(6) IP-Based Mobility Management Technology

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This article reviews recent progress in the study of IP-based mobility management technology for realizing mobility of cell phones and other mobile nodes in Fourth-Generation (4G) mobile communications systems. The architecture and components of the IP-based mobility management technology are described.

1. Introduction

DoCoMo is focusing efforts on the development of an IP-based mobility management technology, a basic technology needed for the deployment of Fourth-Generation (4G) mobile communications systems that will support broadband mobile communications services. IP-based mobility management technology works at the Internet Protocol (IP) layer to enable seamless handoff of mobile nodes (cell phones, PDAs, notebook computers, etc.) while moving around in the 4G system and end-to-end reachability of packets to and from mobile nodes. In short, this technology achieves true mobility by permitting mobile nodes to move freely about anywhere in the 4G system and initiate and carry on communications.

This article presents the architecture of the IP-based mobility management technology, and highlights a number of key components: multiple interface management, active state mobility management, and dormant state mobility management.

2. IP-Based Mobility Management Architecture

In this section we will highlight the key requirements for mobility management in the 4G system, then present an architecture that satisfies these requirements.

2.1 Requirements

The main requirements for mobility management are as follows:

(1) High Quality of Packet Communication

In order to support a diverse range of applications, good packet transmission quality is essential including low packet transmission delay, minimal packet transmission delay deviation, and a low packet loss rate.

(2) Modest Control Costs

To make efficient use of wireless links that have significantly less bandwidth capacity than wired links, it is necessary to reduce the amount of signaling traffic associated with mobility management that are transferred over the wireless links.

(3) Seamless Mobility

The management scheme must implement seamless mobility that supports mobile nodes connected not only to 4G cellular wireless links but to IEEE802.11 and other wireless links, and to Ethernet and other wired links.

2.2 Configuration and Protocol Stack

In principle, mobility management can be implemented at any layer between the link layer and the application layer. However, if mobility management is implemented at the link layer, the applicability would be limited to the same type link, and this would contravene Requirement (3) above in Section 2.1. Moreover, if mobility management is implemented at the transport layer or the application layer, it would have to be separately implemented for all the different transport layer and application layer protocols, an arrangement that would increase the quantity of signaling traffic thus failing to satisfy Requirement (2). In contrast to these other approaches, by implementing mobility management at the IP layer, which is common to all the link layer, the transport layer, and the application layer protocols, Requirements (2) and (3) are both satisfied. This approach is able to handle instantaneous disconnections of the wireless link associated with handoffs and delays in packet route setup processing that are the primary factors in degradation of packet transfer quality, and thus satisfies Requirement (1). This approach thus satisfies all three of our benchmark requirements. Assuming IPversion6 (IPv6) that, with its enormous address space will support an extremely large number of mobile nodes, **Figure 1** shows a schematic representation of the IP-based mobility management scheme and protocol stack.

The Multiple Interface Management (MIM) provides a number of key functions in the protocol stack on the mobile node. It delivers the link layer best matching user preferences to the layers above while minimizing the power consumption of the other link layers on the mobile node that are not used.

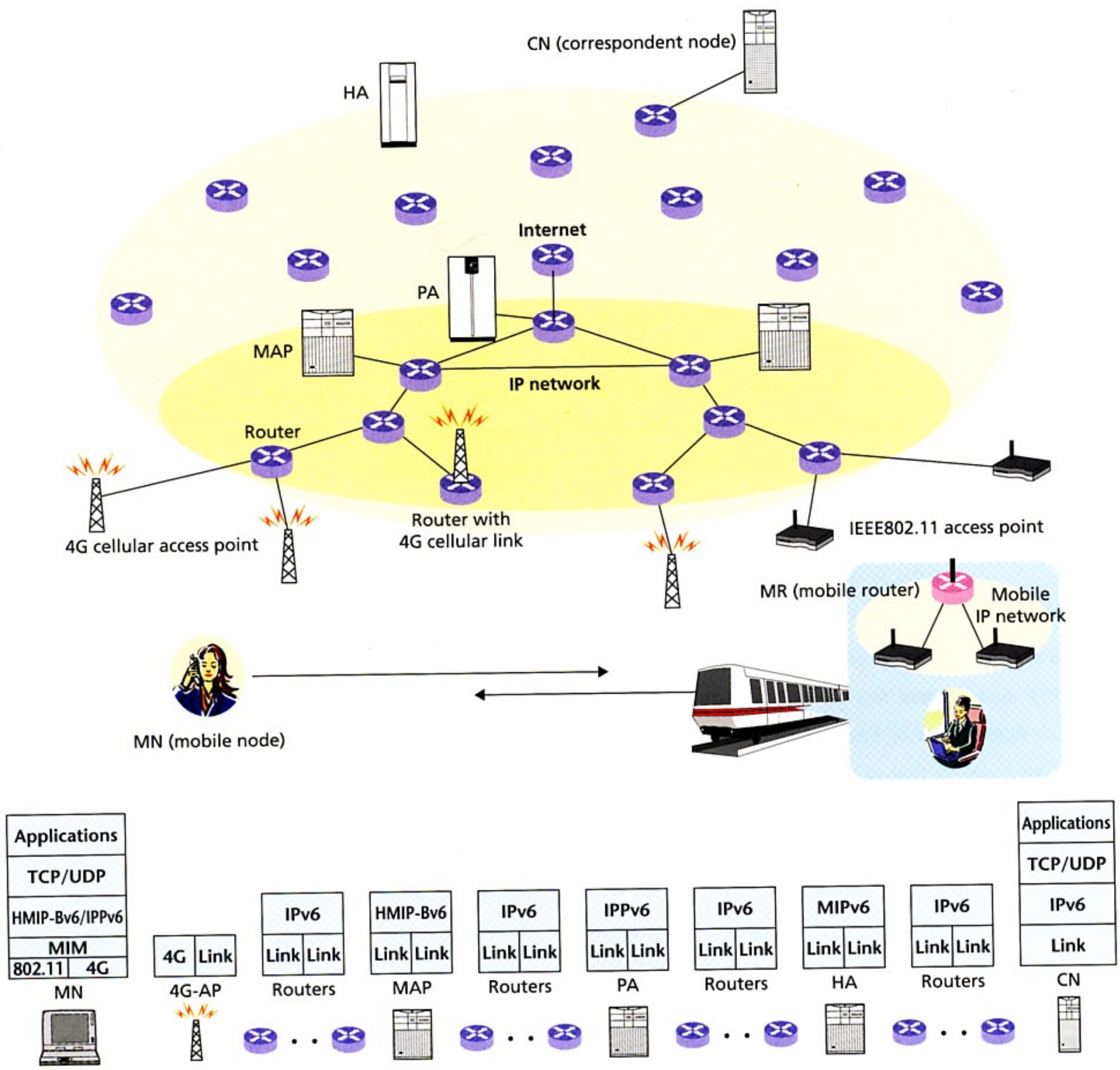

Figure 1 IP-based mobility management architecture

The Hierarchical Mobile IPv6 with Buffering at MAP (HMIP-Bv6) is a mobility management protocol that uses Mobility Anchor Point (MAP) with buffering capability to update packet route every handoffs, and achieves reliable routing of packets to the mobile node in the active state of communication with a low packet loss rate and low packet transmission delay.

Finally, the IPv6 paging protocol is a mobility management protocol that uses Paging Agent (PA) to manage the location of mobile nodes in the dormant state of communication in local area units and notify the mobile node of the arrival of incoming packets.

3. Multiple Interface Management

Generally current cell phones only have a Network Interface Card (NIC) for cellular wireless links, but NICs are rapidly coming down in price and seeing increased levels of chip integration, so it is only a matter of time before single mobile nodes will support multiple NICs. Greater flexibility and richer variety of services can be provided using multiple NICs in a complementary fashion. To provide such services, functionality must be implemented that first determines what NICs are available on a mobile node, then selects the optimal NIC best matching user preferences with respect to bit rate and transmission cost. The MIM provides that functionality [1].

3.1 Requirements

The main requirements of the MIM are as follows:

(1) Ability to Select NIC Based on User Preferences

The MIM first determines which NICs are available on a mobile node, then selects the optimal NIC that best matches the users' preferences.

(2) Battery Savings

With the goal of conserving the battery power of the mobile node, the MIM efficiently manages the power consumption of the NICs.

3.2 MIM Configuration

Figure 2 shows a configuration of MIM that satisfies the requirements outlined above. It is built into the mobile node.

(1) User Preferences Information

User preferences information is input via a graphical user interface and stored in a database. Typical information would include the user's preferences relating to bit rate, transmission quality, and transmission cost.

(2) Optimal NIC Selection Function

The MIM has the ability to select the NIC that best matches the user's preferences. Specifically, status information for each NIC is collected using the L2 trigger exchange function described below. For example, if the user prefers fast bit rate, the MIM selects the NIC from among the available NICs that provides the fastest bit rate. The MIM also helps conserve battery power by turning off the power of all other NICs that are not selected. The MIM also periodically checks to make sure that the NIC being used provides the best match with the user's preferences. If it discovers a NIC providing a better match, then it selects the new one.

(3) L2 Trigger Exchange Function

The NIC is equipped with the Link layer Application Program Interface (LAPI) enabling it to exchange status information between the link layer and the higher layer. This allows the NIC to notify the higher layer of any changes of status information, and the higher layer can obtain the information. For example, the optimal NIC selection function uses LAPI to select the optimal NIC and operate it so as to minimize the power consumption.

(4) Virtual Interface Function

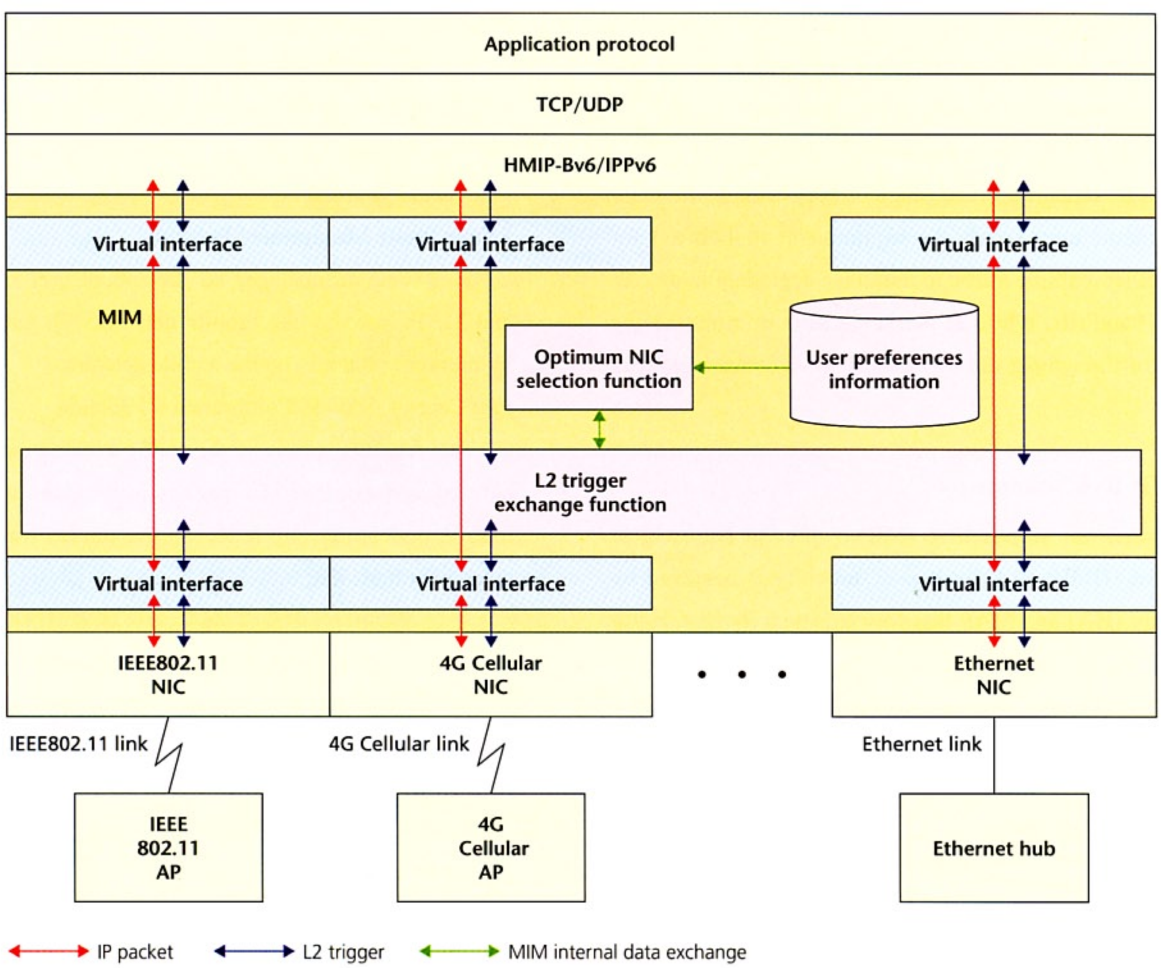

Figure 2 MIM operation

Considering that the existing higher layer protocols are in widespread use and the need to accommodate a diverse range of NICs, the MIM cannot change the specification of them. The MIM accomplishes it with two virtual interfaces to the higher layer and to the NICs. The higher layer sees the virtual interface provided by the MIM as the NIC, while the NIC perceives the virtual interface provided by the MIM as the higher layer.

4. Active State Mobility Management

In this section we will define the requirements for active state mobility management, present an overview of DoCoMo-proposed HMIP-Bv6 scheme, and present its evaluation results.

4.1 Requirements

The main requirements of the active state mobility management are as follows:

(1) Mobile Node and Mobile Network Mobility

Support of standalone mobile nodes goes without saying, but mobility of mobile networks such as groups of mobile nodes traveling in a car or a bus must also be supported.

(2) Ease of Deployment

To promote rapid and cost-effective deployment of 4G systems, the equipment must be easy to introduce.

(3) High Quality of Packet Communication

In order to support a broad range of applications, the management scheme must satisfy the requirements in **Table 1** for voice and other realtime traffic to minimize degradation of quality during handoffs, while at the same time minimizing the slowdown of throughput during handoffs to accommodate data traffic.

4.2 HMIP-Bv6 Scheme

In conventional Mobile IPv6 (MIPv6) [2] and Hierarchical Mobile IPv6 (HMIPv6) [3] schemes, mobility is achieved by Home Agent (HA) and MAP that forwards packets destined to mobile nodes, but these schemes do not satisfy the above requirements due to bursty packet losses that occur during handoffs and other factors. This led us to propose a new approach called Hierarchical Mobile IPv6 with Buffering at MAP (HMIP-Bv6) that adds a number of new capabilities to the HMIPv6 scheme [4], [5]. The following additional capabilities are realized through extensions to just the mobile node and to the MAP.

- MAP Discovery Function

  The MAP discovery function enables a mobile node to dynamically discover a MAP. This enables the mobile node to select the optimal MAP when multiple MAPs are present on the IP network by comparing the relative distance to MAPs, packet processing loads, and other criteria. This capability is defined as an Agent Discovery Protocol (ADP) [6], and can also be used to discover Paging Agents (PAs) as observed later in Section 5. Another advantage of this approach is that no data regarding MAPs and PAs needs to be preconfigured in the mobile nodes or routers, which simplifies the deployment of MAPs and PAs on the IP network.

- MAP Buffering Function

  The MAP buffering function provides buffering of packets destined to mobile node in the MAP to prevent packet loss during handoffs. This is illustrated for the HMIP-Bv6 scheme in **Figure 3**.

- Subnet Prefix Management Function

  This function manages all the subnet prefixes in HAs and MAPs used by the mobile network [7], and supports mobility for all nodes on the mobile network.

- Fast Care-of Address Configuration Function

  This function speeds up the configuration processing for care-of address that is a packet forwarding address of mobile nodes, thereby reducing the packet transmission delay after handoffs.

Table 1 Voice communication quality

Evaluation criteria	Requirement [11]	MIPv6		HMIPv6		HMIP-Bv6	
		Simulation	Experiment	Simulation	Experiment	Simulation	Experiment
Number of packets loss per handoff	3	16.24	17.66	12.93	14.38	0.00	0.00
Packet loss rate (%)	0.1	1.02	1.10	0.81	0.90	0.00	0.00
End-to-end packet transmission delay deviation (ms)	50	0.00	2.91	0.00	2.99	21.02	95.74
Average end-to-end packet transmission delay (ms)	400	111.87	108.94	11.87	108.94	111.88	109.54

Failed to meet requirements

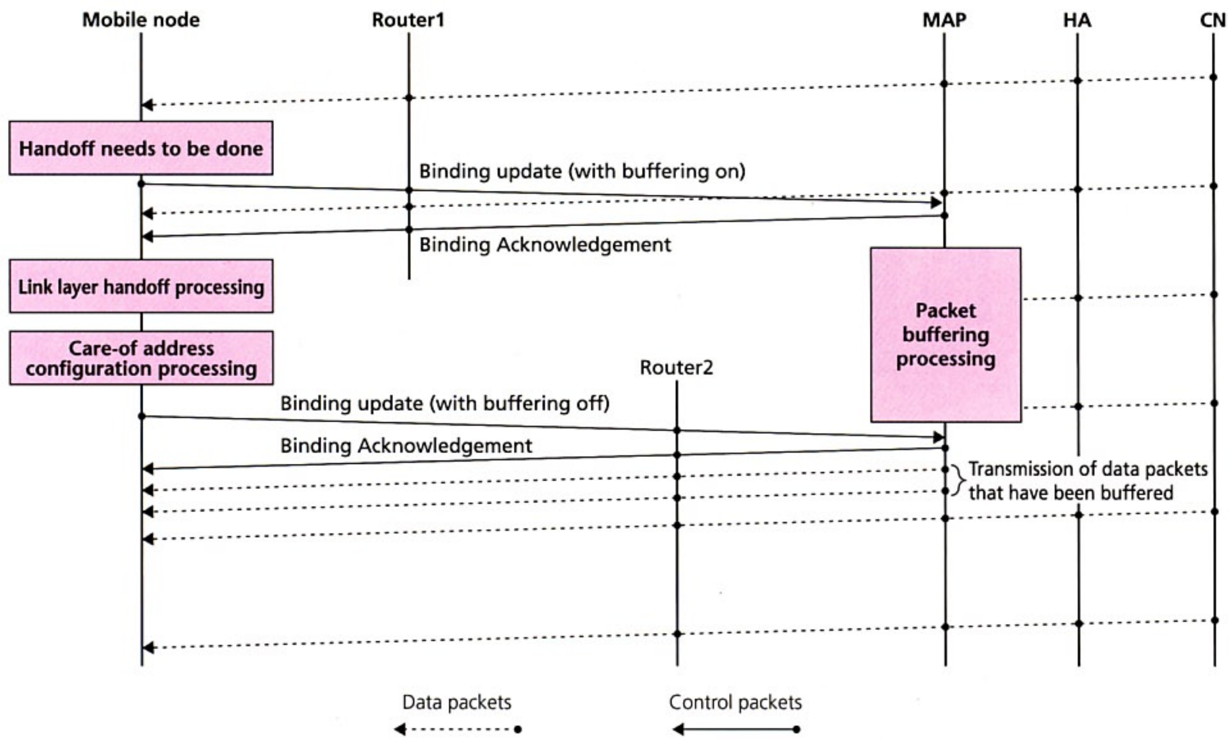

Figure 3 HMIP-Bv6 operation

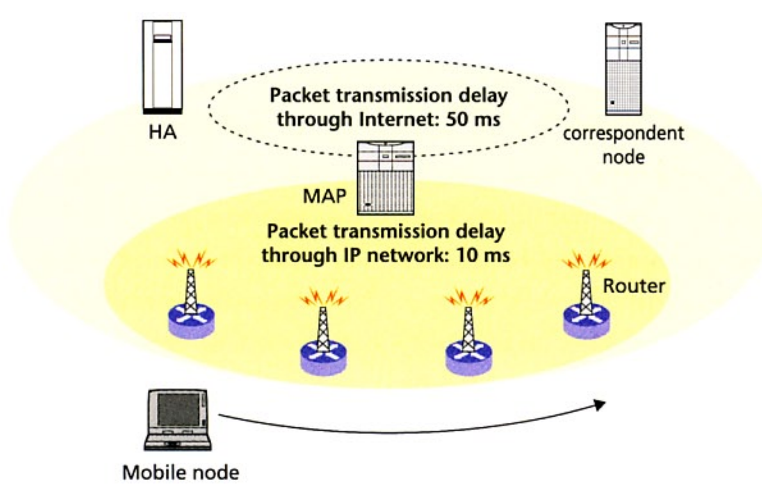

Figure 4 Network model

4.3 Evaluation of the HMIP-Bv6 Scheme

The packet transmission quality of three schemes— MIPv6, HMIPv6, and HMIP-Bv6—was evaluated through simulations and experimental trials, and in this section we report our findings.

(1) Evaluation Criteria

Using the network model shown in **Figure 4**, we evaluated the quality of speech and data communications at the mobile node in the case where the speech and data were sent from the correspondent node to the mobile node. The following criteria were used in making the evaluations:

- Voice over IP (VoIP) speech communications: number of packet loss per handoff, packet loss rate, end-to-end packet transmission delay deviation, average end-to-end packet transmission delay.
- FTP data communications: time required to transfer a file.

(2) Network Model

Fig. 4 shows the network model used in making the evaluations. The network model consists of a correspondent node, an HA, and an IP network interconnected by the Internet; a MAP

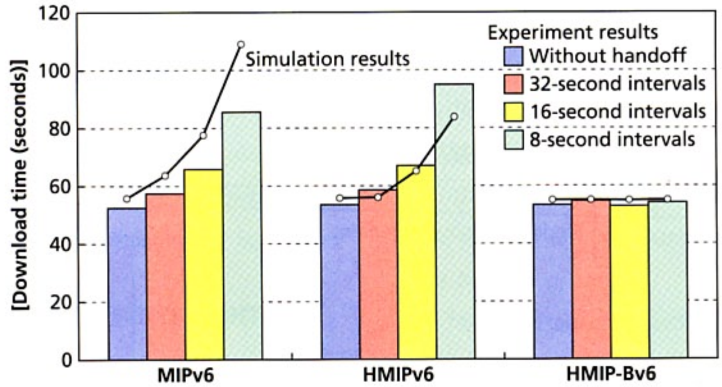

Figure 5 Data communication quality

and several routers are deployed on the IP network; and a mobile node performs handoffs between routers. Packet transmission delay through the Internet and the IP network are 50 ms [8] and 10 ms [9], respectively.

(3) Traffic Model

The traffic models for speech and data sent from the correspondent node to the mobile node over the network model are summarized as follows:

- Voice traffic: The packet rate is 50 packets per second, and the packet size is 80 bytes [10].
- Date traffic: A 5-Mbyte file is downloaded.

Having described the network model, let us next consider the evaluation results. The measurement communication quality results for the voice communication are presented along with requirements in Table 1. It is apparent that only the HMIP-Bv6 scheme satisfied the requirements for the number of packets loss per handoff and packet loss rate as a result of the effectiveness of the MAP packet buffering. The experimental end-to-end packet transmission delay deviation results for the HMIP-Bv6 scheme did not meet our benchmark requirement, but we should be able to bring the performance up to at least that obtained in the simulation by fine-tuning the implementation. All of the schemes satisfied the required benchmark for average end-to-end packet transmission delay.

Figure 5 shows the communication quality measurement results for the data communications. Download times were measured for all three schemes at mobile node handoff intervals of 8 seconds, 16 seconds, 32 seconds, and no handoff. Findings for the experimental system and for the simulation observed similar tendencies. One can see that the downloads took longer as the frequency of handoffs increased for the MIPv6 and HMIPv6 schemes, but the download time stayed more or less constant for the HMIP-Bv6 scheme regardless of the handoff frequency. The primary factor causing the slowdown of downloads is the loss of the Transmission Control Protocol (TCP) data segment, and since this does not occur in the HMIP-Bv6 scheme, the download time is not affected by the handoffs.

5. Dormant State Mobility Management

In this section we will define the requirements for dormant state mobility management and present an overview of DoCoMo-proposed IPv6 Paging Protocol (IPPv6).

5.1 Requirements

The main requirements of the dormant state mobility management are as follows:

(1) Reduction of Control Signals

Mobility management must be implemented in such a way that the volume of control signals is substantially less when the mobile node has no packet to send or to receive (i.e., dormant state) than when the mobile node has packets to send or to receive (i.e., active state).

(2) Interaction with Power Saving Control

To reduce the power consumption of the mobile node when it is running on battery, the link layer must be capable to operate the power saving control when the mobile node is dormant state.

(3) High Packet Communications Quality

The packet communication quality must be equivalent to the quality requirements of the active state mobility management.

5.2 IPPv6 Configuration

IPPv6 has been proposed as a dormant state mobility management scheme that satisfies the above requirements [12]. The

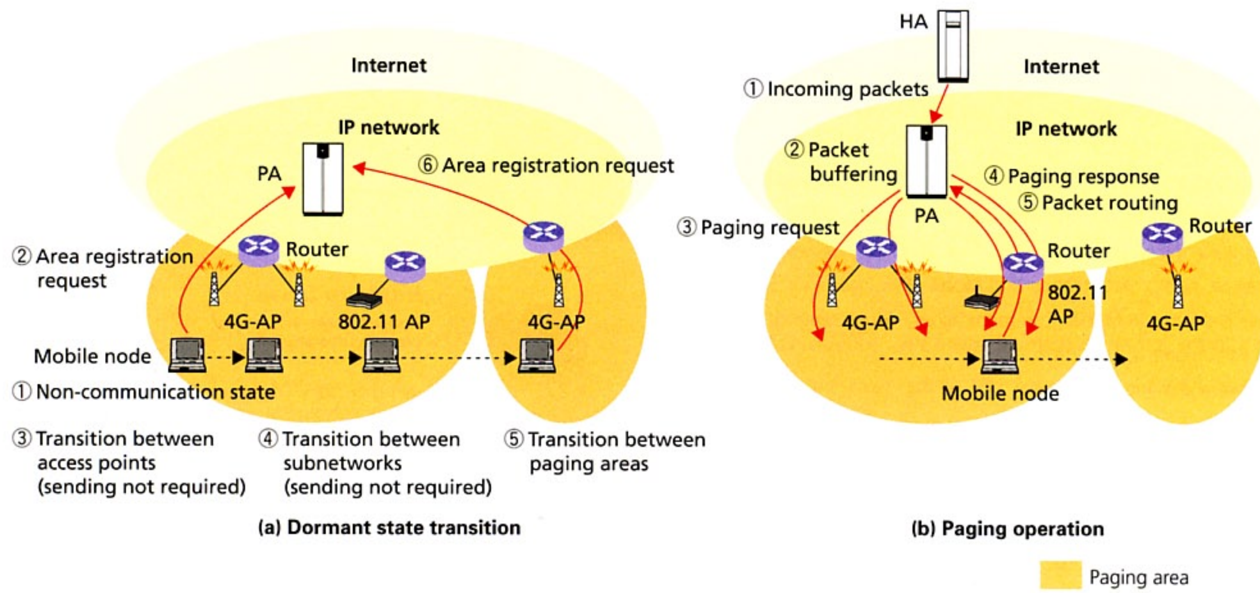

Figure 6 IPPv6 operation

IPPv6 protocol has the following capabilities, and is implemented in mobile nodes and in PAs.

(1) PA Discovery Function

The mobile node has the ability to discover PAs used in dormant states. The mobile node dynamically discovers the nearest PA using the ADP mentioned earlier in Section 4.

(2) Dormant State Detection Function

By monitoring a mobile node's continuous time period in a state of non-communication, IPPv6 can determine transitions to dormant state, and can request that the link layer executes power saving control using the LAPI described earlier in Section 3.2. Power consumption of the mobile node can be further reduced by optimizing the continuous time threshold depending on the communication and mobility characteristics of the mobile node.

(3) Paging Area Formation Function

Figure 6 (a) shows the operation to optimize an paging area in accordance with mobility and communication characteristics of the mobile node, and the location management of the mobile node in terms of paging area units. Since there is no need to form a new paging area as long as the mobile node moves within the same paging area, the volume of control signals is significantly less than in active state mobility management.

(4) Paging Function

Fig. 6 (b) shows the ability to send paging request messages throughout the paging area where a mobile node is located when packets destined to a mobile node are received, and the transition of the mobile node to active state. The volume of the control signals is reduced by multicasting the paging request messages.

(5) Mobile Node Address Packet Buffering Function

The PA provides buffering of packets destined to mobile node to prevent packet loss while the mobile node is notified of incoming packets by the paging function.

6. Conclusions

This article described an IP-based mobility management technology that supports mobility of mobile nodes in 4G systems. Featuring multiple interface management, active state mobility management, and dormant state mobility management, the IP-based mobility management scheme satisfies all key benchmark requirements including high packet communication quality, modest control costs, and seamless mobility. Building on the results reported in this article, we plan to conduct comprehensive evaluations on a testbed that incorporates all constituent technologies, while continuing our proactive involvement in international standardization activities.

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ABBREVIATIONS

ADP: Agent Discovery Protocol
AP: Access Point
CN: Correspondent Node
GUI: Graphical User Interface
HA: Home Agent
HMIP-Bv6: Hierarchical Mobile IPv6 with Buffering at MAP
HMIPv6: Hierarchical Mobile IPv6
IP: Internet Protocol
IPPv6: IPv6 Paging Protocol
IPv6: IP version 6
LAPI: Link layer Application Program Interface
MAP: Mobility Anchor Point
MIM: Multiple Interface Management
MIPv6: Mobile IPv6
MN: Mobile Node
NIC: Network Interface Card
PA: Paging Agent
PDA: Personal Digital Assistant
TCP: Transmission Control Protocol
UDP: User Datagram Protocol
VoIP: Voice over IP