GEMnet2: New Network Testbed for Global R&D

Hisao Uose†, Masayasu Yamaguchi, and Junichi Kishigami

Abstract

NTT has been successfully operating its experimental network GEMnet (Global Enhanced Multifunctional Network) for research and development of global information-sharing services since 1998. To adapt to new requirements in the business environment and technical advances, we have formulated a new testbed concept, GEMnet2, and begun construction. Its three key aims are to let us test technologies for every aspect of communications, provide very wide bandwidth that can accommodate very fast applications without any restraints, and promote collaboration with other research networks. We are using wavelength division multiplexing to build 10-Gbit/s circuits between NTT's R&D centers in Musashino, Yokosuka, and Atsugi.

1. Introduction

GEMnet (Global Enhanced Multifunctional Network) is a network testbed operated by NTT Service Integration Laboratories that was built for research and development of global information-sharing services [1]-[3]. It started operating in 1998 to help verify new technologies in a real network environment by providing network and application researchers with a global network testbed. Since then many research projects have used GEMnet to conduct experiments on their own or jointly with other organizations both within and outside Japan, producing many valuable results [4].

Recent use of GEMnet has focused on experiments aiming to investigate new global information sharing services. At the same time, in light of the changing business environments around NTT and rapid technical development especially in the very-high-speed applications and photonic transmission technology, we felt it was necessary to review the purposes and configuration of GEMnet. In addition, there are urgent demands for a network testbed on which new Internet Protocol (IP) technologies can be tested.

When we consider networks for other research purposes, the recent development of research and education (R&E) networks is astonishing. Most R&E networks are funded by governments and non-profit organizations, which are typically consortiums of research institutes and universities. In Japan, the National Institute of Informatics (NII) operates Super SINET (Science Information Network), which is a nationwide R&E network funded by the Ministry of Education, Culture, Science and Sports of Japan. Its backbone bandwidth is 10 Gbit/s and it has separate Gigabit Ethernet networks for five dedicated scientific applications [5].

In the United States, there are many research networks funded by the federal government as well as ones operated by the private sector. Internet2, a consortium of American universities founded for research on next-generation Internet technologies, operates its own research network called Abilene with the help of vendors and communications carriers [6]. Many countries have equivalent R&E networks and they are rapidly being upgraded in performance.

Experience using those R&E networks led to new requirements for high-performance network testbeds being studied. The U.S. National Science Foundation (NSF) has announced its "Cyberinfrastructure" concept to promote the use of high-performance networks for scientific applications [7]. It stresses the key role played by communications networks in the new methodology of conducting advanced scientific

† NTT Service Integration Laboratories
Musashino-shi, 180-8585 Japan
E-mail: uose.hisao@lab.ntt.co.jp

experiments.

After evaluating the new requirements for the testbed, we came to the conclusion that we should renovate GEMnet in many aspects from the physical configuration to the ways of using it. The idea is to build a new high-performance network testbed that can be used to verify a wide variety of technologies from physical- to application-layer ones. Our approach to building it is to get the most out of existing resources, by unifying GEMnet with the ultrahigh-speed network testbed (GALAXY) also being operated by NTT Service Integration Laboratories [8]. To provide very-high-speed communications links, we decided to utilize photonic transmission technologies more. Many of them were developed at NTT Laboratories and some were already deployed in the GALAXY network. This will enable the testing of very-high-speed applications (several Gbit/s). Reconfiguration of these two experimental networks began last year.

This paper describes the concept and deployment plan of GEMnet2. First, we briefly review the history of GEMnet describing the network configuration and a few examples of experiments conducted on it. Then, we explain the concept of the new testbed and why it has become necessary. We describe our approach to constructing the new testbed focusing on the use of photonic technologies and collaboration with R&E networks. Finally, we mention future plans for GEMnet2.

2. History of GEMnet

2.1 Network configuration

Figure 1 shows the configuration as of March 2002. Since the beginning, the bandwidths between various connection points have been increased/decreased in accordance with actual usage and user requirements. Within Japan, three NTT R&D centers (Musashino, Yokosuka, and Keihan-na) are interconnected through dedicated ATM (asynchronous transfer

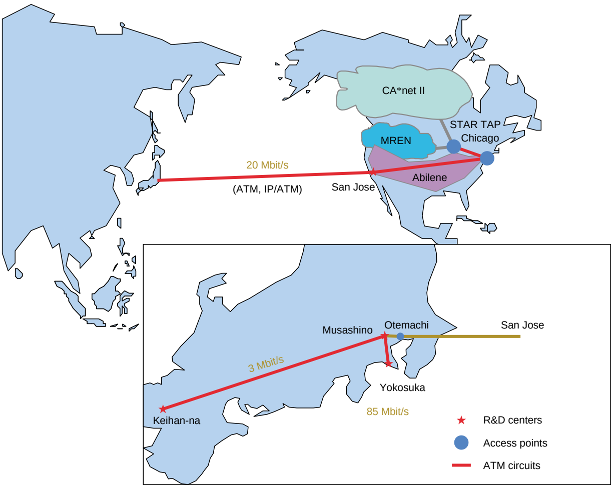

Fig. 1. Configuration of GEMnet as of March 2002.

mode) links. In the U.S. it has been connected to the metropolitan research and education network (MREN), which is an advanced high-performance broadband testbed operated by a consortium of research organizations.

ATM technology was chosen to provide guaranteed bandwidths for a number of application users at the same time. The bandwidth between Musashino and Yokosuka is 85 Mbit/s while that between Musashino and Keihan-na is 3 Mbit/s. Access points to GEMnet are located in the three R&D centers and also in NTT Otemachi building. Connection equipment for ATM links and IP routers is provided at each access point, allowing researchers to choose either ATM or IP/ATM for their experiments.

Internationally, GEMnet has been connected over ATM circuits to NTT facilities in San Jose in the U.S. and NTT MSC in Cyberjaya, Malaysia via the NTT Otemachi building. The circuit between Otemachi building and the MSC has been discontinued due to the termination of the research project involving the MSC. The network did not have an IP connection until June 2001, when it was connected to Abilene, which is the backbone network of the Internet2 project.

NTT Laboratories is a member of UCAID (University Corporation for Advanced Internet Development), a cooperative body running the Internet2 project, which promotes research on the next-generation Internet, with members from more than 200 universities and a number of private companies in the United States and other countries. Internet2 is operating a 10-Gbit/s backbone network called Abilene, which is used by its members for academic research purposes. The interconnection between Abilene and GEMnet opened up the opportunity for joint experiments with not only universities in the United States but also other research institutes connected to Abilene.

2.2 Usage policy

GEMnet was built specifically for use as a testbed in experiments required for NTT's R&D. Its operating policy precludes commercial or business uses other than R&D. Other participating organizations sign a joint research agreement with NTT Laboratories that stipulates the terms and conditions of using GEMnet and its research results. Research partners include the University of Tokyo, Kyoto University, Waseda University, University of Illinois, and University of California - Los Angeles (UCLA).

2.3 Applications

Many experiments have been conducted using GEMnet so far. This section overviews a few examples. Details of these experiments and other experiments are given in ref. [4].

(1) Remote lectures

From 1999 to 2003, NTT Laboratories conducted remote lecture experiments with Kyoto University and UCLA over GEMnet. Up to fiscal 2000, the experiments aimed to identify technical problems in the remote lecture system. Solutions to these have since been implemented. Both professors and students gained valuable experience in remote lecture techniques.

(2) Virtual space sharing network (N*Vector)

NTT Laboratories, the University of Tokyo, and the University of Illinois are conducting joint research on using a network to allow the sharing of a virtual space in different locations. GEMnet and MREN are used to interconnect NTT Yokosuka R&D center and the two universities. In 2001 the three participants built a network system for experiments in operating differentiated services (DiffServ) and are using it to measure quality of service (QoS).

(3) IPv6 operation experiments

NTTv6net, an experimental network using IPv6, stretches from Asia to North America and Europe. It is connected to many ISPs and IPv6 experimental networks at IPv6 native Internet exchanges (IXs), such as NSPIXP6 in Tokyo, PAIXv6, SIX, and 6TAP in the United States, and AMS-IX in Amsterdam. As of September 30, 2001, 42 organizations were interconnected through its border gateway protocol. GEMnet is used as the backbone of this world-leading IPv6 network, linking Japan and the United States.

(4) Data over photonic network (DoPN)

We developed a prototype access system for a variable-rate connection service offering a peak rate of over 1 Gbit/s. To evaluate the scheme's characteristics, GEMnet was used to test its on-demand operation. A bandwidth controller client in Musashino R&D center and an optical line termination (OLT) agent in Yokosuka R&D center were interconnected via GEMnet, and a remote on-demand bandwidth control experiment was successfully carried out.

3. Concept for the new testbed

The requirements for the network testbed have changed as communications technologies have advanced. This prompted us to review the position of GEMnet and its network configuration. The following are the issues that we took into account when we formulated the basic plan for the new testbed.

3.1 Testbed for all layers of technologies

The new testbed should provide an experimental environment for all aspects of broadband communications. In the physical layer, in which photonic technology is pushing up against the physical limitations of transmission speed, minute differences in the characteristics of transmission media affect communication performance and quality. This requires us to test new photonic technologies in the field using actual fibers with a mixture of different specifications and ages.

In the network layer, there are many complicated issues that need to be solved, including traffic engineering, quality control, routing, and security. Because the Internet consists of heterogeneous networks operated by different organizations, measures to solve the problems have many constraints. In addition, conspicuous variations in traffic characteristics and rapid changes in technology require us to verify those measures on an actual network with interconnections to other networks.

Broadband applications using IP technology are emerging very rapidly, so research on applications operating on a very-high-speed network infrastructure is required. At the same time, the network should emulate the actual conditions of commercially deployed networks because the characteristics of an IP network are closely interlinked with those of other layers and applications.

Inter-working among researchers in different specialties is another target of this testbed. Although many experiments covering many technical issues have already been conducted, we feel it is necessary to provide an environment that will boost closer collaboration among trials.

3.2 Focus on IP and photonic technologies

Internet Protocol (IP) technology has begun to play a dominant role in communications networks providing conventional real-time services including voice and video services along with conventional Internet services. This trend requires us to provide a testbed for investigating the specific problems related to IP technologies. This can only be done using a network running many other applications with connections to other networks.

Wavelength division multiplexing (WDM) is the best example of new photonic technologies being rapidly deployed by many carriers, but effective use of dynamic wavelength switching is still being studied. NTT Laboratories is leading this field and the new testbed will enable effective verification of developed technologies because it will be built of actual fibers and will run actual applications.

3.3 Requirements for higher bandwidth

The latest applications require bandwidths from a few hundred Mbit/s to several Gbit/s, so the new testbed should be able to provide this level of bandwidth. Typical examples are scientific applications in fields such as astronomy, physics, and genetic engineering. Super High Definition (SHD) video transmission is another application that requires very high bandwidth [9]. Distributed computing is another interesting application because it requires broadband connections among distantly located processors, and the performance of the network will greatly affect the total processing power. With the use of photonic technology, achieving this target is not difficult.

3.4 International collaboration

The original aim of GEMnet was to promote collaboration with research groups abroad as well as ones within Japan. The significance of international cooperation is growing year by year and partnerships with other R&E networks play an important role in this respect.

One example of international collaboration already started is the joint research project on remote observation using a radio telescope with the National Astronomical Observatory of Japan (NAOJ) and the University of Chile [10]. In this project, astronomers at NAOJ's main campus in Tokyo can access their monitoring equipment located in the Atacama desert in northern Chile via GEMnet. To make this possible we are collaborating with a number of R&E networks, which provide transit services for our experiment, as shown in Fig. 2. In GEMnet2 the connectivity to other R&E networks will be enhanced to make more experiments possible.

4. Approach for GEMnet2

Figure 3 shows the planned configuration of GEMnet2 and the research topics that will be conducted on it.

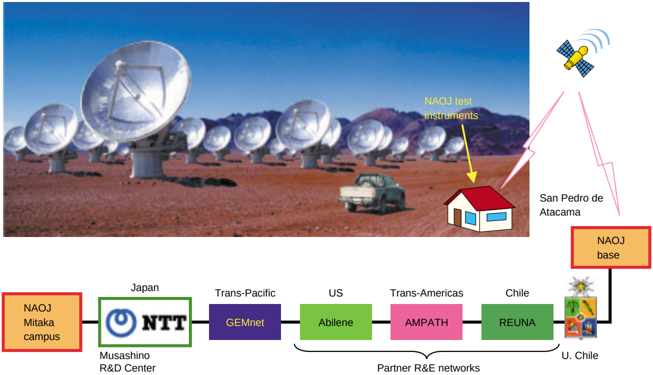

Fig. 2. Remote monitoring of NAOJ test instruments.

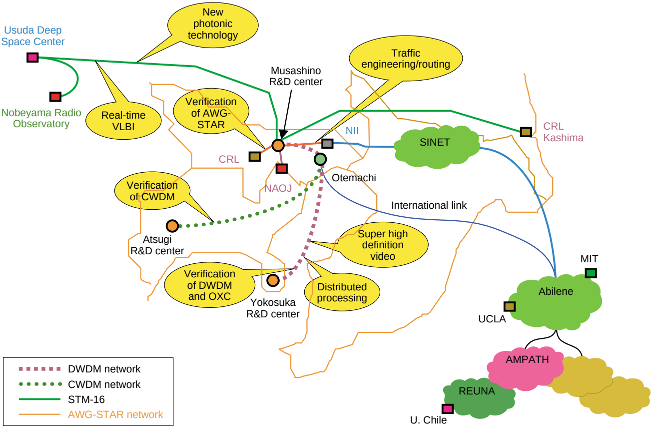

Fig. 3. GEMnet2 and its research topics.

4.1 Unification with GALAXY network

GALAXY [8] is another NTT high-speed experimental network, currently being used for real-time VLBI (very long baseline interferometry) experiments. This network is entirely operated by NTT Laboratories, from optical fibers to applications, without the use of any commercial services. All the synchronous digital hierarchy (SDH) transmission equipment, WDM devices, repeaters, ATM switches, IP routers, and layer-2 switches are owned and operated by us. This gives us great flexibility when conducting experiments with extreme requirements. In addition, we can test lower-layer technologies such as photonic devices using this framework. Through the operation of GALAXY, we have accumulated a lot of know-how that should be applicable to the new testbed.

4.2 Use of photonic technologies

We plan to utilize new technologies developed in NTT Laboratories that are applicable to the new testbed, especially the latest photonic devices and transmission equipment utilizing them. In 2001 we deployed a full-mesh photonic network system (whose product name is AWG-STAR) together with DWDM (dense WDM) multiplexers in the GALAXY network. AWG-STAR is a WDM filter with silica-based PLC (planar lightwave circuit) technology developed by NTT Photonics Laboratories and it can multiplex/demultiplexing several WDM signals simultaneously. It connects two sites in Musashino R&D center with NAOJ and the Communications Research Laboratory (CRL) using eight wavelengths. Figure 4 shows the DWDM equipment installed in Musashino.

We are planning to extend this network to Atsugi R&D center using coarse wavelength division multiplexing (CWDM) this year to make high-speed application trials possible between Atsugi and other sites. Figure 5 shows the testing of optical fiber amplifiers planned to be used for the circuit.

We also plan to deploy photonic transport systems developed by NTT Network Innovation Laboratories. One is a DWMD transmission system which supports optical cross-connection (OXC). Once this system has been deployed, we will be able to investigate new network control schemes using wavelength switching.

4.3 Collaboration with other R&E networks

(1) Collaboration with Super SINET

In December 2002 we connected GEMnet to Super SINET. The link was established using an OC-12 (622 Mbit/s) wavelength through the DWDM network connecting Musashino R&D center and the NII building in downtown Tokyo. This connection made possible broadband experiments with academic sectors within Japan. The GALAXY project also uses this connection for real-time VLBI experiments. We will promote joint research with other research institutes utilizing this connection and may upgrade the bandwidth.

(2) Upgrade of the trans-pacific link

In May this year, the trans-Pacific link connecting GEMnet to R&E networks in the United States was upgraded to OC-3 (155 Mbit/s) from the previous bandwidth of 20 Mbit/s. The circuit is connected to Pacific Wave, which is the main connecting point

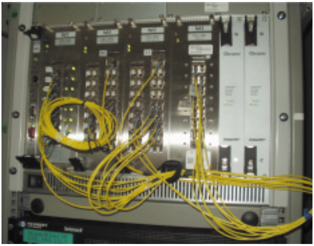

Fig. 4. DWDM multiplexer/demultiplexer used with AWG-STAR.

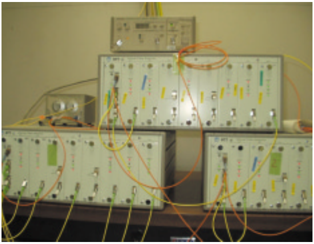

Fig. 5. Optical amplifiers for CWDM signals.

for R&E networks on the west coast of the United States. Pacific Wave is operated by the University of Washington and we have a peering agreement*1 with the Pacific Northwest GigaPoP as well as Abilene. This upgrade greatly expands the possibility of international experiments in combination of Internet2's international transit service.

4.4 Network operation

Although owning and operating the testbed by ourselves is ideal for running a high-performance testbed from the viewpoint of performance and flexibly, its operation is inevitably very difficult and complicated. Because GEMnet is now connected to other R&E networks, proper network management is essential. We have reorganized the GEMnet operations team so that it can handle issues related to new photonic technologies as well as higher layer technologies such as ATM and IP. The new network operations center (GEMnet NOC) is now operating 24 hours a day, every day of the year.

To manage all network equipment centrally, we are developing a special network management system based on ATMView, which has been developed at NTT Laboratories to manage multi-vendor networks built on an ATM network infrastructure. It utilizes an object-oriented database to store operations data. Traffic engineering is another important issue for our testbed. We have deployed a traffic monitoring system called SmartProbe, which was also developed by NTT Service Integration Laboratories. There are currently three SmartProbes installed within GEMnet, and traffic flow data is collected regularly every day.

5. Conclusions and future plans

Based on a thorough review of GEMnet activities we have started to renew the network with new operation concept and technologies. The target is to build a high-performance network testbed (GEMnet2) that can be used to test ultrahigh-speed applications as well as lower-layer technologies within our laboratories. We utilize photonic transmission technologies to enable the testing of very-high-speed applications and the focus is on IP technologies. Although GEMnet2 is a research network owned and operated by NTT Laboratories, it has connections with public funded R&E networks. This is a unique feature of GEMnet2 and allows us to conduct a broader range of experiments. Joint research partners will also benefit from the use of GEMnet2 and collaboration with NTT Laboratories by closely studying the use of high-speed networks with experts.

Network renovation started last year. So far, the connection to Super SINET and the upgrading of the international circuit have been completed. The deployment of the DWMD circuit connecting Musashino and Yokosuka R&D centers is under way and should be completed in September 2003. The CWDM circuit connecting Musashino and Atsugi R&D centers is in the design phase and we aim to complete its installation by the end of 2003. When we have completed these two WDM circuits we will have 10-Gbit/s links among the three R&D centers, and we plan to test several very-high-speed applications using the network this year.

*1 Agreement on exchanging traffic between IP networks on a bilateral basis.

References

[1] S. Suzuki, K. Kinoshita, K. Miyaho, and H. Yamashita, "Global R&D Activities and Development of Global Testbed," NTT REVIEW, Vol. 11, No. 2, pp. 69-78, 1999.
[2] N. Miyaho, F. Hyuuga, R. Arai, and K. Kinoshita, "Network Configuration of GEMnet)," NTT REVIEW, Vol. 11, No. 2, pp. 79-89, 1999.
[3] K. Okada, H. Yamamoto, and H. Yamashita, "NTT's Global R&D Strategy and Testbed after Reorganization," NTT REVIEW, Vol. 12, No. 2, pp. 8-13, 2000.
[4] K. Okada, J. Kishigami, M. Yamaguchi, N. Miyaho, and N. Yamauchi, "Current Status and Future Direction of NTT's Global Networks for Experiments, GEMnet," NTT REVIEW, Vol. 14, No. 2, pp. 26-33, 2002.
[5] S. Asano, "Super SINET," http://www.ccirn.org/general/2002material/SuperSINET-CCIRN.ppt, CCIRN General Meeting, Arlington, U.S.A., 2002.
[6] "Internet2," http://www.internet2.edu/resources/Internet2Overview.ppt
[7] A. Blatecky, "Future Directions in Networking," http://web.haystack.mit.edu/e-vlbi/Blatecky.pdf, First e-VLBI Workshop, MIT Haystack Observatory, U.S.A., 2002.
[8] H. Uose, "Application of Ultrahigh-speed Network to Advanced Science," NTT Technical Review, Vol. 1, No. 5, pp. 39-47, 2003.
[9] T. Yamaguchi, "SHD Digital Cinema Distribution over a Global High-speed Network: Internet2," NTT Technical Review, Vol. 1, No. 5, pp. 10-15, 2003.
[10] N. Yamauchi, E. S. Vera, H. Yamamoto, and H. Uose, "History and Future Prospects of Research Collaboration between NTT Laboratories and the University of Chile: AccessNova, NTT REVIEW Vol. 14, No. 2, pp. 53-58, 2002.

Hisao Uose
Senior Research Engineer, Supervisor, NTT Service Integration Laboratories.

He received the B.E. and M.E. degrees in electrical engineering from Kumamoto University, Kumamoto, in 1978 and 1980, respectively. He joined NTT Laboratories, Tokyo, Japan in 1980. Currently he is in charge of the ultrahigh-speed application experiments and high-performance network testbed at NTT Service Integration Laboratories. He was a guest associate professor and guest professor at the National Center for Science Information Systems in 1994-1998 and 1998-2000, respectively.

Masayasu Yamaguchi
Senior Research Engineer, Supervisor, NTT Network Innovation Laboratories.

He received the B.E., M.E. and Ph. D. degrees in electrical and electronic engineering from Chiba University, Chiba in 1980, 1982 and 1994, respectively.

He joined NTT Electrical Communication Laboratories in 1982, where he mainly engaged in research on photonic switching systems and related technologies. His current interest is metadata technologies enhancing content distribution services on photonic networks. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan and the IEEE/COMSOC (Communications Society), LEOS (Lasers and Electro-Optics Society).

Junichi Kishigami
Director, Project Manager, NTT Service Integration Laboratories. Currently he is a director at NTT Laboratories promoting the concept of "metadata" and RFID, which would be a key function for the new convergence business.

He received bachelor's and master's degrees in physics and doctor degree in electronic engineering from Hokkaido University, Sapporo, Hokkaido. Upon graduation in 1980, he joined NTT as researcher, where he researches the solid state physics of thin film head, a key technology in the development of high capacity magnetic storage devices. In 1989, he was responsible for the design and development of an electronic filing system for Video-on-Demand. He was a vice president and general manager at IP HQs in NTT America from 1994 through 1999. His main mission was to create and promote Internet business both for US and Japan. He is a member of IEICE of Japan and Distinguished Speaker of IEEE, committee at ARIB (Association of Radio Industries and Businesses), INSTAC (Information Technology Research and Standardization Center) and TV Anytime Forum.