4 and IPv6. Other typical IP services include multicast services, such as IP multicast and P2MP MPLS, [14] and application-based prioritized services so as to support real-time applications such as streaming services and video and voice communication services.

Wide-area Ethernet network services are expected to promote several collaborative research efforts among geographically distant research locations. SINET3 provides point-to-point and multipoint-to-multipoint Ethernet services by utilizing the latest multi-protocol label switching (MPLS) technologies [17], [18] on IP routers. Prioritized services in addition to best-effort services will also be provided.

Layer-1 services, in other words circuit services that temporarily hold dedicated network resources, are promising services for leading-edge applications that are sensitive to certain transfer characteristics, such as packet loss, end-to-end delay, and delay variance. The services are also highly secure, so in some ways they provide users with the ultimate research environment. Layer-1 point-to-point services are of two types. One is a lambda service that assures a total bandwidth for user interfaces such as 1-Gigabit Ethernet and 2.4-Gbps SDH/SONET interfaces. The other is a bandwidth-specified dedicated line service that scales up to 1 Gbps or 10 Gbps on a 1-Gigabit or 10-Gigabit Ethernet interface. The granularity of the bandwidth is technically possible to be 50 Mbps or 150 Mbps, but it might be larger when network resource manageability is considered. The layer-1 services will be provided along with scheduling capabilities and eventually on-demand capabilities when the services become popular in the research and education community.

2.2 Multiple Virtual Private Network (VPN) services

To support collaborative research and development among related organizations, it is essential for the network to provide them with a closed user group environment. SINET3 provides a variety of VPN services in terms of layer and quality of service depending on the organizations' requirements.

In addition to the IP-VPN services, layer-2 (Ethernet) VPN services are provided on the same equipment, IP routers, as shown in Fig. 3 (a). The latest MPLS technologies, such as BGP/MPLS-VPN, [15], [16] Ethernet

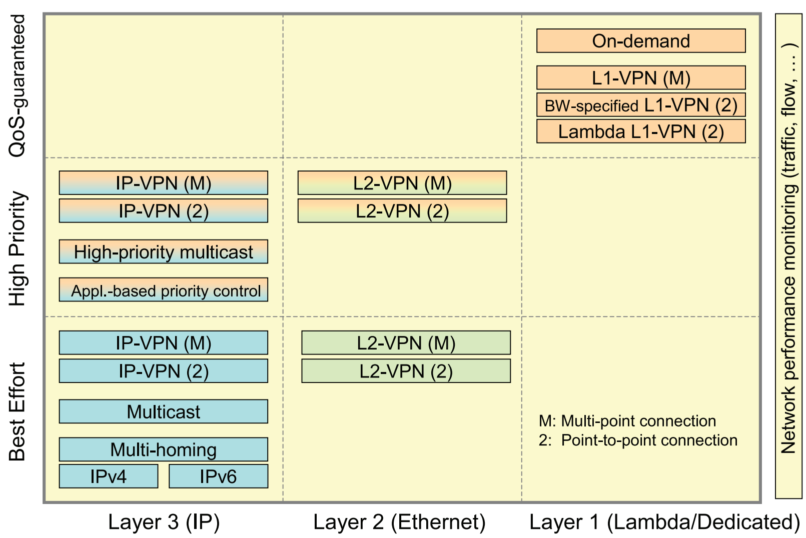


Fig. 2 Scope of network services of SINET3.

over MPLS (EoMPLS), [17] and virtual private LAN service (VPLS), [18] make possible such a great coexistence on a single network. Each layer of VPN service is also managed independently in terms of routing, signalling, and forwarding on the single network using advanced multi-instance technologies, which will be described in Section 4.

Layer-1 VPN services that form virtually closed user groups by layer-1 paths on the common infrastructure will provide unparalleled research and education environments to users. The services will begin on a point-to-point basis as shown in Fig. 3 (b) and will be extended to multiple points in response to user requirements and depending on the progress of the standardization at IETF. [29], [30]

2.3 Multiple quality of service (QoS)

Although every user would be satisfied with the quality of the network without QoS control through abundant network bandwidth, this ideal situation is difficult to realize in the current academic networks, where network resources must be efficiently and cost-effectively utilized among a large number of users and where applications require different network QoS. A QoS control mechanism is therefore essential for our network to meet diverse QoS requirements. Considering more advanced applications, such as an uncompressed high-definition video communication, it is desirable for the network to furnish a complete QoS guaranteeing mechanism even for broadband services. As a packet-based elaborative QoS control mechanism requires a complicated queue design and provisioning and cannot provide a strict QoS guarantee, we decided to utilize a combination of simple circuit-based and packet-based QoS technologies. Circuit-based QoS technologies provide QoS-guaranteed services, while packet-based ones provide high-priority QoS services.

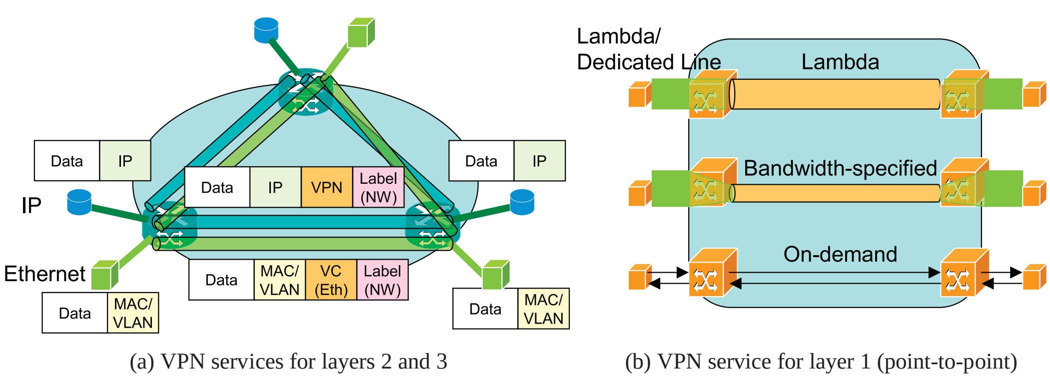
For QoS-guaranteed services, layer-1 resources, i.e. time slots, are assigned to the services with the granularity of 50/150 Mbps. These services provide extremely small packet delay, no delay variance, and no packet loss. We believe that these ultra-high qualities of service will stimulate research and development of new innovative applications.

For high-priority QoS services, application-based priority control with multiple priority classes is performed in order to support up to real-time applications such as video and voice communications. As for IP-VPN and L2-VPN, both which are provided on a common network, multiple priority classes are also designated depending on the sensitiveness of the application data to the transfer performance among the VPNs.

2.4 Network performance monitoring

Network performance monitoring is very important for both network supervisors and users. In order to more reliably operate and manage the network, it is valuable to monitor the amount of network traffic by using indicators of network quality, such as delay, delay jitter, and packet loss, and indicators of network equipment performance, such as CPU and memory usage. We can make good use of this data to improve the network operation and management, thereby attaining higher performance and a more secure environment for users.

The amount of network traffic and the performance of network equipment such as IP routers and layer-1 switches are monitored by using the Simple Network Management Protocol (SNMP) and a general communication based on TCP. Moreover, the network quality is measured by installing active measurement equipment in the network. Detailed information on the traffic flows and network security information, such as on possible DoS/DDoS attacks, can also be gained by installing packet capture equipment and a special network security monitoring system.



(a) VPN services for layers 2 and 3 (b) VPN service for layer 1 (point-to-point)

Fig. 3 Service examples on SINET3: VPN services for layers 1 to 3.

To enhance the network usability, a part of the monitored performance data is provided for users as one of the new services of SINET3. This service can provide the network traffic flow, network quality, captured packet header data, and network security information under SINET3's network management regulation. Furthermore, network and applied network researchers can also apply this data to their research.

3 Network design

This section describes the overall network architecture and the detailed network structure of SINET3 for providing the services described above. It also includes information on other important infrastructural features.

3.1 Overall network architecture

A network infrastructure should be efficiently utilized by fairly and effectively sharing network resources among users and should be highly available even in the event of network failures, as well as being capable of providing a rich variety of network services. In addition, it is preferable for a network to give some open interfaces to users and applications to encourage efficient use of network services. SINET3 therefore has a high-level network architecture design composed of a transport network, an adaptive network control platform, and a user-oriented service control platform for these purposes (Fig. 4).

The transport network is a hybrid optical and IP/MPLS network that is composed of layer-1 switches and IP/MPLS routers. It has a wide variety of service capabilities such as layer-1 circuit services and VPN services as well as IP services. It also provides sufficient network bandwidth (a maximum of 40 Gbps) and is highly reliable and available. As all of the services can be accommodated in the same network link, the link bandwidth is flexibly assigned to multiple layers in response to the demand of each layer. For example, the bandwidth for a layer-1 connection can be assigned by changing the shared bandwidth for layers 2 and 3, which will be described in greater detail in Section 4.

To make optimal use of network resources and strengthen network resilience, the network has to supervise each layer, paying attention to such information as the traffic and failures, and find the optimal resource assignment. The network control platform monitors and checks the network situation and dynamically assigns network resources in response to the service requirements and network failures. It might rearrange resources to accommodate both the existing and new services with optimal resource utilization. A path route calculation capability based on Path Computation Element (PCE), [31], [32] which is used in reserving network resources, will also be placed on this platform. The service recovery procedure is also very important, because each layer has its own recovery mechanism

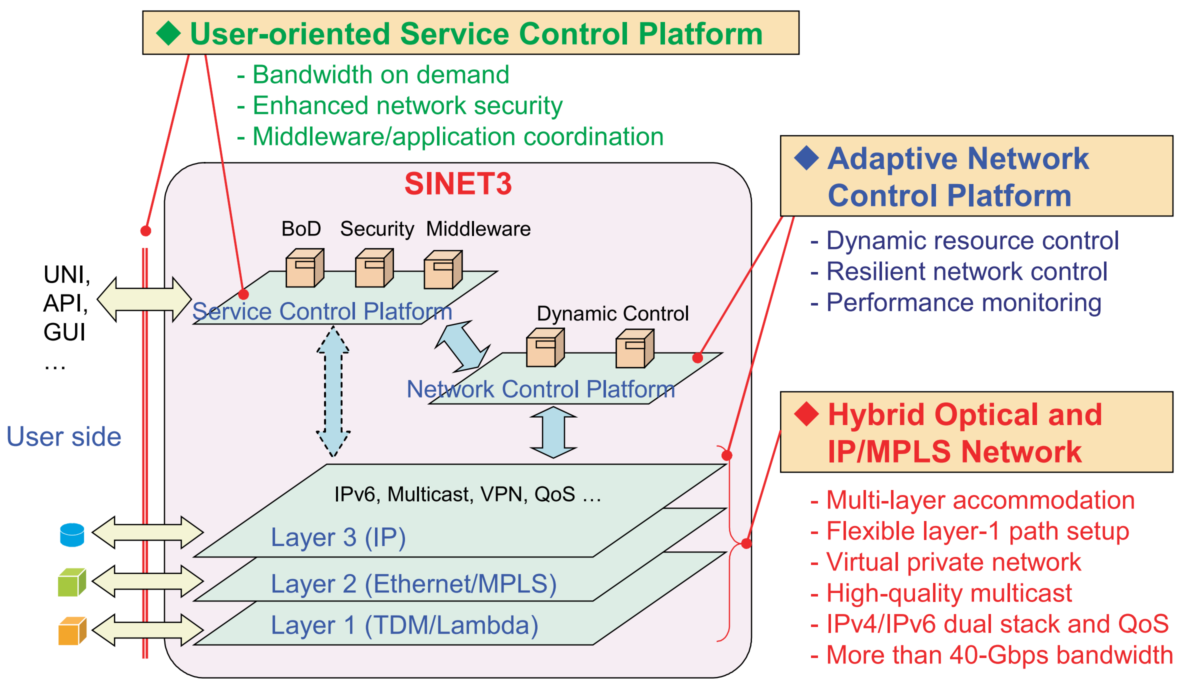


Fig. 4 High-level network architecture of SINET3.

and the network should carefully select the appropriate combination of mechanisms depending on the type of failure. Network traffic and performance monitoring capabilities are also enhanced in this platform.

Network services seem able to evolve with open interfaces for users and applications. A user-oriented service control platform makes it easy to use network services and enables smooth collaboration between user applications and the network. The platform will be built up gradually depending on the user requirements for network services along with access control means to the open interfaces. As the first step in this platform, layer-1 on demand path setup services as well as scheduled services will be given along with some open user interfaces. Enhanced network security capabilities against DDoS, worms, and so on will produce a secure platform. Coordination capabilities with user middleware or applications will evolve through collaborative efforts with cutting-edge application users.

3.2 Network structure

Although SINET3 provides all of the services that SINET and Super-SINET have provided, the hardware stack of SINET3 — based on layer-1 switches — is quite different from that of SINET and Super-SINET.

As shown in Fig. 5, the current network is composed only of IP routers, although Super SINET used to include some OXCs and WDM devices as described in the reference. [13] The IP routers are located at the universities and research institutions, excluding the three backbone sites of Tokyo, Nagoya, and Osaka. The hierarchy primarily depends on the locations of SINET and Super-SINET routers and only the backbone layer has route redundancy in the loop topology.

In SINET3, the network has a two-layered structure with edge and core layers, whose capabilities are clearly separated. Each edge layer node is located at a university or research institution and consists of an edge layer-1 switch that mainly furnishes Ethernet interfaces to accommodate any layer user equipment such as IP, Ethernet, and lambda/dedicated line devices. Each core layer node is located at an independent location, such as a public data center, and consists of a core layer-1 switch and a high-performance IP/MPLS router. The core nodes are interconnected in a redundant topology and will enhance the network survivability in the event of network failures such as node and link outages and natural disasters such as earthquake.

3.3 Network topology

The network topology of SINET3 is shown in Fig. 6. As of April 2007, it will have more than 60 edge nodes and 12 core nodes. The line speed between the edge and core nodes will be 1 to 20 Gbps, and the backbone line speed between core nodes will be a maximum of 40 Gbps. The backbone links form three loops nationwide that enhance network resilience against network failures and natural disasters and enable efficient use of the network bandwidth by sharing the backbone lines among users for all services. This network topology will provide a more flexible and reliable network infrastructure than ever before for the research and education community.

4 Node capabilities and technologies

SINET3 will use a combination of layer-1 switches and IP/MPLS routers in order to provide multi-layer services, as explained in the previous section. The

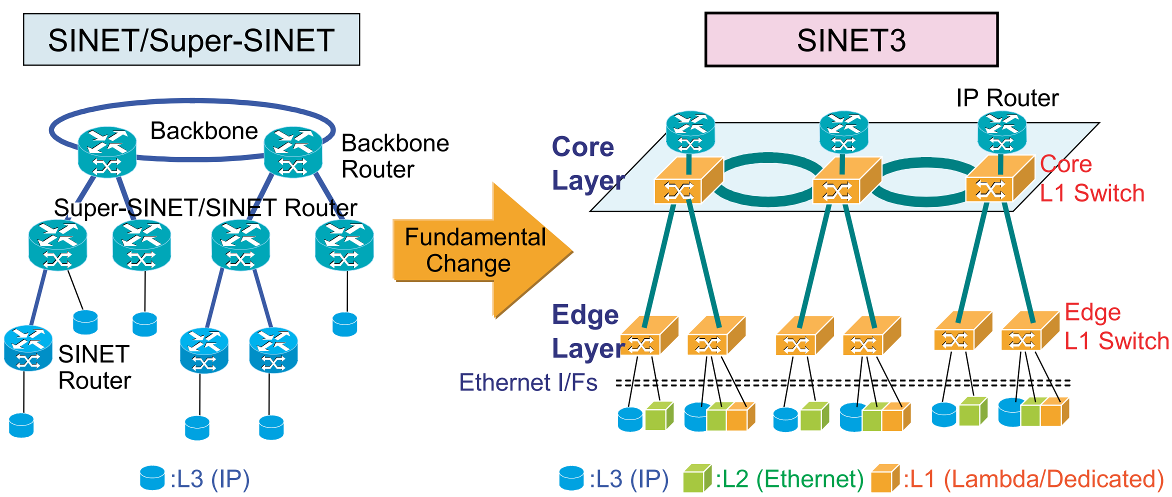


Fig. 5 Network structure of SINET3.

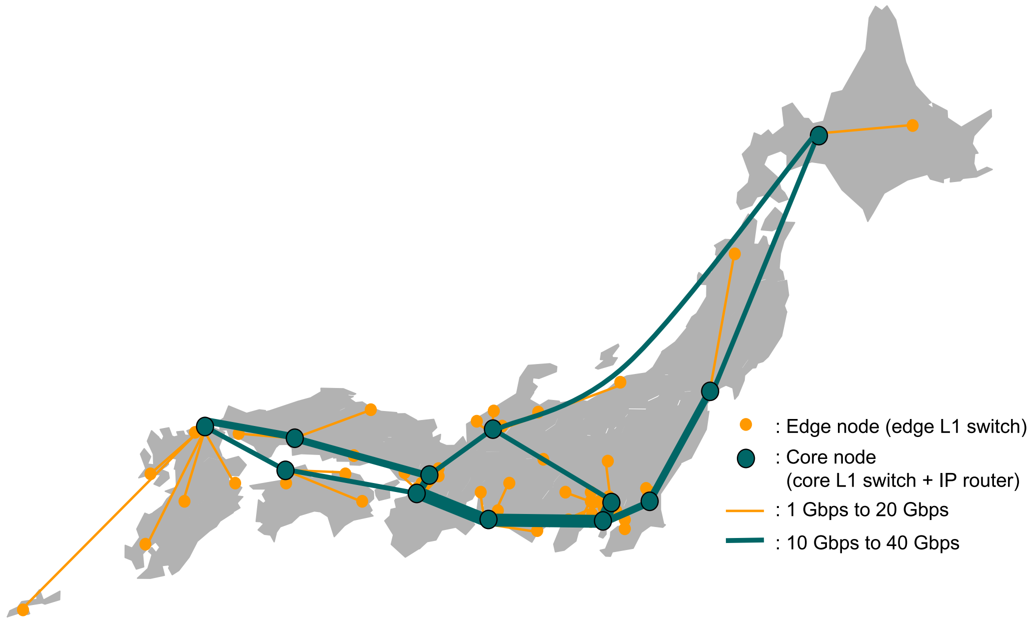


Fig. 6 Network topology of SINET3.

best solution was chosen from several candidates; this choice is mainly based on cost-effectiveness, ease of operation, and technical maturity. In this section, the node structure and capabilities are explained in a high-level description, followed by an explanation of the enabling technologies on the layer-1 switches and IP/MPLS routers.

4.1 Node structure and capabilities

The node structures at the edge and core layers are shown in Fig. 7. The trunk line between the edge and core nodes is shown as a SDH/SONET line of 10 Gbps or 2.4 Gbps, where full network services are available, but Ethernet lines such as 1-Gigabit Ethernet can be used when layer-1 services are not necessary. The backbone line between core nodes is a SDH/SONET line of 40 Gbps or single/multiple 10 Gbps.

An edge layer node is composed of an edge layer 1 switch furnished with Ethernet interfaces to user lines so as to accommodate the users' layer-3 (IP), layer-2 (Ethernet), and layer-1 (lambda or dedicated line) equipment. It uses layer-2 multiplexing to accommodate layer-3 and layer-2 traffic, shown by the blue and green arrows, in the shared bandwidth on the trunk line. Meanwhile, layer-1 traffic, shown by the red arrows, is assigned a dedicated bandwidth on the trunk line and is completely separated from the layer-3 and layer-2 traffic. As for user interfaces, the edge node can also accommodate SDH/SONET interfaces at speeds of 2.4 Gbps and 10 Gbps, in addition to Ethernet interfaces. At the beginning of operation, it will provide 2.4-Gbps layer-1 interfaces to support a large-scale e-VLBI project, which currently uses separate dedicated lines. A 10-Gbps interface will be used to connect the edge node to a user layer-1 system that accommodates multiple-layer user devices.

A core layer node is composed of a core layer-1 switch and an IP/MPLS router. The core layer-1 switch sets up an internal layer-1 connection for layer-1 traffic and forwards layer-3 and layer-2 traffic to the IP/MPLS router. The IP/MPLS router handles layer-3 traffic based on IP headers and if necessary, such as for IP-VPN services, encapsulates the traffic with MPLS labels. It also handles layer-2 traffic based on VLAN/MAC labels, encapsulates them with MPLS labels, and transfers them along IP/MPLS routers via layer-1 switches. The backbone line between core nodes accommodates both the IP/MPLS traffic and layer-1 traffic by completely separating the bandwidth.

The network bandwidth is flexibly assigned to each layer corresponding to the demand. For example, the bandwidth for a layer-1 connection can be assigned by reducing the shared bandwidth for layers 2 and 3.

4.2 Layer-1 switch technologies

As for layer-1 switch technologies, next-generation SDH/SONET technologies such as the generic framing procedure (GFP), [21] virtual concatenation

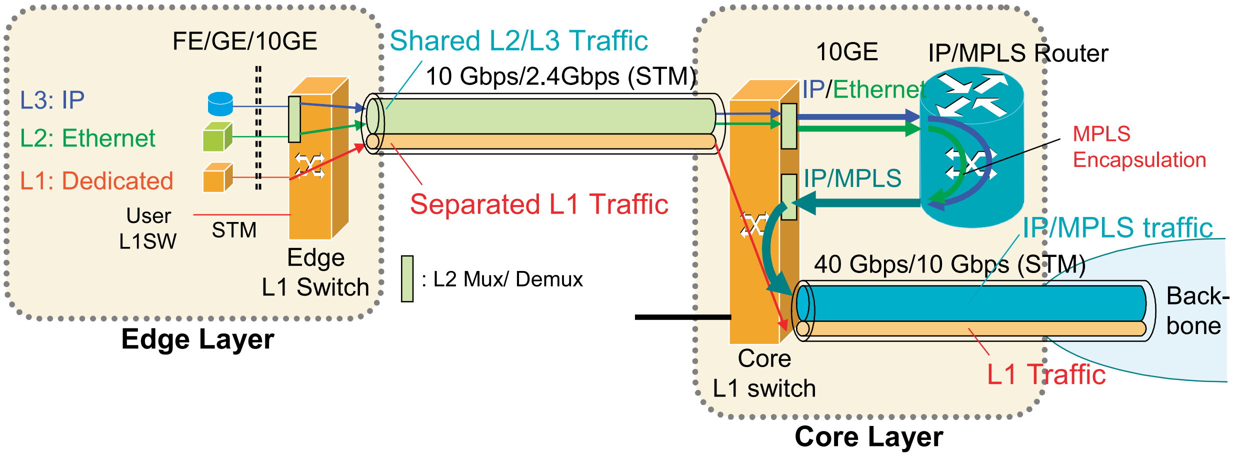


Fig. 7 Accommodation of traffic for layers 1, 2, and 3.

(VCAT), [22] and the link capacity adjustment scheme (LCAS) [23] are all essential for our edge and core nodes. The GFP and VCAT technologies are used to accommodate both SDH/SONET and Ethernet interfaces and assign the bandwidth with fine granularity. LCAS technology allows the network to flexibly change the bandwidth border between the layer-1 traffic and layer-2/3 traffic without packet loss.

For layer-2 multiplexing, the layer-1 switch receives the packets from several Ethernet interfaces and identifies QoS classes of the packets. It then multiplexes the packets into the shared bandwidth configured by VCAT.

At the Ethernet interface between a core layer-1 switch and a core IP/MPLS router, a flow control mechanism compliant with IEEE802.3x is applied to adjust the maximum traffic volume for layer-2/3 traffic or IP/MPLS traffic to the assigned bandwidth.

For handling layer-1 connections, generalized multiprotocol label switching (GMPLS) [25]–[28] is a key technology for fast connection set-up, prompt service recovery, bandwidth on demand, and international interconnection between academic networks. The cooperation between GMPLS and LCAS is also important in our network architecture. In addition, layer-1 VPNs, [29], [30] which are being standardized by IETF and which utilize GMPLS-based protocols, are also promising technologies for enhanced network services, as explained above.

4.3 IP router technologies

SINET3 provides both IP and Ethernet services on IP routers and also manages a rich variety of services. The IP routers use several of the latest MPLS technologies and leading-edge multi-instance technologies, providing a converged IP/MPLS platform for these purposes.

As for native IP services, IPv4/IPv6 dual stack, application-based priority control, and multicast are common infrastructural functions. Using MPLS technologies, the network can have several VPN and tunneling capabilities for layers 2 and 3. For layer 3, BGP/MPLS-VPN [15], [16] and P2MP MPLS [14] are the candidate technologies. For layer-2, EoMPLS [17] and VPLS [18] technologies make it possible for Ethernet packets to be forwarded on IP routers.

To accommodate multiple network services in a single IP router, an IP router should have several logically separated service capabilities and massive transferring capabilities. The IP router should therefore have advanced multi-instances, [24] each of which has independent routing, signalling, and forwarding entities for each network service. In practice, logical router technologies are very useful for attaining these advanced multi-instance capabilities, although the implementation specifications might differ slightly among venders.

As for other important capabilities, the IP routers provide some advanced high-availability capabilities. Fast recovery technologies, such as bidirectional forwarding detection (BFD) for the IP level [20] and fast reroute (FRR) for the MPLS level, [19] achieve a highly reliable infrastructure against network failures. In addition, non-stop packet forwarding and graceful restart in the event of software upgrade are also very important technologies for service availability.

5 Conclusion

SINET3 will start operations in April 2007 and will provide an unparalleled variety of network services, creating a prolific science infrastructure for the research and education community. The extensive leading-edge technologies are essential to this infrastructure and will be introduced in phases after verification of their performance, scalability, stability, and other important aspects. The infrastructure will also be expanded along with the development of an adaptive network control platform and a user-oriented service control platform through collaboration with skilled and enthusiastic users.

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Shigeo URUSHIDANI

Shigeo Urushidani is a professor and the leader of the Network Group at the National Institute of Informatics (NII). He is currently responsible for the design and development of SINET3. Before joining NII in April 2006, he worked for Nippon Telegraph and Telephone Corporation (NTT), where he engaged in the research and development of network service systems for ATM transfer networks, advanced intelligent networks, high-speed IP/MPLS networks, and GMPLS-based optical networks. He was also a visiting researcher at the National Center for Science Information Systems (NACSIS, later NII) from 1998 to 2006. He received B.E. and M.E. degrees from Kobe University in 1983 and 1985, respectively, and received a Ph.D. from the University of Tokyo in 2002. He received the Best Paper Award in 1988 and the Shinohara Memorial Young Investigators Award in 1990 from IEICE. He is a member of IEEE.

Shunji ABE

Shunji Abe received B.E. and M.E. degrees from Toyohashi University of Technology, Japan, in 1980 and 1982, respectively. He received a Ph.D. from the University of Tokyo in 1996. In 1982 he joined Fujitsu Laboratories Ltd., where he engaged in research on broadband circuit switching systems, ATM switching systems, ATM traffic control, and network performance evaluation. He worked at the National Center for Science Information Systems, Japan (NACSIS) from 1995 to 1999. Since 2000 he has worked at the National Institute of Informatics, Japan as an associate professor. He is also an associate professor of the Graduate University for Advanced Studies (SOKENDAI). He is currently interested in Internet traffic analysis, network performance evaluation, optical switching system architecture, and mobile IP system architecture. He is a member of IEEE.

Jun MATSUKATA

Jun Matsukata received B.A. and M.E. degrees from the University of Tokyo in 1979 and 1981, respectively. He joined the Computer Centre at the University of Tokyo as a research associate in 1984. Later, he joined the National Institute of Japanese Literature as an associate professor in 1989 and moved to the Institute of Space and Astronautical Science in 1991. In 1995, he joined the National Center for Science Information Systems as an associate professor. In 2000, he became an associate professor at the National Institute of Informatics. He has been engaged in the research and development of computer networks.

Yusheng JI

Yusheng Ji received B.E., M.E. and D.E. degrees in electrical engineering from the University of Tokyo in 1984, 1986, and 1989, respectively. She joined the National Center for Science Information Systems, Japan (NACSIS) in 1990. Currently, she is an associate professor at the National Institute of Informatics, Japan (NII), and the Graduate University for Advanced Studies (SOKENDAI). Her research interests include network architecture, traffic control, and performance analysis for the quality of service provisioning in communication networks. She is on the board of trustees of IEICE. She is also a member of IPSJ and IEEE.

Kensuke FUKUDA

Kensuke Fukuda is an associate professor at the National Institute of Informatics (NII). He received his Ph.D. degree in computer science from Keio University in 1999. He worked in the NTT laboratories from 1999 to 2005, and joined NII in 2006. His current research interests are Internet traffic measurement and analysis, intelligent network control architectures, and the scientific aspects of the network. In 2002, he was a visiting scholar at Boston University.

Michihiro KOIBUCHI

Michihiro Koibuchi received B.E., M.E., and Ph.D. degrees from Keio University in 2000, 2002, and 2003, respectively. He is currently an assistant professor at the National Institute of Informatics, Japan (NII). His research interests include the area of high-performance interconnection networks on multiprocessor systems. He is a member of IEEE and IPSJ.

Shigeki YAMADA

Shigeki Yamada is a professor and a director at the Research Center for Academic Networks of NII. He received his B.E., M.E., and Ph.D. degrees in electronic engineering from Hokkaido University in 1972, 1974, and 1991, respectively. He worked in NTT laboratories from 1974 to 1999, where he was involved in research and development of high-performance digital switching systems and network-wide distributed systems. He moved to NII in 1999. His current research interests include ubiquitous and mobile networks as well as network security and privacy technologies. He is also involved in the design and deployment of SINET3. From 1981 to 1982, he was a visiting scientist in the Computer Science Department at the University of California, Los Angeles. He is a member of IEICE and IPSJ as well as a senior member of IEEE.