APG-Report: Scalable Mobile Ethernet and Fast Vertical Handover

Masahiro Kuroda et al.

Communications Research Laboratory

3-4 Hikarino-oka, Yokosuka, Kanagawa 239-0847 Japan, +81-46-847-5103

marsh@crl.go.jp

ABSTRACT

The 3G cellular system has infiltrated into market and the next generation wireless system called Beyond 3G is discussed at ITU-R. The Beyond 3G system integrates various wireless accesses including 3G and wireless LANs and provides an all IP wireless solution to offer services taking advantage of each wireless communication of the system. Current approach to integrate wireless systems is to localize wireless dependent functions and to integrate into all IP network using IP technologies. We propose a scalable Mobile Ethernet architecture for the all IP integrated network using MAC layer technologies, such as optical Ethernet, RPR, and IEEE802, and the fast vertical handover introducing common radio resource and signaling managements. We discuss network segmentation with mobility management and multicast management for the scalability of the Mobile Ethernet by reducing network traffic. We evaluate the network from the viewpoint of scalability. In the evaluation we understand that the design that the gateway switch of a segment forwarding MAC frames as an anchor point becomes effective in case that the gateway switch of each segment cannot hold entries for all mobile terminals. We also evaluate the vertical handover comparing to Mobile IPv6 fast handover, and understand that the fast vertical handover consumes less network resources and flexible in having an anchor point for handover.

I. INTRODUCTION

The 3G cellular system has been infiltrated into current market and the next generation wireless system called Beyond 3G is said to come up in the market. The Beyond 3G system integrates various wireless accesses including 3G, wireless LANs and satellite and provides an all IP wireless solution to offer services, taking advantage of each wireless communication of the system. There are activities to integrate heterogeneous wireless networks into all IP network using IP technologies [1-3]. The main idea of that system is to localize wireless dependent functions as much as possible and to have a common IP layer to accommodate mobility management, network level authentication and signaling control. The IP network infrastructure is prevailing as metropolitan and wide area Ethernet using optical Ethernet and Resilient Packet Ring [4] technologies and is becoming available as commercial networks.

For wireless access technologies, on the other hand, the 3G based systems are gradually extending as wireless networks, whereas IEEE802.11 is dramatically expanding its deployment because of the cost efficiency, though service is limited in small areas. The IEEE802.20 MBWA [5] Working Group is developing a specification optimized for high-speed IP data transport and vehicular mobility in a MAN environment. The IEEE802 LMSC [6] based high-speed wide range wireless system becomes a key component of the Beyond 3G system, and many systems will converge on the IEEE802 MAC layer in addition to the IP layer.

There are many discussions of terminal mobility by enhancing Mobile IP [7] to manage the mobility in integrated wireless systems. In the Mobile IP enhancements, efficient route optimization, fast handover [8] and control packet reduction using hierarchical network management [9] are raised. These enhancements are useful in a heterogeneous wireless system, but Mobile IP still needs many message exchanges, such as Binding Update at terminal movement between access routers and Return Routability to check the correctness of the binding update information. These message exchanges increase signaling overheads.

There are proposals to solve these Mobile IP related overheads by using MPLS. A Label, which is distributed along a terminal movement, hides the terminal IP address change and optimizes the route between the terminal and routers [10]. This mobility control has an advantage of using QoS control mechanism, but still there exist overheads to encapsulate packets like Mobile IP.

The mobility management in MAC layer is specified at the IEEE802.11 Task Force F. The Inter-Access Point Protocol (IAPP) [11] is designed to exchange security context of a mobile terminal between current access point (AP) and new AP and provides seamless data transfer to users during handover. The IAPP, furthermore, does not require the mobility control feature provided by Mobile IP because the protocol includes micro mobility that updates entries about the MAC address of a terminal in Layer 2 switches and APs at high speed. All the Layer 2 switches can become an anchor point of traffic during handover so that a signaling of IP address change is not required. These mechanisms realize high-speed handover. The IAPP, however, sends the Layer 2 Update frame to the MAC broadcast address to provide an indication to an AP that may have an older association with a terminal. This feature increases control frames, depending on the number of terminals and frequency of terminal movements, and affects the scalability of the Layer 2 network.

In this paper, we propose a solution for scalable Beyond 3G network along with the enhancement of the wide area Ethernet and a fast vertical handover among various radio systems introducing common radio resource and signaling managers. The solution is one of architectures discussed at the new generation mobile communication project [14]. We describe the architecture of the scalable Mobile Ethernet and introduce network segmentation with mobility management in MAC layer and multicast management for solving the problem of IAPP in the next section. In the section 3, we discuss mobility management of both inter- and intra- segment and a fast vertical handover. In the section 4, we evaluate inter-segment mobility management to look at the network scalability. We discuss advantages comparing to other methods. Lastly, we conclude with the summary and future perspective of the scalable Mobile Ethernet.

II. MOBILE ETHERNET

Our proposing Mobile Ethernet is based on the wide area Ethernet, where every message is virtually broadcasted on the network since Ethernet is operated on shared medium with proper MAC address as shown in Figure 1. We, then, have All IP network on the Mobile Ethernet. To achieve a good scalability, Layer 2 switches with path-learning cache are deployed in the wide area Ethernet. A path to a destination MAC address is learned at all switches on the path and unnecessary broadcast is suppressed once the path is learned.

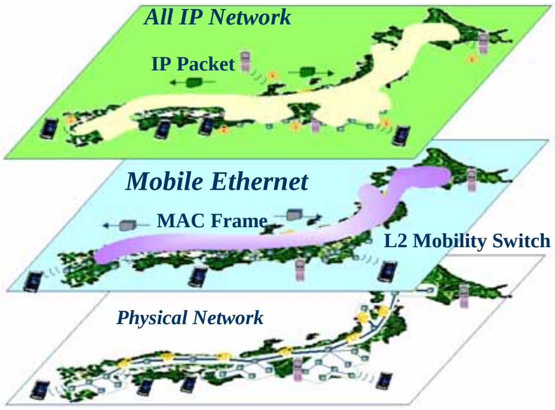

Fig 1: Scalable Mobile Ethernet

Since terminals in a wireless network often change their attach points to the network due to the movement of themselves, frequent updates of learning cache are needed. The Mobile Ethernet provides a signaling mechanism to update learning caches on the switches dynamically. Since this signaling message must be broadcasted in the Mobile Ethernet, suppressing the broadcast signaling traffic is an issue in the Mobile Ethernet for the scalability. A broadcast message of the upper layer communication stack, such as ICMPv6 neighbor solicitation message, is also included in the scope.

A. Network Segmentation

In order to achieve a good scalability of the Mobile Ethernet as providing country-wide service coverage while keeping capabilities of the wide area Ethernet, we bring in a network partitioning scheme to the network, as consisting an aggregate of two or more Layer 2 segments. The segmentation enables the network to suppress broadcast signaling messages, which control the learning caches, at least within the segment. In the Layer 3 point of view, the whole Layer 2 network appears as one broadcasting domain, i.e., a subnetwork.

As shown in Figure 2, the Mobile Ethernet gives a degree of flexibility in designing a segment structure. Each segment is configured as a component of a tree-structured access network, of a tree and a ring structured access network, or of a ring structured access network. Local ring structured part is shown in Figure 2. Segments are connected with a fast ring core network such as RPR. Another advantage of partitioning the network by segments is the flexibility that each segment is independently manageable and that different kinds of access network installation in a segment is applicable as long as the segment interface is kept the same.

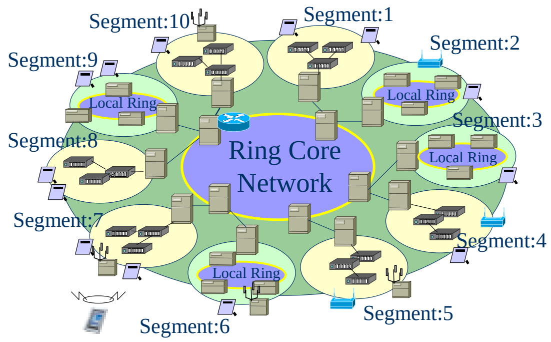

Fig 2: Segmentation of Mobile Ethernet

B. Multicast Management

Since the Mobile Ethernet is regarded as one wide area broadcast domain, the Layer 3 functions expect that broadcast messages, like the neighbor solicitation message in ICMPv6, are spread to the whole network by the flooding mechanism of Layer 2 switches. The Mobile Ethernet has a broadcast domain emulation mechanism for constricting specific Layer 3 broadcast messages. The Layer 2 switches in the Mobile Ethernet forward a specific Layer 3 broadcast message as a Layer 2 unicast message to the destined nodes without broadcasting to the whole domain. In case of the neighbor solicitation message, the message is forwarded to the neighbor discovery server, which holds entries about IP and MAC addresses for terminals, and the server resolves the MAC address on behalf of the target terminal.

III. Mobility Management

We discuss, here, two types of mobility management, Intra-Segment Mobility Management and Inter-Segment Mobility Management.

A. Intra-Segment Mobility Management

The Intra-Segment Mobility Management (IntraSMM) manages mobility in a distributed manner. Each Layer 2 switch in a segment keeps location information of all terminals under the switch. Cellular networks or Mobile IP, whereas, manages location information at a specific node, such as HLR/VLR or HA/FA. The IntraSMM updates location information dynamically in the switch by non-broadcast method to forward a MAC frame to the terminal.

<u>Location Registration</u>

The location registration and update procedure in a tree-structured segment is shown in Figure 3. A closest edge switch to a mobile terminal accommodates several access points. A segment gateway switch, the top node in the network hierarchy in the segment, has entries for all mobile terminals in the segment and interacts with other segment gateway switches. A branch switch located between edge switches and the segment gateway switch forwards frames to the next switch. The symbols of A and B under each switch and access point indicate on the same forwarding path, whereas A1 and A2 indicate separation in the forwarding path A.

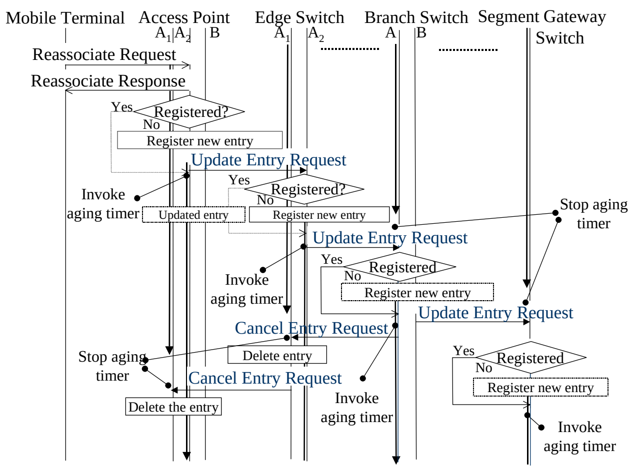

Fig 3: Update and Cancel Entry on Intra-Segment

We adopt a MAC address learning mechanism to reflect a path change immediately when a mobile terminal moves and the path to the terminal changes. In registration or update operations of entries, an AP sends an Update Entry Request Frame to the segment gateway switch. The switches on the way to the segment gateway switch, including the segment gateway switch, learn the MAC address of the terminal. The operation is addition to the normal path learning mechanism of a Layer 2 switch when forwarding user data frames.

An entry is deleted when the information becomes out-dated based on the aging mechanism. The anchor point, a Layer 2 switch common to the mobile terminal before and after the movement, keeps forwarding frames to the terminal at both locations and sends a Cancel Entry Request Frame to the previous AP that was connected by the terminal before the movement. The entries in the switches on the way to the previous AP are deleted.

MAC Frame Forwarding with Learning

In a tree-structured segment, the MAC address learning mechanism expects tree-structured hierarchical network. Each Layer 2 switch has all MAC addresses of mobile terminals under it from the viewpoint of hierarchical relation in the tree. Therefore, it can forward any frame to a mobile terminal by going up the switch hierarchy toward the segment gateway switch.

The frame forwarding has default forwarding feature to reduce traffic in a segment. When data is sent from an edge switch to the upper switch, each switch compares entries kept in the switch by a hash key value generated from the destination MAC address. If the switch has a matched entry, it forwards the frame to the port registered in the entry. If not, the switch forwards the frame to the upper switch not to flood the frame. This takes an advantage of hierarchical network configuration. At learning time, a switch only memorizes the source address and received port of a forwarding frame coming from the edge switch.

The default forwarding provides scalability for Mobile Ethernet, as it reduces traffic within a segment and decreases the memory consumption for entries by this forwarding with learning feature.

B. Inter-Segment Mobility Management

The Inter-Segment Mobility Management (InterSMM) provides a mechanism to manage terminal mobility across segments on the Ring Core Network. A communication path over InterSMM, shown in Figure 4 is created when segment gateway switches communicate between segments.

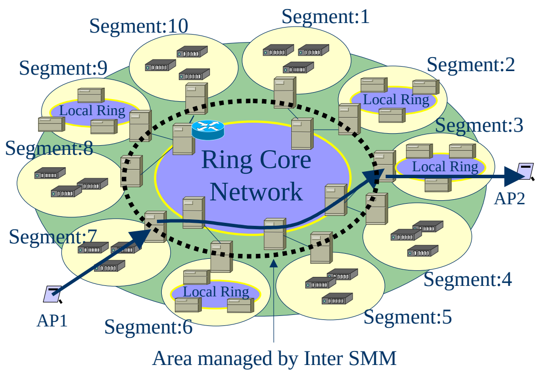

Fig 4: Inter-Segment Mobility Management

The InterSMM on the segment gateway switches functions to set up a path between segments initiated by a mobile terminal movement. A new segment gateway switch on a new segment where the mobile terminal moved into receives the Update Entry Request Frame from the mobile terminal. The switch transmits the request frame to the previous switch where the mobile terminal is connected. The previous switch receives this request frame, sends a Cancel Entry Request Frame to switches along the way down to the terminal's previous location via the learned cache path to clear the former path in the previous segment.

An Update Entry Request Frame and MAC frames to a mobile terminal are transferred between the previous and the new segments according to message passing policy which is based on either broadcasting communication (using broadcasting method) or unicast communication (using MAC learning method and anchor method) described below.

Broadcast Method

Using the broadcast method, a segment gateway switch does not have MAC address entries of mobile terminals in other segments. MAC frames always go around the ring. MAC frames to a mobile terminal and an Update Entry Request Frame are transmitted by broadcast to all segment gateway switches except itself. Each segment gateway switch receives a MAC frame and scrutinizes the destination address in the frame. If the switch has the entry matching the destination address, it transmits the frame to branch switches in its segment. If not, the switch discards the MAC frame.

MAC LEARNING METHOD

In the MAC learning method, a segment gateway switch has MAC address entries to mobile terminals in other segments too. Therefore, as shown in Figure 4, communication between segment gateway switches is always guaranteed the optimum route. For this reason, a segment gateway switch sends an Update Entry Request Frame by broadcast to other segment gateway switches and the frame goes around the Ring Core Network. Layer 2 switches, not only in the segment where a mobile terminal exists, but also on the Ring Core Network and segment gateway switches, receive the frame, and add an entry by learning the MAC frame. Meanwhile segment gateway switches protect their segments from unnecessary messages to mobile terminals not registered in the segments by the same way as the broadcast method.

ANCHOR METHOD

In the anchor method, one segment gateway switch is specified to each mobile terminal irrespective of the terminal current location. That segment gateway switch is called a Home Segment Gateway Switch and only the Home Segment Gateway Switch recognizes the segment at the current terminal location.

A MAC frame destined to a mobile terminal is forwarded to a Home Segment Gateway Switch at once, and the Home Segment Gateway Switch transmits the frame to the segment gateway switch at the current terminal location.

For this purpose, when a segment gateway switch receives an Update Entry Request caused by a mobile terminal movement, it specifies a Home Segment Gateway Switch to the terminal. Then, the switch registers or updates the link of the MAC address to the terminal.

C. Fast Vertical Handover

The Mobile Ethernet accommodates different types of radio systems such as 3G and WLAN. Deploying Common Radio resource Management Server (CRMS) and Common Signaling Server (CSS), AP's of respective radio systems are integrated to an Edge Switch. The AP of each system and a terminal prepare a convergence function to correspond the CRMS and the CSS. This scheme defines a common signaling mechanism independent of properties of each radio system between a terminal and the network, and operates network initiated handover seamlessly. This signaling is defined in Layer 2 control framework and is hidden from IP layer.

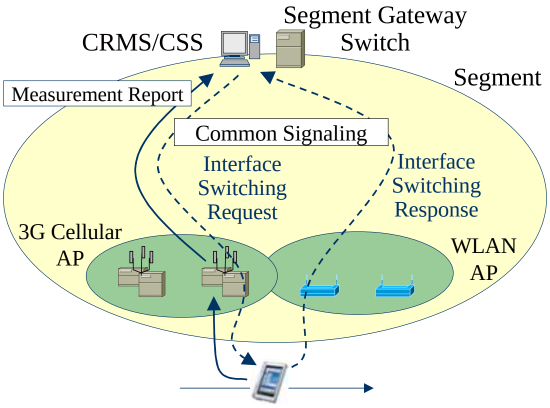

Fig 5: Fast Vertical Handover

The CRMS collects radio status information such as Received Signal Strength Indicator (RSSI) and error correction rate by exchanging reporting method including format, timing (periodical, event driven) among terminals and APs in advance, cooperating with Radio Resource Management (RRM).

Since WLAN does not have a certain RRM mechanism like 3G currently, the measurement interface discussed in the IEEE802.11 Task force K [12] is able to be applied to a RRM of WLAN. The CRMS calculates the necessity of handover by weighting each item of radio resource measurement result of a moving terminal. Once a handoff is decided, the CRMS sends a interface switching request to the CSS. Then the CSS let the terminal change the radio interface. The fast handover is achieved by establishing an association with the AP moved to, and route updates on the switches operated by the IntraSMM simultaneously.

IV. EVALUATION

In this paper, we focus on the traffic on the Ring Core Network where data are transmitted between segments, and the fast vertical handover between different radio systems. We evaluate the former quantitatively, and the latter qualitatively.

A. Inter-Segment Mobility Management

The segment gateway switches attached to the Ring Core Network apply the leaning cache mechanism for controlling the data traffic on the Ring Core Network as well as controlling the data traffic inside the segment. From the viewpoint of bandwidth in the Ring Core Network, it is desirable for the broadcast traffic to be suppressed by these leaning cache mechanisms. But suppressing the broadcast traffic consumes resources, such as memory for entries and CPU runtime for searching for an entry.

As discussed the three methods of the inter-segment mobility control, the broadcast method requires minimum entries of mobile terminals and can simplify the segment gateway switch implementation. The MAC learning method can reduce the broadcast traffic. However the MAC learning method is not applicable when the network becomes large, because all segment gateway switches need to have entries of all mobile terminals and may lack of resources. The anchor method can avoid the explosion of entries but may generate additional traffic and delay for message redirection.

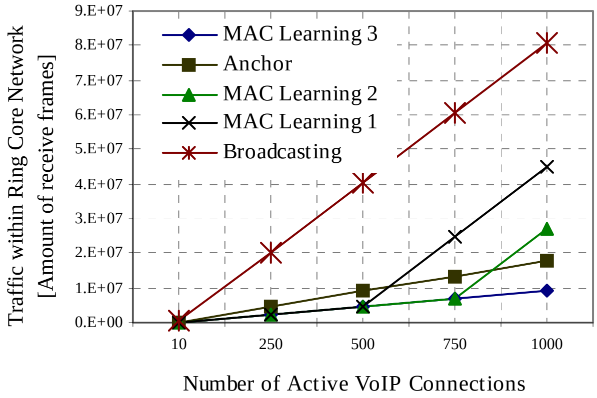

Fig 6: Evaluation of the Inter-Segment Ring Mobility

We organized simulations to estimate the inter-segment mobility control methods on MIRAI-SF network simulator [13]. We defined a simulation agent that emulates the Ring Core Network and a traffic generating agent that emulates the segment in the MIRAI-SF. 10 traffic generating agents are attached to the Ring Core agent. The traffic generating agent generates VoIP data traffic. We analyze the relationship between the number of active VoIP connections and traffic within Ring Core Network quantitatively, and evaluate the each method for InterSMM. In this simulation, we assume 2,000 users in a segment and 20,000 users in 10 segments in total. We also assume 1,000 active VoIP connections in case of usage ratio 10% and 2.5% loss probability per user.

Figure 6 shows the result of the simulations. The number of active VoIP connections is plotted in the horizontal axis and the total traffic of the Ring Core Network is plotted in the vertical axis. In the case of the MAC address learning method, we have three cases to evaluate the influence of the number of entries. MAC learning 1 shown in Figure 6 has entries for a half number of mobile terminals in the network. MAC learning 2 expects the 3/4 of entries and MAC learning 3 has all entries. The simulation result shows that the traffics of the Ring Core Network increase at the same ratio with the broadcast method in the case that the number of active VoIP connections exceeds the maximum entries kept in a segment gateway switch in MAC learning 1 and 2. The MAC learning methods are better than the anchor method when the number of active VoIP connections does not exceed the number of entries kept in a segment gateway switch, but the anchor method does not increase so much traffic in the case of high load traffic situations. We need to understand the characteristics of the network usage to decide which method is suitable for the network. The MAC learning method reduces traffic within Ring Core Network to 1/8 of the broadcast method and 1/2 of the anchor method if all entries are saved. In case that segment gateway switch does not have entries of all mobile terminals, the anchor method is the most effective for scalability in InterSMM.

Each method does not change its characteristics as the number of active VoIP connections is proportional to the traffic within a Ring Core Network, even though we target the number of users as 20,000 in a segment.

We also understand that anchor and broadcast methods are feasible to be implemented in a segment gateway switch in terms of the memory consumption because a Layer 2 switch needs only 6MB memory for 20,000 users with 30 bytes for each entry. Processing delay for searching an entry among 20,000-30,000 entries will not be an issue on ground of the actual performance of the legacy Layer 2 switch.

B. Fast Vertical Handover

The fast handover proposal of the Mobile IPv6 intends a fast handover by allocating a Care of Address (CoA) in advance at an access router moving into, as shown in figure 7. Moreover, allocating a bidirectional tunnel between the previous and the current access router, the proposal avoids data loss by forwarding packets arrived at the previous access router, enables a mobile terminal to transmit packets using old CoA during the handover process.

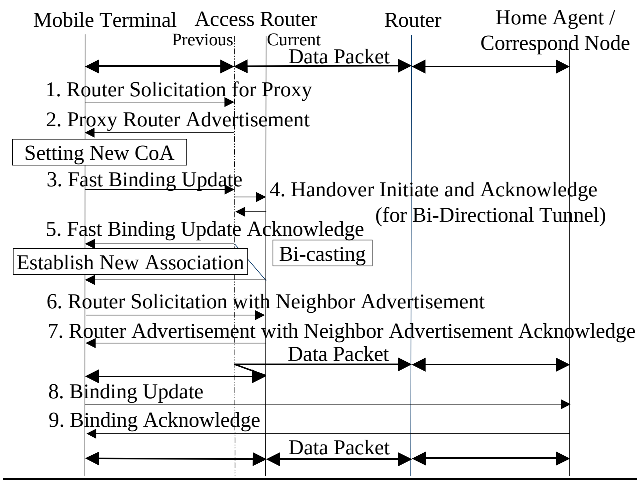

Fig 7: Mobile IPv6 Fast Handoff Procedure

The proposal, however, adopts a proxy based route search and binding update, which causes the increased overhead of the signaling. It also takes more time to complete the route change, since a binding update is also needed between the Home Agent and Correspondent Node after the handover.

The Fast Vertical Handover, on the other hand, updates the route synchronizing the association establishment with the new radio system, with a movement prediction and the network controlled handover as depicted in Figure 8. The mobile terminal does not change its IP address, but update a mapping between IP address and MAC address in the neighbor discovery server. The segment gateway switch swaps MAC address of receiving frames for the new address, and forwards the frames. Since the handover process is handled within the Layer 2, neither the CoA allocation nor the binding update is needed. Therefore, the fast vertical handover is achievable in the Mobile Ethernet.

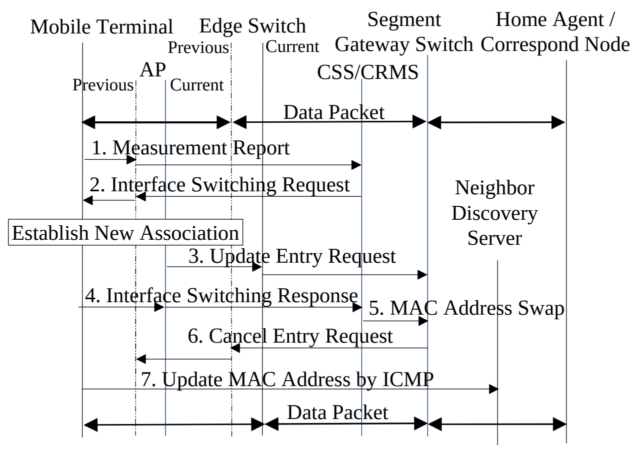

Fig 8: Fast Vertical Handover Procedure

In the Mobile IPv6 Fast Handover, data forwarding path from the previous access router to the current access router is allocated as an extended path via the Home Agent. It consumes the network resource and generates additional communication delay during the handover until the binding completion. As the Fast Vertical Handover takes its advantage of hierarchal network structure, the shortest path from the previous AP to the current AP is allocated by utilizing the anchor point mechanism. The Mobile Ethernet achieves the Fast Vertical Handover at this point as well.

Table1: Comparison with Mobile IPv6

Issues	Mobile Ethernet	Mobile IPv6 Fast Handover
IP Address Allocation	Not needed	Needed
Signaling Procedure	Simple	Complex
Signaling Round Trip Delay	Low	High

Anchor Point	Flexible (Any switch can be anchor point)	Fixed and pre-set
Transfer Delay	Low	High

V. Conclusion and Future Work

We proposed a scalable Ethernet based mobile network for the Beyond 3G system and the fast vertical handover mechanism. We introduced the segmentation management and broadcast traffic reduction to the network to achieve a good scalability. For handover, we explained common radio resource and signaling managements. We evaluated the Inter-Segment Mobility Management in an aspect of data traffic control and showed the effect of the mobility management and the vertical handover for the viewpoint of network resource consumption and flexibility. The network is expected to achieve fast handoff efficiently comparing solutions in IP layer since a signaling of IP address change is not required and any switch can be anchor point. We will organize further evaluation for the scalability of the system and functional evaluations in an aspect of wireless network such as anticipated handover and paging mechanism.

References

[1] H.Lach, C.Janneteau and A.Petrescu, “Network Mobility in Beyond-3G Systems”, IEEE Communication Magazine, pp.52-57, July 2003

[2] H.Yumiba, K.Imai, and M.Yabusaki, “IP-Based IMT Network Platform”, IEEE Personal Communication Magazine, vol.8, no.5, pp.18-23, October 2001.

[3] T.Otsu, I,Okajima, N,Umeda and Y.Yamao, “Network Archtecture for Mobile Communication Systems Beyond IMT-2000”, IEEE Personal Communication Magazine, vol.8, no.5, pp.31-37, October 2001.

[4] “IEEE 802.17 Resilient Packet Ring”

[5] “IEEE 802 Mobile Broadband Wireless Access”

[6] “IEEE 802 LAN/MAN Standard Committee”

[7] D. Johnson, C. Perkins, and J. Arkko, “Mobility Support in IPv6”,

[8] R.Koodli, “Fast Handovers for Mobile IPv6”, http://www.ietf.org/internet-drafts/draft-ietf-mobileip-fast-mipv6-06.txt, Internet-Draft, March 2003.

[9] Hesham Soliman, Claude Castelluccia, Karim El-Malki and Ludovic Bellier, “Hierarchical Mobile IPv6 mobility management (HMIPv6),

[10] Fabio M. Chiussi, Denis A. Khotimsky and Santosh Krishnan, “Mobility Management in Third-Generation All-IP Network”, IEEE Communication Magazine, pp.124-135, September 2002.

[11] “Draft Recommended Practice of Multi-Vendor Access Point Interoperability via Inter-Access Point Protocol Across Distribution Systems Supporting IEEE 802.11 Operation”, IEEE 802.11f/D5 January 2003.

[12] “Specification for Radio Resource Measurement”, IEEE 802.11k/D0.6 August 2003

[13] T. Sakakura, M. Kuroda and Gang Wu, “MIRAI (6) ~ Simulation and Implementation Environment Based on SSF”, B-5-16, IEICE General Conference, March 2002.

[14] H. Harada, M. Kuroda, H. Morikawa, H. Wakana, and F. Adachi, "The Overview of the New Generation Mobile Communication System and the Role of Software Defined Radio Technology," IEICE Trans. Commun. Dec., 2003, in press.