6-4 Mobile Ring Network for Large-Scale Mobile Internet

INOUE Masugi, HASEGAWA Mikio, MAHMUD Khaled, RYOKI Nobuo, PYO Chang Woo, RAN Ha Nguyen, KUBO Takeshi, YOKOTA Hidetoshi, IDOUE Akira, TAKEUCHI Kazunori, and YAMAMOTO Shu

Mobile networking technologies for use in metropolitan areas are needed to realize IP-based new-generation mobile networks. For this purpose, provision of high scalability in the number of mobile devices to be accommodated and the volume of traffic they receive and transmit as well as low latency in switching connection from one access point to another while accommodating a huge volume of traffic are of great importance. We proposed a new mobility management architecture where multiple Localized Mobility Agents (LMA) are interconnected on a flat ring to decentralize location information of the visiting mobile devices and packet forward processing. Performance evaluations of the packet forwarding and outdoor experimental demonstration using testbed network were carried out. The proposed Mobile Ring has an advantage in a large-scale network that accommodates tens of thousands of mobile devices against conventional hierarchical networks.

Keywords
Mobile Internet, Micro mobility, Ring network, Fast handover

1 Introduction

Hoping to facilitate the implementation of new information and telecommunications networks by 2010, researchers are investigating and developing a range of new networks, including fourth-generation cellular systems and the so-called “new-generation network” (NGN). These researchers intend to apply Internet Protocol (IP) technology to equip these networks with the diverse services and applications now running on the Internet. However, the Internet was originally designed based on the assumed use of wired networks; various modifications and improvements will therefore be required for the application of IP to mobile environments. In these new environments, computers and communication terminals will be connected to networks via radio (an inherently less stable medium than wire) under constantly changing connection conditions.

With the aim of implementing a mobile-compliant IP network that can be used in large cities such as Tokyo, this study focused on two issues: “high scalability” for the handling of a large number of mobile devices; and “ensured continuity” to prevent disconnection of the mobile devices. To address these problems, we have focused research and development on a “Mobile Ring network”, a structure based on a novel architecture that differs significantly from conventional hierarchical structures. This article presents an overview of the relevant technology.

2 What is the Mobile Ring network?

2.1 Concept of deployment

Figure 1 shows a conceptual diagram of the Mobile Ring network. In large cities, metropolitan-area optical ring networks are in wide use, in which fiber optic connections are linked in a ring topology. The proposed technology implements the desired network by placing a newly developed packet-forwarding device, the Localized Mobility Agent (LMA), at the nodes of each ring. The LMA connects base stations of next-generation IEEE802.11, IEEE802.16 and cellular systems. The ring network forms an IP sub-network. Mobility across different Mobile Ring networks and mobility to and from external networks are guaranteed by a macro mobility protocol such as Mobile IP.

When this technology is commercialized, we will be able to enjoy an enormous array of services, from Internet video delivery to videophone via rapid, wireless LANs—even as we circle the city on the JR Yamanote Line. What's more, this technology will not be limited to metropolitan areas; applications will arise in many locations: commercial buildings, amusement facilities, along roads or railways, and in numerous municipalities.

2.2 Scope

The Mobile Ring is a network that can connect to an arbitrary wireless base station using IP technology. Two or more Mobile Ring networks can be used to cover an urban area[1] (Fig. 2). The size of a single Mobile Ring network depends on the traffic to be accommodated and the transmission and switching technology available at the time of its installation. A Mobile Ring forms an IP sub-network, and the IP address of a terminal is unchanged as long as it moves within the Mobile Ring network. In other words, the Mobile Ring network acts as a so-called micro mobility network, which takes charge of local mobility management. On the other hand, the movement of a mobile device between two Mobile Ring networks or between a Mobile Ring network and another network invokes

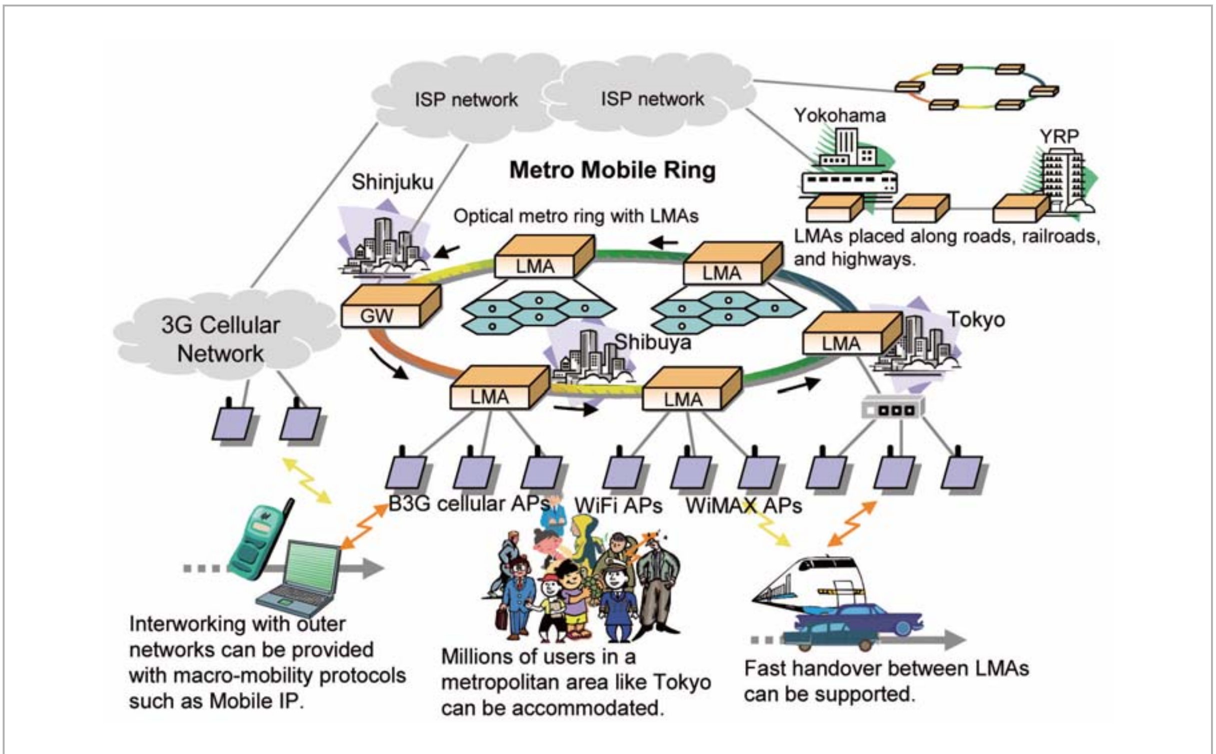

Fig.1 *Mobile Ring network conceptual diagram*

so-called "macro mobility" management. The IP address of the mobile device changes when it moves from one network to another. For example, in the representative macro mobility protocol, Mobile IP, the home agent (HA) manages the mobility of the mobile device and forwards the relevant data.

2.3 Traffic to be accommodated

When we began this research, we performed the following estimation to determine the approximate amount of traffic that the Mobile Ring network should accommodate[1]. According to statistics provided by the Tokyo Metropolitan Government, there are approximately 800,000 people living and working in the central Tokyo area per 100 km^2 during the day. Thus, we assumed 1 million mobile devices per 100 km^2. According to the 2001 White Paper on Information and Communications in Japan, approximately 0.4 % of all mobile phones are active (connected to the network) at any given time. Thus, we assumed a connection ratio of 1 %. In terms of the amount of information transmitted, we considered two cases: 100 kbps, for relatively slow transmissions such as voice communications; and 100 Mbps, for high-quality video transmission. We determined that a Mobile Ring network covering 100 km2 needs to accommodate an estimated 1 Gbps of traffic with outgoing terminal traffic of 100 kbps, and 1 Tbps of traffic when terminals are operating at 100 Mbps. Since there will be a range of data traffic in addition to voice communications, we can conclude that we will need a Mobile Ring network of at least 1 Gbps, equivalent to speeds obtained over wires.

3 Why a ring structure?

There are two main approaches to the implementation of micro mobility[2].

Tunnel-based approach: The mobility agent establishes a "tunnel" for forwarding packets with destination addresses that are outside of the agent's network. As long as the endpoint of the tunnel supports the relevant protocol, the relay nodes do not need to have a special function for recognizing the tunnel. Regional Registration[3] and Hierarchical MIPv6 are two examples of this approach.

Host-routing-based approach: The mobility agents within the micro mobility network manage the next hop, which will forward the packet to the mobile node (MN); these agents thus relay packets addressed to the MN. Although it takes no overhead to establish a tunnel, all nodes need to support the same protocol. Cellular IP[4] and HAWAII[5] are two examples of this approach.

Although each of the above examples uses

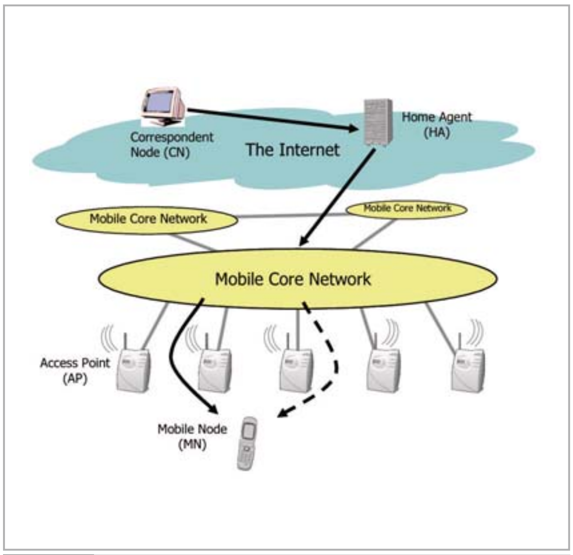

Fig.2 Scope of Mobile Ring network

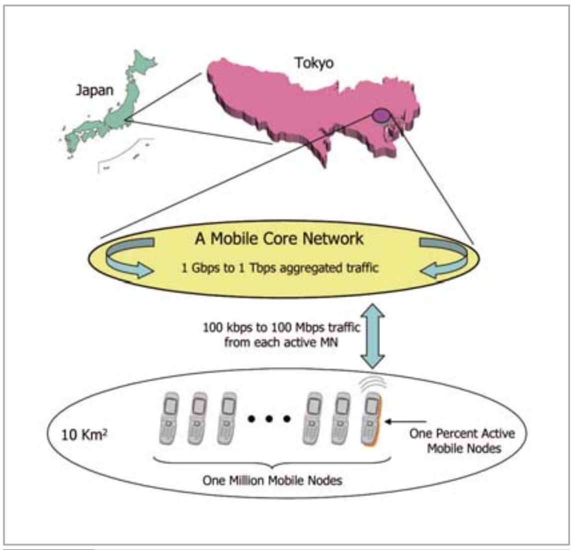

Fig.3 Estimation of traffic accommodated in Mobile Ring network

a different route control technology, all involve the use of hierarchical network structures for local mobility management. As shown in Fig. 4, the hierarchical approach can implement simple route management for routes to the upper hierarchy. When a given MN is subject to minimal motion, this approach has the advantage of minimizing the size of the control message. However, given the number of registered locations, nodes in the higher hierarchy must hold a larger amount of route information. In other words, the router in the topmost hierarchy needs to manage the routing information of all lower mobile devices, which increases the routing processing load and reduces overall scalability.

Figure 4 shows a topmost router managing routing information for a number “4 n” of lower mobile devices. The router looks up the address of an arriving packet and searches for corresponding information within the address information for the 4 n nodes. The load entailed in this process presents a problem. The proposed method, on the other hand, distributes routing information management using a flat network structure (both ring and linear structures are possible), thus increasing scalability. In Figure 4, the gateway directly connected to the external network forwards the packet into the Mobile Ring network, but the gateway itself does not do the searching. In other LMAs that have to perform packet-forwarding, since the number of mobile devices to be managed is distributed (here we assume that the mobile devices are uniformly distributed), each LMA needs to perform the search only for n nodes. In addition, the Mobile Ring network takes advantage of the flat structure to implement fast handover, by forwarding the packets to adjacent LMAs one after another at wire-equivalent speeds.

The comparison above applies to the IP layer. Figure 5, on the other hand, shows an example of micro mobility management within the data link layer. A layer-2 switch has a logical tree structure based on protocols such as the Spanning Tree Protocol. The MAC address learning function efficiently filters packets addressed to a particular MN. In this manner, the gateway node does not need to have the same number of routing entries as the number of MNs connected within a single segment. This approach appears to be more scalable than the layer-3 approach. However, when the gateway forwards a packet addressed to an MN, the gateway needs to resolve the MAC address of the MN, and thus needs to hold this address information in an ARP table. For this reason, the number of ARP entries increases according to the number of active MNs connected in a single segment.

In existing fixed networks, addresses of

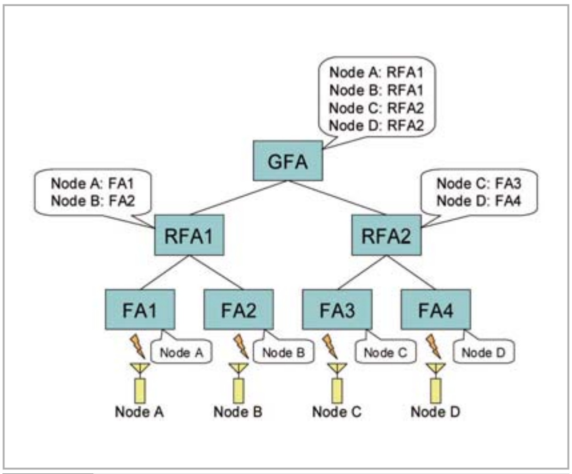

Fig.4 *Example of layer-3 micro mobility network*

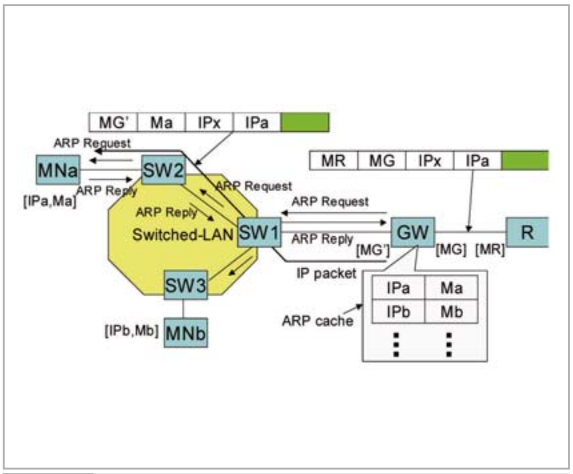

Fig.5 *Example of layer-2 micro mobility network*

network nodes to be assigned associate with the network topology. Thus, the routing information can be aggregated by arranging the network in a hierarchical structure. This structure offers significant advantages in terms of scalability with an increasing number of terminals. On the other hand, in a mobile network where the mobile devices move freely, the address of a mobile device is not necessarily compatible with the address architecture of the network to which it is currently connected. Thus, a hierarchical topology has fewer advantages than in a fixed network; furthermore, a mobility agent in the upper hierarchy is required to manage the location registration information of all lower mobile devices.

4 Operating mechanism of Mobile Ring network

To address the bottleneck issue discussed above, we have proposed a new mobility management method within a large-scale micro mobility network[6]. This approach uses a flat network architecture (shown in Fig. 6) to "delocalize" the routing information. We assume that the ring network in the figure is of a scale enabling an MN entering the management area to move about the area for a given period of time—here, the scale corresponds specifically to that of a metropolitan area. The location information of the MN is registered in a dedicated mobility agent referred to as the Localized Mobility Agent (LMA).

The LMA rapidly forwards packets within the ring and also delivers packets to the access network to which the registered MN is connected. The LMA has location information only for registered MNs. One of the LMAs operates as a gateway (GW) to the external networks; it delivers the packet from an external network to the MN and from the MN to the external network. The packet is forwarded in a one-way direction within the ring. When an LMA receives a packet from an adjacent LMA, it transfers the packet to the next adjacent LMA in the forward direction and determines whether the destination address of the packet is registered. If the address is registered, it also transfers the packet in the direction of the access network to which the MN is connected. All packets are subject to transfer control to ensure that they precisely follow the correct paths.

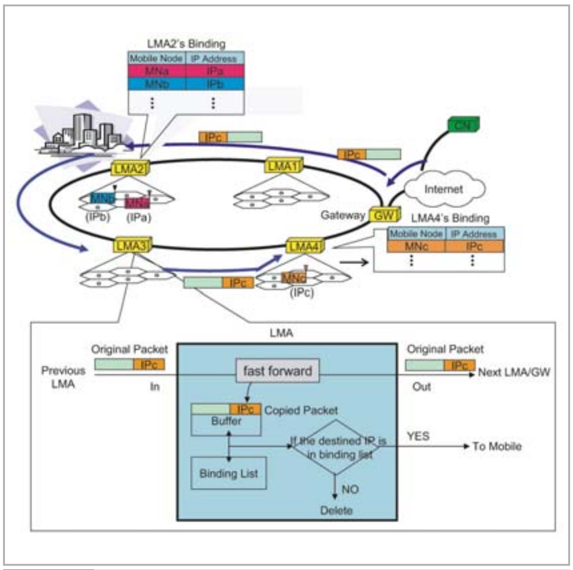

Fig.6 *Configuration of Mobile Ring network*

Even when the mobile device moves and one controlling LMA is switched for another, the packet is transferred within the ring network as described above in a short time without requiring routing processes; a mobile device can thus receive the packet from the second LMA. On the other hand, a hierarchical network requires modifying the route of the packet forwarding. The Mobile Ring network thus offers the added advantage of faster handover relative to a hierarchical network.

As shown in the example above, the LMA and GW do not resolve the MAC address of the destination MN. This is the essential difference between the Mobile Ring network and a layer-2 ring network such as RPR, where the local stations on the ring and the remote client bridged by the station require the MAC address of the destination host. The proposed method does not need to cache all MAC addresses of the destination MNs that the GW has resolved. This mitigates the type of bottleneck that would otherwise become increasingly problematic with an increasing number of

MNs. Furthermore, in addition to the unicast communication described above, the system can be extended such that multicast addresses are registered in a binding list, allowing for multicast communication through the same mechanism applicable to unicast traffic.

5 Evaluation

5.1 Comparison between the Mobile Ring and hierarchical networks

In the early stages of research, we installed LMAs in Linux PCs to verify the basic functions of the Mobile Ring network and to compare its performance with that of a hierarchical network[6][7]. Figure 7 shows the configuration of the Mobile Ring network, and Figure 8 shows the configuration of the hierarchical network. To prepare the same conditions for the two systems, we used four LMAs in the Mobile Ring network and four FAs in the hierarchical network. Table 1 shows the specifications of the LMAs in the Mobile Ring network and the GFA, the RFAs, and the FAs in the hierarchical network. Each node of the hierarchical network is installed with HUT Dynamics[8] software to form a hierarchical Mobile IP network.

In the experiment, packets with frame sizes of 1,500 bytes were transferred from a correspondent node (CN) on an external network to an MN (via the GW and the LMA). The maximum number of MNs per LMA was set at 100,000, and the maximum number of active MNs was set to 10,000. With this system, we measured the throughput of the link between the LMA and its subsidiary access network. Similarly, in the hierarchical network the frames were transferred from an external network to the MN (via the GFA, the RFA, and the FA). Figure 9 shows example results. In the hierarchical network, throughput rapidly decreases when approximately 6,000 MNs are registered. On the other hand, the Mobile Ring network maintains throughput even in an environment with more than this number of

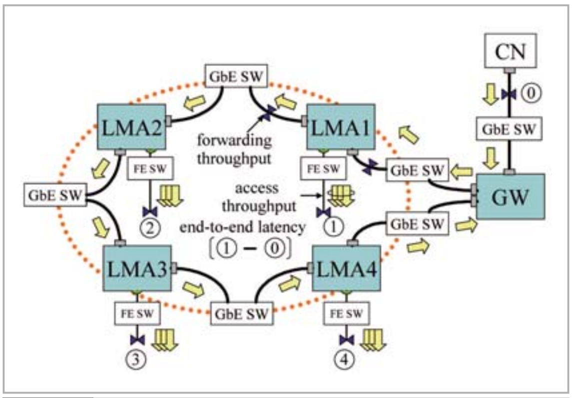

Fig.7 Measuring system for Mobile Ring network

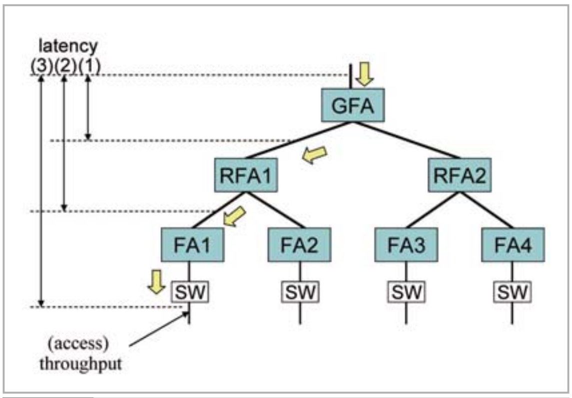

Fig.8 Measuring system for hierarchical network for comparison

Table 1 Specifications of software-based system

Components	Specifications
CPU	Intel Xeon 2.8GHz
Memory	1 GBytes
OS	Linux 2.4.18
LMA ←→ LMA, GW	1000Base-SX
LMA ←→ Access NW	100Base-TX

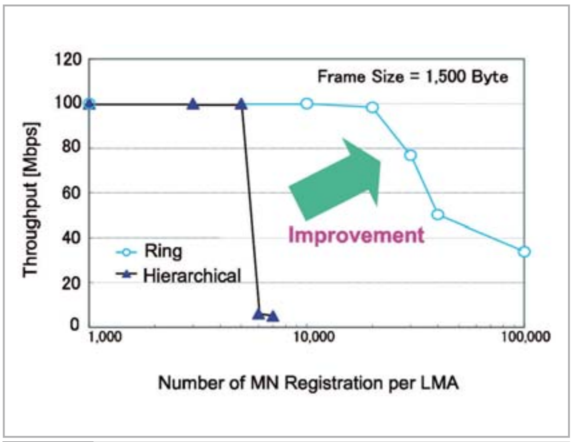

Fig.9 Performance comparison between Mobile Ring and hierarchical network (software-based system)

MNs. The decrease in throughput is also gradual. These results reveal the advantages of the Mobile Ring over hierarchical networks, as discussed earlier. Nevertheless, the throughput of the Mobile Ring network decreases significantly when approximately 100,000 MNs are registered. However, this reduction is due to the Linux-dependent software control for packet forwarding, and does not reflect the basic performance of the LMA packet-forwarding method.

5.2 Implementation by network processor

To verify the basic performance of the LMA packet forwarding method, we performed an evaluation using a hardware-based implementation with network processors[9]. This evaluation involved the use of a Radisys ENP-2611[11] board installed with an Intel IXP2400 network processor[10]. Table 2 shows the relevant specifications. Figure 10 illustrates the installation of the LMA and GW. Figure 11 shows the processing configuration. A multithread micro-engine is used for data-plane processing, which handles receiving, processing, and transmission of packets. Intel's XScale core is used for control-plane processing, which handles mobility management (MN registration) and ring management (connection management with the adjacent LMAs). The binding list is recorded in the DRAM managed by the kernel. The LMA/GW, installed in a 1 U chassis featuring a board installed with a network processor, has three GbE interfaces. Two of the interfaces are used for connections within the ring network, and the remaining interface is used as the wireless access network interface in the case of an LMA and as the external network interface in the case of a GW.

We constructed the same network as indicated in Fig. 7 using four LMAs and one GW and measured the transfer throughput within the ring as well as the transfer throughput to and from the access network. In addition, we measured the delay when the packet passed through each LMA, with reference to the external network (which was assumed to have a delay value of 0). Each LMA features 100,000 registered MNs, and 100 Mbps of

Table 2 Specifications of LMA and GW

Components	Specifications	
LMA, GW	Processors	8×Microengines (32-bit 600 MHz)
		Intel XScale core (32-bit 600 MHz)
	Memory	DRAM 256 MB
		SRAM 8 MB
	OS	Linux 2.4.18 (on XScale core)
LMA←→ LMA(GW)	1000Base-SX	
GW ←→ Outer NW	1000Base-SX	
LMA ←→ Access NW	100Base-TX	

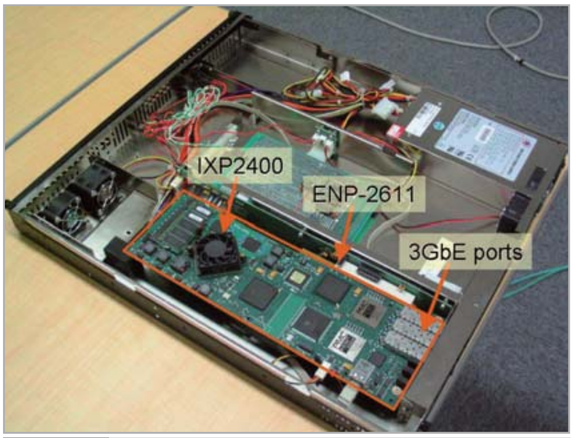

Fig.10 Installation of LMA based on network processor

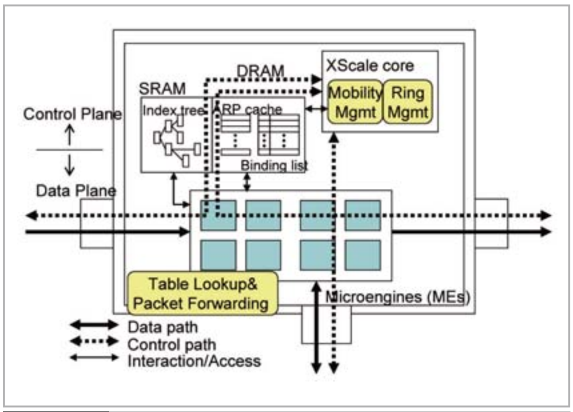

Fig.11 Processing configuration of LMA and GW based on network processor

traffic is transferred to each LMA from an external network, to destinations corresponding to 10,000 of the 100,000 registered MNs.

Figure 12 shows an example of measurement results. The figure shows that throughput values in the ring network and the access network are maintained at 400 Mbps and 100 Mbps, respectively, regardless of frame size. In other words, packet losses do not arise in the GW or the LMAs. The delay at the maximum frame size is 200 microseconds between the external network and LMA4, for which the delay is the largest. This value suggests that the delay is several tens of microseconds per LMA. We thus conclude that this system can be used for voice communication and video distribution, applications subject to stringent requirements in the minimization of delay times.

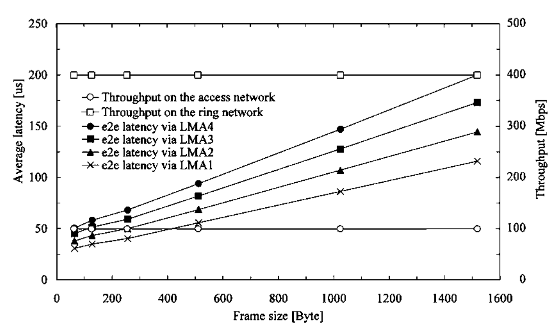

Fig.12 Performance of Mobile Ring network based on LMA with network processor

6 Outdoor demonstration experiment and future development

Based on the confirmation of basic performance, we conducted an outdoor demonstration experiment at the Yokosuka Research Park in March 2006, in collaboration with KDDI R&D Laboratories, Inc.[12][13]. Figure 13 shows the configuration of the experimental system. In this experiment, we connected wireless LAN base stations and LMAs to an outdoor fiber-optic network to form a Mobile Ring network. We used an experimental vehicle and successfully demonstrated handover within the Mobile Ring network at the speed of a running vehicle. We also successfully demonstrated handover between the Mobile Ring network and EV-DO, the third-generation cellular system. Based on these results, we are now performing tests for practical application of the technology in commercial networks.

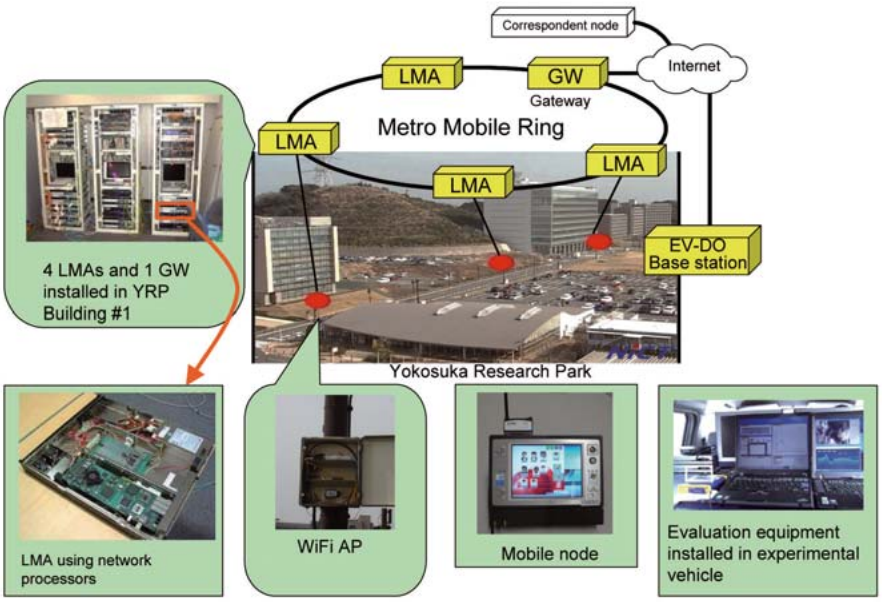

Fig.13 Network configuration of demonstration experiment

7 Conclusions

This article presented a discussion of the Mobile Ring network, a large-capacity mobile network technology that will enable implementation of a mobile Internet in large cities. Most proposals for such a mobile Internet have been tested only in small laboratory networks. However, if the technology is to be put to practical use, high scalability—to accommodate several hundred thousand to several millions of users—is indispensable. From this perspective, we have proposed a Mobile Ring network, evaluated basic performance, and assessed hardware-based implementation, in addition to outdoor experiments on a testbed network. We have now completed pre-commercialization research and development and are eagerly looking forward to future commercialization.

References

1 M. Inoue, K. Mahmud, H. Yokota, T. Kubo, and A. Idoue, “Scalable Mobile Core Network Architecture for All-IP Wireless Access”, WPMC, Vol.2, pp.18-22, Oct. 2003.

2 A. T. Campbell, et al. “Comparison of IP Micromobility Protocols”, IEEE Wireless Communications Magazine, Vol.9, No.1, pp.72-82, Feb. 2002.

3 E. Gustafsson, et al. “Mobile IPv4 Regional Registration”, draft-ietf-mip4-reg-tunnel-00, IETF, Nov. 2004.

4 A. Valk´o “Cellular IP: A New Approach to Internet Host Mobility”, ACM SIGCOMM Computer and Communication Review, Vol.29, No.1, pp.50-65, Jan. 1999.

5 R. Ramjee, et al. “HAWAII: A Domain-Based Approach for Supporting Mobility in Wide-area Wireless Networks”, Proc. IEEE Int'l Conf. Network Protocols, Nov. 1999.

6 H. Yokota, T. Kubo, A. Idoue, M. Inoue, and K. Mahmud, “Metro Mobile Ring for High-speed and Scalable Micro-mobility Management”, IEEE LANMAN, pp.151-156, Apr. 2004.

7 H. Yokota, T. Kubo, A. Idoue, M. Inoue, and K. Mahmud, "Study on Decentralized Micro-mobility Management for Large-scale Mobile Networks”, IPSJ Journal, Vol.47, No.4, pp.1239-1247, Apr. 2006. (in Japanese)

8 http://dynamics.sourceforge.net/

9 H. Yokota, T. Kubo, A. Idoue, N. Ryoki, and M. Inoue, “Network Processor Implementation of Scalable Micro-Mobility Management for Metropolitan Mobile Networks”, WPMC, pp.1483-1487, Sep. 2005.

10 Intel Corp. “Intel IXP2400 Network Processor”, http://www.intel.com/design/network/products/npfamily/ixp2400.htm

11 Radisys Corp. “ENP-2611 Data Sheet”, http://www.radisys.com/files/ENP-2611 07-1236-04 1004 datasheet.pdf

12 “Success in development and experimental demonstration of Mobile Ring Network technology for next-generation mobile Internet”, NICT Press Release, Mar. 22, 2006.

13 C. W. Pyo, N. Ryoki, M. Hasegawa, M. Inoue, H. Yokota, T. Kubo, K. Takeuchi,and A. Idoue, “Scalable and Seamless Mobile Core Network Architecture”, WPMC, Sep. 2006.

***INOUE Masugi**, Dr. Eng.*

Research Manager, Network Architecture Group, New Generation Network Research Center

Ubiquitous Networks, Mobile Networks

***MAHMUD Khaled**, Dr. Eng.*

Assistant Professor, North South University, Bangladesh (Previously with Mobile Networking Group as an Expert Researcher)

Wireless Networks

***PYO Chang Woo**, Dr. Eng.*

Expert Researcher, Ubiquitous Mobile Communication Group, New Generation Wireless Communications Research Center

Ubiquitous Mobile Communication Networks, Ad hoc Media Access Control, Cognitive Ad hoc Networks

KUBO Takeshi

Research Engineer, KDDI R&D Laboratories, Inc.

Mobile Network

IDOUE Akira

Senior Manager, Mobile Network Laboratory, KDDI R&D Laboratories, Inc.

Mobile Network

***YAMAMOTO Shu**, Dr. Eng.*

Senior Manager, IP Development Laboratory, KDDI R&D

Communication Networks

***HASEGAWA Mikio**, Dr. Eng.*

Senior Researcher, Ubiquitous Mobile Communications Group, New Generation Wireless Communications Research Center

Ubiquitous Networks

***RYOKI Nobuo**, Ph.D.*

Expert Researcher, Kyushu Research Center, Collaborative Research Management Group

Mobile Networks, Ubiquitous Networks

***TRAN Ha Nguyen**, Ph.D.*

Expert Researcher, Ubiquitous Mobile Communication Group, New Generation Wireless Communications Research Center

Mobile Networking, Ubiquitous computing

***YOKOTA Hidetoshi**, Ph.D.*

Senior Research Engineer, KDDI R&D Laboratories

Mobile Communication Architecture and Protocols

***TAKEUCHI Kazunori**, Dr. Eng.*

Director, YRP Research Center, KDDI R&D Laboratories Inc.

Mobile Wireless System and Radio Transmission Technology