IP-based Mobility Management Technology

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Abstract

This article reviews recent progress in the study of IP-based mobility management technology for enhancing the mobility of cellular phones and other mobile nodes in fourth-generation mobile communications systems. The architecture and components of this management technology are described and some experimental and simulation results are presented.

1. Introduction

NTT DoCoMo is developing IP-based mobility management technology, which is basic technology needed for the deployment of fourth generation mobile communications systems (4G 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 (such as cellular phones, personal digital assistants (PDAs), and notebook computers) while they are moving around in the 4G system and to give packets end-to-end reachability to and from mobile nodes. In short, this technology enables true mobility by permitting mobile nodes to move about freely anywhere in the 4G system and initiate and perform communications.

This article presents an overview of the architecture of IP-based mobility management and describes its key components: multiple interface management, active state mobility management, and dormant state mobility management.

2. IP-based mobility management architecture

This section outlines the key requirements for mobility management in the 4G system and presents a management architecture that satisfies them.

2.1 Requirements

There are three main requirements for mobility management.

(1) High packet transmission quality

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 cost

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

(3) Seamless mobility

The management scheme must implement seamless mobility that supports mobile nodes connected to not only 4G cellular wireless links but also 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 from the link layer to the application layer. However, if mobility management is implemented at the link layer, the applicability would

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* Handoff: The act of transferring a wireless signal from one cell site to another. Equivalent to handover.

be limited to the same type link, and this would contravene Requirement (3). Moreover, if mobility management is implemented at the transport layer or the application layer, it would have to be implemented separately for each different transport and application layer protocol, which would increase the amount of signaling traffic and thus fail to satisfy Requirement (2). In contrast, if we implement mobility management at the IP layer, which is common to all link layer, transport layer, and application layer protocols, then Requirements (2) and (3) can both be satisfied. This approach can handle the wireless link disconnections associated with handoffs and delays in packet route setup processing that are the primary factors in the degradation of packet communication quality, so Requirement (1) is also satisfied. Consequently, this approach satisfies all three of the basic requirements. **Figure 1** shows a schematic representation of our IP-based mobility management scheme and protocol stack, assuming the use of IPv6 (Internet protocol version 6), which has an enormous address space that can support an extremely large number of mobile nodes. Three of the key terms related to mobile nodes shown in Fig. 1 are explained below.

Multiple interface management (MIM) provides the link layer that best matches user preferences to the layers above from among the several link layers available for the mobile node while minimizing the power

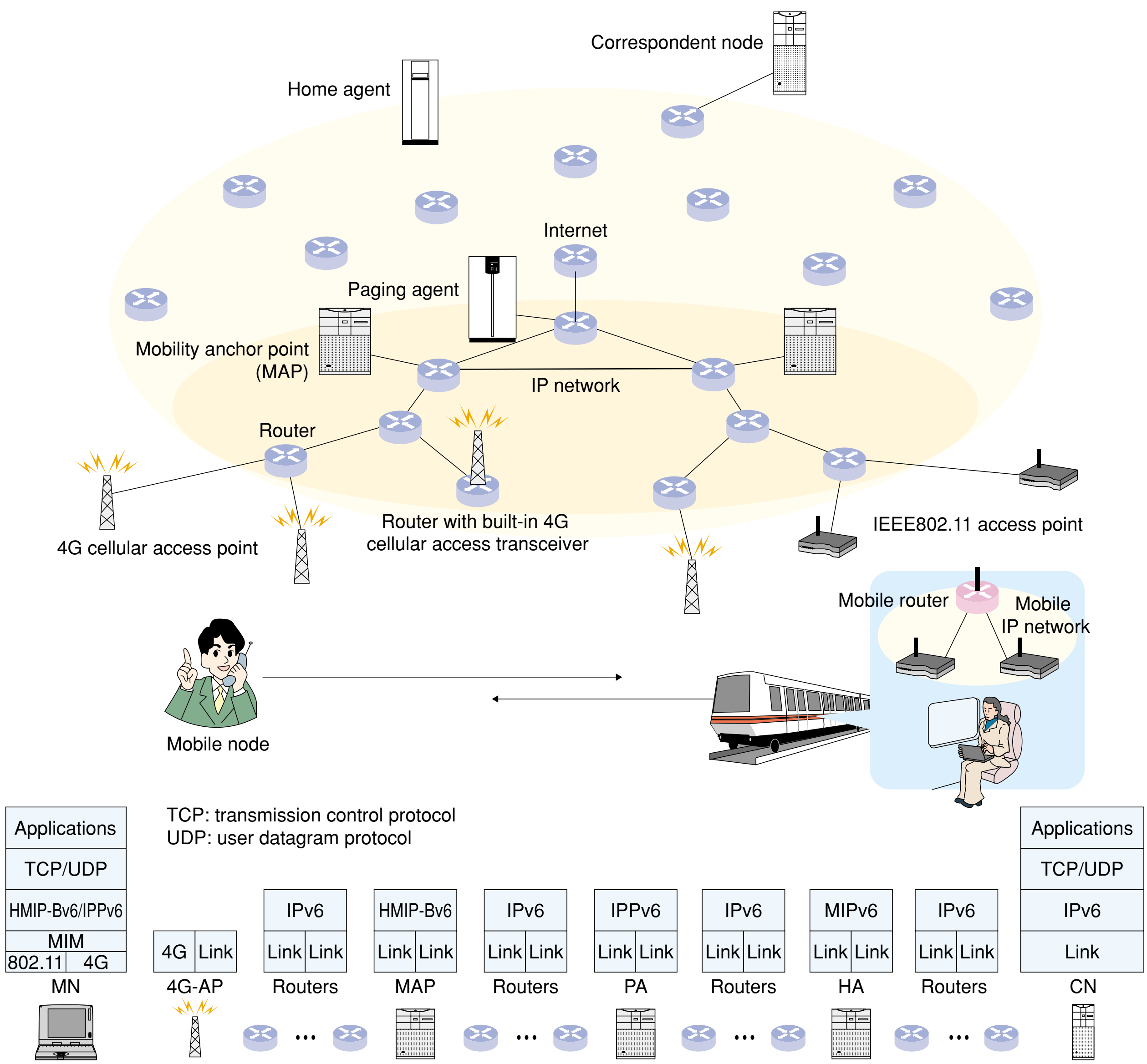

Fig. 1. IP-based mobility management architecture and protocol stack.

consumption of the mobile node's other link layers that are not used.

HMIP-Bv6 (hierarchical mobile IPv6 with buffering at MAP) is a mobility management scheme that uses a mobility anchor point (MAP) with buffering capability for handoffs. It 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.

IPPv6 (IPv6 paging protocol) is a mobility management protocol that uses a paging agent (PA) to manage the location of mobile nodes in the dormant communication state in local areas and to notify the mobile node of the arrival of incoming packets, thus enabling it to have less frequent packet route setup processing.

3. Multiple interface management

This section defines the requirements for interface management with multiple kinds of link layers and then presents an overview of NTT DoCoMo's proposed MIM.

3.1 Requirements

There are two main requirements for MIM.

(1) NIC selection based on user preferences

A network interface card (NIC) is the communication interface hardware that implements the link layer protocol. NICs are rapidly coming down in price and levels of chip integration are increasing, so it is only a matter of time before a mobile node can support multiple NICs. When that happens, MIM will need to be able to determine what NICs are available on a mobile node and select the one that best matches the user's preferences.

(2) Lower battery consumption

To conserve the mobile node's battery power, MIM must efficiently manage the power consumption of the NICs.

3.2 MIM configuration

Figure 2 shows an MIM configuration that satisfies the above requirements [1]. It is built into the mobile node.

(1) User preference information

User preference information is input via an MIM

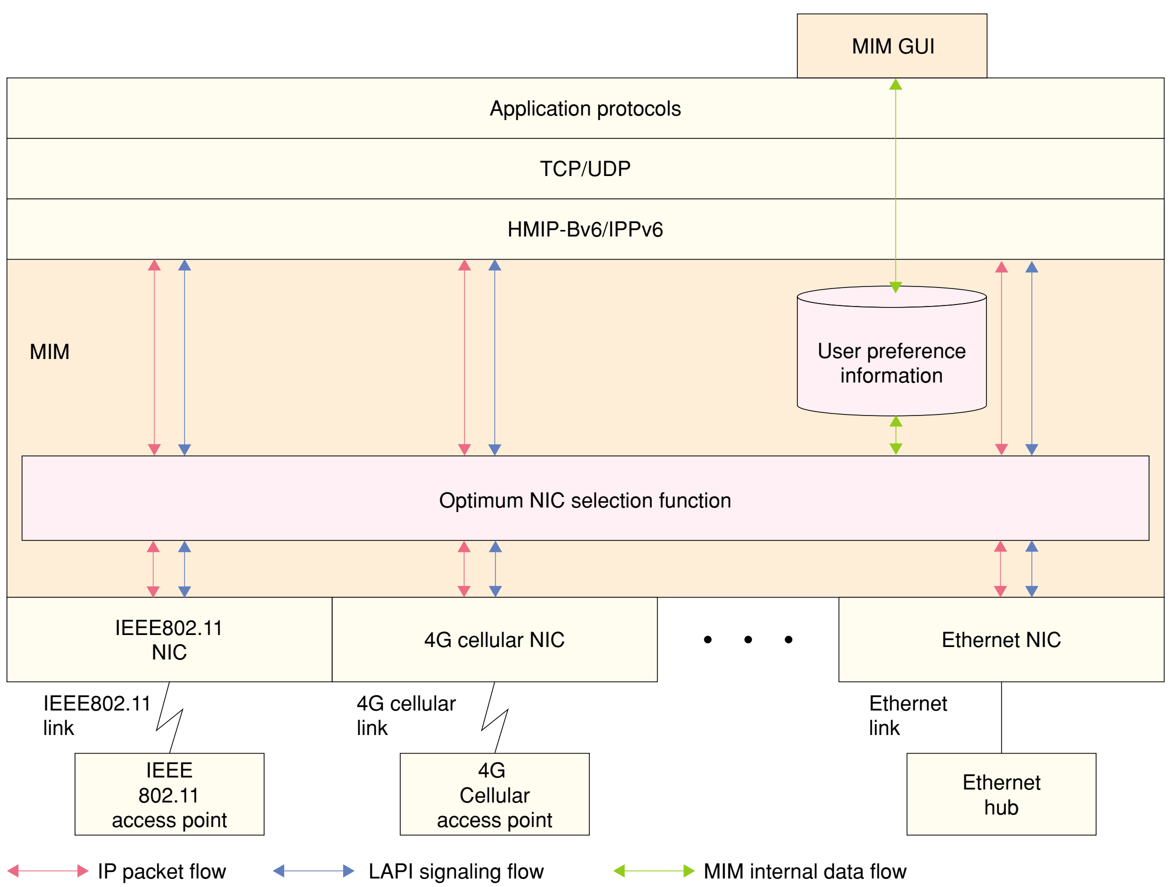

Fig. 2. MIM configuration.

graphical user interface and stored in a database. Typical information will include the user's preferences for bit rate, transmission quality, and transmission cost.

(2) Optimal NIC selection function

The MIM periodically checks to make sure that the NIC being used best matches the user preferences and, if necessary, changes NICs. The MIM also helps conserve battery power by turning off the power to all NICs that are currently not selected. This optimal NIC selection function utilizes the link layer application programming interface (LAPI) [2] to control the link layer and exchange status information between the link layer and the higher layer. For example, if the user prefers a high bit rate, this function selects the NIC that provides the highest bit rate.

4. Active state mobility management

This section defines the requirements for active state mobility management, outlines NTT DoCoMo's proposed HMIP-Bv6 scheme, and presents some recent evaluation results for this scheme.

4.1 Requirements

There are three main requirements for active state mobility management.

(1) Mobile node and mobile network mobility

Support of standalone mobile nodes is essential, but the mobility of mobile networks such as groups of mobile nodes traveling in a train or 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 packet communication quality

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 the conventional mobile IPv6 (MIPv6) [3] and hierarchical mobile IPv6 (HMIPv6) [4] schemes, mobility is achieved by a home agent (HA) and a MAP, which forwards packets destined for mobile nodes, but these schemes do not satisfy the above requirements due to bursty packet losses that occur during handoffs. This led us to propose a new approach called hierarchical mobile IPv6 with buffering at MAP (HMIP-Bv6), which adds a number of new capabilities to the HMIPv6 scheme [5], [6]. The four described below are achieved through extensions made only to the mobile node, MAP, and HA.

(1) Agent discovery function

This function enables a mobile node to dynamically discover a MAP. This enables the mobile node to select the optimal MAP when there are multiple MAPs on the IP network by comparing the relative distances to MAPs, packet processing loads, and other criteria. We define this capability in an agent discovery protocol [7] and can also use it to discover PAs, as mentioned in section 4. Another advantage of this approach is that no data about 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.

(2) MAP buffering function

Packets destined for a mobile node are buffered in the MAP to prevent packet loss during handoffs. This is illustrated for the HMIP-Bv6 scheme in **Fig. 3**.

(3) Subnet prefix management function

This function manages all the subnet prefixes in HAs and MAPs used by the mobile network [8] and supports mobility for all nodes on the mobile network.

(4) Care-of address fast configuration function

This function speeds up the configuration process-

Table 1. Voice communication quality requirements and measured results.

Evaluation criteria	Requirement [12]	MIPv6		HMIPv6		HMIP-Bv6	
		Simulation	Experiment	Simulation	Experiment	Simulation	Experiment
No. of packets lost 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	28.60
Average end-to-end packet transmission delay (ms)	400	111.87	108.94	111.87	108.94	111.88	109.54

Failed to meet requirements

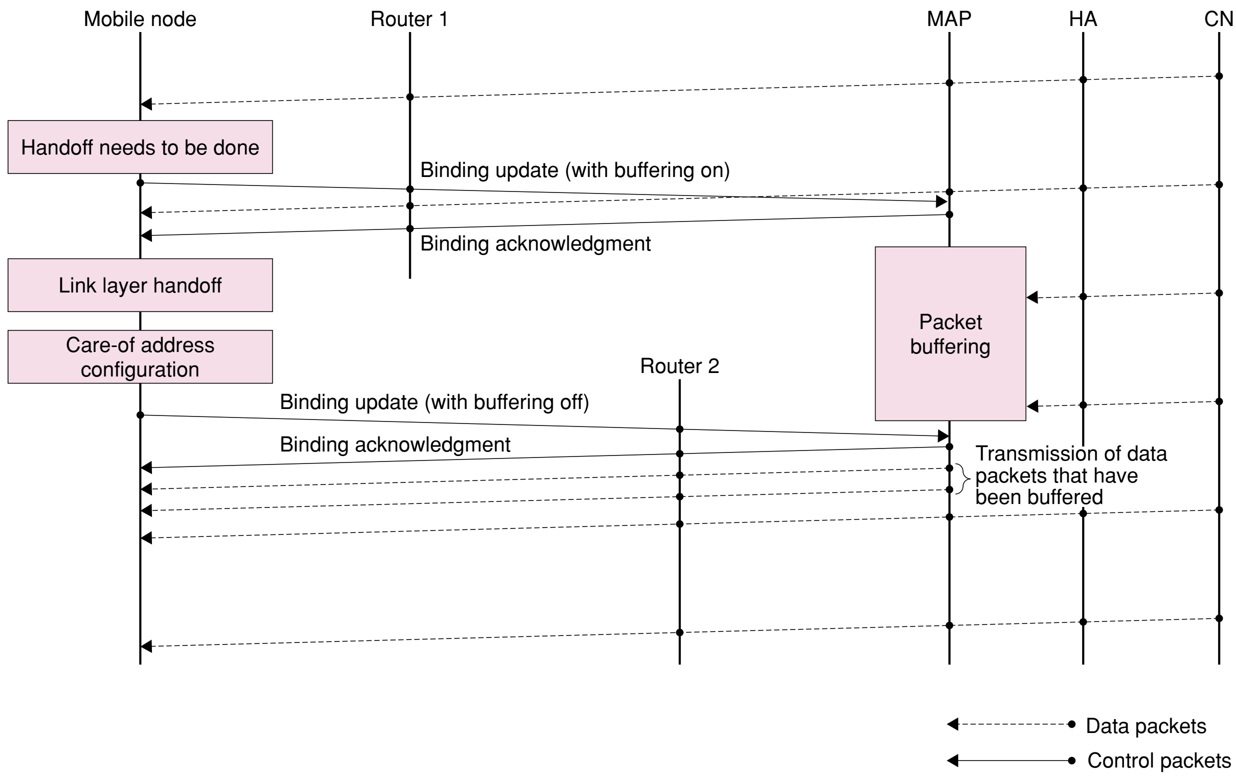

Fig. 3. HMIP-Bv6 scheme.

ing during handoffs for care-of addresses (packet forwarding addresses of mobile nodes), thereby reducing the packet transmission delay after handoffs.

4.3 Evaluation of HMIP-Bv6 scheme

The packet transmission quality of three schemes (MIPv6, HMIPv6, and HMIP-Bv6) was evaluated through simulations and experimental trials. This section presents our findings.

4.3.1 Evaluation method

1) Evaluation criteria

Using the network model shown in **Fig. 4**, we evaluated the quality of voice and data communications at the mobile node when the voice and data were sent from the correspondent node to the mobile node. For VoIP (voice over IP) speech communications, the criteria were the number of packets lost per handoff, packet loss rate, end-to-end packet transmission delay deviation, and average end-to-end packet transmission delay. For data communications, the criterion was the time required to transfer a file.

2) Network model

The network model consists of a correspondent node, an HA, and an IP network interconnected by the Internet. A MAP and several routers are deployed on the IP network and a mobile node performs handoffs between routers. Packet transmission delays through the Internet and the IP network were 50 ms [9] and 10 ms [10], respectively.

3) Traffic models

We used two traffic models. For voice traffic, the packet rate was 50 packets per second and the packet size was 80 bytes [11]. For data traffic, a 5-Mbyte file was downloaded by FTP (file transfer protocol).

4.3.2 Measured results

The measured voice communication quality and the requirements are shown in Table 1. The HMIP-Bv6 scheme was able to satisfy the requirements for the number of packets lost per handoff and packet loss rate as a result of the effectiveness of the MAP packet buffering, but the other two schemes failed to meet these requirements. All of the schemes met the requirement for end-to-end packet transmission delay deviation and average end-to-end packet transmission delay.

Figure 5 shows the measured data communication quality. Download times were measured for all three schemes for mobile node handoff intervals of 8, 16, and 32 s and without handoff. The experimental measurements and simulation results showed similar tendencies. The downloads took longer as the interval between handoffs decreased for the MIPv6 and

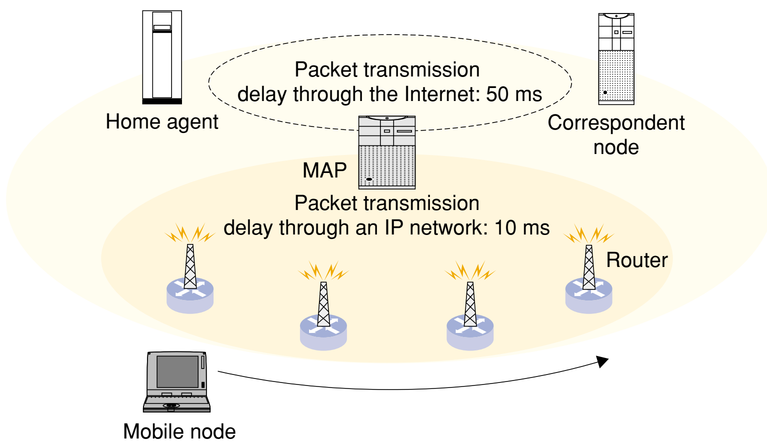

Fig. 4. Network model.

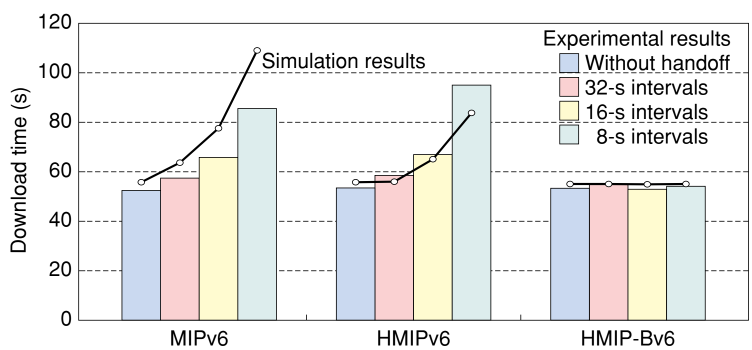

Fig. 5. Data communication quality.

HMIPv6 schemes, but stayed more or less constant for the HMIP-Bv6 scheme. The main factor degrading download speed is the loss of the TCP (transmission control protocol) data segment. Since this does not occur in the HMIP-Bv6 scheme, the download time was unaffected by handoff.

5. Dormant state mobility management

This section defines the requirements for dormant state mobility management and overviews and evaluates NTT DoCoMo's proposed IPPv6.

5.1 Requirements

There are two main requirements for dormant state mobility management.

(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 packets to send or receive (i.e., dormant state) than when the mobile node does have packets to send or receive (i.e., active state).

(2) Seamless resumption of communication

The packet communication quality must be equivalent to the quality requirements of the active state mobility management so that the dormant state mobility management can resume communications with high packet communication quality whenever the mobile node transits from the dormant state to the active state.

5.2 IPPv6 configuration

IPPv6 has been proposed as a dormant state mobility management scheme that satisfies the above requirements [13]. This protocol has five functions, which are implemented in mobile nodes and PAs.

1) PA discovery function

The mobile node can discover PAs. It dynamically discovers the nearest PA using the agent discovery protocol.

2) Dormant state detection function

Figure 6(a) shows the transition of the mobile node to the dormant state. By monitoring how long a mobile node is in a continuous state of non-communication, IPPv6 can determine transitions to the dormant state and send an area registration request to the PA.

3) Paging area formation function

Figure 6(a) also shows the mobile node's location management 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 with active state mobility management.

4) Paging function

Figure 6(b) shows how paging request messages are sent throughout the paging area of a mobile node when packets destined for the mobile node are received. It also shows the transition of the mobile node to the active state when the mobile node receives the paging request.

5) Mobile node address packet buffering function

The PA buffers packets destined for a mobile node to prevent packet loss while the mobile node is being notified of incoming packets by the paging function.

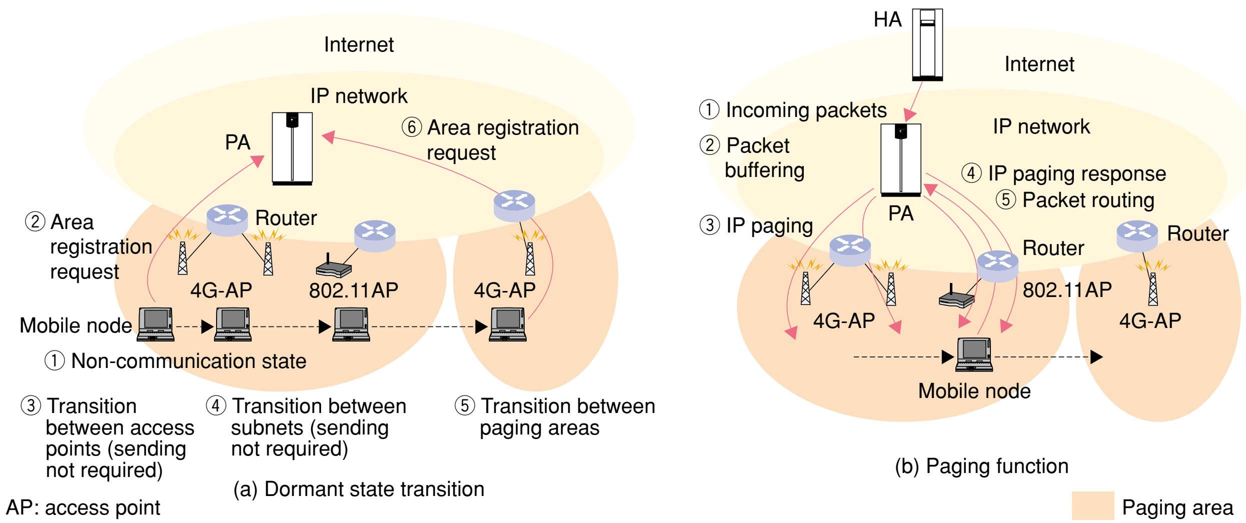

Fig. 6. IPPv6 operation.

5.3 Evaluation of the IPPv6 scheme

The effectiveness of IPPv6 at reducing the number of control packets was evaluated through simulation. **Figure 7** shows the number of control packets versus the mobile node handoff interval for four different numbers of subnets per paging area. The number of control packets was normalized by the number of control packets in active state mobility management. The traffic session of mobile nodes had an average interval of 1800 s. The shorter the handoff interval of mobile nodes was (i.e., the more frequently the mobile nodes moved), the more effective IPPv6 was at reducing the number of control packets. This was true for all numbers of subnets. When the paging area consisted of seven subnets and the average handoff interval was 20 s, IPPv6 halved the number of control packets. Thus, IPPv6 greatly reduced the number of control packets.

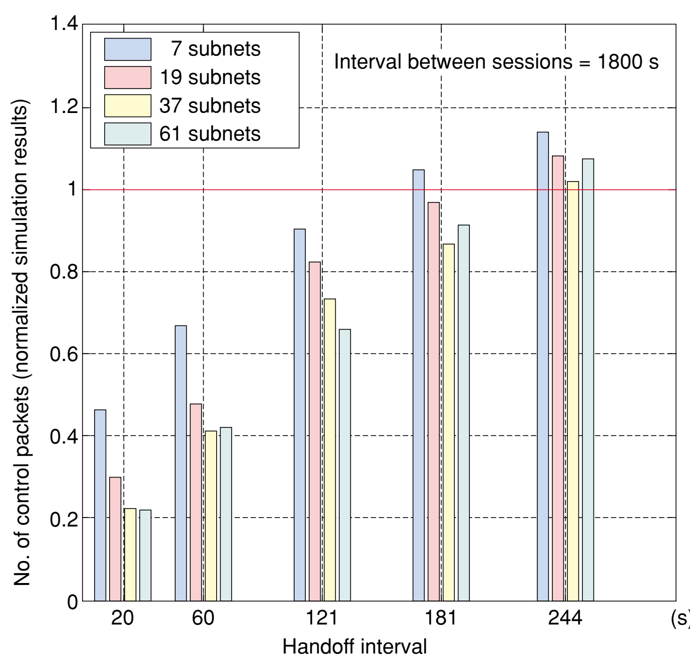

Fig. 7. Reduction in number of control packets achieved by IPPv6 (simulation results).

6. Conclusion

This article described IP-based mobility management technology that enhances the mobility of mobile nodes in 4G systems. Featuring multiple interface management, active state mobility management, and dormant state mobility management, it satisfies all the key requirements, including high packet communication quality, modest control costs, and seamless mobility.

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