UDC 621.391:006.2:681.3

R&D for the Next-Generation IP Network

●Toshitaka Tsuda ●Koichi Ohta ●Hiroaki Takeichi
(Manuscript received February 1, 2001)

In this paper, we propose a shift from the current data-pipe view network paradigm to a virtual-server view network paradigm via the intermediary stage of a virtual-router view network paradigm. The proposed shift forms the basis of our R&D for the next-generation IP network. Based on this shift, we propose a double-plane network architecture, consisting of a simplified data forwarding plane and a service control plane that performs all the complex processing tasks. The data forwarding plane is based on an advanced photonic network. The service control plane consists of agent, service, and policy control layers with open interfaces between them. Leading-edge information processing technologies such as active node, agent, distributed processing, and policy-based management are used in this plane. Since mobile communication is becoming a major access technology, an approach to integrating mobile and fixed networks into this framework is also proposed. This paper also reports on the current status of some key technologies, for example, photonic networks, agent technology, and policy based management.

1. Background

This paper describes our view of a possible series of IP network paradigm shifts and proposes a next-generation IP network architecture which fully utilizes the capability of photonic networks and leading-edge information processing technology. This view of network paradigm shifts forms the foundation of the R&D activities described in this special issue. A brief overview of the current R&D status of some key technologies is also included in this paper.

The explosion of the Internet is causing an exponential increase in the demand for capacity. This increase is greater than the doubling increase that can be achieved due to the improvement in semiconductor performance predicted by Moore's Law. The next-generation IP network must be designed to cope with this increase.

Although the transmission link capacity can be supported by using dense WDM technology, there may be a node processing bottleneck in the near future. This is because the current network paradigm, shown in **Figure 1**, is a data-pipe system that connects a series of routers to realize hop-by-hop linking. All packets that arrive at a node are stored and processed, which means that the required node processing power will increase in proportion to data traffic.

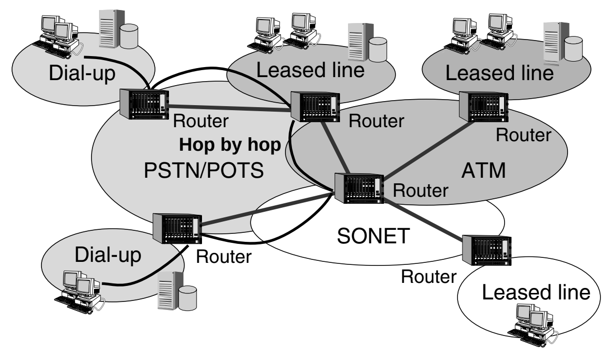


Figure 1
Current data-pipe view network.

The virtual-router view network we propose for the next step of the IP network can overcome this node bottleneck problem by providing network users with a single virtual-router view. Node cut-through with different granularities is a key technology in the proposed network. This releases the node from the need to process transit packets, and only the packets which need to be terminated at the node are processed. In addition, this approach can also provide a better QoS.

The proposal is based on the advantages of using photonic network technology. WDM technology is being developed with a set target of 1000 wavelengths per fiber, and a dynamic wavelength routing function is being made available. This enables wavelength routing for wavelength node cut-through and the construction of a logical full-mesh network with optical paths.

When the availability of low-cost, high-capacity communication becomes a matter of course, users' interests will move to the types of services that are provided, how easily the users can access a desired service, and how well the services can be received. For network operators, it will become less profitable to provide a communications pipe and the larger part of their profit will be derived from the services they offer. The virtual-server view network is a network paradigm we propose to meet the demands of the 21st century. Our proposal is to provide users with a network that looks like a huge server. The objective of the single-server view network paradigm is efficient delivery of services. The network will provide a variety of functions to help the users obtain the required services, and these services will be provided in a way that best suits the users' situations. Edge nodes will play a major role, and an advanced network/service management and cutting edge information processing technologies such as software agents will become important requirements.

In the following sections, the essence of each network paradigm and the current status of the key technologies will be described.[1)-10)]

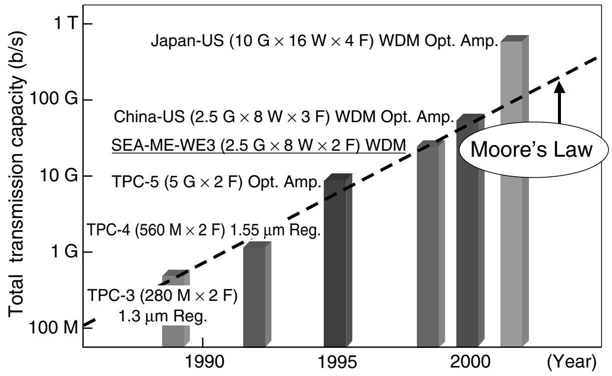


Figure 2
Capacity increase.

2. Recent trends of IP traffic and the node processing bottleneck

Two trends must be considered regarding the next-generation IP transport network:

- There will be a continuous increase in traffic volume.
- There will be an increasing demand for better Class of Service (CoS) and Quality of Service (QoS).

Because of the increase in IP traffic, the total communication traffic is estimated to keep growing exponentially at an annual rate of 100% or even 300%, which is much higher than Moore's law can keep up with. **Figure 2** shows the total transmission capacity of deployed submarine transmission systems around Japan. The dotted line indicates the 60% annual rate of increase in traffic capacity that is obtained from Moore's law. The figure shows that the total capacity of a single cable was increased by a factor of 1000 during the past 10 years, which is equivalent to a 100% annual growth rate. The rate of increase is currently increasing, and a 300% annual increase has been reported in the US. Owing to WDM technology, the increase in transmission capacity in optical fiber has jumped beyond what we could expect according to Moore's law and is good enough to meet demands for a high rate of increase (**Figure 3**).

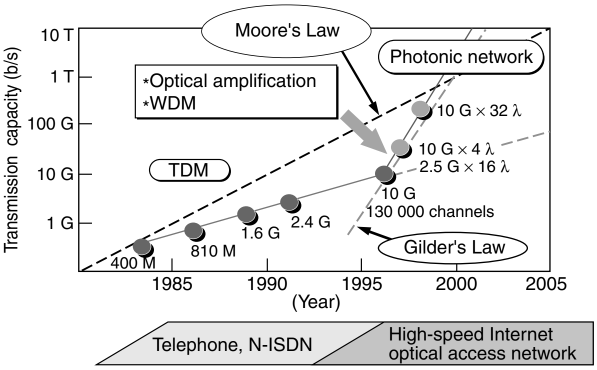


Figure 3
Capacity improvement in optical transmission system.

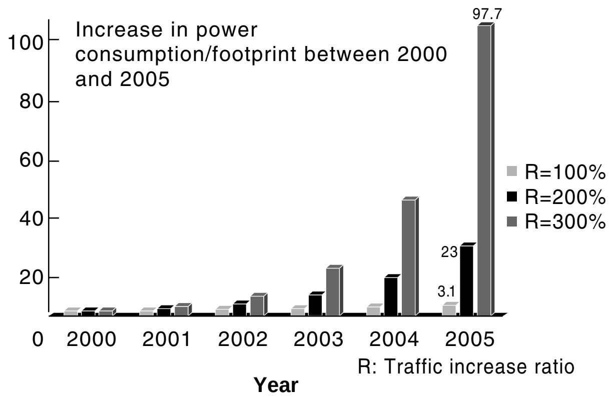


Figure 4
Node power/footprint increase.

However, despite this increase in transmission capacity, it seems that the implementation of switching/routing nodes will be a key problem when the next-generation network is constructed. Since the increase in capacity demand exceeds the rate predicted by Moore's law, the node implementation cannot be achieved simply by advances in semiconductor technology. **Figure 4** shows projections for the power consumption/footprint increases that can be expected if traffic increases at an annual rate of 100%, 200%, and 300% between 2000 and 2005. These projections take into account the 60% yearly reduction in power consumption and footprint achieved by improvements in semiconductor technology. As can be seen, if the traffic keeps growing at an annual rate of 300% (R=4), node power consumption will grow almost 100 times in 5 years. Even with a 200% annual increase, the node power consumption would grow by a factor of 23. Since these figures are not acceptable from the economic viewpoint, a fundamental change in network architecture is required to accommodate the anticipated growth of IP traffic.

The second point is that the demands for a high CoS and QoS are increasing. This is because a variety of information processing systems that execute mission critical applications are being built on the Internet infrastructure and some of these applications demand guaranteed high-bandwidth, high-availability communication. The change in the type of contents being delivered by the Internet is also strengthening the need for a high CoS and QoS. Real time streaming services such as voice and video are sensitive to bandwidth, delay, and performance, and therefore require a high QoS. One solution is to use the dynamic label path setup concept used in MPLS coupled with traffic engineering technology. However, this will make the processing performed at the nodes more complex and the required improvement in node processing power would be greater than the improvement achieved in traffic capacity.

The above discussion makes it clear that a fundamental change in network architecture is necessary to guarantee there will be no node processing bottleneck in the future. Our proposal is that we make a network paradigm shift toward a virtual-router view network that fully exploits the capabilities of photonic networking technology.

3. Virtual-router view network based on photonic technology

Figure 5 shows the virtual-router view network which we propose. Basically, our approach is to make the public network operate and look like a single virtual router. Most of the intelligence is moved to the edge nodes and the core consists of a simple, very high capacity, data transport mechanism. Incoming IP packets are terminated at the ingress node, and their paths

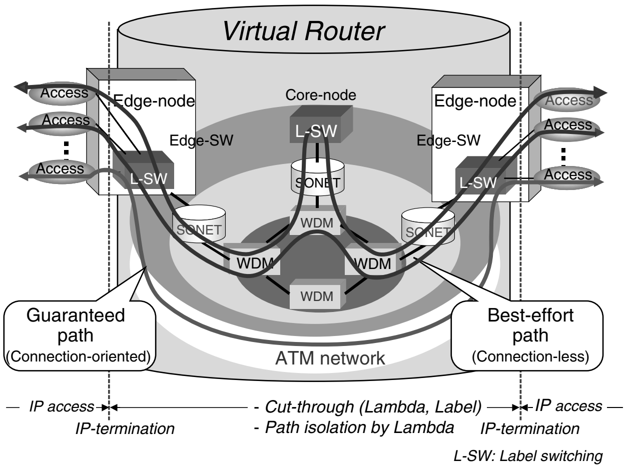


Figure 5
Virtual-router view network.

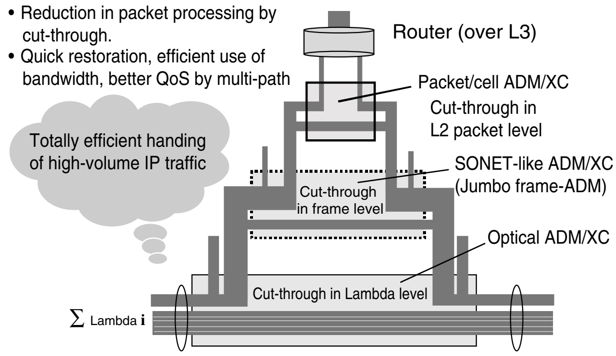


Figure 6
Photonic node structure.

are assigned. Internal transfer of IP packets is done based on the path using efficient switching technologies such as layer 1 wavelength switching, SONET-like jumbo frame switching, and layer 2 label switching. At the egress edge node, IP packets are terminated again and sent out to the access line. This architecture avoids the need for hop-by-hop processing of IP data.

The best-effort path and a guaranteed path are prepared, and each IP packet is properly assigned to the appropriate path at the edge nodes. Guaranteed paths can be provided by IP QoS routing, but they could also be provided, for example, by ATM when the use of a different transport mechanism is appropriate. This type of configuration could be built using a WDM-based photonic network. The main benefit provided by WDM is wavelength transparency, which makes it possible to maintain independence between wavelengths. As a result, different transport systems, different bit rates, and different QoS class paths can be realized by assigning different wavelengths in a single fiber.

Node cut-through by wavelength routing is essential for the proposed network. It can be realized by giving the network a logical full-mesh structure so that only the traffic that is terminated at the node is processed and the transfer traffic cuts through the node without any routing processing. Using WDM, multiple independent optical wavelength channels can be accomodated on a single fiber. Currently, 256 optical wavelength channels are within reach, and we have set a target of 1000. In addition, optical add drop and cross connection functions, which route optical wavelength channels with wavelength information as a routing key, have become available. These make it economically feasible to provide a wavelength path on a fiber and to drop only the necessary optical wavelength channels at the termination node.

Figure 6 shows the candidate transport node for this network. Node cut-through is applied at different granularities: the wavelength base, SONET-like jumbo frame base, and layer 2 label base. The first two methods do not process packets at all, which eliminates the packet processing delay time and also releases the node from the need to process packets by off-loading the processing of the transfer packets.

4. Virtual-server view network architecture

Figure 7 shows the virtual-server view network which will be the final stage of the network paradigm shift. The virtual-router view network forms the foundation of the physical data transport network. Since the value of the network at this stage is measured by how easily and comfort-

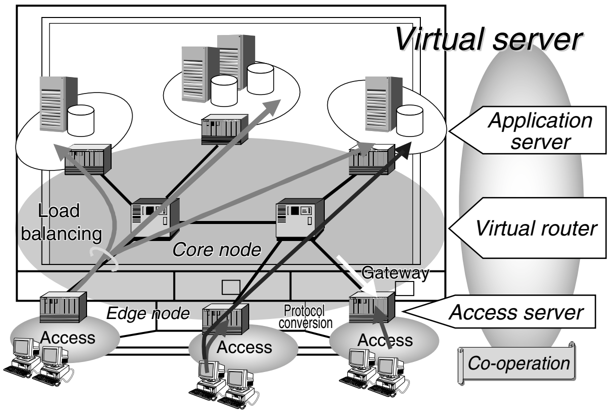


Figure 7
Virtual-server view network.

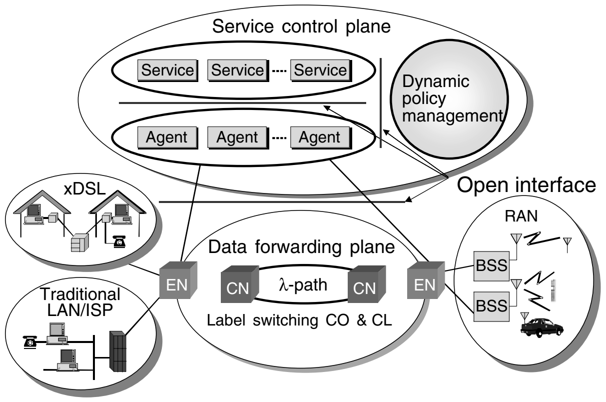


Figure 8
Network architecture.

ably users can obtain services, our network will differ from other networks in terms of architecture and functionality; for example, it will enable dynamic allocation of functions, easy addition of new services, and efficient navigation to services. Leading-edge information processing technologies, for example, an active network, agent technology, distributed processing, and policy-based management, will play a major role.

Another compelling reason for the network paradigm shift is that mobile access will become an important access mode on networks. In Japan, the number of mobile phones in use has already reached around 60 000 000, which is more than the number of wired telephone lines in use, and it is still increasing. The third-generation mobile communication system (IMT-2000) can provide a higher capacity and a 10-fold improvement in the bit error rate, which will greatly improve the quality of mobile data communications. In addition, the IP development world is working hard to provide mobile IP. Therefore, we propose an integrated fixed/mobile network that treats all the terminals as mobile terminals with the fixed terminals considered to have zero mobility.

The network architecture we propose is shown in **Figure 8**. The network is logically separated into two planes: a data forwarding plane and a service control plane. The data forwarding plane uses a very simple data transfer mechanism based on the wavelength path, while the complex processing is integrated on the service control plane. The virtual-router view network provides the mechanism for realizing the data forwarding plane.

The service control plane consists of an agent layer, a service layer, and a dynamic policy management layer. Open interfaces are defined at the boundaries of layers and planes. An agent layer is provided to help the users easily reach services and to connect to them in a manner appropriate for their needs. Agents are also used for network management, collecting the dynamically changing information about the network environment and services and collaborating with policy managers. A policy-management layer is provided to automate system management based on the management policy. This layer also controls the behavior of agents to harmonize the operations of the system. One new feature of our proposal is the use of dynamic policy management instead of the currently used static policy management. Since we assume that services and node functionalities change dynamically, as has been proposed in active network concepts, the addition of this feature is necessary for policy management.

Figure 9 shows how we plan to integrate mobile and fixed networks in the proposed network architecture. All terminals are treated as mobile ones, with the fixed terminals regarded as

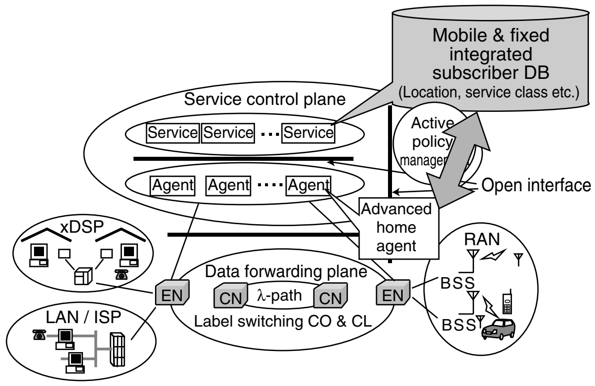


Figure 9
Fixed/Mobile convergence.

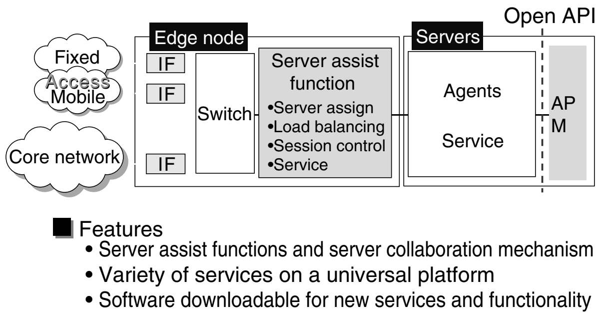


Figure 10
Next-generation edge node.

mobile terminals having zero mobility.

The core is the subscriber database, which contains information such as the subscriber locations, accessible systems, and service classes. To provide a service to a user, the communication agent accesses the database and retrieves the user's location for routing purposes. At the same time, the agent collects information about the system to be accessed and determines various details about the service to be offered, for example, the type of media, coding scheme, bandwidth, and protocol. The agent also collects information about the encoding scheme, protocol, bit rate, and service class. When the user moves to another location, the advanced home agent detects the change and informs the database agent of the current location so that the database can be updated.

In this architecture, most of the network intelligence and services are provided at the edge nodes. **Figure 10** shows the edge node structure we propose. Functionally, it is separated into two parts: the circuit termination and the service gateway. Circuit termination deals with a variety of access networks, including wireless ones, and changes the transmission format into that of the data forwarding plane. The service gateway is the key part for providing a user with a single-server view. It provides network middleware functions such as QoS mapping and traffic monitoring/load balancing, network interface conversion functions, proxy service functions such as mobile agents and firewalls, and the service navigation function for providing an efficient connection to servers. The servers can either be a part of the service gateway fabric or outside the edge node and connected by the service control plane. **Figure 11** shows GeoStream, which is a carrier IP edge node that Fujitsu has developed. GeoStream is a suitable platform for realizing the network we propose. We are now developing the key functions to be implemented in GeoStream to make it an advanced edge node.

Figure 11
GeoStream.

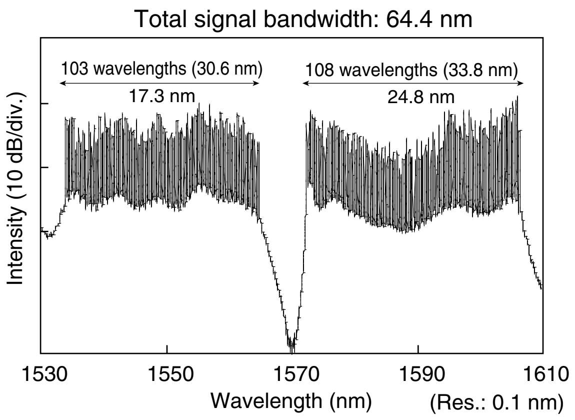
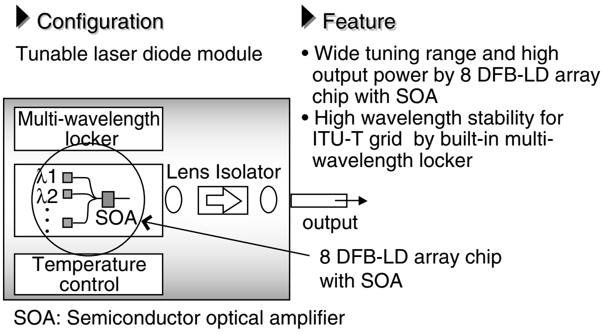


Figure 12
WDM spectrum with 211 wavelengths.



Characteristics

Parameters	*Characteristic*
Wavelength tunable range	26 nm (1535 to 1561 nm ITU-T grid)
Wavelength stability	< ±0.05 nm
Output power	> +10 dBm
RIN	< –140 dB/Hz

Figure 13
Tunable laser diode.

5. Current status of key technologies

5.1 WDM transport

To increase the number of wavelengths, a combined C + L-band optical amplifier was developed. The C-band is from 1530 to 1570 nm, and the L-band is from 1570 to 1610 nm. An example of this amplifier's performance is shown in **Figure 12**. This example shows the WDM spectrum after a 7221 km transmission with 211 wavelengths having a 0.3 nm spacing. We are currently aiming to achieve 1000 wavelengths by further narrowing the wavelength spacing to 0.2 nm. We are also developing an optical amplifier which can cover shorter and longer wavelength regions.

5.2 Wavelength routing

The optical add drop multiplexer (OADM) and the optical cross connection switch (OXC) are typical functional blocks for wavelength routing. A fixed wavelength type OADM which adds and drops predetermined wavelengths is already on the market, and a dynamic OADM which can change the add and drop wavelengths is under development. The key devices in these OADMs are a tunable filter and a tunable laser diode (LD). For the tunable filter, we have developed a unique device called an Acousto-Optic Tunable Filter (AOTF) which can selectively pick up a wavelength while letting the other wavelengths pass through. The wavelength to be picked up is selected by varying the frequency of a sinusoidal control signal of around 170 MHz. Multiple wavelengths can be selected by simultaneously adding multiple control signals. The performance of our AOTF makes it suitable for use in practical systems. **Figure 13** shows the structure of our tunable LD. In this example, eight LD arrays, an optical coupler, and a semiconductor optical amplifier are monolithically integrated on a single chip. Each LD has a tunable range of more than 400 GHz, and the module can cover 32 wavelengths with a 100 GHZ spacing.

An optical cross connect switch (OXC) is another important functional block for wavelength routing. Small-scale OXCs are commercially available. We have demonstrated a 32 × 32-port OXC and are now expanding the scale to 256 × 256 ports.

5.3 Agent technology

The key agent technology functions we expect to provide in the proposed network are 1) easy access to services by hiding the differences of systems, 2) adaptive selection of services, 3) user-customization of provided services, and 4) collaboration between different systems. These functions will be realized using various technologies, for example, a mobile agent that hides the low transmission quality of wireless systems and achieves a reasonable throughput with TCP/IP-based services, network plug-and-play that seamlessly provides personalized service access independent of the network access environment, and an agent that connects a CORBA-based network management system to the Common Management Information Protocol (CMIP). An example of a virtually integrated database is shown in **Figure 14**. The mediator provides the user with a single virtual-database view by hiding the differences between connected database systems and access locations and gives them the ability to access data using their own database access methods. The system is already in use within Fujitsu and currently has more than 10000 users.

5.4 Policy-based management

Policy-based management is gaining popularity, especially in IP network management. Also, policy-based networking (PBN) is a hot discussion-item among the members of the IETF, and some products have recently been announced. We have developed a policy-based enterprise management system that uses PBN to manage the network part of the system. Current PBN, however, is based on a scenario in which the functionality and network resources are predetermined. Since the network we propose dynamically changes the node functionality to introduce new services and change the bandwidth on demand, a new aspect, which we call "dynamic policy management," must be added to policy management.

Figure 15 illustrates our concept of a dynamic policy-management system. As a special feature, it has a hyper-knowledge space, which is a loosely connected set of different agent groups which function as a pluggable or dynamically expandable part of the hyper-knowledge space. Since each network application, for example, e-mail, requires application-specific knowledge, these application-specific issues are handled by special agent groups. A new service can be introduced simply by adding a special agent group. Each agent collects and stores network information in a distributed manner by walking through the nodes in the network. Active policies, which are agents themselves, can communicate with agents in hyper-knowledge space to implement policies and retrieve information from agents. These active policies also serve as a medium between a network management system (NMS) or active policy based management system (APBMS) and other agents in hyper-knowledge space.

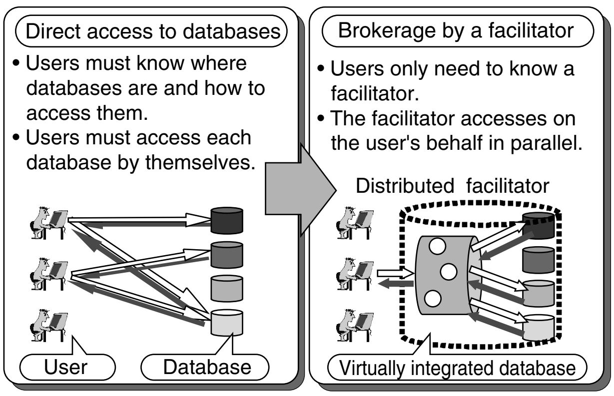


Figure 14
Virtually integrated database.

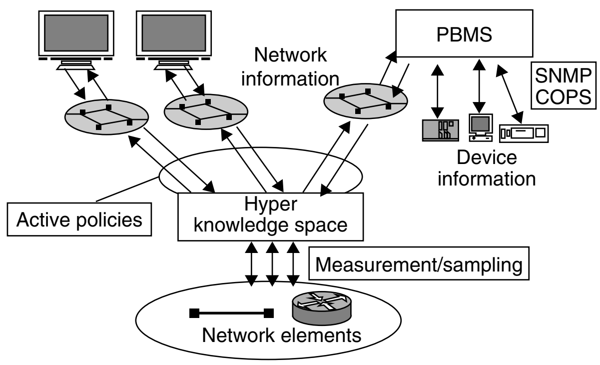


Figure 15
Dynamic policy management.

6. Conclusion

This paper proposed a shift in the network paradigm based on the view that the value of a network in the 21st century will be measured by how easily it provides services. The third stage of this shift involves providing users with a virtual-server view network. For the data transport platform of this network, we have also proposed a second stage network called the virtual-router view network. The double-planed network architecture we proposed uses a photonic network and leading-edge information processing technologies. The current status of key technologies was also described as a foundation of the proposal. We look at this network from our viewpoint as a service solution provider.

Because of our advanced communication, information processing, and system/service integration technologies, we at Fujitsu can contribute to society by providing technologies and knowledge to end-users through a network. The service control plane, which is independent of the physical network structure, is the platform upon which we will achieve our objective.

References

1) IETF draft: LDAP and COPS.
2) H. Kuwahara et al.: Photonic Network Architecture towards 1000 Wavelengths. Telecomm'99 Forum, Oct. 1999.
3) D. Blight and T. Hamada: Scalable PBN. Proc. of IM'99, May 1999.
4) K. Nahrstedt and J. M. Smith: The QoS Broker. Univ. of Pennsylvania, 1995.
5) J. M. Smith: Active network. IEEE Computer Magazine, Mar. 1999.
6) Brenner and R. Stadtler: Active Network Framework. Proc. of IM'99, May 1999.
7) Forrest: Emergent Computation. 1990.
8) Y. Takada, T. Mohri, and H. Fujii: A Multi-Agent Model for Virtual Integration of Distributed Databases. CALS Expo INTERNATIONAL 1997. Proceedings Track 7, pp.1-7, 1997.
9) A. Moridera, K. Murano, and Y. Mochida: The Network Paradigm of the 21st Century and Its Key Technologies. *IEEE Communication Magazine,* Nov. 2000, pp.94-98.
10) T. Tsuda, Y. Mochida, and H. Kuwahara: Photonic Solution for Next Generation IP Transport. Proc. Telecom Asia, Dec. 2000.

Toshitaka Tsuda received the B.S., M.S., and Ph.D. degrees in Electronic Engineering from the University of Tokyo, Tokyo, Japan in 1970, 1972, and 1975, respectively. From 1978 to 1979 he was with the University of California, Berkeley, as a research associate. He joined Fujitsu Laboratories Ltd., Kawasaki, Japan in 1975 and has been engaged in research and development of DSP LSI, picture coding, ICs for ISDN and high-speed optical communication systems, data networks, and microprocessors. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan, and a senior member of the IEEE. Currently, he is Director and Network Systems Laboratories President of Fujitsu Laboratories Ltd.

Koichi Ohta received the B.E. and M.E. degrees in Electrical Engineering from Tokyo Institute of Technology, Tokyo, Japan in 1968 and 1970, respectively. He joined Fujitsu Laboratories Ltd., Kawasaki, Japan in 1970 and transferred to Fujitsu Ltd., Kawasaki, Japan in 1971. Since then, he has been engaged in research and development of transport systems. Currently, he is Senior Vice President and Transport Systems Group President of Fujitsu Ltd.

Hiroaki (Harry) Takeichi received the B.S. degree in Electronic Communications from Waseda University, Tokyo, Japan in 1971. He joined Fujitsu Ltd., Kawasaki, Japan in 1971, where he was engaged in the development of core switching systems. He was stationed in the U.S. from 1987 to 1995 as senior technical manager to promote the carrier-oriented switch business, and was closely involved in the world's first commercial ATM network, the North Carolina Information Highway (NCIH). He moved back to Fujitsu Ltd. Japan in 1996, and eventually became responsible for the network systems business, including the IP and cellular mobile infrastructure. Currently, he is Director and Network Systems Group President of Fujitsu Ltd.