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Technological Trends in Internet Routers
–Toward Construction of Next-Generation Communications Infrastructures–

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1 Introduction
–A turning point in every ten years–

Trends in network technology are about to see the next turning point, which emerges about every 10 years. The mid-1980s was the time when computer networks were introduced to general society, and universities and enterprises began implementing local area networks (LANs). This brought a drastic change in telephone-based information communications and the ways of office document management. By the mid-1990s, optical fibers became a common type of transmission line, ushering in the advent of technologies such as asynchronous transfer mode (ATM) communications and gigabit Ethernet. These technological advances resulted in a significant reduction in communication cost per bit. It was also the time when personal computers came into widespread use, and Internet browsers running on them entirely changed how information was processed[1].

Now, in the 21st century, some argue that the technologies that constitute the Internet infrastructure have entered a period of next transition. Such an argument is convincing, with the following factors.

(1) An increase in user traffic

There has been a considerable increase in demand for data communications traffic because of the widespread use of ADSLs (Asymmetric Digital Subscriber Lines) and mobile phones. In the near future, multimedia or other applications that require heavy traffic are expected to emerge. Assuming that the rise in demand for data traffic continues at the current pace, existing infrastructures will be subject to drastic structural changes in a few years.

(2) A need for sophisticated and diverse network management capabilities

There is a growing need for sophisticated network services such as QoS (Quality of Service), which ensure communications performance in accordance with the mode of service, and network security protection. While the existing Internet has been designed on the basis of the “best-effort” concept, next-generation infrastructure designs will have to embrace a different point of view.

(3) New research and development trends in network communications equipment

A new breakthrough, such as the commercialization of optical switching, the development of a networsk processor, and the invention of a chip that enables sophisticated controls, is demanded from the perspective of enhancing hardware capability.

This article examines these aspects, while explaining technological trends in routers, a device that supports the communications infrastructure for data communications, followed by a discussion on challenges on technological policies that should be addressed during such a transitional period.

2 An overview of the Internet communications infrastructure

Before describing technological trends in communications infrastructures, represented by Internet routers, the author will sort out network technologies containing a variety of constituent technologies. The results will be used for discussing past efforts toward technological accumulation and future challenges in the communications infrastructure sector.

2.1 Classification of network technologies

Table 1 lists current hot issues in the network research community, based on the lecture material by Professor Maurizio Decina, Politecnico di Milano. The focus of attention is on the fields in which commercialization or proliferation of relevant technologies is intended in the next few years[7].

For the purpose of explanation, relations between these constituent technologies are shown in Figure 1 through categorization using two axes. The vertical axis corresponds to network communications protocol layers. The upper part represents technologies related to applications that utilize networks, while the lower part indicates technologies associated with facilities such as switching equipment. The horizontal axis represents whether the displayed field is pertinent to the communications service provider or the service recipient. Service provider refers to those who are usually known as ISPs (Internet Service Providers), offering infrastructures such as wide area networks that serve as the backbone, and network management capabilities. Service recipient consists of companies and households who use connectivity services. The infrastructure for them includes equipment that is used to consolidate locally distributed small-scale networks.

Constituent technologies positioned closest to the user side are those related to so-called "ubiquitous communication," which usually refers to the development of new applications that exploit home information appliances, mobile phones, and so forth. These are technological fields where significant growth is forecasted and where technologies of Japan are expected to develop in years to come. These fields are shown in the right half of the chart.

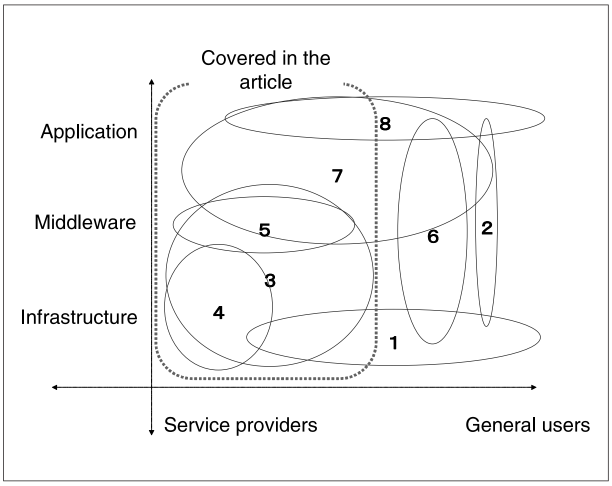
The discussions in this article are presented from the perspective that communications infrastructure technologies, in particular, contained in the left half of the chart is now in a period of technological transition. The following sections provide a description of "routers," a key element to the construction of infrastructures, by dividing them into two types: "core routers," which are indispensable for building network backbones; and "edge routers," which exist closer to the user end.

Table 1:Important R&D fields in the future

1. Broadband access	• Cable • Wireless
2. Home/personal networks	• Wireless • Wearable information devices
3. Switching/routing	• Soft switches • Qos, MPLS, DS • IPv6 • Activity network • Peer-to-peer networks
4. Backbone networks	• IP/ATM/SDH/WDM, GMPLS
5. Service platforms	• Open service architecture • Messaging, Positioning
6. Mobile communications	• Third-generation IP cellular phone • Ad-hoc networks • Sensor networks
7. Content distribution	• Storage networks
8. Security	• Network security • User security

Source: Author's compilation based on the lecture material by Professor Maurizio Decina of Politecnico di Milano

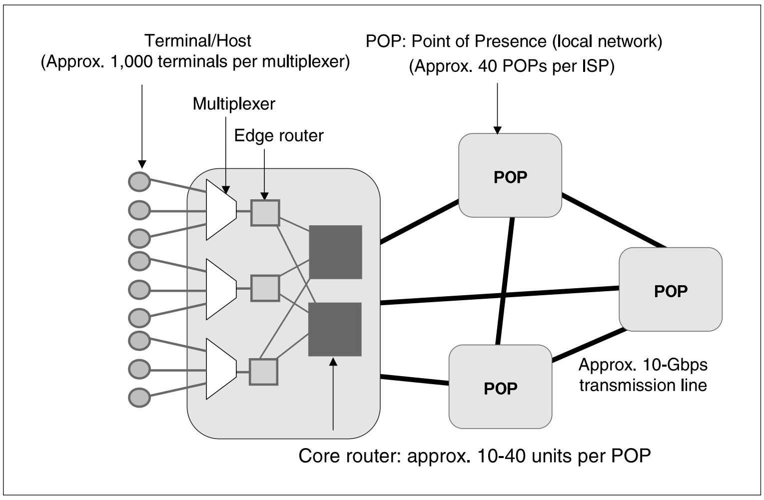
Figure 1:Classification of important technological R&D fields



2.2 Edge routers and core routers

This section provides an overview of the Internet infrastructure and one of its components, the router. There are two types of routers: "edge routers," which handle complex processing such as routing and traffic control as described below, and "core routers," which

Figure 2:Edge routers and core routers



Source: Author's compilation based on the lecture materialby Professor Nick McKeown of Stanford University

perform high-speed processing of large volumes of traffic flowing into the trunk network, using relatively simple methods. The distinction between the two is not definite, because router functions vary depending on the network scale, traffic type, the size of capital investment, and so forth.

The original design concept of the Internet was to interconnect networks that had been constructed by different organizations for their own use. Communications infrastructures evolved in line with this concept, and thus Internet connectivity in the 1980s and earlier was based on a simple architecture. However, as networks expanded in scale, its systems became hierarchical. In today's hierarchical systems, where each layer requires constituent technologies covering a broader scope, greater emphasis is placed on techniques to manage such technologies in an integrated manner.

Figure 2 shows a block diagram of network communications devices that support current communications infrastructures. General connectivity to the Internet is provided through these devices operated by service providers[8].

A core router assumes a role of collecting traffic flows in the backbone networks. Incorporating 16 LSI boards, each providing 10-Gbps-per-port switching capacity (one port accommodates a pair of physical communications lines), a core router delivers an aggregate switching capacity of approximately 160 Gbps. A core router costs about ¥100 to 200 million. An edge router, located in a network layer lower than core routers, is responsible for processing traffic flows in a smaller range. With 16 2.5-Gbps-level integrated boards, an edge router's switching capacity ranges from 20 to 30 Gbps. An edge router is priced at about several tens of million yen.

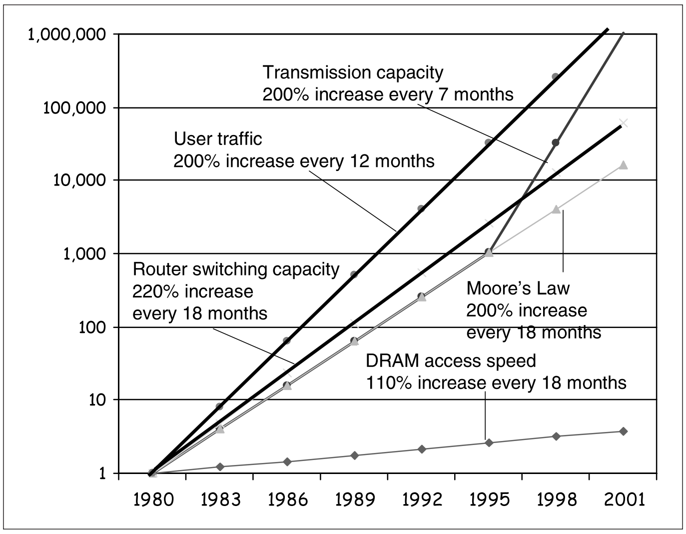
2.3 Router market size and its future growth

Let us now look at the scale of the communications infrastructure equipment industries. Global Information, Inc. (GII), a U.S. survey company, reported that the 2002 worldwide sales of all network devices, including routers and end-user network equipment for small networks, reached approximately ¥2,770 billion. GII forecasts that the figure will continue to grow hitting ¥3,300 billion by 2004, ¥4,910 billion by 2006, and ¥7,470 billion by 2008[6].

Routers account for over 50% of the entire communications infrastructure equipment market, forming an industrial sector whose sales reached well beyond ¥1 trillion in 2002. The ratio is expected to remain almost flat for years to come, indicating that the market size of the router as a basic element of communications infrastructures will increase to the ¥4 trillion level worldwide in three to four years.

Cisco Systems claims the overwhelming share in the router market. Cisco held the lion's share of 69% in terms of sales of overall network equipment for 2001, followed by 3Com Corporation in second place (7%) and Nortel

Figure 3:Traffic growth and change in related technologies



Source: Author's compilation based on the lecture material by Professor Nick McKeown of Stanford University

Networks in third place (3%). Among Japanese companies, none has a market share greater than 1%.

2.4 Network traffic on the rise

Then, how challenging are the requirements for R&D on these router products as an indispensable component of communications infrastructures? As widely known, the integrity and the computing power of a semiconductor chip have been increasing exponentially to maintain the Moore's Law trend. Meanwhile, the volume of traffic flowing into networks swelled to the point where access line speeds exceed a few Mbps, driven primarily by ADSL connections, which have recently become widely available to ordinary households in Japan. In addition, the user population of mobile phones and the demand for data traffic between mobile phones are on a sharp rise.

Figure 3 compares past growth rates in different sectors, including the processing speed of electronic devices, demand for traffic, and router switching capacity, based on observed trends. Provided that traffic maintains its upward trend and that routers' traffic processing capacity rises at the current pace, in a few years processing capacity will need to expand to a few times the size of what is demanded. Although this is nothing but a prediction, if the demand for communications applications remains brisk into the future and user traffic continues to grow at the same rate, new innovations will be needed in the arena of developing communications infrastructure equipment[2].

Future growth in traffic will widely vary in terms of volume and quality, depending on the content of communications applications that will be introduced. One likely scenario is that so-called multimedia traffic will increase, resulting in higher demand for realtime transmission of digital video data. Potential progress in use of home information appliances is also expected to generate frequent flows of small amounts of data, thereby increasing the overall traffic.

3 Technological trends

The foundation of current routing devices is a technology known as "IP switching." At the boundaries between individual networks constituting the Internet, "IP packets," which act as the containers of information to be delivered, are given forwarding information. Unlike telephone line switching, the forwarding process in IP switching is required on a packet-by-packet basis and, therefore, takes time. An IP switching technology that appeared in the 1990s presented a solution to this problem by adopting an approach called "cut-through routing." In cut-through routing, packets that are recognized to belong to the same logical connection and be addressed to the same destination are labeled as a single stream at a communication level near the hardware, in order to bypass the routing process and reduce the time to forward. The method has improved switching capacity.

Nevertheless, switching capacity remains a bottleneck in communications capabilities, which can be divided into transmission capacity and switching capacity, with the former surpassing the latter. This is attributed to that while optical communications technology has been implemented for the transmission path, the mainstream technology for switching is still electronics.

Next-generation routers are required to provide sophisticated routing ability in terms of both volume and quality. This means that at the core of the communications infrastructure, even higher transmission and switching capacities will be demanded, while at the edge, complex functions will need to be performed at high speed. In response to these requirements, there has been progress in functional differentiation between the two categories as well as advancements in each side. Technological challenges in both core and edge arenas are described below.

3.1 Increasing core router speeds

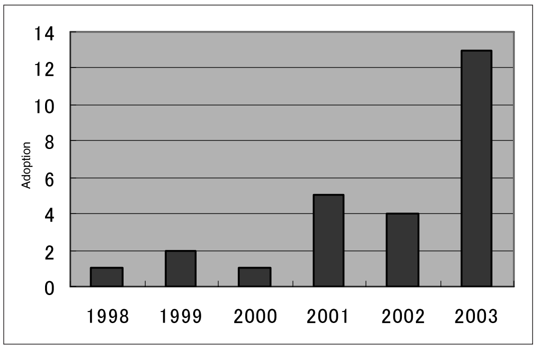
At a time when optical switching technology is moving toward commercialization, the development of next-generation network devices is also in progress in the area of core router technology. The transmission path that is principally fiber-optic allows for Tbps-class transmissions, whereas the switching process for forwarding still consists of electronic technologies. However, it is expected that recent achievements in R&D on photoelectronics will contribute to the implementation of optical switching technology into routing devices.

3.2 Enhancing edge router functionality

Under the circumstances discussed above, functional requirements for edge routers will most likely increase further toward the future. And it is no doubt that technologies to be accumulated in this area will form the core to construct the next-generation Internet.

Figure 4 shows the recent trend in the number of technical specifications, called "Requests for Comments" (RFCs), adopted by the Internet Engineering Task Force (IETF), a standardization organization on Internet protocols. MPLS (Multi-protocol Label Switch), a technology to process a variety of packets at high speed by using the above-mentioned cut-through routing, is a basic architecture that shapes the current routers. The chart indicates that proposals related to MPLS technology have been increasing in recent years[4, 5].

Figure 4:Growth in MPLS technologies



Source: Author's compilation based on Reference[5]

The proliferation of technical proposals on MPLS suggests active innovations, especially those concerning edge routers, have been under way. A factor behind this is a need for edge routers that provide more powerful network management capabilities, as discussed in the next section.

3.3 R&D challenges

The Internet has been designed as a "best-effort" system. The concept originated in the 1960s to the early 1970s, a time when the computer network was in its infancy. In those days, individual organizations built their own networks, and these networks were interconnected to create an "inter-" "net (work)" or what is now known as the Internet. The routers, the key element of the Internet infrastructure, have been developed as a means to embody best-effort technologies. A concept opposed to this has been adopted whenever the nation provides public infrastructures such as telephone switching networks, electricity and water-all users equally receive uniform quality of service.

Described below are areas where R&D is moving into a new phase. In other words, they are the areas in which new ideas beyond the traditional architectural concept of the Internet are needed for augmenting network management capability.

(1) Traffic quality control

A key issue in R&D on best-effort networks is the difficulty of guaranteeing the communications bandwidth in accordance with the type of communications service. There has been extensive debate over the importance of bandwidth guarantee as a technological challenge since the 1990s. The lack of bandwidth guarantee did not cause a serious problem in the past, because multimedia applications that accompanied broadband digital video transmissions failed to come into widespread use. However, now that an increased number of ordinary households are given access to circuit speeds of about 100 Mbps, it is necessary, in order to allow communications applications to take advantage of such high-speed circuits, that technology for bandwidth guarantee be embodied as a major factor that determines the direction of the technological change. This technology should be able to guarantee QoS in communications between individual connections, a requirement that could be satisfied by managing and controlling traffic volume across all network devices. Such a project, hardly feasible if conducted by a limited number of communications carriers, needs to involve multiple organizations that operate communications infrastructures, with the view of implementing sophisticated information switching and their control.

(2) Network management and control

The best-effort concepts naturally lead in the direction of "distributed" network management and control. Such architectural concepts contributed to the quick development and expansion of the Internet as a communications infrastructure. Distributed monitoring and control, however, are vulnerable from a security point of view, an aspect that is particularly emphasized these days.

For example, when illegitimate traffic is generated by a virus or the like to conduct a denial-of-service (DoS) attack, the origin of the attack needs to be tracked down across the boundary of an "area," which is a distributed element of networks. Capabilities like this are recognized as essential to next-generation edge routers, which should be able to provide controls that can affect multiple network operators, at any security protection stage ranging from attack prevention to attack response to subsequent tracking.

As this example indicates, applying only the "best-effort" concept, which has been the basis of the Internet's development, is insufficient to facilitate the future evolution of communications infrastructures. From a different perspective, this can be considered a good opportunity for Japan to utilize its technologies to make contributions in the area of fundamental Internet technology, which has become part of data communications infrastructures. The following section discusses technological policies from this standpoint.

4 The initiative in technological evolution

4.1 The age of the telephone switching network

In the age when telephone switching networks were built as a communications infrastructure, the laboratory of Nippon Telegraph and Telephone Public Corporation and other central research laboratories of NTT Public Corp. related companies served as the engine that drove Japan's technological growth in the communications infrastructure sector. Technological accumulation was facilitated through large-scale telecommunications carriers' capital investments expended as scheduled in their annual plans. Through the process of planning and developing "de jure" standards for a few years forward, technological accumulation took place in a well-planned manner. This approach was adopted not only in Japan but also elsewhere in the world with respect to communications infrastructures. In terms of human resources supplied from higher education institutions, graduates from technical colleges and the communication engineering course at universities favored NTT Public Corp. and its related companies as the places to start their careers. This fact can be seen as an indication of how such a traditional model functioned well.

4.2 The age of the Internet

In the subsequent age when the Internet was invented, a change occurred in the traditional model of technological growth. Those who drove the technological advances in this age were companies that aimed to set up “de facto standards” by introducing products with new capabilities onto the market ahead of others. Take the strategy of Cisco Systems of the U.S. as a typical example. Cisco’s technological accumulation has been mainly enabled by acquiring venture firms that own cutting-edge technologies. The reasons that such a technique was feasible and proven highly effective had something to do with the “best-effort” architecture of the Internet. In this architecture, networks have been operated by individual companies and universities, who could promptly adopt as part of their communications infrastructure any new products containing functions useful to them. Consequently, the driving force of R&D in this sector has shifted from large telecommunications carriers, who operate in line with national policy, to Cisco and other venture firms in Silicon Valley[3].

4.3 The course of next-generation R&D

NTT Corp. (formerly NTT Public Corp.) still assumes the major role in R&D among communications equipment manufacturers. It remains unchanged that the firm holds superior talent and is making enormous investments in R&D. However, now privatized, it can no longer explicitly take the national strategy-oriented initiative in the industry in responding to environmental changes as mentioned in the previous section. In addition, among other Japanese communications equipment manufactures, there has been a general tendency to scale down their central research laboratories. Yet another concern is that new entrants to the data communications business seem to pay little attention, concerning investing in R&D, to the aspect of long-term development of communications infrastructures.

As has been discussed, communications infrastructures are, from a technical point of view, in a period of transition, a time when technologies should be developed outside the traditional boundaries of the “best-effort” architectural concept. Under such circumstances, an initiative that is different from the traditional one should be taken in technological progress, for the purpose of facilitating further development of the Internet.

5 Challenges and proposals on technological policies

In the age of telephone switching networks, state-run corporations were given important and clear responsibilities. Now, at a time when the communications business is in the private sector, what the nation is expected to do are to define specific guidelines to set the course of the R&D on next-generation communications infrastructures and to promote basic research in this field. In the meantime, communications carriers will roll out their operations pursuant to their business principles and, consequently, conduct R&D activities as required. Then, it should be the academic sector that plays the role of continuously conducting basic research from a long-term perspective. The national government, with its strategy, needs to guide universities in what kind of leadership they should have and what kind of partnership they should forge with businesses in the related industries. More specifically, the following concrete measures should be considered.

5.1 Contribution to standardization

The adoption of RFCs, which serve as de facto standards as mentioned in section 3.2, is more reliant on past personal contributions to the standardization process and personal influence on the IETF than the presence of organized approaches. There exist some academic researchers in Japan who can attract certain attention in discussions on such issues. Given the scale of the Japanese industry, however, the number of people who can be qualified for such a role is limited. Japan should start with allowing its universities to conduct studies that will potentially contribute to international standards and establishing a system to actively support and evaluate such activities in the academic sector.

5.2 Formulation of an original vision

The current process of defining Internet standards, although claimed to be open, is said to be strongly influenced by a small group of people who share the same vision and made significant contributions to the invention of the existing Internet. Therefore, the future of technology will see no fundamental changes in the current picture in which the accumulated Internet technologies form the foundation of data communications technology. However, Japan needs to formulate its own vision on how to develop the national communications infrastructure in the future.

5.3 The future direction of research activities

The development of network processors, which would be essential to next-generation network management, requires not only practical knowledge on router design techniques but basic research efforts in areas such as parallel processing. To achieve research results of superior practical value in these fields, universities should embrace young researchers who have practical experience. Nowadays, a number of overseas universities have many competent researchers who once worked in private-sector research institutes such as those owned by vendors and communications carriers. This trend is particularly remarkable in Asian universities, whose number and quality of presentations at international conferences have reportedly been improving dramatically. Japanese universities should follow suit and actively recruit qualified talent.

R&D results on network management technology should be embodied, for example, as an ASIC (Application-Specific Integrated Circuit), a chip that incorporates control logic. Japan should allow academic research results to be commercialized in such a way and the resulting products to achieve competitiveness in the communications equipment component market. Universities play a significant role in the effort to produce such practical results, which require research in basic fields such as traffic theory.

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