

# Trends in Optical Fiber Communication Technology and Industry, and Proposals for Future Directions

## — Towards the Fusion of Seeds and Needs —

KIMIO TATSUNO

*Information and Communications Research Unit*

### 1 Introduction

Optical fiber communication technology enables ultrahigh-speed, high-capacity, long-distance transmission. Because there is no alternative technology, it is indispensable basic infrastructure supporting society's information and communication functions. The spread and improved performance of photonic infrastructure therefore has a major influence on a country's overall social life. For example, mobile telephones using wireless utilize wireless communication to reach nearby antenna stations, but the stations utilize photonic networks among themselves, and optical-fiber cables on the ocean floor enable real-time communication with people all over the globe. In addition, while the asymmetrical digital subscriber lines (ADSL) now widely used for the Internet use metal wires, station-to-station transmission utilizes photonic networks, connecting the world's personal computers. The scale of the world market for the photonic device industry that utilizes this technology as its core is ¥10 trillion. If optical fibers are connected not only to backbones but also to ordinary homes as exemplified by "fiber to the home" (FTTH) and to information devices, the scale of the photonic device industry's market can expand even further.

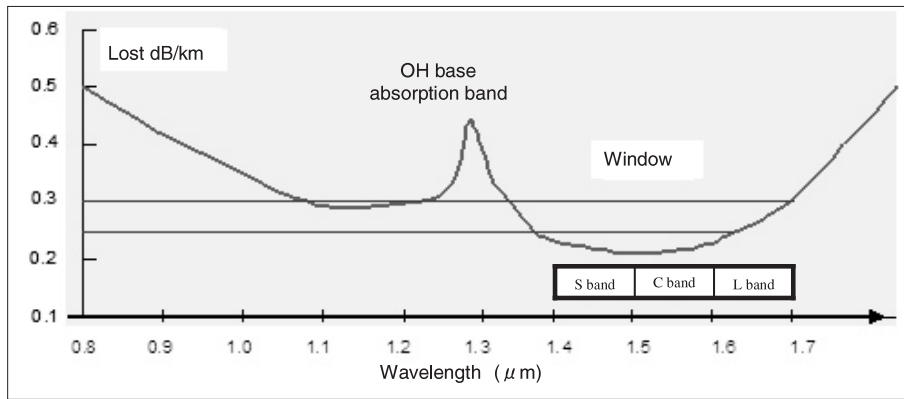
However, for the past several years the optical communication industry has been confronted with the collapse of the IT or dot-com bubble, and with the world in the throes of a recession led by North America, demand for backbone in particular has cooled off and the market has stagnated. Meanwhile, traffic over Internet lines

has been increasing since immediately after the collapse of the optical communication bubble. Led by peer-to-peer sending and receiving of motion pictures, the conversion of the work of business and national and local government is gradually spreading through e-commerce, e-government, e-education, e-medicine, and so on. These add up to the working of synergies that are peculiar to the Internet.

Therefore, at some point in the near future we may awake to find that traffic is congested at various points in society. The reliability and safety of communication may be damaged, and declining quality of service (QoS) may become a major social issue. In other words, bottlenecks may occur in the photonic networks that form the backbone of communications infrastructure. For that reason, we must not relax research and development efforts directed towards future photonic technology.

Based on the current awareness and future vision described above, this article discusses questions such as the following. (1) What is the background of the optical communication recession, and why did it occur? (2) In relation to the continuously increasing volume of traffic, what will the next bottleneck in photonic technology be? (3) Is a structure in place for creative research into new communications services actively utilizing broadband infrastructure made possible by photonic technology? In addition, the article offers proposals regarding the direction of R&D designed to fuse the seeds of optical communication infrastructure with the needs that require it.

**Figure 1 :** Optical fiber transmission loss bands and optical fiber amplifier operation frequency



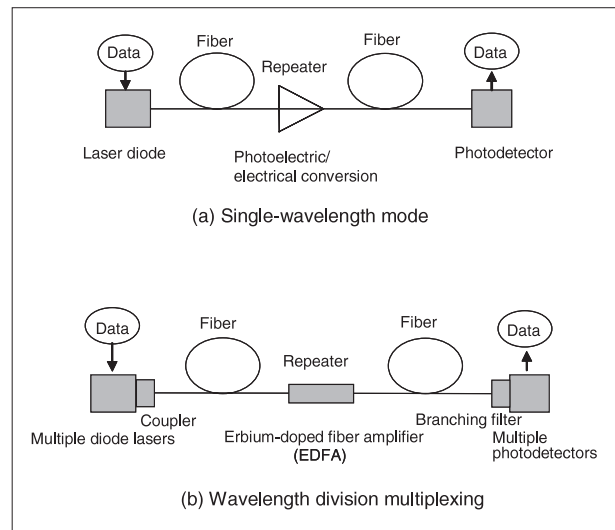
## 2 Optical fiber communication technology

### 2-1 Optical communication principles and wavelength division multiplexing

Within photonic technology there are modes such as the propagation of light through space, but this article discusses optical fiber communications utilizing optical fibers of glass materials with silicon oxide ( $\text{SiO}_2$ ) as the signal transmission medium. For the sake of simplicity, the article will refer to this as “optical communication.” Figure 1 shows transmission loss characteristics of optical wavelengths on currently installed typical optical fibers<sup>[1]</sup>. The peak in the center is the absorption band created by the harmonics of the OH base of residual moisture inside the fiber. Ordinarily, optical communication utilizes the wavelength bands, called “windows,” that avoid the peak. The wavelength used at first was  $0.85\mu\text{m}$  to the left of the peak. That was because the materials for laser diodes of the time were GaAs-based. Later, InP-based laser diodes were developed, and the band from  $1.3\mu\text{m}$  to  $1.6\mu\text{m}$ , where transmission loss is lowest, came into use. Furthermore, optical fibers are low cost at under ¥10 per meter, they are long-lived and reliable, and their tensile strength is greater than that of steel. In practice, such optical fibers ( $125\mu\text{m}$  diameter, approximately  $10\mu\text{m}$  core) are bundled by several hundred into optical fiber cables when installed.

Figure 2(a) shows the basic structure of optical communication utilizing optical fibers with characteristics like these. There is a laser diode light source on the data transmission end, and the

**Figure 2 :** Principles of optical communication



strength of that light is digitized as an electrical signal that modulates on/off. The modulated light signals are propagated in the optical fibers, but absorption and dispersion in the optical fibers cause loss of data and attenuation. For long-distance communications, therefore, repeaters are placed every few tens of kilometers to transmit optical signals over long distances. On the receiving side, photodetectors and electric amplifiers are in place, and the optical signal is converted into an electrical signal and the original data are recovered. In conventional single-wavelength mode, repeaters temporarily convert attenuated optical signals into electrical signals, and reactivate a laser diode after electrical amplification. In other words, each repeater must perform photoelectric conversion and electrical conversion. This conversion must be carried out for each wavelength channel, so utilizing wavelength division multiplexing with this method is difficult.

In contrast, as shown in Figure 2(b),

wavelength division multiplexing (WDM) passes beams from multiple laser diodes for different wavelengths through a coupler before inputting them into a single optical fiber. Therefore the transmission capacity of a single optical fiber is the product of one wavelength channel's transmission speed multiplied by multiple wavelengths. For example, if the interval between wavelength channels is 0.4nm, and the entire wavelength used is 400nm, it can be multiplied by 1,000 channels. If each wavelength channel transmits 40Gbps, 40-Tbps ultrahigh-capacity optical communication becomes possible. If we explain this astonishing communications capacity in terms of digital versatile discs (DVDs), the data stored in a two-hour movie on DVD is 4.7GB (about 40Gb), so the information stored in 1,000 DVDs can be transmitted to a destination across the Pacific in about one second.

Optical fiber amplifiers<sup>[1]</sup> such as erbium-doped fiber amplifiers (EDFAs) make this wavelength multiplexing transmission possible. Using them renders photoelectric and electrical conversion

by repeaters unnecessary. This is because these optical amplifiers function like optically-pumped lasers, enabling them to amplify optical signals in batches as light and on a relatively wide wavelength band. Furthermore, it is fortunate that the operation frequencies of optical fiber amplifiers, referred to as the S, C, and L bands, happen to be the optical fiber wavelength bands with the least loss, as can be seen in Figure 1. As depicted in Figure 3, the cable across the floor of the Pacific Ocean has 180 repeaters equipped with optical fiber amplifiers strung together about every 50 kilometers.

## 2-2 The structure of optical communication networks

As shown in Figure 4, the extremely high performance optical communication method described above comprises a network constructed of a transmission system and exchange node system that ties it together. The transmission system can be roughly divided into three layers, the backbone system (10-40Gbps)

Figure 3 : Repeaters for the Transpacific Cable

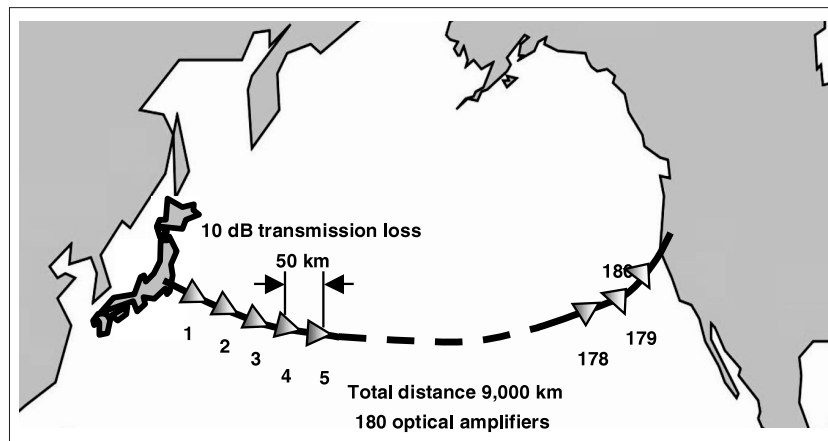
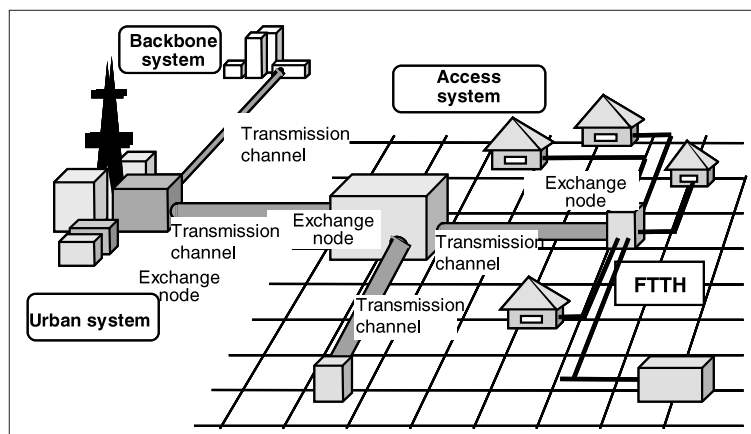


Figure 4 : Structure of the optical communications network



connecting cities and undersea networks, the urban system (1 G-10 Gbps) inside cities, and access system (0.1-1 Gbps) exemplified by “fiber to the home (FTTH).”

These transmission channels are connected to each other by exchange nodes. The exchange nodes are equipped with routers, which they use to control the destinations of traffic. If we liken exchange nodes to an expressway, they are the equivalent of interchanges. With the increase in traffic, faster switching throughput and higher capacity processing scale are needed. As I will explain below, in contrast to the transmission network, for which capacity has been sufficiently prepared through wavelength division multiplexing, the exchange node system may become the bottleneck for photonic networks in the future.

### 3 The optical communication industry and the collapse of the IT bubble

#### 3-1 *The beginnings of photonic technology*

Regarding the high-performance photonic technology described above, a 1991 speech by Vice-president Al Gore<sup>[2]</sup> shows the great expectations the United States Government had for it as essential technology for Information Society infrastructure. “Now, the most important thing is to announce the creation of an information superhighway. This information superhighway will be the greatest single factor in raising the curtain on the Information Age. However, the United States’ current policy of basing this on a network of metal wires is interfering with the dawn of the new age of optical fibers. This problem is nonexistent not only in advanced countries like Japan and Germany, but also in developing countries where metal telephone networks are under construction. If the United States does not break through this information bottleneck and retains the status quo, American technology will be left behind that of other countries. In the past, the quality of a country’s transportation infrastructure determined victory or defeat in economic competition. Countries with ports that could handle large ships were the winners in

economic competition. Ports, canals, railroads, superhighways, waterworks and sewers, and so on, were all invested in as infrastructure that would empirically increase national competitiveness. A corporate investment of \$100 billion would be enough to lay optical fibers to every home, office, factory, school, library, and hospital.”

Financial support for such expectations for photonic technology began in 1990 with part of the surplus US military budget created by the end of the Cold War. This ample budget was channeled through the Defense Advanced Research Project Agency (DARPA) to many US universities and companies, such as Bell Labs, the past Mecca of photonic technology, and research and development grew active. The US activity spread to Japan as well. At Japanese communications companies such as NTT and KDDI, communications device manufacturers like Fujitsu, NEC, and Hitachi, optical fiber manufacturers such as Furukawa Electric, Sumitomo Electric, and Fujikura, as well as at universities and national laboratories like NICT, the race to research and develop photonic technology grew heated. In Europe as well, it spread not only to public research institutes like the UK’s British Telecom (BT), Germany’s Heinrich Hertz Institute (HHI), and France Telecom, but also to the labs of companies such as Germany’s Siemens, the Netherlands’ Philips, France’s Alcatel, and the UK’s Nortel, and concentrated investment in the installation of optical fibers moved forward.

#### 3-2 *The WDM jump*

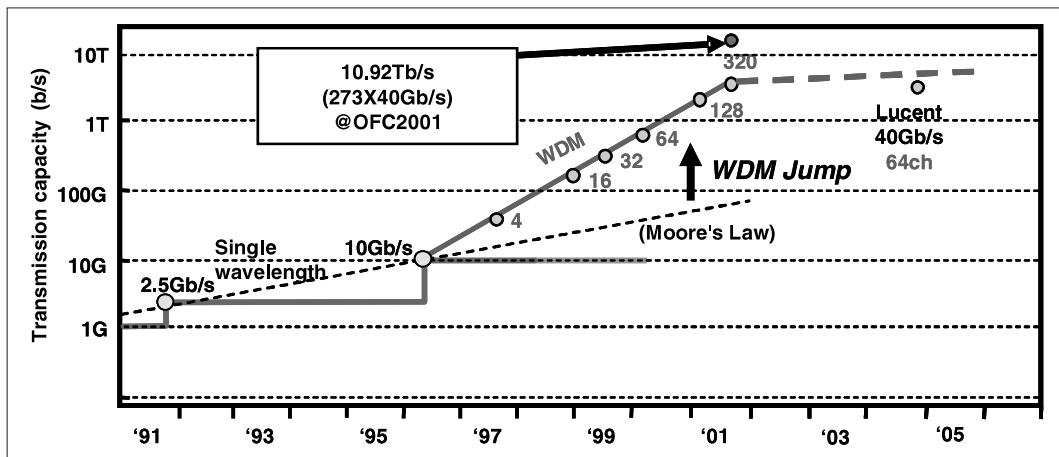
The result, as can be seen in Figure 5, was that the transmission capacity of optical communication at a practical level took a sudden and remarkable leap forwards. In the Chart, the staircase-like line represents transmission speed per wavelength, while the line above that represents transmission capacity per optical fiber through wavelength multiplexing. The arrow indicates the so-called WDM jump, where the transmission capacity of multiplex wavelengths alone exceeded that of single wavelengths. The practical application of this technology advanced at a pace faster than that of Moore’s Law, the

accepted timescale (doubling every two years; the broken line in Figure 5), for advances in information and communications technology and electronics. LSI drives the laser diodes that are the light source for optical communication, and the modulation rate of LSI grows in accordance with Moore's Law<sup>[1]</sup>, wavelength division multiplexing exceeds it in principle. The amazing technological innovation of wavelength division multiplexing sparked public investment by the above-mentioned DARPA, and numerous venture and investment companies gathered around it seeking business opportunities. At first, no one could have predicted that it would lead to excessive investment in optical communication that would cause a bubble effect. In addition, unrealistic expectations for the spread of the Internet and the unbundling of communications infrastructure through deregulation in the United States also contributed to such investment.

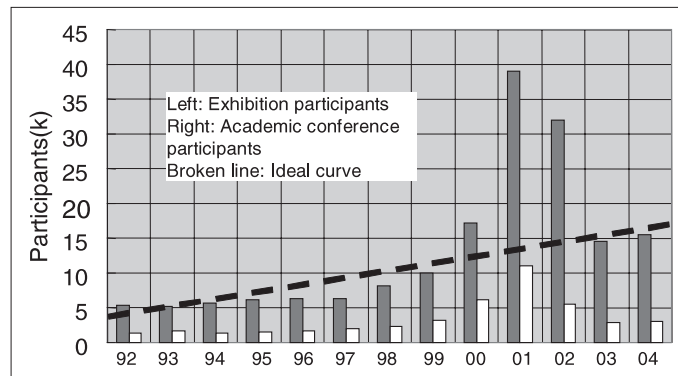
### 3-3 The optical communication market

Now we will look at the correlation between the rapid growth of wavelength multiplexing technology and participants at the annual Optical Fiber Communication Conference and Exhibition (OFC) as depicted in Figure 6. The OFC is held in the United States every year and is the world's largest exhibition at which optical communication businesses and technologies are exhibited all at once. Annual changes in the size of the optical communication can be seen in it. According to these data, participants increased rapidly to a peak in 2001. Clearly, this is because participants from major corporations and venture capital companies rushed in seeking the above-mentioned business opportunities in wavelength division multiplexing. I also attended for five consecutive years from 1997 through 2001. I gave an oral presentation each time, including the opportunity to deliver an invited

**Figure 5 :** The WDM jump (remarkable growth in transmission capacity through wavelength division multiplexing)



**Figure 6 :** OFC participants (Exhibition and Academic conference)



Source: Author's compilation based on data from Optical Society of America (OSA)



address before approximately 1,000 people, so I personally witnessed that amazing expansion.

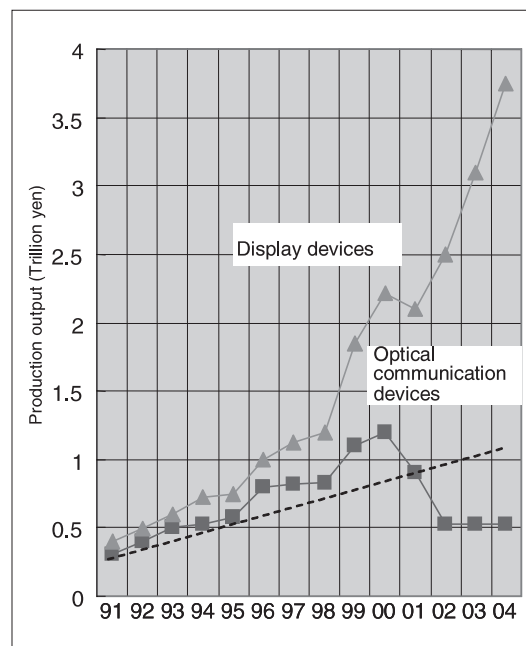
A majority of the new participants were from venture corporations spun off from universities, public research institutes, and major corporations. Venture corporations from universities and public institutions in particular were protected by the Bayh-Dole Act of 1980. Traditionally, when universities carried out research funded by the US government, the government retained any patents. The law made it possible for universities and researchers to retain patents. This enabled universities to own and patent the results of government-funded research, opening the way to technology transfer between universities and corporations through licensing agreements.

In addition, a 1996 revision to the Telecommunications Act provided for unbundling. Invested grew heated as deregulation of the communications infrastructure enabled companies to lease competitors' infrastructure to provide services.

Since the peak in 2001, however, the number of companies exhibiting and the number of participants in the academic conference have dropped sharply. This is clearly caused by the rapid decline in the formerly numerous venture enterprises. In other words, the communications systems companies that are the venture firms' most important customers have been hit hard by the collapse of the IT bubble and have had to stop ordering from the venture companies. This has destroyed the supply-and-demand that is the basis of healthy economic activity, and the venture firms that once sprouted like weeds are now facing the dismal fates of merger and acquisition, if not dissolution.

The cooled demand is the result overheated investment competition carried out without careful analysis of demand. At the time of the peak, it was reported that optical fibers were being laid at three times the speed of sound. It is said that globally 0.5 terameters of fiber have been installed, enough to circle the Earth 10,000 times. Ten percent of that is said to be in China<sup>[3]</sup>. The small optical communication infrastructure market that should have been grown over 10 years instead became saturated

**Figure 7 :** The markets for optical communication and display devices



Source: Author's compilation based on data from Optoelectronic Industry and Technology Development Association

in only a few years. As a result, the current optical communication market is merely trading water. Competitive market economies can bring out great power when times are good, but afterwards investors must always watch whether to keep investing and avoid bubbles created by speculation without substance. Ironically, the optical communication industry took a major hit from the WDM bubble that was created by the revolutionary technical innovation of wavelength division multiplexing.

Naturally, the influence of the North American optical communication recession spread to Japan as well. At one time, Japanese corporations were thriving on orders for parts and equipment from North American optical communication companies. Figure 7 shows annual domestic production of photonic devices in Japan<sup>[4]</sup>. Display-related devices are shown for comparison. After declining following a peak in 2000, production immediately rebounded and has grown steadily since then. In contrast, domestic production of photonic devices has not recovered since the 2000 peak, taking on the aspect of a bubble collapse. The project on mass production of transceiver modules for access-system optical communication<sup>[5-6]</sup> in which I was personally involved was no exception. It began in 1996,

and by 2000 we had a production line capable of completing several hundred thousand units per month, but just after we began trying to sell them to customers, the project was canceled, to our great disappointment.

## 4 Trends since the collapse of the bubble

### 4-1 Traffic growth and trends in communication services

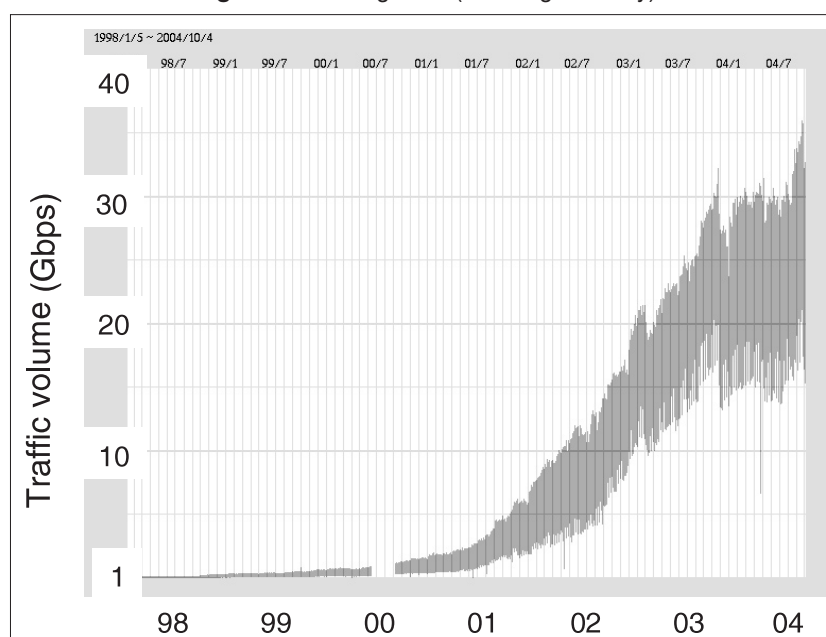
Will the optical communication market recover? To answer that question, I examined growth in Internet traffic and its causes. Figure 8 shows traffic measurements taken at a traffic measurement point in Tokyo's Otemachi<sup>[7]</sup>. Ironically, since immediately after the collapse of the optical communication bubble (Figures 6 and 7) in 2001, traffic has been doubling every year. If it continues at this pace, future traffic volume increases may put pressure on photonic networks, and traffic bottlenecks may occur, causing declining Quality of Service (QoS) to become a serious social issue.

The wave of information technology that has a major impact on economic system and industrial structure reform throughout the country is advancing in a number of fields, including electronic government, electronic trading, logistics management (IC tag systems),

risk management, electronic medicine, electronic education, and "ubiquitous Internet." For example, looking at commercial transactions between companies, over the past few years the percentage of electronic transactions has been increasing by 11 percent annually<sup>[8]</sup> in accordance with the e-Japan Plan. Of course, several tens of percentage points of transactions such as individual stock trading, airline and hotel reservations, and individual bank payments are already taking place over the Internet, becoming a cause of the increasing traffic.

Conventionally, Internet connections were limited to personal computers and mobile telephones, but in the near future digital consumer electronics such as widescreen televisions, video recorders, digital cameras, portable movie cameras, and personal data assistants (PDAs), as well as home appliances such as refrigerators, microwave ovens, and washing machines will connect to the Internet by modem. In addition, automobiles will connect by wireless. Furthermore, if IPv6 standardization advances and a society of ubiquitous Internet connections is realized, almost all goods will have IC tags attached. The amount of information associated with each item will not be large, but the number of items will be enormous. It is estimated that in 2010 there will be 15 billion devices connected to the Internet<sup>[9]</sup>, so traffic

Figure 8 : Traffic growth (doubling annually)



Source: Author's compilation based on data from the Japan Internet Exchange (JPIX)<sup>[7]</sup>

volume may further increase.

Data volume is particularly high for moving pictures. The spread of video telephones that utilize broadband capabilities, or the Internet exchange of videos made at home or work are definitely expected to increase. Just as digital music transmission services that send ringtones to mobile telephones have become active recently, currently high-quality video services for consumers, such as video on demand (VOD) to replace DVD rental, as well as Internet transmission of high-definition video and digital cinema, are expected to spread.

VOD was actively researched and developed in the second half of the 1990s, and trials have been carried out in certain areas. At that time, though, both user fees and the set-top boxes (STBs) used as receivers were expensive, and the service did not spread. However, if broadband fees fall sufficiently from those prices, and if additional charges are less than those for a video shop, video-on-demand may reappear on the market. In fact, beginning next January, services<sup>[10-11]</sup> that transmit new movies on DVD over the Internet will open with fees equivalent to those of video stores. Although it is gradual, VOD services are beginning. They will begin with current DVD image quality, but Internet-distributed digital cinema with high definition (HD) and super high definition (SHD) is in sight. Digital cinema represents the digitization of the ancient 35-millimeter film system that has been in use for 100 years. Standardization work led by NTT and the University of Tokyo<sup>[12]</sup> in conjunction with Hollywood is well underway. In addition, NHK and other television networks all over the world have vast archives that are stored without ever seeing the light of day.

Protecting copyrights of stored data that is transmitted over the Internet in this way is not easy. Currently the Copyright Council is discussing the idea<sup>[13]</sup>, and eventually a solution is expected. In fact, a number of waves are approaching. There is consumer demand for content that can be more conveniently and easily viewed over the Internet than any other way. There are immediate business opportunities for copyright holders and service providers to charge fees. More advanced technologies exist to prevent

illegal copying of digital music distributed by Internet services, which are ahead of video services. Competitive markets for content have formed in the United States, where the business model is to use each window, from theaters to rentals to Internet distribution to pay TV to free TV, as a window to maximize sales. Therefore Japan must also quickly resolve the bottleneck to Internet distribution created by copyright issues.

In addition, in the future when each home will have a high-capacity hard disk drive (HDD) or a low-cost server bundled with a recordable high-capacity optical disk, desire for Internet distribution will be stimulated even more. In other words, the arrival of an era in which people can use specialized terminals and Internet terminals to enable electronic program guides (EPGs) to automatically reserve recordings and build collections of desired content is expected. Clearly, if Internet distribution and digital broadcast services fuse, and digital video travels back and forth all over the IP Internet, the photonic networks that underlie the communications infrastructure will be pressured.

#### 4-2 *New FTTH trends*

The traffic described above currently moves through communication lines such as the 72 million mobile telephone subscribers, 12.6 million ADSL subscribers, 2.8 million cable TV subscribers, and now 1.75 million FTTH households. Among them, the most notable recent development is high-speed FTTH. It may be preparing broadband users for the Internet distribution of video described in the previous section. Looking at the number of FTTH and ADSL subscribers as depicted in Figure 9<sup>[14]</sup>, although ADSL growth appears saturated, FTTH growth is steep.

This is because at 100 Mbps FTTH transmission speed is faster than other types of broadband lines and that speed does not depend on transmission distance between stations and subscribers. Other reasons include high technical potential, with plans to expand soon to 1 Gbps. Regarding user fees, price-cutting and service competition are underway. In addition to NTT East and NTT West, Tokyo Electric Power Co. (TEPCO) is entering FTTH by utilizing the



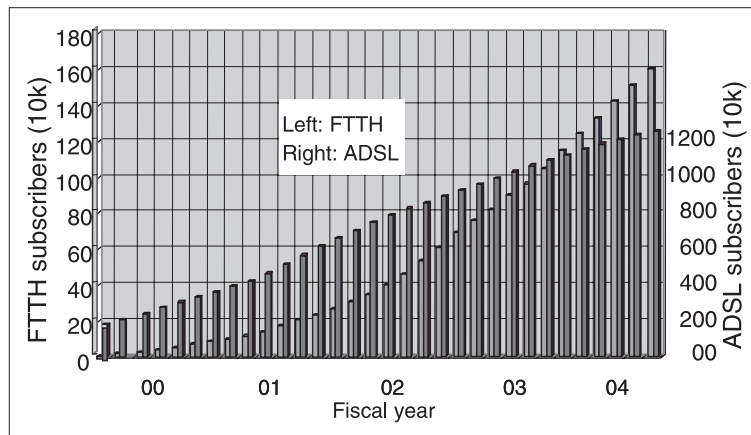
optical fiber network it uses to monitor electric lines, and thanks to unbundling policy, vigorous Yahoo BB is entering by renting NTT's optical fiber network<sup>[15]</sup>. Since the backbone market has cooled, FTTH is drawing investment instead. In November 2004, NTT announced its policy to switch 30 million telephone landline customers, about half the total, to FTTH by 2010. It is to invest ¥5 trillion over the next six years. NTT has also announced plans to replace all landline telephones with optical IP telephones.

With this progress in broadband infrastructure, Japan is leading the world in FTTH as communication and broadcasting fuse to create new services as shown in Figure 10. The concern that Vice-president Gore voiced in the 1991 speech<sup>[2]</sup> quoted in section 3-1 above, that Japan and developing countries will lead the United States on the information superhighway, may be becoming a reality. Japan is number one in

FTTH subscribers in the world, so that trend is capturing the attention of concerned parties all over the world<sup>[13, 16]</sup>. This situation can be seen as an excellent opportunity for Japan to display even greater leadership on international standards for FTTH. With its existing cable television system (74 million households, a 67.7 percent penetration rate), the United States is advanced in terms of triple-play service, video, audio, and data. However, the actual service speed of cable TV's data speed of 30 Mbps slows when it is shared among 100-500 subscribers. In contrast, Japan's FTTH speed of 100 Mbps to 1 Gbps is shared among 32 or 64 customers, so the ability to provide service that is faster by a factor of 10 may prove superior.

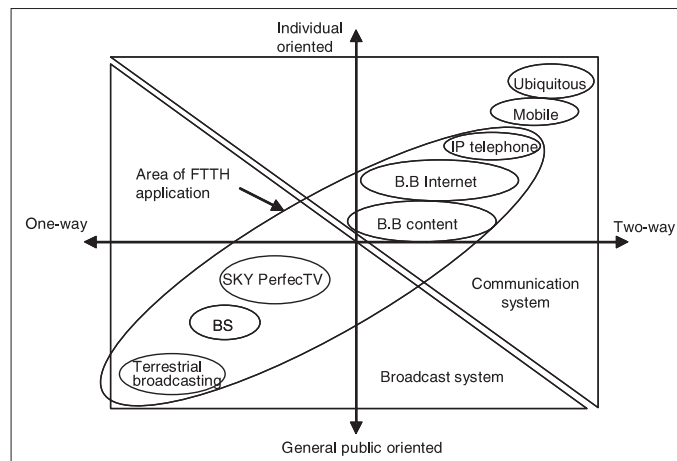
In South Korea<sup>[18,19]</sup>, Taiwan, China, Singapore, and some countries in Southeast Asia, conditions are similar to those in Japan in that cable TV is not as widespread as in North America and

**Figure 9 : Number of FTTH and ADSL subscribers**



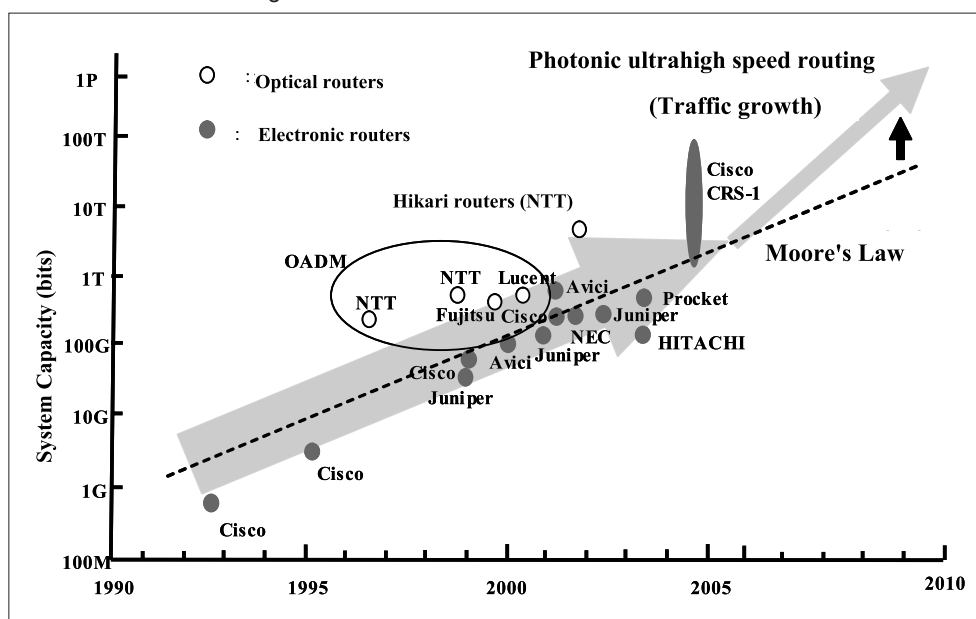
Source: Author's compilation based on Ministry of Internal Affairs and Communications data<sup>[14]</sup>

**Figure 10 : The fusion of communication and broadcasting: applications for FTTH**



Source: Author's compilation based on Opticast materials<sup>[17]</sup>

**Figure 11 :** Router growth (doubling every one and a half years) and router processing speed improvement in relation to traffic growth



Europe. Those countries are therefore tending towards implementing IP Internet broadband services through FTTH or low-cost fiber to the building (FTTB) + DSL for housing complexes or through hybrid fiber coaxial (HFC, a mix of optical and cable TV). Japan is likely to lead the East Asia region in setting standards for access systems such as FTTH. To do so, tie-ups with China and its gigantic 1.3 billion person market are vital. Indeed, an IPv6 project led by the governments of China and Japan in which Japan provides IPv6 routers for insertion into China's education and science networks is currently underway. Hitachi, Fujitsu, and NEC IPv6 routers have been placed in nodes in universities in Beijing, Shanghai, and Guangzhou. Applied research on connections to Japan and IPv6 networks is also developing<sup>[20]</sup>. Such achievements should be continuously utilized to promote standardization in access systems. The above section has described trends in access systems.

### 4-3 Router bottleneck

Looking at backbone systems, we find situations such as the following. As described in section 2-2, photonic networks can be divided into transmission systems and exchange node systems. The capacity of transmission systems has been radically expanded through the wavelength division multiplexing described above. Therefore,

although the market for transmission-system transceiver modules has rebounded from last year's low and shows signs of a mild recovery this year, no sudden leaps forward can be expected from the market. The prevailing view is that demand will eventually recover and that only companies that patiently take on the challenge of mass production of 40 Gbps transceiver modules and the full-fledged technical development of 160 Gbps modules will be able to make it through the difficult period until recovery.

We must also look at routers, which affect the processing performance of the exchange nodes that comprise the other basic element of photonic networks. As shown in Figure 11, the processing speed of electronic routers is doubling every one and a half years. This speed may not be sufficient to keep up with traffic, which is doubling every year (see Figure 8). This is because, as explained above, wavelength division multiplexing that utilizes the properties of light is able to exceed Moore's Law, while the switching speed of electronic routers is decided by the performance of LSI circuits and has not been able to surpass Moore's Law.

As denoted in Figure 11, recently in this field Cisco Systems announced routers with the shocking system throughput of 92 Tbps<sup>[21]</sup>. The equipment links several electronic routers with an optical interconnection that uses laser diodes and optical fibers. Cisco succeeded in technical

**Table 1** : Technical issues in the optical communications field

	Backbone systems	Access systems
Communications services	QoS, security, encrypted communication, multicasting, e-commerce, e-government, triple play, VOD, digital consumer electronics, ubiquitous, etc.	
International standards	GMPLS	FTTH (FSAN)
Exchange nodes	Optical routing Hybrids 0.1-1 Pbps	Electronic routers Low cost Energy saving
Transmission channels	160 Gbps and beyond	Low cost
	100-1,000 waves	Transceiver modules

development that leaped past previous trends. The system is a hybrid that adds the advantages of light to conventional electronic routers, and it may start a trend. As for optical routers, ultrahigh speed parallel processing utilizing two-dimensional wave fronts (e.g., Fourier transformation by lenses) is possible, raising expectations for the technology.

Currently, electric power, including air conditioning, consumed by photonic networks and other information communication devices is only about 5 percent of the whole. It is feared, however, that the spread of telecommunications equipment in response to traffic growth could lead to power shortages. Therefore it is extremely important to develop systems that consume little power. In that sense, technical development to take advantage of the low power consumption of light is also important. With the advent of optical fiber amplifiers, photoelectric/electrical transformation in repeaters in transmission systems became unnecessary. In the same way, challenging research to create all-optical networks in which light travels as light from transmitter to receiver by replacing electronic routers in exchange nodes with optical routers is making progress.

Generalized multiprotocol label switching (GMPLS), which requires advanced photonic technology prowess, is emerging as the next protocol for high-speed photonic networks. GMPLS carries out processing by using optical signal wavelength as a label to decide routing, preparing a specially controlled IP channel to route data as an optical signal<sup>[22]</sup>. Because transforming an optical signal into an electrical signal when performing routing causes a loss of speed and consumes power, ways to route

data as unchanged optical signals are being sought. Table 1 is a summary of the future R&D issues just described. Recently, research and development in quantum communication and quantum cryptography communication<sup>[23]</sup>, which are intended to surpass wavelength division multiplexing in optical communication capacity and security, have become active as well, but space does not permit me to address them in this article.

## 5 Future directions

### 5-1 Overseas R&D trends

Although the United States, like Japan, is in an optical communication recession, the National Science Foundation (NSF) and DARPA are funding R&D test beds using photonic technology. Joint government-private sector public projects to create new services utilizing high speed 10-20 Gbps optical fibers are being strongly pushed. Major projects<sup>[24]</sup> include the “vBNS+” project on IPv6, multicasting, and digital libraries, the “Abilene” project on QoS verification and security, the “TeraGrid” project on applying photonic technology to grid computing, and the “StarLight” project on Internet exchange (IX) points and optical switching and routing research. Emphasis is placed on projects involving services and applications using high-speed networks including optical communication. It is worthy of particular attention that a balance is being kept with projects on optical communication devices and equipment. In addition, numerous corporations and universities are actively involved in the projects, and cycles to transfer technology to the private sector through industry-academia tie-ups are in place.

**Table 2** : With software at the top and commodities at the bottom

	Optical disks	Personal computers	Communications networks
Software, systems (content)	Motion picture companies (Hollywood)	4 Windows (Microsoft Corp.)	Communications protocols Services
Key devices	DVD disks Decoders MPEG standards	CPUs (Intel)	Routers (Cisco)
Hardware	Players	PCs	Transceivers, servers
Commodities	Optical pickups, semiconductor memory, circuits, mechanisms	Memory (HDD, DRAM)	Laser diodes, modulators, photodetectors, optical fibers

In Canada, “CA\*net4,” the world’s first national optical network has been deployed, and research in broadband service like e-business, e-content, e-health, and e-education is being pushed. It is also connected to other R&D networks in Europe and the United States.

In Europe, from the perspective of emphasizing the public nature of information communications infrastructure, the EU and national governments are showing strong leadership and operating projects to create new services. The projects include “GEANT” on QoS and multicasting research. “6NET” on IPv6, and “SURFnet6” on interconnectivity, electronic corporations, and e-business.

In Asia, projects such as China’s “CERNET” on IPv6 and distance education, South Korea’s “KOREN” and “KREONet2” on QoS, multicasting, IPv6, and MPLS, Taiwan’s “TANet2,” and Singapore’s “SingAREN” are being promoted. All of those test beds are linked to other test beds in the United States, and R&D on proving new services through international tie-ups is being advanced<sup>[24]</sup>.

To begin with a long-term, panoramic view, underlying the economic success of the United States in the 1990s was a system driven by the revival of weakening hardware industries through the introduction of information technology along with the software industries that were already leading. The economy rode those two vehicles to sustained economic growth<sup>[25]</sup>. Naturally therefore, in the field of optical communication as well, along with hardware investment, the United States will not stop investing in the software and services that are its specialties.

As shown in Table 2, an overview of the industrial structure of information technologies

such as optical disks and personal computers can be illustrated with the brains at the top in the systems and software where knowledge is most concentrated, the heart in key devices, and commodities as the extremities<sup>[26-27]</sup>. In this diagram, the higher one goes, the more knowledge is concentrated and business value is added. Of course, leadership on international standards is also closely involved. How well Japan’s technologies and businesses can break into the top of this structure can be seen as an index of the success or failure of Japan’s IT industry until the present and into the future.

## 5-2 Support for research investment by Japanese corporations

As described above, conditions surrounding photonic technology and industry have begun to change now that a few years have passed since the bubble collapsed. Indeed, the market seems to have hit bottom and to be showing signs of recovery (see Figure 6). We can hypothesize that because shortly after the bubble’s collapse Internet traffic began increasing even more than it had been (see Figure 8), investment is gradually reviving in light of predictions of the arrival of a true IT Society.

Japanese corporations, however, were hit hard by the semiconductor recession that followed the bursting of the real estate bubble in the 1990s as well as the collapse of the IT bubble. Negative investment factors followed in succession, and the ability of corporations to invest in research is now weak. They therefore lack the ability to sustain very risky research themes, and a shift of resources away from optical communication fields to other research is also taking place, leaving the future uncertain.

If corporations are unable to perform research on themes for which the research phase carries great risk, the orientation of researchers towards leading-edge research issues that forms the most important element of research and development will be weakened, and opportunities for groundbreaking discoveries may be lost. Furthermore, if researchers do not have a grasp of R&D issues involving the most-advanced technologies, the vitality of corporate R&D, which has had the greatest impact, will be lost. When government, academics, or foreign researchers announce technical innovations, corporations will no longer have the ability to tackle them at the practical application stage. Moreover, a danger of having to accept miserable defeat in competition not only with advanced countries but also with developing ones will arise.

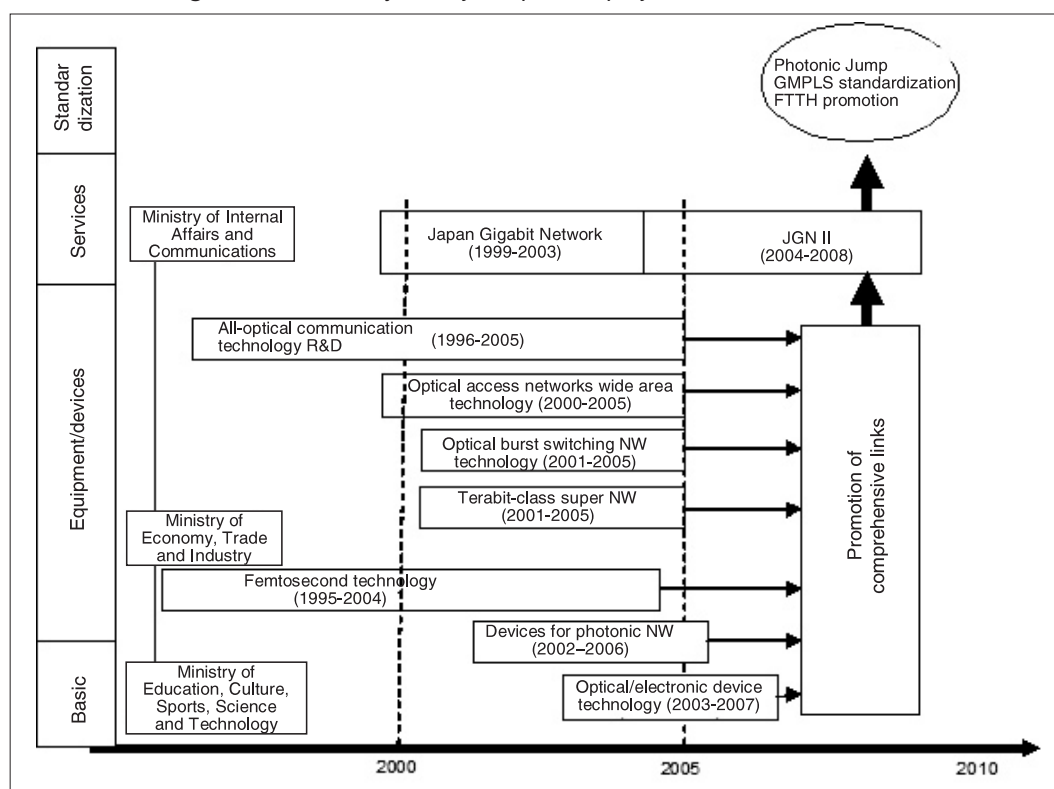
It is a time like this when public investment in research and development is vital. Continued support from public investment is required if Japan is to avoid losing its lead in the optical communication fields in which it has maintained its competitiveness.

### 5-3 The status of Japan's public projects

In regards to the situations described above, Japan is engaged in the public projects shown in Figure 12. The chart summarizes basic research that will be the foundation of future photonic technology, applications in devices and equipment, and research on systems and services. However, a tendency for the themes of this research and development to be biased towards research in devices and equipment, which has been Japan's specialty, is visible. It is as if the projects are designed to supply commodities to demand in the IT services and businesses that are progressing in the United States. Moreover, most of them began at the height of the IT bubble, and they seem as if they may end next fiscal year in the wake of the collapsed bubble.

Of course, Japan also has a world-class test bed for research and development on IT services utilizing high-speed optical fiber communication technology: Japan Gigabit Network (JGN). It was carried out from 1999 through 2003, with much success. It is being followed by JGN II, which is to be operated by NICT from fiscal 2004 through 2008. JGN II is a joint R&D system on a communication network with transmission

Figure 12 : Summary of major Japanese projects and future directions





speeds of 10-20 Gbps. Its purpose is to develop Japan's own communications services, security systems, and so. In addition, the National Institute of Informatics operates the Super SINET network. However, most participants in these projects are universities and public research institutes, and corporate participation is rather lukewarm.

If this continues, Japan will never be more than a parts store. The situation is similar to Microsoft's overwhelming power in personal computers and Hollywood's lead in providing content for optical disks, as shown in Table 2. American companies' commodity strategy for Asia appears to be operating in the field of optical communication as well. In other words, business focus and R&D on the communication protocols that will form the basis for international standardization, on services, and on applications remains centered on the United States, which takes leadership on international standards. Therefore, no matter how much Japan touts the technical prowess of its parts and equipment, if it is lacking in the software and service applications needed to operate them as systems, Japanese companies will lose out to European and North American firms in the competition for orders.

## 6 Conclusion

Based on the above awareness of the situation and view of the future, I will offer some proposals for the future direction of research and development in the field of optical communication as a whole.

The optical communication industry, which provides the basis for IT infrastructure, was hit hard by the bursting of the optical bubble. However, looking at the history of technological innovation in areas such as railways, broadcasting, and automobiles, in each of them bubble effects have formed and oversupply destroyed the balance with demand leading to an industry recession. Whenever society clearly needed that technical infrastructure, however, the technology gradually permeated society after the bubble collapse and became indispensable infrastructure for living in society<sup>[28]</sup>. If we look seriously at the recent rapid increase in traffic, and take the optical bubble as another example of

the economic phenomenon, snuffing out research and development when the flame is burning low is not good policy. It is therefore necessary to remind ourselves that optical communication by nature is public infrastructure and to continue investing public funds in it.

Investment should not be made in the traditional way of simply prioritizing seed research themes in commodities supply. Instead, R&D to create demand should be set up through test beds such as JGN II and Super SINET to create new communication services, and that should be the vehicle driving research. Using that strength, Japan demonstrate leadership in worldwide technology and business, beginning with international standardization activities<sup>[29]</sup>.

Regarding access systems, Japan's FTTH subscribers lead the world, having exceeded 1.75 million. This is an opportunity for Japan to have a stronger voice in initiatives for international standards. For example, The United States is taking the lead in the triple-play service of video, audio, and data with its existing cable television system. In Japan, on the other hand, high-speed FTTH, which has faster data speeds than cable TV, is more widespread and may lead to advantages through the creation of superior communication services. In addition, South Korea, Taiwan, China, Singapore, and some other Southeast Asian countries are similar to Japan in that cable television is not as widespread in as it is in Europe and North America. Therefore it is very likely that Japan could cooperate with other countries in East Asia to take the lead on standardization of FTTH and other access systems. In particular, Japan should build on the success of the joint government-led project on IPv6 with China to continue cooperation with that country.

In addition, copyright issues, which are one hindrance to developing the market for the Internet distribution of content, should be resolved quickly. This would stimulate the creative ambitions of content creators and vitalize the content market. The uniqueness of Japanese animation in particular is recognized worldwide, and the spread of Internet distribution would further vitalize such creative activities.

Regarding backbone systems, Japan should

demonstrate leadership on GMPLS, the communication protocol that is advancing as the next-generation international standard in exchange nodes, where future bottlenecks are anticipated. The technology of Japan's world-leading parts and equipment, which have been boosted by Japan's technical prowess, will be a formidable argument.

For those reasons as well, the various device development projects under the jurisdiction of different ministries should be periodically checked from the perspective of JGN II as a test bed for the creation of new services, and the direction of new projects should be clearly announced. Concretely, the leader of each project should form a comprehensive committee spanning all their projects. There they could bring their results, exchange technologies, and seek future directions. They could integrate related technologies, as well as actively bringing together people from private, public, and academic research institutions more often.

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### References

- [1] Shimada, Shibata, and Toba: "Photonic technology in the broadband era", Shingijutsu Communications Co. (2004)
- [2] Al Gore: "Infrastructure for the global village," Scientific American, Sept. p.108 (1991). Yamashita, Kawase, and Ota: Hikari access houshiki ("Optical access methods"), Ohmsha (1993)
- [3] H. Kogelnik; Technical Digest, Mo 1.1.1, ECOC '04 (Stockholm)
- [4] Optoelectronic Industry and Technology Development Association, ed. "Report on optical technology roadmap" (2004)
- [5] K. Tatsuno, et al, IEEE, J. of Lightwave Technology, Vol. 17, pp.1211-1216, July 1999
- [6] K. Tatsuno, et al., IEEE, J. of Lightwave Technology, Vol. 21, No. 4, pp.1066-1070, 2003
- [7] <http://www.jpix.co.jp>
- [8] <http://www.ecom.jp>
- [9] <http://www.storm.com>
- [10] <http://www.artisthouse.co.jp/>
- [11] <http://www.pod.tv/contents/help/gaiyou.html>
- [12] T. Aoyama; Technical Digest, Mo 1.1.2, ECOC '04 (Stockholm)
- [13] [http://www.mext.go.jp/b\\_menu/shingi/bunka/gijiroku/013/04110401.htm](http://www.mext.go.jp/b_menu/shingi/bunka/gijiroku/013/04110401.htm)
- [14] [http://www.soumu.go.jp/s-news/2004/040930\\_2.html](http://www.soumu.go.jp/s-news/2004/040930_2.html)
- [15] <http://bbpromo.yahoo.co.jp/promotion/hikari/index.html>
- [16] Y. Maeda; Technical Digest, Mo 4.1.1, ECOC '04 (Stockholm)
- [17] Masao Nito: "Opticast characteristics and business development", RBB TODAY/SSK Special Joint Seminar (2004)
- [18] Y-K Lee: Technical Digest (CD-ROM), Plenary Talk, OFC '04 (Los Angeles)
- [19] J. Hongbeom: Technical Digest, Mo 3.1.3, ECOC '04 (Stockholm)
- [20] Masahiro Ojima: "China watching," Optronics, No. 258, 6, 2003
- [21] <http://www.cisco.com/en/US/products/ps5763/>
- [22] Kenichi Sato and Tadashi Koga: "Wide area optical networking technology: photonic networks", Institute of Electronics, Information and Communication Engineers (2003)
- [23] [http://www.ieice.org/jpn/event/program/2004S/html/outline/floor/k\\_202.html](http://www.ieice.org/jpn/event/program/2004S/html/outline/floor/k_202.html), <http://www.magiQtech.com>
- [24] [http://www.soumu.go.jp/s-news/2003/030725\\_4.html](http://www.soumu.go.jp/s-news/2003/030725_4.html), Ministry of Internal Affairs and Communication: "Report on the meeting to study the proper fashion of next-generation R&D networks for the ubiquitous network age", (Tadao Saito, Chair)
- [25] Motoshige Ito: "Digital economy", Nihon

Keizai Shimbunsha (2001)

[26] Kimio Tatsuno: Science and Technology Trends - Quarterly Review , July 2004, No. 12  
“Latest Trends in the Optical Disk Industry —The Superiority of Japanese Companies and a New China-U.S. Joint Effort for Standardization—”

[27] Kimio Tatsuno: Science and Technology Trends —Quarterly Reveiw, October 2004,

No. 13 “Recent Trends in Semiconductor Microfabrication Equipment Technology — Proposals for Industry-Academy Collaboration on Research and Development in Japan —”

[28] Koichiro Hayashi and Nobuo Ikeda, eds.: “Designing systems for the broadband era”, Toyo Keizai (2002)

[29] <http://www.yamanaka.ics.keio.ac.jp>

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