A New Generation Network: Beyond the Internet and NGN

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ABSTRACT

This article describes requirements and fundamental technologies to enable the provision of a new generation network beyond the Internet and the next generation network, both of which are based on IP protocols. Although the Internet has grown into a social infrastructure and the NGN will replace legacy telephone networks and cellular phone networks in the near future, it is time to start R&D on revolutionary network technologies and clean-slate designed architecture beyond the IP structure. Here some R&D activities for a new generation network are shown. This article is a revised version of the author's presentation in the First ITU-T Kaleidoscope Academic Conference [1] held in Geneva last May.

INTRODUCTION

The broadband Internet and third-generation (3G) cellular phone networks are rapidly expanding, and advanced applications such as content search, YouTube type image services, SNS, and Second Life type cyber space applications have been born and grown up day by day. The world standards for next generation network (NGN) are being proceeded in the International Telecommunication Union — Telecommunication Standardization Sector (ITU-T). The objectives of NGN are to replace legacy telephone networks using state-of-the-art IP network technologies, and support triple-play and quadruple-play services over quality of service (QoS) controllable IP networks. In Japan NTT started NGN services at the end of March last year [2]. Telecommunications vendors are now concentrated their resources on the deployment of the NGN systems. Figure 1 shows an image of the evolution of the commercial communication networks in a few decades, and in the near future two types of IP-based networks will coexist.

Figure 2 presents some differences in characteristics between the Internet and NGN, although both are applying IP. One of the most important characteristics of the Internet is a best effort bearer function to interconnect multiple IP packet router-based networks, which means:

- No overall network planning, and no clear responsibility and common control rule exist among networks.
- TCP/IP is the only common rule for connections.
- Users have freedom to install any applications.

In contrast, NGN is considered as an effort to re-establish QoS control bearer functions to interconnect multiple networks with clear responsibility, and three kinds of interfaces: the user-network interface (UNI), network-network interface (NNI), and application-network interface (ANI) are defined. NGN applies TCP/IP, but is not based on the "end-to-end argument," which is one of the fundamental principles for the network architecture of the Internet.

Although in these few decades two types of IP-based networks coexist, merging legacy non-IP-based networks, it is time to start research on a future network architecture and protocol beyond the Internet and NGN. Here this is called the *new generation network (NWGN)* to distinguish it from NGN. NWGN is to have a clean-slate designed architecture, and is not intended to improve TCP/IP-based networks.

R&D on a future network with a completely new architecture has just started globally. For example, Global Environment for Network Innovations (GENI) [3] and Future Internet Design (FIND) [4] programs funded by the National Science Foundation (NSF) have started in the United States, and the Seventh Framework Program (FP7) [5] by the European Commission includes some projects similar to NWGN. In the next section the research on NWGN in Japan is mainly introduced.

RESEARCH APPROACH FOR NWGN

The history of communication networks tells us that there have been three paradigms so far: the telegraph, the telephone, and the Internet. Each network has a very clear objective. The telegraph is a network to transmit Morse code by on-off key terminals over electric current. The telephone network is to transmit electrical waveforms made by vocal air vibration. The Internet is to transmit data between computers. Three paradigms originally apply only one type of appliance each to interconnect. It is therefore noted that the appliance to be interconnected determined the network architecture and main protocols to realize the objective of the network.

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How about the fourth network paradigm? Can we identify a major appliance to be interconnected in NWGN? The important difference from the previous three paradigms is that we cannot identify a major appliance, and versatile appliances should be taken into account to determine the network architecture and protocol. Figure 3 shows a scheme to define a new network architecture through a clean-slate approach, not through an improvement of current network architecture. The bottom-up approach, the top-down approach, and the design principle are equally important, and all the research outputs from each approach should be merged into one solution for NWGN architecture and protocol as a fourth communication network paradigm.

RESEARCH ON NWGN IN JAPAN

The systematic research on NWGN in Japan started around 2006. In 2006 the Ministry of Internal Affairs and Communication (MIC) formed a committee to discuss future network R&D issues. In the committee the author proposed NWGN as a network beyond the Internet/NGN, which are both based on IP, and according to the recommendation of the committee, an all-Japan NWGN Promotion Forum (NWGN Forum) [6] was established in November 2007. Japanese industry cannot afford to use their large amounts of resources for R&D on NWGN at this moment due to the NGN business deployment, so the National Institute of Information and Communications Technology (NICT) should be at the core of the NWGN R&D together with the academic community. NICT set the NWGN Strategic Section to guide NWGN R&D in Japan, and started the AKARI Project [4], which is a core research group to study the NWGN architecture and protocols. Furthermore, NICT is operating a network testbed, named JGN2plus [7], and is providing funding with a competition process to academia and industry for NWGN research. This means that NICT has three functions: a funding function like NSF, operation of the network testbed, and their own research by NICT researchers.

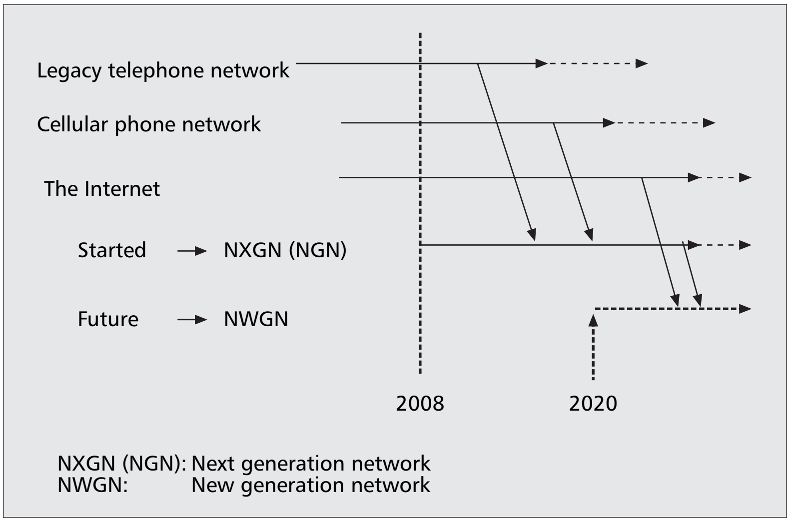


Figure 1. *Network evolution.*

The Council for Science & Technology Policy (CSTP), which belongs to the Japanese Prime Minister's Cabinet Office, has a mission to evaluate the importance of R&D projects proposed by all ministries from the national point of view, and in 2008 CSTP selected six R&D items with the highest priority of 92 R&D proposals in the all the areas of science and technology; one of them is the R&D on NWGN technologies, which means that NWGN R&D is one of the most important national projects.

Figure 4 shows the requirements for NWGN that the AKARI Project pointed out. Each item is rather vague at this point in time, and it should be made clear quantitatively from now on. It is noted that the important requirements are especially:

- How to cope with complexity (versatile appliances and heterogeneous networking)

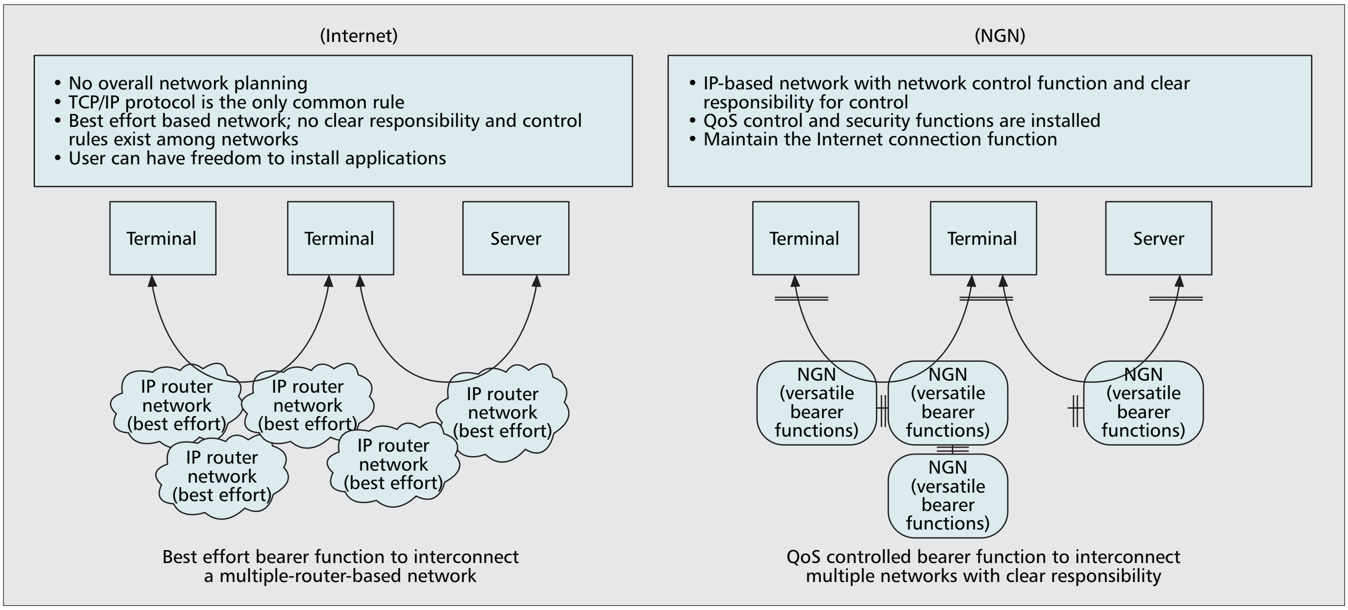


Figure 2. *A comparison between the Internet and NGN.*

- Low energy consumption for a low carbon society
- Compromise between openness and transparency vs. high security

Taking account of those requirements, the AKARI Project is publishing "AKARI Architecture Conceptual Design" v. 1.2 in 2009.

Technological Issues to be Studied

As shown in Fig. 3, clean-slate design for network architecture needs three study approaches. Allocation of various networking functions heavily relies on the fundamental design concept. The end-to-end concept in the Internet determines the allocation of networking functions to routers and end hosts. The concept means that a network should be as stupid as possible and an end host should be intelligent, but the current Internet cannot keep this concept, as shown in Fig. 5. In addition, it is difficult to support strong security functions under the end-to-end concept, so the AKARI Project is now working on a concept for the allocation of networking functions to meet the requirements. The AKARI Project is also examining all the networking elements shown in Fig. 6, taking into account the three approaches in Fig. 3. Although the conclusions of the examination have not yet been reached, the important considerations are introduced below.

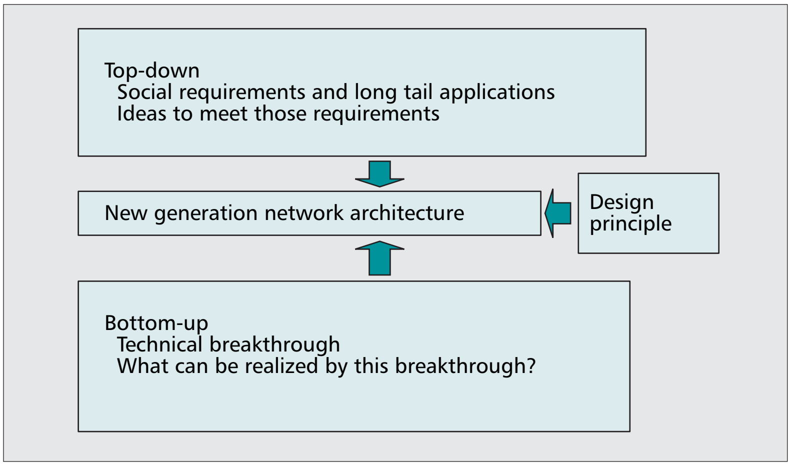


Figure 3. *Research approach for a clean-slate designed architecture.*

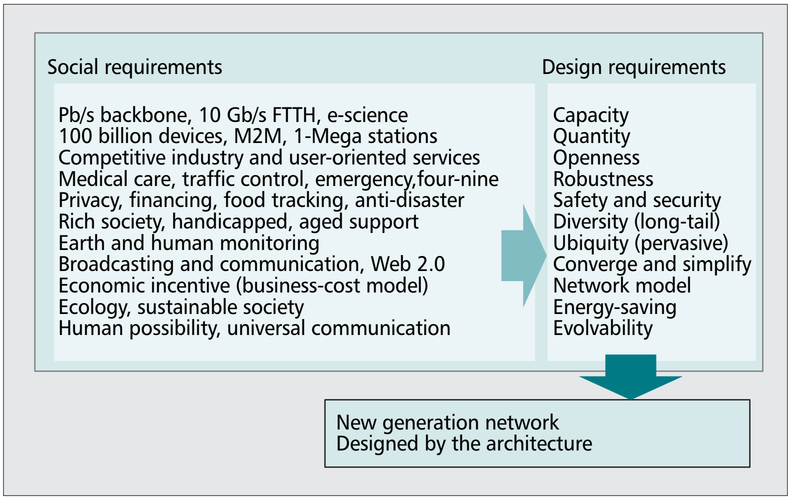


Figure 4. *New generation social and design requirements in the 2020s (source: National Institute of Information and Communications Technology).*

End Host

In the Internet an end host is a computer such as a PC, server, or cellular phone, but appliances ranging from a very tiny chip of radio frequency identification (RFID) or a sensor that sends only 100-bit-level data, to a large-scale tailed display that handles 100 Mpixels/system should be connected to the NWGN. The functions of end hosts may vary widely, and we have to identify the end host functions for the NWGN architecture.

Layering

The role of a network layer is to help recognition of the behavior of protocols, and build network systems and software on a layer-by-layer basis. The layer structures of the Internet and NGN are quite different from each other due to the different concepts. Some ideas of protocols without layer structure have been proposed. The AKARI Project is now discussing a layering structure for NWGN taking account of all the network elements shown in Fig. 6.

Data Format Transported

The Internet and NGN use an IP packet format, and NWGN may also apply a packet format for data, but there can be many other approaches to be applied. We have to examine merits and demerits for other formats such as *flow* and *circuit/path*. Video streaming content may be transferred by flow or circuit/path better than by packet structure from the QoS or low delay performance point of views. The AKARI Project is studying the possibility of combining such data formats, and an experimental photonic path/packet combination switching system is being built in NICT.

Separation of Identifier and Locator

The current IP address contains two different functions, identification and location in a network. In the ITU-T standardization of NGN, the separation of these functions is being discussed. NWGN may apply separation of the identifier and locator, and the AKARI Project is studying a separate structure.

Network Virtualization and Overlay Network

A history of the technological advancement of a computer can be seen from the viewpoint of virtualizing a computer element. A computer user can utilize a machine without any knowledge of the precise physical structure of his/her computer. But in the 1960s, a computer user needed to know the real memory address to make a program compute using the memory. Since then the memory address has been virtualized; then all the elements of a computer were virtualized, and a user can write a program without any knowledge of the real physical structure of memory,

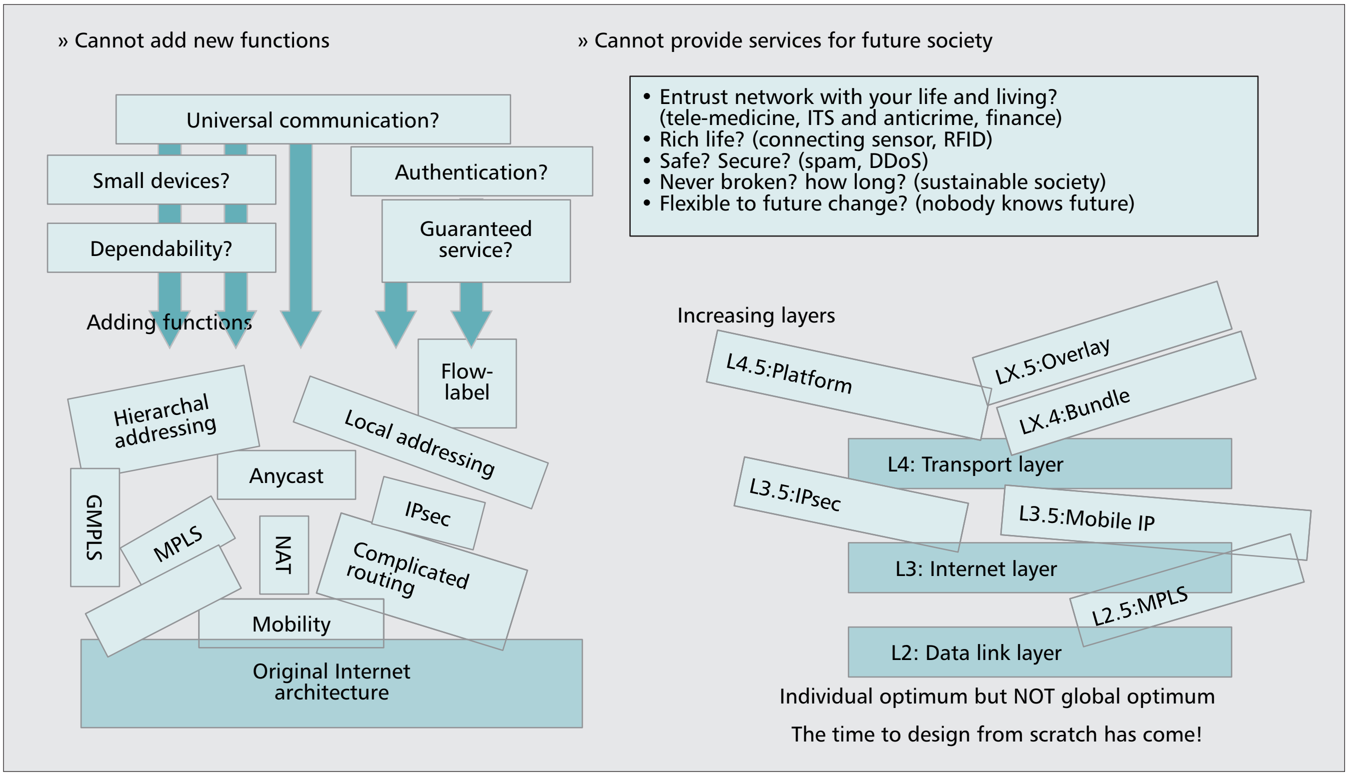


Figure 5. *The Internet: too complicated.*

processor, interfaces, and input/output devices. Why not virtualize a whole network so that we can utilize the network for our own purposes without any knowledge of its physical structure as we do when using a computer? In order to realize network virtualization, each element of a network should be virtualized. Research activities on a virtual router and server can be observed globally, and the AKARI Project is also concentrating its study resources on this research item. An experimental testbed of an overlay network with the virtualization concept, Planet Lab [8], is operating. Figure 7 illustrates a conceptual diagram of a network virtualization architecture.

NETWORK SCIENCE

One of the most difficult items to be solved in NWGN is how to simplify very complex and dynamic network functions, and control the whole network in a stable and safe manner. Cconventional network theory is not enough to cope with these requirements, and new network science should be studied. Recently new network theory such as scale-free and bio-inspired networks have received attention. NWGN may need autonomous functions and self-organization capability to handle complex and heterogeneous networking. These new theories or algorithms should be verified as to whether they can contribute to handling NWGN.

NETWORK TESTBED

Since NWGN is not an improvement of existing IP networks, many ideas to realize a clean-slate designed network, and experiments to verify such new ideas and protocols are very important. In the case of the Internet, the contributions of ARPANET and NSFNET, on which any researchers were able to test their ideas, were so great that those network testbeds evolved into the commercial Internet. In case of NWGN, the importance of its testbed is the same. NSF is promoting the GENI testbed, and NICT is now operating JGN2plus, which will be revised to be capable of experiments to verify the NWGN architecture, protocols, performance, security, and applications. A large-scale NWGN testbed is planned to start in 2011. NICT is considering a connection with another clean-slate designed network testbed such as GENI, and global con-

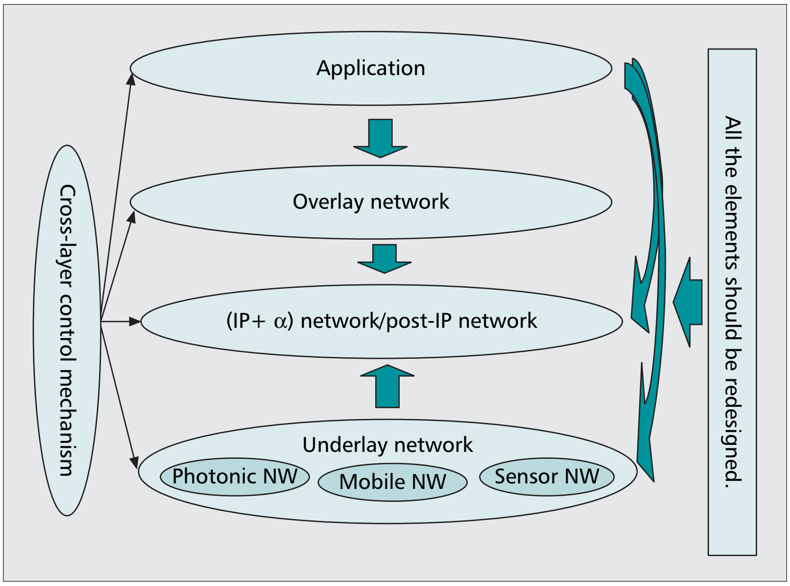
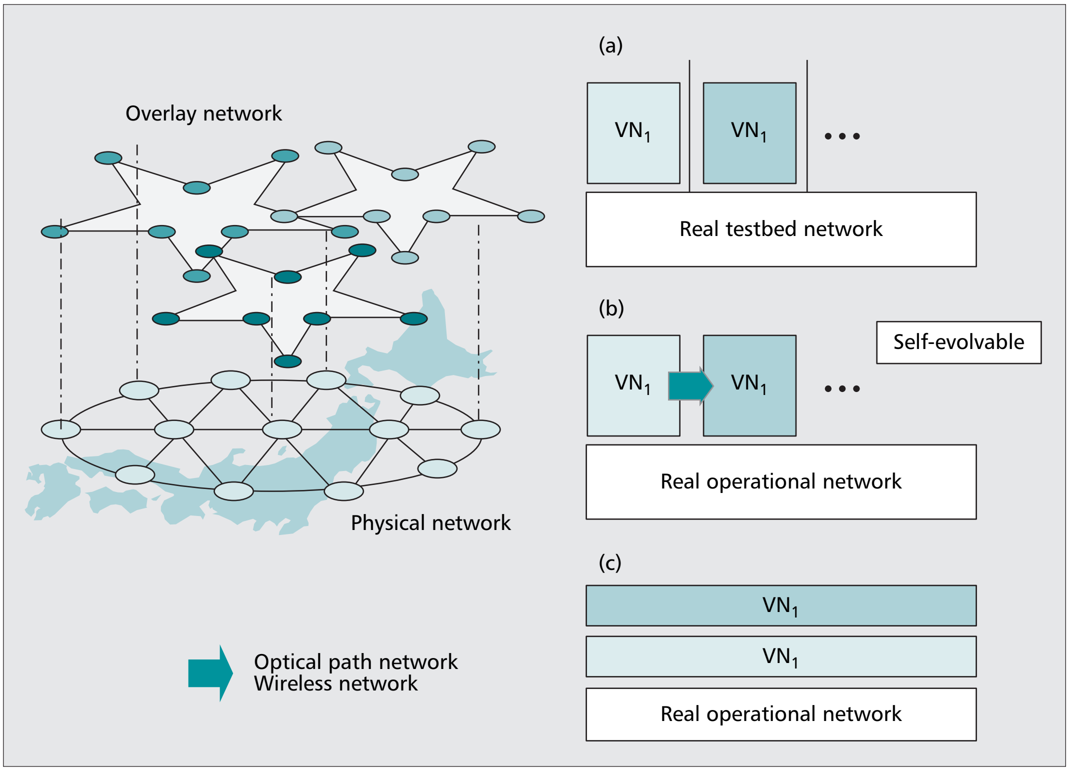


Figure 6. *Study items for NWGN architecture.*

Research on NWGN and Future Internet, which are aiming at building a new paradigm beyond the Internet, and the success of this attempt relies on good competition and tight collaboration among research community in US, Europe, and Asia.



■ **Figure 7.** *AKARI architecture for network virtualization (concept): a) isolated virtual networks; b) transitive virtual networks; c) overlaid virtual networks.*

nections between future network testbeds are eagerly expected.

Long Tail Applications

As shown in Fig. 8, innovations in network technologies have been derived from so-called long tail applications. The Internet and Web were not originally applications for the general public, but for a small number of researchers and scientists. The top-down approach in Fig. 3 should take up advanced applications that need very high-level performance or functions even though the number of users is quite small. In case of NWGN, examples of long tail applications are grid computing, large-scale tailed display, advanced digital entertainment such as digital cinema, other digital stuff (ODS), networked games, and so on. The OptIPuter [9] project is developing a 100 Mpixel display system with 30 × 10 GE interfaces (total 1/3 Tb/s) and a 60 Tbyte disk.

As for digital cinema, the Digital Cinema Initiative (DCI) [10] made the digital cinema specification with 4K (4096 × 2160 pixels/frame) definition according to Digital Cinema Consortium of Japan (DCCJ) [11] contributions; based on this specification, Warner Brothers, Toho Cinema Co, and NTT Group performed the world's first joint trial for 4K digital cinema distribution from a Hollywood studio to digital screens in Tokyo and Osaka over broadband IP networks across the Pacific Ocean. This trial was called 4K Pure Cinema Trial [12]; very popular movies such as "Harry Potter" and "The Da Vinci Code" were digitalized with 4K resolution, and the digital cinema contents were compressed by JPEG2000, encrypted for security in a Hollywood studio, and then transmitted over to NTT network operation centers in Tokyo and Osaka. Then the contents were distributed to movie theaters there, unencrypted, decoded, and projected on the screen by SONY SXRD 4K cinema projectors. A two-hour movie with 4K DCI specification has 6 Tbytes; streaming of 4K non-compressed digital cinema content needs 6 Gb/s speed, and compressed cinema with JPEG2000 needs 300 Mb/s. The 4K Pure Cinema Trial has successfully finished, and an actual business in digital cinema distribution over broadband IP networks has recently been announced. Content (high definition video of musicals, operas, Kabuki, etc.) will be distributed to a large-scale flat TV display in a home theater. These high-level applications will have a great impact on the performance of NWGN.

International Collaboration and Standardization

Research on future networks beyond IP has begun in the United States, the European Union, Japan, and Korea. Research and development inherently involves competition as well as collaboration. It is noted, however, that collaboration is more important in this case because the period of R&D may be very long, possibly more than 10 or 20 years, and research items are quite broad and difficult to solve, so no single organization or even country can afford to study all the technologies required. International symposia and workshops concentrating on topics beyond

IP should be held, and conventional conferences shoud be utilized as well. Some new workshops and symposia have been held or are being planned this year.

ITU-T held a new conference, the ITU-T Kaleidoscope Academic Conference, in Geneva, Switzerland last May with IEEE Communications Society co-sponsorship. I was invited to talk about the new generation network, and this talk made some impact on the discussions about future network standardization in ITU-T.

ITU-T Study Group XIII has just established a Focus Group to investigate the status of R&D beyond the Internet and NGN in the world. This policy of ITU-T and IEEE Communications Society to host such an international conference to discuss future network technologies before the standardization process with the academic community seems excellent, and collaboration among network researchers' communities in academia and the standardization community can be well performed. This new event will impact on a standardization process.

NICT participated in the U.S.-Japan Joint Workshop on New Generation Network and Future Internet held in Palo Alto, California, last October, and also the EU-Japan Symposium on New Generation Network/Future Internet held in Brussels, Belgium, last June. These opportunities contributed to exchanging information on the R&D status in each region and more detailed research collaboration among research groups in both areas.

The next important collaboration is to interconnect the network tesbeds to verify new ideas and technologies for beyond IP over large-scale global models.

CONCLUSION

This article overviewed research activities on beyond the Internet and NGN especially in Japan. We can remember that the US government continued to support ARPANET and NSFNET for more than 20 years, and from those network research platforms, excellent new ventures such as CISCO, Yahoo, Google, Amazon, etc. were born, and the new Internet industry has grown up. Research on NWGN and Future Internet, which are aiming at building a new paradigm beyond the Internet, and the success of this attempt relies on good competition and tight collaboration among research community in the United States, Europe, and Asia.

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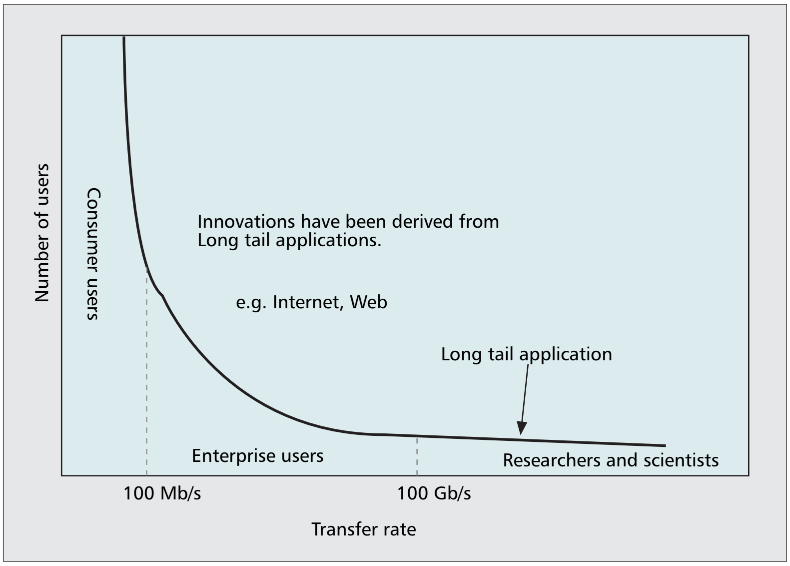

Figure 8. *Long tail application in the future, 4K digital cinema, and ODS.*

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BIOGRAPHY

TOMONORI AOYAMA [F] (aoyama@dmc.keio.ac.jp) received his B.E., M.E. and Dr.Eng. from the University of Tokyo, Japan, in 1967, 1969, and 1991, respectively. Since he joined NTT Public Corporation in 1969, he has been engaged in research and development on communication networks and systems in the NTT Electrical Communication Laboratories. From 1973 to 1974 he was at MIT as a visiting scientist. In 1994 he was appointed director of the NTT Opto-Electronics Laboratories, and in 1995 he became director of the NTT Optical Network Systems Laboratories. In 1997 he left NTT and joined the University of Tokyo. In April 2006 he moved to Keio University, and is currently a professor at the Research Institute for Digital Media and Content, Keio University. He is a member of the Science Council of Japan and an IEICE Fellow. He is currently serving as President-Elect of IEICE. He serves as Chair of the Photonic Internet Forum in Japan, the Digital Cinema Consortium of Japan, and Vice-Chair of the Ubiquitous Networking Forum and New Generation Network Promotion Forum.