R&D for a Broadband and Flexible Network Infrastructure

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(Manuscript received November 10, 2003)

This paper surveys the R&D trends in broadband communication and describes some of the relevant activities of Fujitsu Laboratories Ltd., which cover both fixed and mobile networks. In 1999, we proposed a network vision called the Virtual Router Network (VRN) to realize a network that can accommodate a huge amount of IP traffic by fully implementing photonic network technology and aligned our R&D activities in that direction. Since then, we have achieved many important research results. This paper introduces some of our key achievements in network architecture, network management, photonic networks, and mobile communication.

1. Introduction

This paper surveys worldwide R&D trends and Fujitsu's current status of R&D and product development related to the broadband network infrastructure.

Construction of broadband communication networks started from the trunk line system. Thanks to dense WDM (Wavelength Division Multiplexing) technology, a Terabit capacity transmission system on a single optical fiber has already been commercialized. In addition, deployment of broadband access networks such as ADSL (Asymmetric Digital Subscriber Loop) and FTTH (Fiber to the Home) have advanced rapidly over the last few years and the number of broadband access subscribers has exceeded 13 000 000 in Japan. This implies that end-to-end broadband connectivity is now ready for use and users are waiting for attractive broadband services to appear.

The driving force of the broadband network deployment is the expansion of the Internet. Since the burst of the Internet bubble, it has sometimes been mentioned that networks have too much capacity and investment in the telecom infrastructure has drastically decreased. However, the facts that Internet traffic keeps doubling every year, the access network has increased its bandwidth more than 100 times, and new broadband services such as video streaming have started indicate that there will be a capacity shortfall in the core network in the near future.

Another new aspect of the Internet is that a certain amount of QoS (Quality of Service) provisioning is requested, which is very different from the situation with the conventional Internet, which is based on a best-effort policy. The new request for QoS provisioning has come about because many of the applications, including mission critical ones, are now using the Internet as their communication infrastructure and also because services that request QoS such as VoIP (Voice over IP) and video streaming have started.

In addition to broadband communication capability, freedom of access is another important feature that networks should provide. Freedom of access includes mobility and on-demand provisioning. Key technologies for freedom of access are wireless communication and network management.

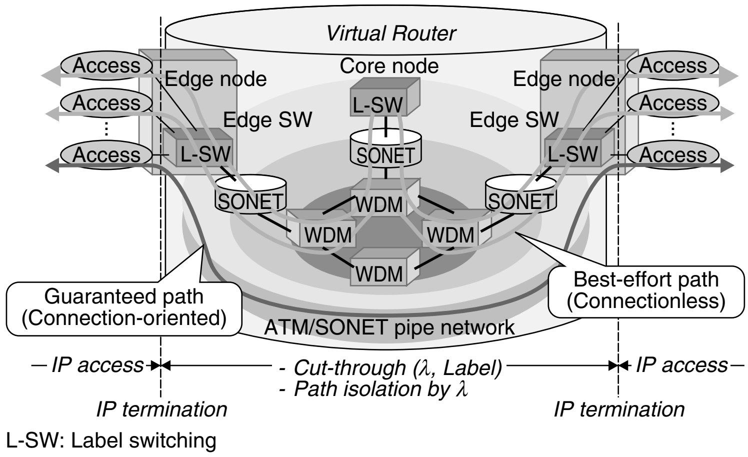

Figure 1
Virtual Router Network.

One thing that does not change in the Internet is the expectation of low costs, which is one of the main reasons for the Internet explosion. Taking these things into account, the next-generation network should be one that can efficiently accommodate a huge amount of Internet traffic and also provide some QoS guarantee. This can be realized by a total approach that combines the use of a new network architecture, photonic network technology, and advanced network management.

In the following sections, we describe worldwide R&D trends and Fujitsu's R&D and product status in the field of network architecture, network management, photonic networks, and wireless communication.

2. Network architecture and network management

2.1 Virtual router network

About five years ago, we proposed a network view called the Virtual Router Network (VRN)[1)-3)] and aligned R&D activities toward this direction. We selected the VRN approach to realize a next-generation network that can economically accommodate a huge amount of IP traffic and also provide QoS. The concept is shown in **Figure 1**. The core idea is to terminate IP packets at the ingress and egress nodes, and data transfer within the network is done using connection-oriented paths. This avoids tandem IP processing and releases the core network nodes from the huge processing capability requirement, resulting in lower core network node costs and better delay performance. To provide data paths, photonic network technology based on WDM is efficiently used. The use of WDM enables the coexistence of different transmission schemes in a single optical fiber, which means that the system can utilize the most appropriate transmission schemes for best-effort traffic and QoS guaranteed traffic.

Figure 2
"Photonic Virtual Router" laboratory prototype model.

Based on this vision, we built a laboratory prototype model called the Photonic Virtual Router[4)] shown in **Figure 2**. In this prototype, on-demand optical path provisioning is provided using the

GMPLS (Generalized Multi Protocol Label Switching) protocol. The DOADM (Dynamic Optical Add Drop Multiplexer) is adopted for optical path control using an AOTF (Acousto-Optic Tunable Filter) as the key device. To enhance the flexibility, we developed a unique switch using an FPGA (Field Programmable Gate Array) that can handle both packet and STM (Synchronous Transfer Mode) signals. By using this switch, we are able to provide label-switched paths based on MPLS (Multi Protocol Label Switching) and STM paths with a virtual concatenation function, which is a technology for providing variable-bandwidth STM by aggregating remaining capacities on different paths.

Dynamic IP traffic engineering (TE) is installed in this prototype as one of the network management functions.[5),6)] **Figure 3** shows the concept of dynamic IP traffic engineering. Compared to the usual IP routing, which establishes a single path between the ingress and egress node, TE technology enables automatic traffic load balancing and QoS path provisioning by dynamically setting up extra paths according to the level of traffic congestion. This enables efficient use of network resources and better QoS provisioning and also helps to reduce the cost of operating a network by automating the network management.

2.2 Network management for QoS

Network availability, which is a QoS factor, is another important IP traffic engineering issue of network management. Because of the increased capacity of fibers, a single fiber breakdown can severely disrupt social activities. Therefore, a quick recovery mechanism is needed for the core network, and this should be realized at a minimum cost. The IETF (Internet Engineering Task Force), which is the main standardization body of the Internet, has already started to study this problem, and Fujitsu is contributing to this activity by using its extensive knowledge of network management. In the proposal we submitted to the IETF ccamp meeting in July 2002, protection is done on a subnet basis, where the error notification can be accomplished within 10 ms.[7),8)] To improve the error notification speed, information flooding is applied and each node performs path switching autonomously. Compared to the conventional link protection scheme, the cost of preparing the protection path is reduced by about 60%, and a 50 ms recovery time is realized.

These network management technologies, including the above-mentioned IP traffic engineering and on-demand provisioning, are installed or are being installed in Fujitsu's network node products such as the GeoStream carrier edge router, the GeoServe network server, and the Proactnes element manager.[3)] **Figure 4** shows the GeoStream, which can provide high availability and broadband packet handling capability for streams up to 10 Gb/s.

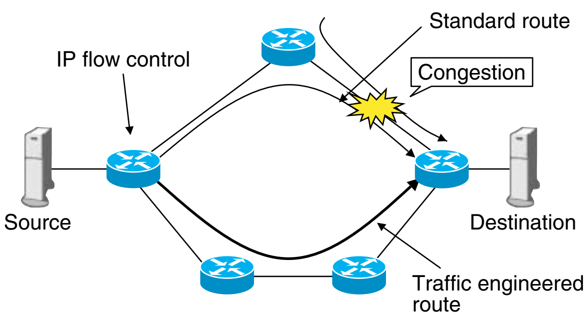

Figure 3
Concept of dynamic IP traffic engineering.

Figure 4
GeoStream carrier edge router.

A variety of network functions are installed that include VPN (Virtual Private Network) support, traffic engineering, and packet priority handling. Also, GeoStream can accommodate IPv6 packets.

2.3 Access and metropolitan area network

Some activities for realizing a cost-effective broadband access area network can be seen. One direction is to provide direct Ethernet access to the public network and offer enterprise customers Ethernet WAN (Wide Area Network) services. Fujitsu has developed FW (Flash Wave) 4500,[9] which is a Multi-Service Platform Product (MSPP) for the North American market based on the SONET (Synchronous Optical NETwork) infrastructure, and also the FW5500[10] series of carrier-grade Ethernet switches. The FW5540 realizes high availability and provides guaranteed bandwidth by implementing traffic policing and shaping. Our GeoStream carrier router also provides an Ethernet interface.

The second direction is to realize a cost-effective photonic network in the metropolitan and access area network. **Figure 5** shows the FW7500,[9] which is designed for metropolitan area networks and has a reconfigurable optical add-drop function. In addition, Fujitsu Laboratories is developing a low-cost metro access ring network system called the Smart Lambda. Using AOTF as a key device, this system provides dynamic wavelength add-drop functionality and also wavelength multicast capability. Because of its simple structure, the system can be realized at a cost almost equivalent to that of a fixed WDM ring network.

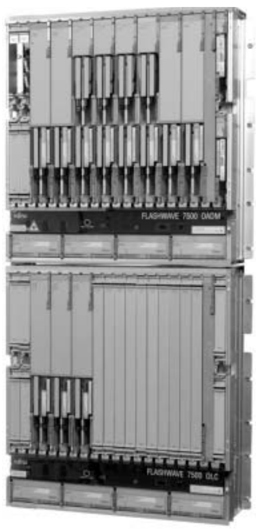

Figure 5
WDM FW7500 Metro.

3. Photonic network[11]

3.1 High-capacity optical transmission

Dense WDM is the foundation of broadband communication. Fujitsu has commercialized the world's highest capacity WDM system: the FW7700.[12] This system achieves a 1.76 Terabit capacity by using 176 waves, each of which carry 10 Gb/s signals. At present, R&D for achieving higher capacities is focused on increasing the signal speed and the wave number. In addition, photonic networking with optical switching is gaining more attention because of its ability to make networks more flexible.

To increase the signal speed, we are nearing completion of a 40 Gb/s system for commercial introduction. However, a 40 Gb/s system requires sophisticated dispersion compensation when applied to long-haul transmission. Therefore, we are developing technologies for adaptive chromatic dispersion compensation and polarization mode dispersion compensation and have built a prototype 3.5 Tb/s system,[13] the performance of which is shown in **Figure 6**. This system uses 88 waves, each of which carries a 43 Gb/s signal stream. It also performs two types of adaptive dispersion compensation: 1) multi-wavelength simultaneous chromatic dispersion compensation using a VIPA (Virtually Imaged Phase Array), which is an original Fujitsu device, and 2) wave-by-wave polarization mode dispersion compensation. The current challenge is how to realize these functions in a cost-efficient manner, and we are examining possible solutions ranging from device solutions to algorithmic ones.

In our basic research, we are investigating very high speed optical transmission of over 160 Gb/s. We have introduced an experimental 160 Gb/s optical signal processing system to recover the original signal from a distorted optical signal.[14] **Figure 7** shows the configuration of the world's first experimental 160 Gb/s transmission system and its waveforms.

3.2 Photonic network[3)]

To match the trend in IT systems, which is towards on-demand resource provisioning such as Grid Computing and Utility Computing, networks should be capable of on-demand capacity provisioning. Photonic networking, which realizes optical switching capability, is a key technology in this area. Photonic networks require tunable light sources, tunable optical filters, tunable wavelength converters, and optical switches. Through close collaboration between the device and system groups at Fujitsu Laboratories, we are developing these key devices and implementing a

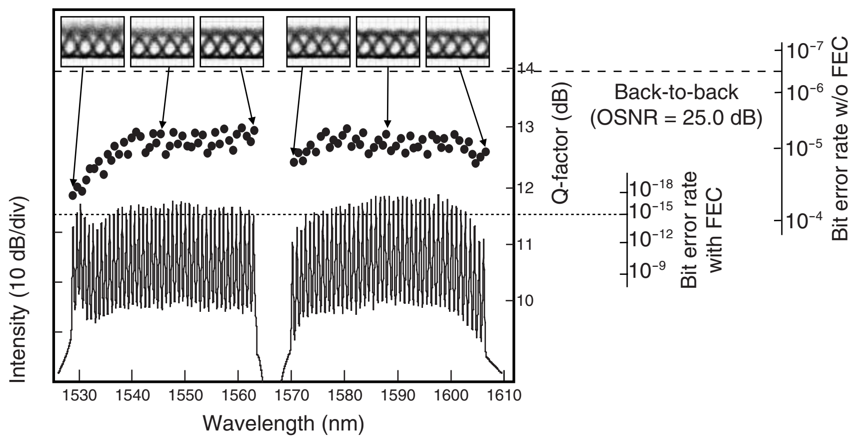

Figure 6
3.5 Tb/s system experiment.

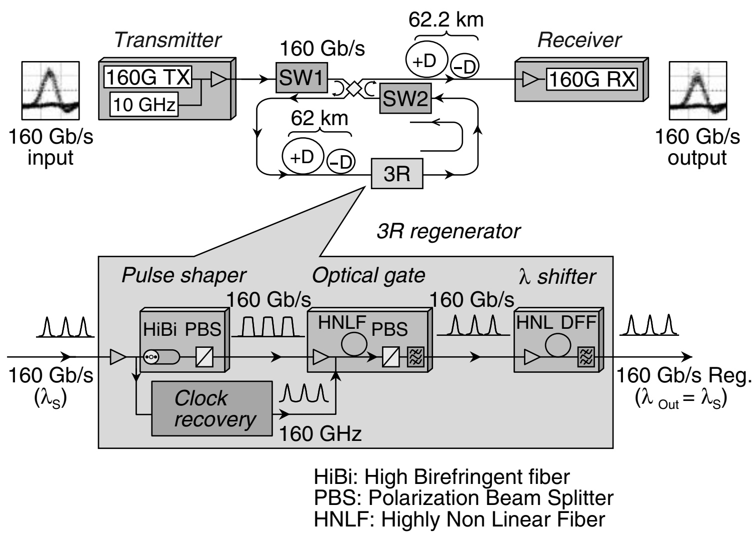

Figure 7
3R repeater functions in optical domain.

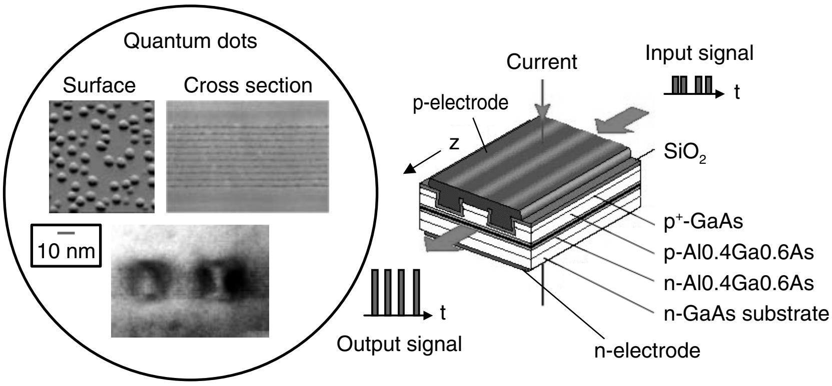

Figure 8
Quantum-dot semiconductor optical amplifier.

prototype photonic network. Typical examples of the devices being developed in this work are a tunable LD (Laser Diode) with 44 wavelength tenability, a tunable optical filter AOTF that can cover both the C band and L band, a quantum-dot semiconductor optical amplifier (SOA), and a three-dimensional MEMS (Micro Electro Mechanical System) optical switch with 80 × 80 ports. **Figure 8** shows the quantum-dot SOA.[15] Compared to a conventional SOA, which has difficulty in handling even 10 Gb/s signals, our quantum-dot SOA can provide good performance for 40 Gb/s signals. **Figure 9** shows another of the key devices, a MEMS optical switch module.[16),17)] By combining new device structures such as a comb-shaped actuator and triangular torsion bar with a new control algorithm, this module can be operated at 50 V, which is about 1/3 the operating voltage of conventional devices, and can switch at less than 3 ms, which makes it almost one order of magnitude faster than conventional devices.

Figure 9
MEMS optical switch.

3.3 Off-the-shelf optical components and modules

A clear trend in optical transmission is the effort to make off-the-shelf components and modules, for example, for MSAs (Multi Source Agreements). This brings down the price and expands the application field of optical technology. **Figure 10** shows Fujitsu's activities for MSAs and other optical modules for expanding the application fields.

The photonic crystal has great potential in this direction, because it enables the integration of optical components in a small monolithic device.[18)] Even though it is still in the basic research stage, a 1st generation device has already become commercially available. If everything goes well, the photonic crystal is expected to become a very important device, and it may even become the IC of the 21st century.

4. Wireless communication[19)]

Because of the freedom of mobility, wireless communication has become dominant in the access part of networks. **Figure 11** shows the

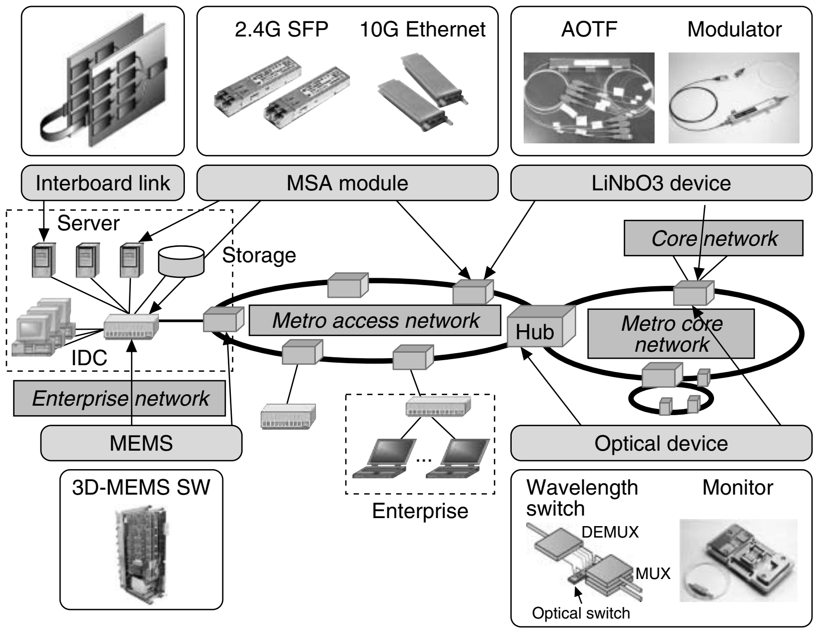

Figure 10
Optical modules and application fields.

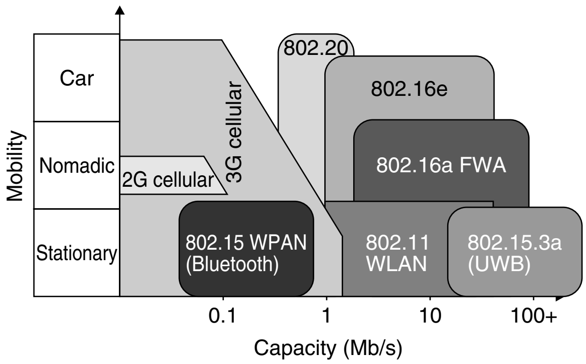

Figure 11
Wireless communication standards.

wireless communication standards for both mobile phones and wireless LANs. From this figure, it is clear that there is a trade off between the speed of movement that a system can cope with and its capacity. However, given that the capacity of wireless communication systems is rapidly increasing, this may not be such a problem.

4.1 Wireless LANs

For wireless LANs, 54 Mb/s is already available and the next step will be 100 Mb/s followed by Gb/s capacity. A capacity between 100 Mb/s and several Gb/s is good enough for most broadband services, including video streaming services, but the QoS issue remains to be solved. A new specification having QoS guarantee functionality is under discussion and will be specified as IEEE802.11e. Another problem with wireless LANs is security—weaknesses have been pointed out even in the WEP (Wired Equivalent Privacy) system. This aspect is being standardized in IEEE802.11x.

4.2 Mobile phones

Compared to wireless LANs, mobile phone systems provide much less capacity but far more mobility support. Fujitsu is a leading-edge mobile phone system vender. **Figure 12** shows Fujitsu's total equipment set for the 3rd generation mobile phone system. The high-efficiency power amplifier is a typical example of the many technologies that Fujitsu has developed for the 3rd generation mobile phone system. This amplifier has a 13% power conversion efficiency, which is almost 80% higher than that of conventional power amplifiers. This efficiency was achieved by developing digital pre-distortion technology,

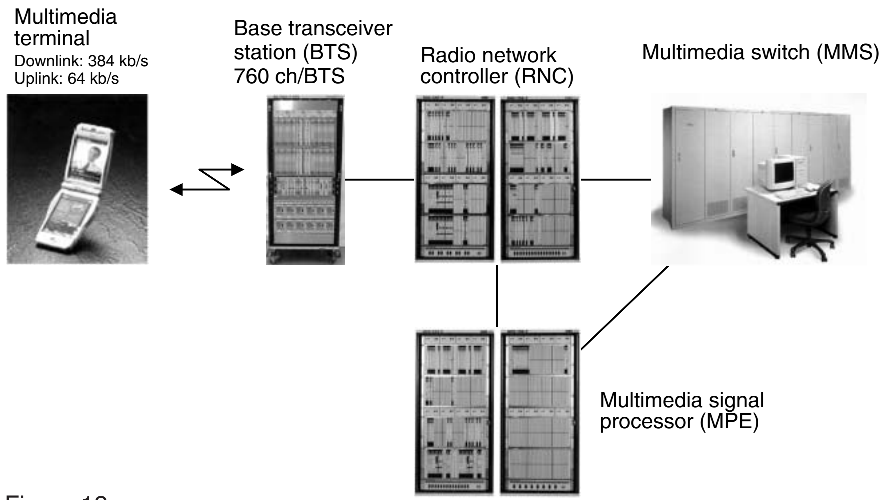

Figure 12
Fujitsu's 3G mobile phone equipment.

which modifies the input signal before it is input to the amplifier in such a way that the nonlinearity of the power amplifier produces an output that is an almost undistorted amplification of the input signal. Because of this technology, we were able to build a 3000-channel BTS (Base Transceiver Station) in a single rack.

The current data transmission capacity of the 3rd generation mobile system is 384 kb/s. However, in the near future, the downlink capacity will enter the Mb/s range, thanks to HSDPA (High Speed Downlink Packet Access). The 4th generation (sometimes referred to as "beyond 3G") mobile system will achieve a further capacity increase to around 100 Mb/s, and we are preparing new 4th generation technologies such as OFDM (Orthogonal Frequency Division Multiplexing), AAA (Adaptive Array Antenna), and MIMO (Multi Input Multi Output).

4.3 Seamless roaming

Because of the differences in the character of each system, a variety of wireless access systems will coexist. Therefore, efficient use of each system is the key for service delivery. When a user is in an area where wireless LAN is available, the user should receive broadband services via wireless LAN, because of its broadband capability. However, while moving in a car or train, the best method for communication is the mobile phone. To provide users with the most appropriate access method, smooth roaming is essential. Fujitsu has developed roaming capability between a wireless LAN and mobile phone based on the mobile IP and has also developed service-level roaming using agent technology. To realize these types of roaming, we offer the dual-mode wireless card shown in **Figure 13**. Further study in various areas, for example, security roaming, is underway to realize smooth roaming.

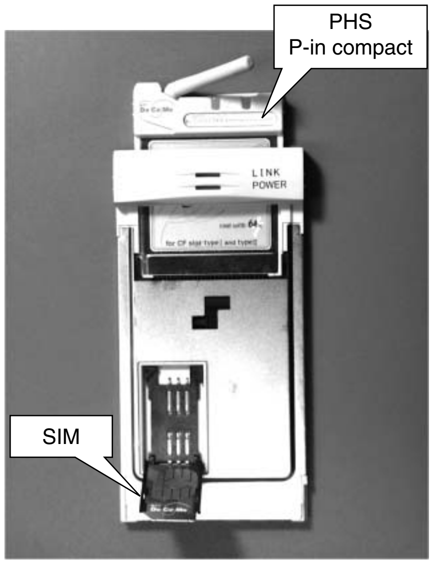

Figure 13
Dual-mode wireless card.

5. Conclusion

The realization of a broadband and flexible network requires a total approach that includes all aspects of the network, ranging from its basic devices to its overall architecture, and various activities are currently in progress towards meeting this goal. Fujitsu Laboratories has proposed a network vision called the Virtual Router Network to efficiently accommodate a huge amount of IP data traffic and has aligned its research efforts in this direction. We have developed a laboratory prototype that uses WDM photonic networking technology, IP traffic engineering based on GMPLS, and a hybrid packet and circuit switch.

In a fixed network, photonic technology-based WDM plays a key role. WDM systems that can provide sufficient bandwidth for current needs have already been realized. R&D for realizing even more capacity is in progress, but there seems to be an emphasis on providing network flexibility using photonic switching. Another development direction is to make off-the-shelf optical components and modules and thereby reduce equipment costs so that optical communication can be easily implemented throughout the datacom system.

In this paper, we looked at the above developments and then briefly discussed the trends in wireless LAN and mobile-phone communications. Then, we introduced some of the leading-edge 3rd generation mobile phone equipment that Fujitsu Laboratories has developed and presented some expectations for the 4th generation system. Lastly, we briefly discussed the realization of seamless roaming.

At present, the Network R&D group is expanding its intensive collaborations with the Information Processing group and the Service group and is trying to make networks more suited to broadband service provisioning. We expect that as a result of this activity, Fujitsu will be able to present even more attractive proposals for broadband networks.

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