A 6LoWPAN Sensor Node Mobility Scheme Based on Proxy Mobile IPv6

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Abstract—In this paper, we focus on a scheme that supports mobility for IPv6 over Low power Wireless Personal Area Network (6LoWPAN) sensor nodes. We define a protocol for 6LoWPAN mobile sensor node, named 6LoMSN, based on Proxy Mobile IPv6 (PMIPv6). The conventional PMIPv6 standard supports only single-hop networks and cannot be applied to multihop-based 6LoWPAN. It does not support the mobility of 6LoMSNs and 6LoWPAN gateways, named 6LoGW, cannot detect the PAN attachment of the 6LoMSN. Therefore, we define the movement notification of a 6LoMSN in order to support its mobility in multihop-based 6LoWPAN environments. The attachment of 6LoMSNs reduces signaling costs over the wireless link by using router solicitation (RS) and router advertisement (RA) messages. Performance results show that our proposed scheme can minimize the total signaling costs and handoff latency. Additionally, we present the design and implementation of the 6LoMSN mobility based on PMIPv6 for a healthcare system. According to the experimental results, the 6LoMSN of the proposed PMIPv6-based 6LoWPAN can be expected to use more of the battery lifetime. We also verify that the 6LoMSN can maintain connectivity, even though it has the freedom of being able to move between PANs without a mobility protocol stack.

Index Terms—6LoWPAN, proxy mobile IPv6, sensor node mobility

1 Introduction

IPv6 over Low power Wireless Personal Area Network (6LoWPAN) [1], [2] is a simple low-cost communication protocol that allows wireless connectivity in applications with limited power. 6LoWPAN adopts the IPv6 protocol stack for seamless connectivity between IEEE 802.15.4 [3]-based networks and the IPv6-based infrastructure. Moreover, the 6LoWPAN is suitable for smaller devices with lower energy consumption.

In this paper, we focus on a scheme that supports mobility for each 6LoWPAN mobile sensor node, named 6LoMSN. In order to provide mobility for these sensor nodes, an efficient mobility supporting protocol is needed to maintain connectivity while on the move. Such protocols can be classified as host-based mobility and network-based mobility protocols.

In the case of the host-based mobility approach, as shown in Fig. 1a, when a 6LoMSN moves to another PAN, it requires an exchange of signaling messages with its home agent (HA) in order to maintain the session. Hence, the host-based mobility approach is unsuitable for energy-constrained sensor nodes because all of the 6LoMSNs should have a mobility stack such as Mobile IPv6 (MIPv6), which is specified in RFC 3775 [4].

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On the other hand, in the case of the network-based mobility approach, as shown in Fig. 1b, it is possible to support mobility for 6LoMSNs without any additional mobility function. If network-based mobility is applied in 6LoWPAN, the 6LoMSN itself does not require any mobility related to the signal messages, rather, a special mobility agent in the network is responsible for detecting the movements of the 6LoMSN, exchanging mobility-related signaling messages and managing the mobility on behalf of the 6LoMSN. Therefore, the network-based mobility approach is the optimal solution for supporting mobility for 6LoMSNs. The network-based mobility management protocol is specified in RFC 5213 [5] as Proxy Mobile IPv6 (PMIPv6). The mobility of 6LoMSNs can be supported by an interoperable architecture between 6LoWPAN and PMIPv6.

However, the conventional PMIPv6 protocol only supports single-hop-based networks. It cannot be applied to multihop-based 6LoWPAN networks because a 6LoWPAN gateway, namely 6LoGW, cannot directly detect the PAN attachment of the 6LoMSN. To solve this problem, we propose a protocol architecture for the 6LoMSN mobility based on PMIPv6. In this paper, in order to apply the single-hop-based PMIPv6 protocol to multihop-based 6LoWPAN networks, we define a PAN attachment detection scheme for the 6LoMSNs, using router solicitation (RS) and router advertisement (RA) messages, which is a modified lightweight neighbor discovery protocol. Furthermore, we present the design and implementation of our scheme as it applies to a healthcare system.

Our paper is organized as follows: In Section 2, we briefly introduce related works on host-based mobility and network-based mobility schemes. In Section 3, we describe our scheme for PAN attachment notification in detail. Section 4 presents the performance evaluation in terms of

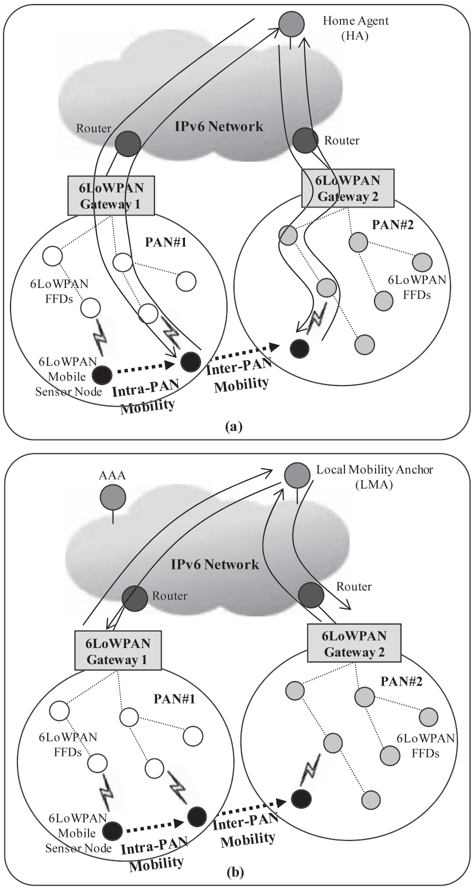


Fig. 1. (a) Mobile IPv6-based 6LoWPAN, (b) Proxy Mobile IPv6-based 6LoWPAN.

signaling costs and handoff latency. In Section 5, we present the implementation overview and the experimental results on the power consumption of 6LoMSN mobility, based on PMIPv6. In Section 6, we provide the conclusions of our research.

2 Related Works

Mobility in 6LoWPAN is one of the most important technologies in wireless sensor networks for practical applications, such as healthcare, vehicle communication systems, and logistics applications, where sensor nodes sense and transmit the data to a monitoring server. In this section, we introduce related works on IPv6 mobility management schemes in 6LoWPAN including host-based mobility and network-based mobility schemes.

2.1 Host-Based Mobility in 6LoWPAN

MIPv6 [4] is the Internet Engineering Task Force (IETF) standard communications protocol that is designed to allow mobile users to move from one network to another, while maintaining a permanent IP address. MIPv6 supports host mobility using two IP addresses: a home of address (HoA) that represents the permanent address of the mobile node (MN) and a care of address (CoA), which is a unicast routable address associated with the network that the MN is visiting. When the MN moves from a home network to a foreign network, it can make the CoA using visited network prefix which is advertised by an RA message from access router (AR). The MN sends notice of the CoA to the HA using a binding update (BU) message. The HA then sends a binding acknowledgement (BA) message to the MN. At the same time, the HA updates the binding cache entry for mapping between the HoA and CoA. This means that the CoA indicates the current location of the MN. Therefore, when a corresponding node (CN) sends packets to the MN, it sends the packet to the MN HoA. The HA intercepts all packets and then forwards the packets to the current location of the MN.

In [6], an MIPv6-based 6LoWPAN scheme is presented to provide mobility support in 6LoWPAN. Since the current version of the 6LoWPAN packet format only considers UDP, TCP, and ICMP headers as an IPv6 next header of the 6LoWPAN packet, the MIPv6-based 6LoWPAN scheme identifies a compressed mobility header that follows the same rules used to adapt the 6LoWPAN packet format, which is presented in RFC 4944 [2]. Additionally, compression and encoding schemes of mobility messages and respective options, which are defined in MIPv6, are proposed for applying MIPv6 in 6LoWPAN.

However, the MIPv6-based 6LoWPAN scheme requires the mobility protocol stack on the 6LoMSN, as well as signaling message exchanges over the wireless link whenever the 6LoMSN moves to another PAN area. Signaling costs over the wireless link that are too high can have a very negative impact on energy consumption, which is the most important factor of mobility in 6LoWPAN. Additionally, whenever the 6LoMSN performs a handoff, the MIPv6-based 6LoWPAN scheme needs a duplicate address detection (DAD) [7] procedure in order to configure the CoA. This causes large handoff latency since the DAD procedure takes at least 1 second for address autoconfiguration.

In order to reduce the mobility-related signaling messages, the HMIPv6 [8] protocol can be considered for providing mobility support in 6LoWPAN. In HMIPv6-based 6LoWPAN, a new mobility entity called the mobility anchor point (MAP), which acts as a local HA, is added to improve the performance of MIPv6-based 6LoWPAN in terms of total handoff latency and signaling costs. The MAP domain contains several PANs, which include one 6LoGW, acting as a default gateway in the PAN. The 6LoMSN configures two CoAs, namely a regional care of address (RCoA), and an on-link care of address (LCoA). The RCoA represents an address on the MAP subnet, and is created based on receiving an RA message with MAP options from the 6LoGW, while the LCoA is used within an intra-MAP domain, and is configured by the prefix advertisement option the RA message. The binding procedure of the HMIPv6-based 6LoWPAN performs a local binding update (LBU) for intra-MAP domain mobility, and a BU, same as the MIPv6, for inter-MAP domain mobility. In the case of the inter-MAP domain mobility, when the 6LoMSN hands-off to the new MAP domain, it is required to send the BU message with the RCoA to the HA, as well as the LBU message with the LCoA to the MAP. On the other hand, in the case of the intra-MAP domain mobility, when the 6LoMSN moves to another PAN area, it only sends the LBU message with the LCoA to the MAP in order to update the location within the MAP domain [9].

Even though HMIPv6-based 6LoWPAN is an enhanced version of MIPv6-based 6LoWPAN, it reduces only the total handoff latency and signaling costs for the intra-MAP domain mobility. Considering the inter-MAP domain mobility, the number of signaling messages is increased rather than reduced, since the 6LoMSN should perform binding procedures, including both LBU and BU. Like the MIPv6-based 6LoWPAN, the HMIPv6-based 6LoWPAN has not reduced the signaling costs over the wireless link for either the intra-MAP or inter-MAP domain mobility, and it still requires the DAD procedure whenever the 6LoMSN performs a handoff.

In other words, the host-based mobility support scheme requires additional stacks and signaling resulting in additional overhead for battery power and computation resource consumption. Therefore, the MIPv6-based 6LoWPAN and HMIPv6-based 6LoWPAN schemes are not suitable for mobility in 6LoWPAN.

2.2 Network-Based Mobility in 6LoWPAN

In the network-based mobility support scheme, the MN is unnecessary for installing additional mobility protocol stacks or signaling exchange. The IETF NETLMM working group [10] has standardized the PMIPv6 protocol for the network-based mobility support scheme. PMIPv6 proposed special mobility agents in the network, which include a local mobility anchor (LMA) and a mobile access gateway (MAG), for performing the mobility-related signaling, and handling the mobility management on behalf of the MN. The LMA performs HA operations for maintaining the MN binding information, which is defined by MIPv6 [4], and is the topological anchor point for the MN home network prefix (HNP). The MAG performs mobility-related signaling to the LMA on behalf of the MN, and detects the MN movements.

The operation of the PMIPv6 protocol is as follows: The MAG obtains the MN profile, which includes its identifier, when the MN attaches to the MAG. The MAG then sends a proxy binding update (PBU) message to the LMA in order to update or register the current point of attachment of the MN. If the LMA receives the PBU message, it updates or creates a binding cache entry and a bidirectional tunnel between the LMA and the MAG for the MN HNP. The LMA then sends a proxy binding acknowledgement (PBA) message with the MN HNP to the MAG. The MAG emulates the home interface of the MN on the access interface by sending an RA message with the MN HNP to the MN. Therefore, the MN always believes that it is located in the home network.

The network-based mobility management approach, PMIPv6, is more suitable than the host-based approach for supporting mobility for 6LoWPAN since there are no mobility-related signaling message over the wireless link and DAD procedure [11]. Accordingly, the performance of the network-based mobility scheme in terms of energy consumption, signaling costs, and handoff latency can be certainly reduced compared to the host-based mobility scheme. However, the single-hop-based PMIPv6 protocol of the network-based mobility scheme cannot be applied to the multihop-based 6LoWPAN. In the conventional PMIPv6, if the 6LoMSN enters the multihop-based PAN area, the 6LoMSN has no way to inform the 6LoGW of PAN attachment since there is no mobility-related signaling message.

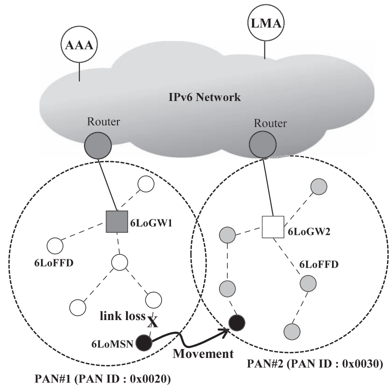


Fig. 2. Network topology of 6LoWPAN.

In [12], the Bag et al. proposed a network-based intra-PAN mobility scheme for 6LoWPAN, LoWMob, in order to ensure multihop communications between a gateway (GW) and the MN via static nodes (SNs) within the intra-PAN area. LoWMob proposed a new mobility support packet format at the adaptation layer of 6LoWPAN, such as join_request, association_request, new_node, and location update packets. They also presented a distributed version of LoWMob, DLoWMob, which employs mobility support points (MSPs) to reduce the signaling traffic at the GWs, so that the SNs and MSPs are responsible for handling the mobility of the MN within the PAN area. DLoWMob uses join_request, association_request, and new_node messages as an IPv6 neighbor discovery, which includes RS and RA messages, for PAN attachment of the MN. However, this solution only supports the intra-PAN mobility scenario. Additionally, even though the MN is not involved in mobility-related signaling messages, the extra signaling message such as the location update packet, which is handled by both SNs and MSPs, is required over the wireless link while the MN performs the intra-PAN mobility.

We aim to minimize mobility-related signaling messages over the wireless link, which can reduce the power consumption of the 6LoMSN and total signaling costs, in order to support efficient mobility in multihop-based 6LoWPAN.

3 Proposed Scheme

In this section, we present a proposed PAN attachment notification scheme for the 6LoMSNs to support mobility in the multihop communication-based 6LoWPAN environment. We explain our scheme with an example of the 6LoMSN mobility scenario, based on the network topology and address configurations as shown in Fig. 2 and Table 1, respectively.

An IPv6 network includes an LMA, two 6LoGWs, and an Authentication-Authorization-Accounting (AAA) server. The AAA server manages the 6LoMSN profile, such as its HoA and HNP. The LMA and 6LoGWs perform the PMIPv6 functions to support the 6LoMSN mobility.

TABLE 1
Address Configurations

Entity	Interface	Address
6LoWPAN Mobile Sensor Node	Home Network Prefix	*3ffe:1:3::/64*
	16-bit address	*0x0009*
	IPv6 home address	*3ffe:1:3::20:ff:fe00:9/64*
	Link-local address	*fe80::20:ff:fe00:9/64*
6LoWPAN Gateway 1	Ingress interface (PAN)	*3ffe:10:1::20:ff:fe00:1/64*
	Egress interface (Proxy-CoA)	*3ffe:20:1::1/64*
6LoWPAN Gateway 2	Ingress interface (PAN)	*3ffe:30:2::20:ff:fe00:1/64*
	Egress interface (Proxy-CoA)	*3ffe:40:2::2/64*
LMA	-	*3ffe:100::1/64*
AAA	-	*3ffe:200::1/64*

The multihop communication-based 6LoWPAN networks are divided into two PANs, each having one 6LoGW with a unique PAN ID. Each 6LoGW acts as an MAG that functions as an access router; it manages the mobility-related signaling for the 6LoMSN that is attached to its PAN area. The 6LoGW includes two interfaces; an egress interface, which is connected with an IPv6 router and is responsible for performing the proxy binding process on behalf of the 6LoMSN, and an ingress interface, which supports IEEE 802.15.4 and acts as a default gateway to the 6LoMSN. The 6LoWPAN networks consist of 6LoWPAN full function devices, namely 6LoFFDs, which support all IEEE 802.15.4 functions and features, and the 6LoMSN. The 6LoFFDs are fixed nodes in the PAN and, which are capable of multihop packet communications for its associated neighbors, including the 6LoMSN. That is, the 6LoFFDs perform multihop RS and RA messages forwarding to handle the PAN attachment of the 6LoMSN. Furthermore, the 6LoFFDs have the functionality of sending a beacon message periodically in order to provide movement detection for the 6LoMSN.

PAN#1 is the home PAN area of the 6LoMSN, with a PAN ID set to *0x0020*. The 6LoMSN initially starts up at PAN#1, and its HNP is set to *3ffe:1:3::/64*. The 6LoMSN 16-bit address, which is available only within the home PAN, is assigned to *0x0009* by the 6LoGW. A unique IPv6 HoA (128-bit) of the 6LoMSN is obtained by concatenating the 64-bit HNP, 16-bit PAN ID, 32-bit as specified previously (i.e., *00ff:fe00*), and the assigned 16-bit address. The PAN ID and the 16-bit address are used as parts of the HoA. Therefore, the 6LoMSN HoA is autoconfigured with *3ffe:1:3::20:ff:fe00:9/64*. Since all of the link-local prefixes in the 6LoWPAN network are generated from *fe80::/64*, a link-local IPv6 address (128-bit) of the 6LoMSN, which can be used within a PAN area, is autoconfigured with *fe80::20:ff:fe00:9/64*.

3.1 Movement Detection and Association

In this section, we describe how the 6LoMSN can detect its own movement and associate itself with a new PAN after leaving from the coverage area of the previous PAN,

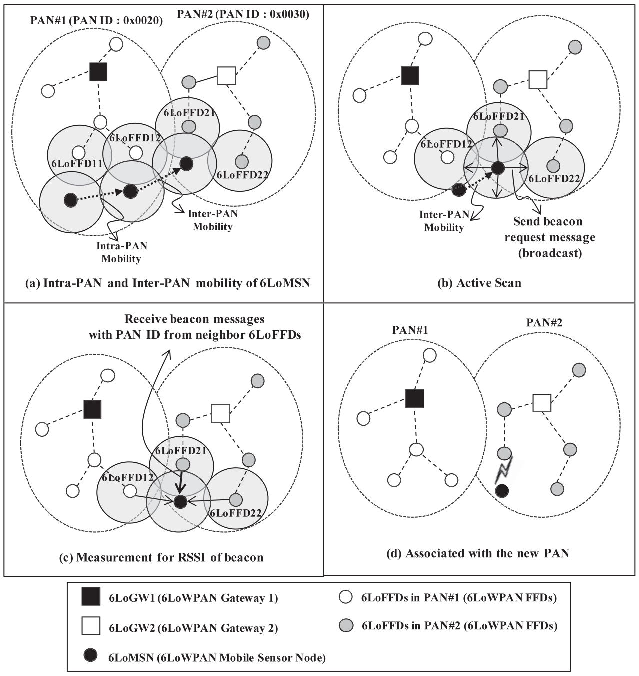


Fig. 3. 6LoMSN mobility scenario that includes intra-PAN and inter-PAN mobility.

especially in the MAC layer. We assume that all 6LoWPAN networks are in beacon-enabled mode [3]. Fig. 3a shows the 6LoMSN mobility scenario that includes intra-PAN and inter-PAN mobilities. The 6LoMSN performs an active scan that searches a list of all of the available channels by periodically sending a beacon request to all nearby 6LoFFDs, as shown in Fig. 3b. All nearby 6LoFFDs that receive the beacon request from the 6LoMSN advertise a beacon message, including their PAN IDs. For this scenario, the 6LoMSN is able to receive beacon messages from 6LoFFD12, 6LoFFD21, and 6LoFFD22, as shown in Fig. 3c.

Upon receipt of the beacon messages, the 6LoMSN decides whether it is still in the same PAN or has moved to another PAN by comparing the current PAN ID with the previous PAN ID contained in the beacon message. If the results of the comparisons of all of the PAN IDs in the received beacon messages are the same, it is obvious that this movement represents intra-PAN mobility, and the 6LoMSN has moved within the same PAN area. In the case of intra-PAN mobility, the 6LoMSN only performs the routing protocol in order to support multihop communication for updating the routing path. Furthermore, it is unnecessary to allocate 16-bit addresses. Subsequently, the detailed routing scheme is the out of scope of this paper. On the other hand, if the 6LoMSN moves to PAN#2, away from PAN#1, it is able to detect its movement since the current PAN ID (*0x0030*) is different from the previous PAN ID (*0x0020*), as contained in the received beacon messages. The 6LoMSN can then be associated with the new PAN, as shown in Fig. 3d.

3.2 Home Registration

In this section, we describe the proposed interoperable operation between 6LoWPAN and PMIPv6 for a multihop-based 6LoWPAN network, especially at the network layer. In

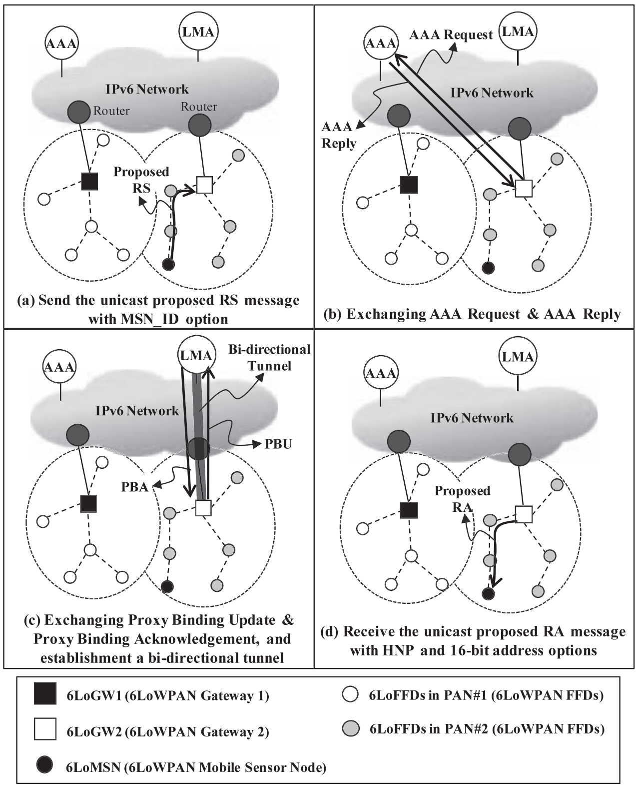


Fig. 4. Overall home registration scenarios for a 6LoMSN moving to a foreign PAN, away from the home PAN area.

the case of inter-PAN mobility, in order to maintain session connectivity and to support the mobility of the 6LoMSN, the home registration procedure should be performed to inform the LMA about the 6LoMSN movement.

Fig. 4 shows an overall home registration scenario for a 6LoMSN moving to a foreign PAN, away from the home PAN area. The exchanges of the AAA Request, AAA Reply, PBU, and PBA messages are the same as they would be in a conventional PMIPv6 operation. In this paper, we redefine the format of RS and RA messages to be applied in an extended PMIPv6 protocol, which supports the multihop-based 6LoWPAN networks. The proposed RS and RA messages can perform the notification of the 6LoMSN PAN attachment. They can also determine the 6LoGW in which the 6LoMSN searches a default gateway after moving into another PAN area.

The following text describes the detailed home registration procedure of a 6LoMSN.

3.2.1 Router Solicitation

If the 6LoMSN is aware of the new PAN attachment, it sends a proposed unicast RS message, in a 6LoWPAN packet format, to the 6LoGW, in order to notify the attachment to PAN#2. The original and the final addresses in the mesh header of the 6LoWPAN RS message have been set to the 6LoMSN 64-bit IEEE 802.15.4 media access control (MAC) address and the 6LoGW2 16-bit address (*0x0001*), respectively. The compressed IPv6 header only includes a 64-bit source interface identifier (IID) (*20:ff:fe00:9*). The following header is an RS header and option that includes the 6LoMSN unique MSN_ID (64-bit identification of 6LoMSN) information.

The RS message is forwarded to the 6LoGW2 according to the final address of the mesh header. If the 6LoGW2 receives the RS message coming from the 6LoMSNs, the 6LoWPAN adaptation stack performs the decompression of the IPv6 packet, including the proposed RS message. The decompression involves the attachment of both the source and the destination 64-bit link-local prefix (*fe80::/64*) of the RS message.

The receipt of the RS message and the transmission of the RA message functions are not provided by the 6LoWPAN stack itself in the 6LoGW. Instead, these messages are managed by the Linux IPv6 stack. Therefore, the 6LoWPAN adaptation stack delivers the uncompressed RS message to the Linux IPv6 stack through the 6LoWPAN tunnel interface.

3.2.2 AAA Request and AAA Reply

Upon receipt of the RS message, the 6LoGW2 extracts the 6LoMSN MSN_ID from the RS option. The MSN_ID is a unique 64-bit identifier which distinguishes it among the 6LoMSNs. Additionally, the 6LoGW2 sends an AAA Request message, including the MSN_ID, to the AAA server in order to obtain the 6LoMSN related information, such as the HNP and its LMA address. The AAA server manages a list of all of the 6LoWPAN sensor nodes' information, which includes the MSN_ID, HNP, and their LMA addresses. If the AAA server receives the AAA Request message, it responds with an AAA Reply message, which includes the 6LoMSN, HNP, and LMA address.

3.2.3 Proxy Binding Update and Proxy Binding Acknowledgement

The 6LoGW2 can transmit a PBU message to the LMA since it obtains the 6LoMSN's LMA address from the AAA Reply message. Upon receipt of the AAA Reply message, the 6LoGW2 requests the PBU message to the LMA, on behalf of the 6LoMSN, in order to establish the binding between the 6LoMSN HNP and its current Proxy-CoA. The source address of the PBU message is set to the Proxy-CoA, which is configured on the egress interface of the 6LoGW2 (*3ffe:40:2::2/64*). The LMA recognizes the Proxy-CoA as the care of address of the 6LoMSN and makes an entry in the binding cache for the 6LoMSN. The LMA also establishes its endpoint of the bidirectional tunnel to the 6LoGW2.

After that, the PBA message, including the 6LoMSN HNP, is sent by the LMA in response to the PBU message, which is received from the 6LoGW2. The 6LoGW2 also establishes its endpoint of the bidirectional tunnel to the LMA and sets up the forwarding for all of the 6LoMSN traffic. When the bidirectional tunnel is successfully established between the 6LoGW2 and the LMA, the 6LoGW2 has then obtained all of the information for emulating the 6LoMSN home PAN.

3.2.4 Router Advertisement

Finally, the 6LoGW2 sends a unicast proposed RA message to the 6LoMSN to advertise its HNP as the hosted on-link prefix, and assigns a 16-bit address which is only available within the PAN area. The Linux IPv6 stack in the 6LoGW2 generates the uncompressed RA message and delivers it to the 6LoWPAN adaptation stack through the 6LoWPAN

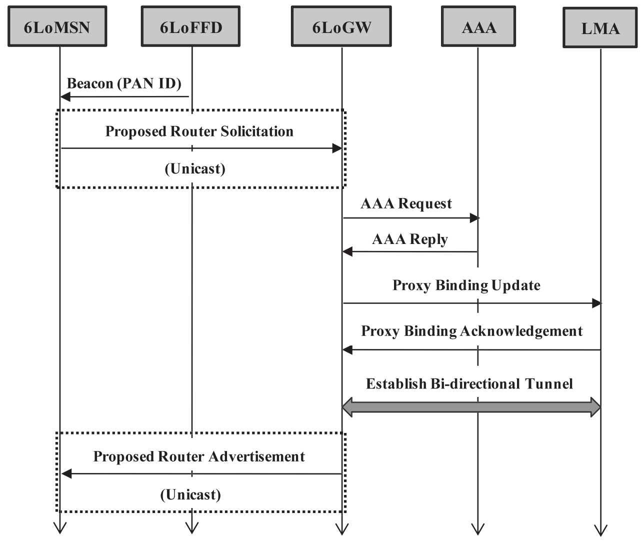


Fig. 5. The entire signaling flow for an extended PMIPv6 operation in order to support 6LoMSN mobility, including redefined RS and RA messages.

tunnel interface. The 6LoWPAN adaptation stack performs the compression of the IPv6 packet, including the proposed RA message, to make a 6LoWPAN packet format.

The compression implies detaching both the source and the destination 64-bit link-local prefix (*fe80::/64*) of the RA message. The original and the final addresses in the mesh header of the 6LoWPAN RA message have been set to the 6LoGW2 16-bit address (*0x0001*) and the 6LoMSN 64-bit MAC address, respectively. The compressed IPv6 header includes both the 64-bit source and the destination interface identifiers that are set to *30:ff:fe00:1* and *20:ff:fe00:9*, respectively. The following header is an RA header and an option that includes the 6LoMSN HNP (*3ffe:1:3::/64*) and its 16-bit address (*0x0005*) which is assigned by the 6LoGW2. The RA message is forwarded to the 6LoMSN according to the final address of the mesh header. When the 6LoMSN receives the RA message from the 6LoGW2, the 6LoMSN deems itself to be in the home PAN area, since the 6LoGW2 advertises the HNP to the 6LoMSN.

Specifically, the 6LoGW2 emulates the 6LoMSN home PAN in the PAN area. Additionally, the 6LoGW2 assigns the 16-bit address to the 6LoMSN, and it manages a list of all 6LoWPAN sensor nodes' 16-bit addresses that are part of the PAN area.

Fig. 5 presents the entire signal flow for an extended PMIPv6 operation in order to support 6LoMSN mobility, including the redefined RS and RA messages.

3.3 Proposed Router Solicitation Message Format

The proposed RS message format discussed in this paper is used for notification of the PAN attachment to the 6LoGW when the 6LoMSN moves to another PAN area. Fig. 6 shows the forwarding scenario of the unicast RS message between the 6LoMSN and 6LoGW, and the RS message format which is sent by the 6LoMSN. When the 6LoMSN is attached to another PAN area, it detects its movement via a beacon message and sends the RS message to the 6LoGW using unicast to avoid broadcast. The following describes

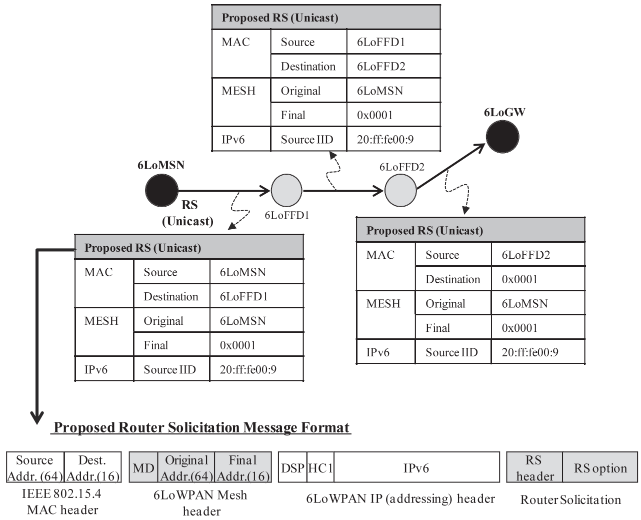


Fig. 6. The forwarding scenario of the unicast RS message.

all of the necessary headers for sending a detailed RS message, as shown in Table 2.

IEEE 802.15.4 MAC header. Source and destination addresses are set to the 6LoMSN 64-bit MAC address and the 6LoFFD1 16-bit MAC address, respectively. The 6LoFFD1 address is recognized by a beacon message.

6LoWPAN mesh header. The RS message should contain the 6LoWPAN mesh header for layer-2 routing. The 6LoWPAN mesh header original address flag and final address flag are set to 16-bit. The original address field of the 6LoWPAN mesh header is set to the 6LoMSN MAC address. We assume that all of the 6LoGW 16-bit addresses are *0x0001*. Subsequently, the final address field of the 6LoWPAN mesh header can be set to *0x0001*, which is the

TABLE 2
Detailed RS Message Format

Header	Field	Data
IEEE 802.15.4 MAC header	Source Address	6LoMSN's 64-bit MAC address
	Destination Address	6LoFFD1's 16-bit MAC address
6LoWPAN Mesh header	MD (Mesh Dispatch)	• Original address flag=64-bit • Final address flag=16-bit • Hop Left
	Original Address	6LoMSN's 64-bit MAC address
	Final Address	*0x0001* (6LoGW's 16-bit address)
6LoWPAN IP (addressing) header	DSP (Dispatch)	Compressed IPv6
	HC1 (IPv6 Header Compression)	• Source prefix: compressed • Source IID: non-compressed • Destination prefix: compressed • Destination IID: compressed • Next header=ICMP
	IPv6 Header	• Source address: 6LoMSN's link-local address (64-bit) • Hop Limit (8-bit)
Router Solicitation	RS Header	Router Solicitation header
	RS Option	MSN_ID (6LoMSN's profile: 64-bit) option

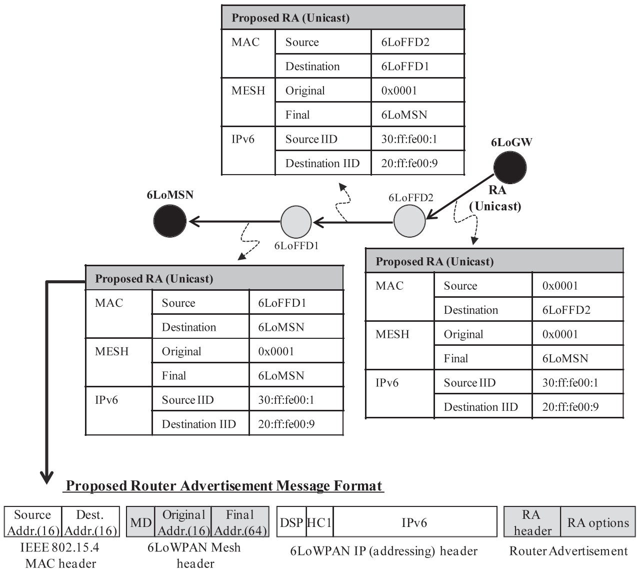


Fig. 7. The forwarding scenario of the unicast RA.

fixed 16-bit address of the 6LoGW; therefore, the unicast RS message can be sent directly to the 6LoGW.

6LoWPAN IP (addressing) header. Dispatch indicates the compressed IPv6 header. In the HC1 header, the source prefix is set to "compressed," the source interface identifier is set to "noncompressed," and the destination prefix and destination interface identifier are set to "compressed." The next header indicates the ICMP to appear in the RS message. The compressed IPv6 header only includes the 6LoMSN source interface identifier. The source and destination prefixes can be compressed since all of the 6LoWPAN sensor nodes' link-local prefixes can be represented by *fe80::/64*.

Router solicitation. The RS message, which is included after the compressed IPv6 header, contains an MSN_ID option that represents the 6LoMSN profile information. The RS message enables the 6LoGW to obtain the 6LoMSN MAC address, link-local address, and MSN_ID. The signaling messages can be reduced within the PAN area since the RS message is being sent in direct unicast, not broadcast.

3.4 Proposed Router Advertisement Message Format

The proposed RA message format in this paper has two options; an HNP and a 16-bit address. The HNP option is used to emulate the 6LoMSN home PAN area. The 16-bit address option needs to assign a unique address, available only within a PAN area, to the 6LoMSN. Fig. 7 shows the forwarding scenario of the unicast RA message between the 6LoGW and the 6LoMSN, and the RA message format which is sent by the 6LoGW. The 6LoGW sends the unicast RA message to the 6LoMSN in response to the RS message. Before sending the RA message, if no routing information to the 6LoMSN is available, the 6LoGW should perform a route discovery to establish the shortest path with the 6LoMSN. The routing path can be established by exchanging RREQ and RREP messages. The following describes all of the necessary headers for sending a detailed RA message, as shown in Table 3.

TABLE 3
Detailed RA Message Format

Header	Field	Data
IEEE 802.15.4 MAC header	Source Address	6LoGW's 16-bit MAC address
	Destination Address	6LoFFD2's 16-bit MAC address
6LoWPAN Mesh header	MD (Mesh Dispatch)	• Original address flag=16-bit • Final address flag=64-bit • Hop Left
	Original Address	6LoGW's 16-bit address
	Final Address	6LoMSN's 64-bit address
6LoWPAN IP (addressing) header	DSP (Dispatch)	Compressed IPv6
	HC1 (IPv6 Header Compression)	• Source prefix: compressed • Source IID: non-compressed • Destination prefix: compressed • Destination IID: non-compressed • Next header=ICMP
	IPv6 Header	• Source address: 6LoGW's link-local address (64-bit) • Destination address: 6LoMSN's link-local address (64-bit) • Hop Limit (8-bit)
Router Advertisement	RA Header	Router Advertisement header
	RA Option	• 6LoMSN's HNP option (8 bytes) • 6LoMSN's 16-bit address option (2 bytes)

IEEE 802.15.4 MAC header. Source and destination addresses are set to the 6LoGW 16-bit MAC address and the 6LoFFD2 16-bit MAC address, respectively.

6LoWPAN mesh header. The RA message should contain the 6LoWPAN mesh header for layer 2 routing, similar to the RS message. The 6LoWPAN mesh header original address flag and final address flag are set to 16-bit and 64-bit, respectively. The original address field of the 6LoWPAN mesh header is set to the 6LoGW 16-bit MAC address. The final address field of the 6LoWPAN mesh header can be set to the 6LoMSN 64-bit MAC address since the 6LoGW has already received the 6LoMSN address when it received the RS message. Therefore, the RA message is directly forwarded to the 6LoMSN as a unicast packet.

6LoWPAN IP (addressing) header. Dispatch indicates the compressed IPv6 header. In the HC1 header, the source and destination prefixes can be set to "compressed," since all 6LoWPAN sensor nodes' link-local prefixes can be represented by *fe80::/64*. Since the source interface identifier and the destination interface identifier are set to "non-compressed," the source and the destination addresses include a link-local address in the compressed IPv6 header. The next header indicates that the ICMP will appear in the RA message. The compressed IPv6 header includes the source and destination interface identifier set to the 6LoGW link-local address and the 6LoMSN link-local address, respectively. The source and destination prefixes are not included in the compressed IPv6 header.

Router advertisement. The RA message, which is included after the compressed IPv6 header, contains the

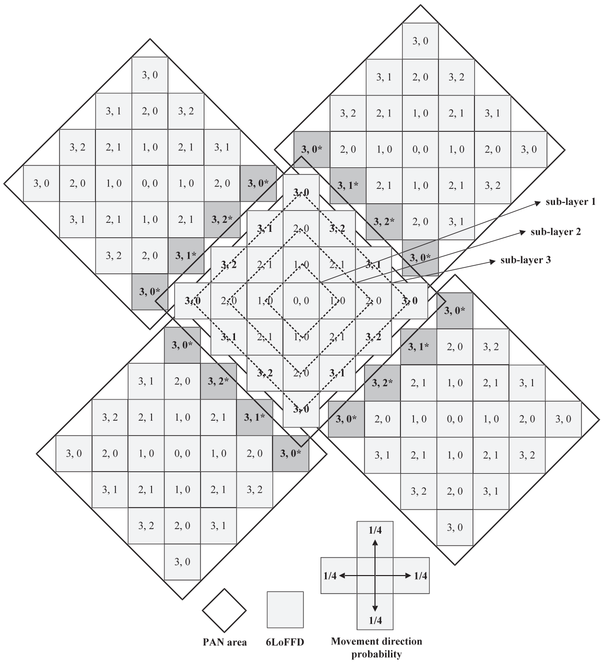
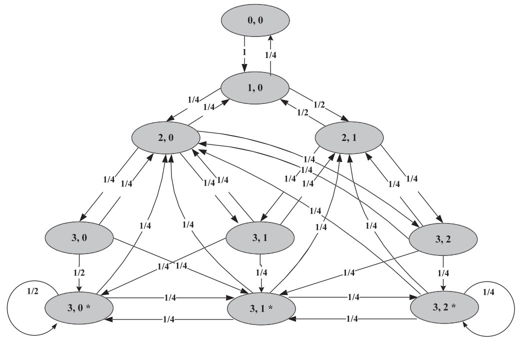


Fig. 8. Example of n-layer PAN model, where $n = 4$.



$P = [P_{ij}] =$

	3.0*	3.1*	3.2*	3.0	3.1	3.2	2.0	2.1	1.0	0.0
3.0*	1/2	1/4	0	0	0	0	1/4	0	0	0
3.1*	1/4	0	1/4	0	0	0	1/4	1/4	0	0
3.2*	0	1/4	1/4	0	0	0	1/4	1/4	0	0
3.0	1/2	1/4	0	0	0	0	1/4	0	0	0
3.1	1/4	0	1/4	0	0	0	1/4	1/4	0	0
3.2	0	1/4	1/4	0	0	0	1/4	1/4	0	0
2.0	0	0	0	1/4	1/4	1/4	0	0	1/4	0
2.1	0	0	0	0	1/4	1/4	0	0	1/2	0
1.0	0	0	0	0	0	0	1/4	1/2	0	1/4
0.0	0	0	0	0	0	0	0	0	1	0

Fig. 9. Example of the state transition diagram and probability matrix for the four-layer PAN model.

6LoMSN HNP option and its 16-bit address option, which is assigned by the 6LoGW. Signaling messages can be reduced in the PAN area since the RA message is being sent in direct unicast, not broadcast, similar to the RS message.

4 Performance Evaluation

To evaluate the performance in terms of signaling costs and handoff latency, we compare the performance of the proposed PMIPv6-based 6LoWPAN scheme with the MIPv6-based 6LoWPAN, HMIPv6-based 6LoWPAN, and LoWMob schemes. For the performance evaluation, we adopt a 2D random walk mobility model [13], [14], which is based on the properties of regular and absorbing Markov chains.

4.1 Network and Mobility Model

We assume that PAN networks can be configured as a square topology. 6LoMSNs in 6LoFFDs belonging to a PAN area have identical movement patterns within and across PANs. The 2D random walk mobility model is designed for dynamic location areas, and is suitable for user movements where the mobility is generally confined to a limited geographical area such as a residence, building, or hospital [15]. In this paper, we reuse this network and mobility model with some modifications for an n-layer PAN model. In our network model, a PAN consists of a cluster of square 6LoFFDs, as shown in Fig. 8 (e.g., $n = 4$).

The 6LoFFD at the center of the PAN area is called sublayer 0. The dotted lines indicate the 6LoFFDs which surround the sublayer $(x-1)6$ LoFFDs, and are called sublayer x. The bold lines indicate the boundary of the PAN. We assume that a 6LoMSN can move to one of its four neighboring 6LoFFDs with an equal probability of *1/4* in each direction. All of the 6LoFFDs are formed by $<x,y>$, where x indicates that the 6LoFFD is in subarea x and y indicates the type of sub-area x. In the case of the four-layer PAN model, states $<3,0>$, $<3,1>$, and $<3,2>$ are in the boundary of the PAN, and are called the boundary states. We further define the asterisked boundary states, which are the boundary states in the neighboring PANs, such as $<3,0>^*$, $<3,1>^*$, and $<3,2>^*$. Fig. 9 shows an example of the state transition diagram for the random walk mobility model, where the four-layer PAN model on a regular Markov chain. Movement into an asterisked boundary state indicates an inter-PAN mobility, which can be used to study the binding update costs.

4.2 Analytical Model

The Markov chain has a single ergodic set with only one cyclic class, and is a regular Markov chain. Therefore, the properties of a regular Markov chain can be applied to analyze the chain, and we can obtain the expected number of binding update messages required for the PAN networks. There are $m + n$ states in the chain. The number of states within a single PAN is m, with n boundary states in the nearby PANs. If the process moves to any of the n states, it needs to send a location update message.

Let $P = [p_{ij}]$ denote the one step transition probability for the chain. The steady state probability for the chain can be found by solving the balance equations given

$$\pi P = \pi, \tag{1}$$

$$\sum_{i=1}^{m+n} \pi_i = 1, \tag{2}$$

where vector π is the steady state probability, which constitutes the limiting matrix, S. Each row of S is comprised of the limiting vector π, where $\pi = \pi_1, \pi_2, \ldots, \pi_{m+n}$. Furthermore, π_i represents the fraction of time the process is expected to be in state s_i for a large number of steps, independent of the starting states. However, for a regular chain, the starting state has an influence in determining the number of times the process visits a particular state in the first k steps [16]. We can determine the expected number of times the process visits the state s_i, starting from state s_j, using the fundamental matrix of the chain [16]. The fundamental matrix, denoted as Z, can be given by [16]

$$Z = (I - (P - S))^{-1}, \quad (3)$$

where I is an identity matrix. Let $\bar{y}_i(k)$ represent the number of times the process is in state s_i in the first k steps, i.e., the initial position plus $k-1$ steps. Subsequently, for any initial probability vector α, the average number of times the process is in state s_i, denoted as $M_\pi[\bar{y}_i(k)]$, is given by [16]

$$M_\pi[\bar{y}_i k] = (\pi Z - S) + k\pi. \quad (4)$$

Now, if we choose a particular starting state (for example, state s_j) for the chain, using the above equation, we then have

$$M_j[\bar{y}_i k] = (z_{ji} - \pi_i) + k\pi_i. \quad (5)$$

We can apply the above result to find the number of binding update messages. Because we need to send a binding update message when the 6LoMSN moves from one PAN to another PAN, each time the process enters into an asterisk state (i.e., state $<3,0>^*$, $<3,1>^*$, and $<3,2>^*$), a binding update message is generated. Therefore, we need to find the expected number of times the process enters into an asterisk state within k steps.

Let the 6LoMSN starts from cell <0,0> within the PAN. Subsequently, the number of binding update messages required for all of the n asterisked 6LoFFDs, denoted as B, is given

$$B = \sum_{j=1}^{n} M_j[\bar{y}_i k]. \quad (6)$$

Finally, the 6LoMSN needs to send B binding update messages if it experiences a total of k transitions between 6LoFFDs. Therefore, the proportion of intra-PAN mobility is denoted as P_{intra}, expressed by $P_{intra} = (k - B)/k$. The proportion of inter-PAN mobility is denoted as P_{inter}, expressed by $P_{inter} = B/k$.

4.3 Simulation Results

Using this network and mobility model, we perform a number of simulation experiments in order to evaluate the performance of total signaling costs and handoff latency based on our 2D random walk mobility model for the n-layer square PAN using the Objective Modular Network Testbed in C++ (OMNeT++) simulator [17]. OMNeT++ is an open source, component-based, and discrete event simulation environment, and is becoming very popular, especially in mobile communications networking. We implement the proposed PMIPv6-based 6LoWPAN scheme and related schemes, which include MIPv6-based 6LoWPAN, HMIPv6-based 6LoWPAN, and LoWMob.

For a fair evaluation of all schemes, we configure under the same network architecture that includes a total of 9-PANs, with the n-layer square PAN (e.g., Fig. 9 shows an example of 5-PANs with $n = 4$). Each PAN includes a 6LoGW, and n^2 square 6LoFFDs, which are configured with clustering topology. We use n, the number of layers, as a PAN size in this simulation (e.g., if $n = 4$, there are 16 square 6LoFFDs within a PAN area). As the number of layers n increases, the PAN size also increases. The coverage of each 6LoFFD is defined as 100 m^2, and a 6LoMSN can move with different movement speeds over the entire PAN area based on our mobility model. The parameter values for the analysis are referenced in [9], and [11].

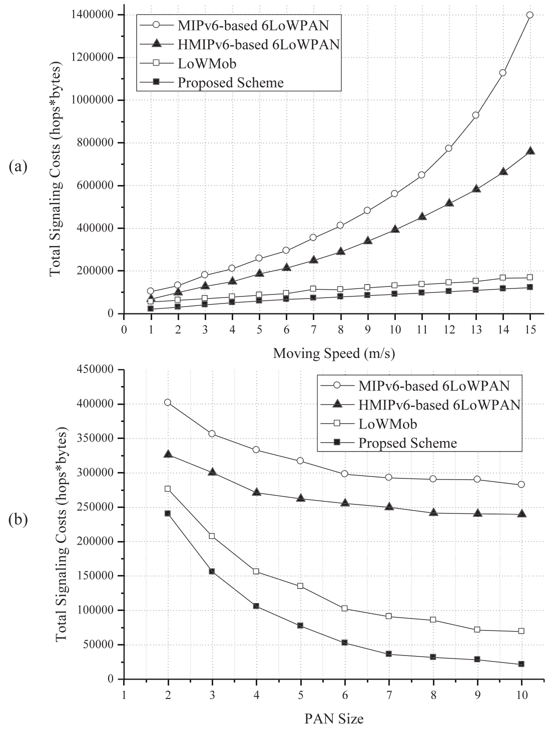


Fig. 10. (a) The impact of the 6LoMSN movement speed on total signaling costs, and (b) The impacts of the PAN size on total signaling costs.

4.3.1 Total Signaling Costs

Fig. 10a shows the impact of the 6LoMSN movement speed on total signaling costs at different movement speeds from 1 m/s to 15 m/s, and n set to 4. For all of the schemes, the results of the total signaling costs are rapidly increased with faster movement speeds since the 6LoMSN performs an increased number of movements and high frequently handoff as the movement speed is increased.

The MIPv6-based 6LoWPAN scheme is most significantly affected by increasing the movement speed in the total signaling costs because it is necessary in order to exchange the largest signaling messages between the 6LoMSN and the HA in order to maintain the session whenever the 6LoMSN performs either intra-PAN or inter-PAN mobility. In the HMIPv6-based 6LoWPAN scheme, the signaling costs can be reduced over the wired link between the MAP and HA during the intra-MAP domain mobility. Although lower than the MIPv6-based 6LoWPAN in terms of total signaling costs, the 6LoMSN of HMIPv6-based 6LoWPAN scheme should perform the BU procedures over the wireless link while the 6LoMSN handsoff within the MAP domain.

The total signaling costs of the network-based mobility protocols, which include LoWMob and the proposed PMIPv6-based 6LoWPAN, are significantly less as compared to the host-based mobility protocol. In the LoWMob scheme, even though the 6LoMSN is not involved with the signaling messages for the PBU procedure, the additional signaling messages in the adaptation layer are needed over the wireless link for the movement detection between the 6LoFFD and the 6LoGW while the 6LoMSN performs the intra-PAN mobility. On the contrary, the 6LoMSN of the proposed PMIPv6-based 6LoWPAN does not require any mobility related signaling messages since the 6LoGW is responsible for managing mobility on behalf of the 6LoMSN. The proposed PMIPv6-based 6LoWPAN only performs the modified neighbor discovery for movement detection.

Fig. 10b shows the impact of the PAN size on total signaling costs with the 6LoMSN movement speed set as $2\ \mathrm{m/s}$, and n varied from 2 to 10. In this simulation, we assume the 6LoMSN travels at a steady velocity over the entire the PAN area so that the 6LoMSN performs the handoff for either the intra-PAN or inter-PAN mobility every 5 seconds. The total signaling costs during a given time period depend on the number of handoffs for the location updates.

According to the square PAN model used in this paper, decrease in the PAN size means that the number of 6LoFFDs is decreased in the PAN area. That is, the 6LoMSN has a high probability of inter-PAN mobility compared to intra-PAN mobility. Since the total signaling costs of the inter-PAN mobility are obviously higher than the cost of the intra-PAN mobility for all of the schemes, the network-based schemes have high total signaling costs, and there are no major differences in total signaling costs for the case of the small sized PAN, in comparison between the network-based mobility schemes and host-based mobility schemes. Nevertheless, there is a gap in the performance of the signaling costs between the proposed scheme and the other scheme.

Overall, the results of the total signaling costs are decreased for all of the schemes as the PAN size is increased, as shown in Fig. 10b. Especially, in the case of a large PAN size, the network-based mobility schemes have dramatically decreased the total signaling costs. This is because the host-based mobility schemes still require higher signaling costs for the intra-PAN mobility over the wireless link, while the network-based mobility schemes minimize the signaling messages that travel through the wireless link. The total signaling costs of the proposed PMIPv6-based 6LoWPAN scheme consume the lowest cost, so that the proposed scheme is most suitable for either small or large-scale mobile sensor network environments.

4.3.2 Total Handoff Latency

Fig. 11a and 11b show the impact of the wireless link delay and wired link delay on total handoff latency, respectively. In this simulation, the delay over the wireless link is caused by the congestion or transmission delay between 6LoMSN and 6LoGW via the 6LoFFDs in all of the schemes. The delay over the wired link is caused by the congestion or transmission delay between 6LoGW and HA in the MIPv6-based 6LoWPAN, between 6LoGW and HAMAP in the HMIPv6-based 6LoWPAN, or between 6LoGW and LMA in both the LoWMob and the proposed PMIPv6-based 6LoWPAN, respectively.

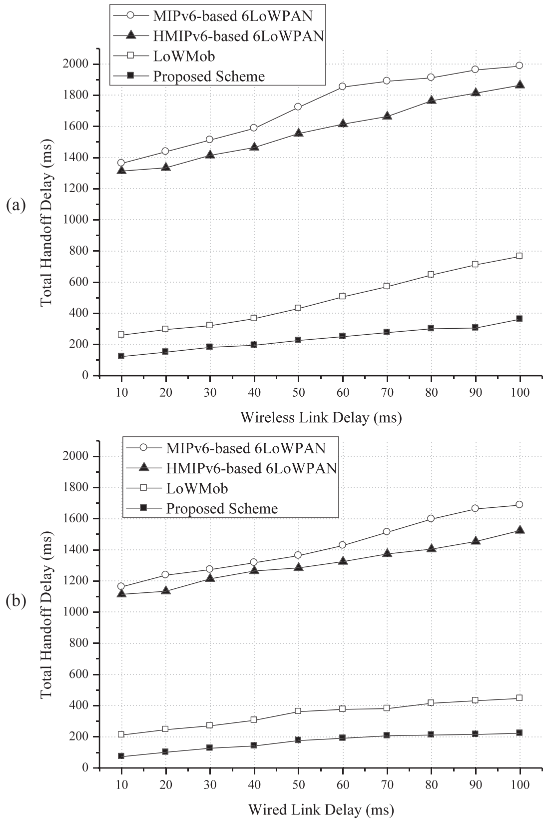


Fig. 11. (a) The impact of the wireless link delay on total handoff latency, and (b) The impact of the wired link delay on total handoff latency.

The total handoff latency is the sum of the delay of the movement detection, address configuration (DAD [7]), and signaling messages exchange. We assume that all of the schemes have the same movement detection delay. The address configuration procedure of the MIPv6-based 6LoWPAN and HMIPv6-based 6LoWPAN consumes a long time to configure a CoA whenever the 6LoMSN performs the handoff, since those schemes are basically based on IPv6 stateless address autoconfiguration (RFC 2462 [7]), which specifies that the DAD process requires at least $1{,}000\ \mathrm{ms}$. Hence, the major reason for handoff latency in the host-based mobility schemes is the address configuration procedure. This simulation considers the optimistic DAD (oDAD) as specified in RFC 4429 [18], so as to reduce the handoff latency.

Although the optimized address configuration mechanism is considered for host-based mobility schemes, it can minimize the delay only if there is no address collision. Furthermore, due to the features of the host-based mobility protocols, there is a much greater impact on the delay over the exchange of signaling messages than in the network-based mobility protocols. The LoWMob and the proposed PMIPv6-based 6LoWPAN schemes do not require any address collision mechanism and there is no delay for address configuration, since the 6LoGW is responsible for address allocation of all 6LoFFDs and 6LoMSNs. However, in the LoWMob, the total handoff latency is

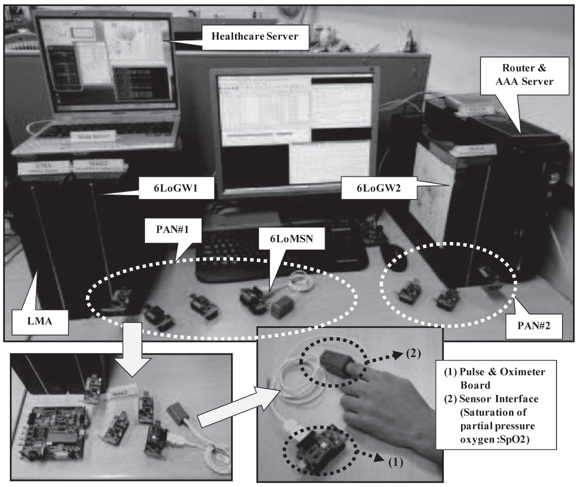


Fig. 12. Testbed for the 6LoMSN mobility.

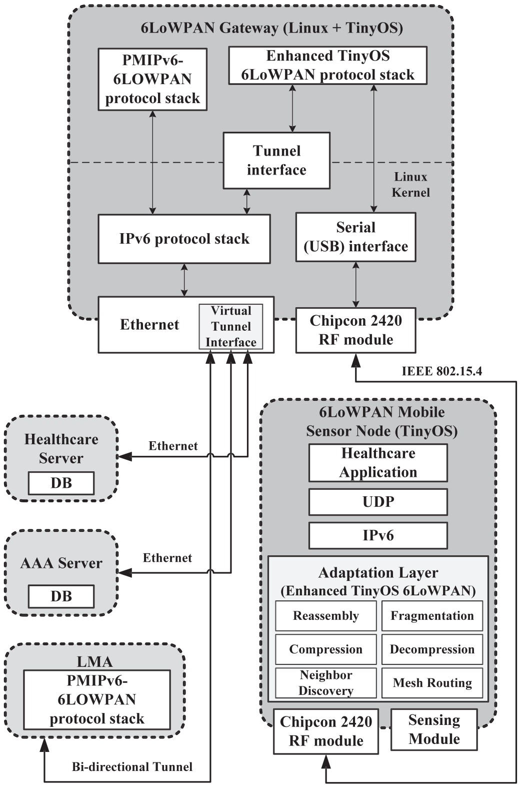


Fig. 13. Proposed functional architecture.

larger than the proposed PMIPv6-based 6LoWPAN due to the additional exchange of signaling messages between the 6LoMSN and 6LoGW. The proposed PMIPv6-based 6LoWPAN scheme is the least affected by the wireless link delay since there is no mobility-related exchange of signaling messages within the wireless PAN area.

It can be observed from Fig. 11a and 11b that the total handoff latency for the wireless link is significantly higher than the wired link for each scheme. This means that the delay of the link between the 6LoMSN and 6LoGW, which is a wireless link delay, has a greater impact than the wired link delay on the total handoff latency. Therefore, signaling offloading and minimized signaling overhead within the wireless link is the most important feature in order to efficiently support 6LoWPAN mobility in the multihop communication environment.

5 Experimental System Development

5.1 Implementation Overview

We have implemented a realistic testbed, a healthcare system application, for our proposed interworking mechanism between 6LoWPAN and PMIPv6, as shown in Fig. 12. The 6LoMSN initially belongs to PAN#1, having the freedom of movement between PAN#1 and PAN#2. The 6LoMSNs sense vital body information, such as a person heart rate and blood oxygen saturation. The sensing data is sent to the Main Server.

To accomplish our scheme, we developed the following two major protocol stacks: the enhanced TinyOS 2.0-based 6LoWPAN protocol stack and the PMIPv6-6LOWPAN protocol stack for supporting the 6LoMSN mobility based on the PMIPv6. Fig. 13 shows the proposed functional architecture. The 6LoMSN is able to get sensing data from the sensor interface, and transfer the sensing information over 2.4 GHz IEEE 802.15.4 communications using the Chipcon2420 RF module. The 6LoGW uses the universal asynchronous receiver/transmitter (UART) component for universal serial bus (USB) interface to communicate between the Linux kernel and TinyOS.

First, we implement the 6LoWPAN protocol stack using nesC, a component-based programming language for embedded environments in the TinyOS 2.0 [19] framework. We then perform tests on the TelosB motes hardware platforms [20], which are equipped with a MSP430 processor having 10 KB of RAM and 48 KB of ROM. A 6LoWPAN implementation for the TinyOS 2.0 embedded operating system has been previously developed in [21]. It supports the 6LoWPAN adaptation layer with the handling of the compression of the IPv6 and UDP header, decompresses its headers, and performs the fragmentation. However, this 6LoWPAN protocol stack does not provide all of the requirements for the 6LoWPAN functions. Therefore, we have added the following new features for the 6LoMSN PAN attachment detection and multihop communication within the PAN areas: a lightweight neighbor discovery mechanism for 6LoWPAN to use the proposed RS and RA messages, and a multihop routing protocol to handle the mesh header.

Second, the PMIPv6-6LOWPAN protocol stack is developed for the 6LoGW and LMA which are implemented in Linux kernel 2.6.11 using the modified Network Mobility Platform for Linux (NEPL) [22].

5.2 Experimental Results

We experiment on how much the network-based mobility scheme (i.e., the proposed PMIPv6-based 6LoWPAN) can increase the lifetime of the battery in the 6LoMSN with a differnt number of handoffs, compared with the host-based mobility scheme (i.e., HMIPv6-based 6LoWPAN). Fig. 14 shows the impact of the frequency of handoffs during a given time, in the case of packet processing (such as the transmission or receipt of packets) with a low rate and high rate, on the actual power consumption in joules, according

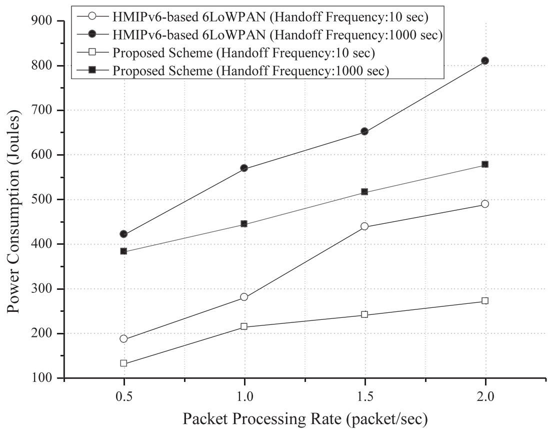


Fig. 14. The impact of the frequency of handoffs on the actual power consumption of the 6LoMSN.

to the following equation: $E = C * VT * 3.6$, where E is the energy in joules, C is the capacity in milliamp hours, and VT is the voltage of the 6LoMSN.

For the measurement of the actual experimental results, each test is performed for five hours, and during this time the 6LoMSN performs the handoff between PAN#1 and PAN#2 according to a frequency of handoffs with a low rate or high rate (every 100 or 10 seconds, respectively). Furthermore, the 6LoMSN transmits a data packet to the CN and receives a data packet from the CN such that the packet processing rate follows a Poisson distribution with a mean rate of λ (0.5, 1.0, 1.5, or 2.0 packets per second). The TelosB mote hardware platform of the 6LoMSN, which is used by our testbed, is powered by two AA batteries (the maximum battery capacity: $3{,}000\ \mathrm{mAh} * 2$). The power consumption for the TelosB mote is $17.4\ mA$, while transmitting at $0\ \mathrm{dBm}$ and $23\ \mathrm{mA}$ in the receiving mode. If the RF transceiver is in idle mode and the voltage regulator is on, the current draw of the 6LoMSN is $21\ \mathrm{uA}$. When the RF transceiver is in sleep mode and the voltage regulator is off, the current draw is $1\ \mathrm{uA}$.

In the case of a low frequency of handoffs (the 6LoMSN performs handoffs every 100 seconds), the power consumption is more affected by the packet processing rate than the handoffs. With a high packet processing rate, the 6LoMSN has a greater chance to switch to the active mode than the idle or sleep mode in order to handle the packet transmission and reception, so that the lifetime of the battery is reduced. The HMIPv6-based 6LoWPAN scheme consumes more power than the proposed PMIPv6-based 6LoWPAN, as the packet processing rate is higher. This is because the HMIPv6-based 6LoWPAN is necessary to establish an additional bidirectional tunnel between the 6LoMSN and the HA, and all tunneled packets should pass through the bidirectional over the wireless link. On the contrary, the proposed PMIPv6-based 6LoWPAN scheme does not require any tunneled packet over the wireless link.

In the case of a high frequency of handoffs (the 6LoMSN performs handoffs every 10 seconds), as the packet processing rate is increased, the power consumption of the HMIPv6-based 6LoWPAN scheme has a widening gap, compared to the power consumption with a low frequency of handoffs. This is because the 6LoMSN, based on the host mobility, is involved in all mobility-related procedures such as address configuration and signaling message exchange over the wireless link, whenever the 6LoMSN handsoff between PANs. This means that the handoff performance has a significant impact on the power consumption of the 6LoMSN with a high handoff rate since the 6LoMSN performs the handoff procedure more frequently for its mobility support. On the other hand, the proposed PMIPv6-based scheme is not involved in the address configuration and mobility-related signaling over the wireless link. Therefore, even though the frequency of handoffs is high, the gap of the power consumption shows no rapid increase when compared to the power consumption with a low frequency of handoffs.

As shown in Fig. 14, the power consumption of the proposed PMIPv6-based 6LoWPAN is as much as 44-60 percent more efficient with a low frequency of handoffs, and 34-47 percent more efficient with a high frequency of handoffs, than that of the HMIPv6-based 6LoWPAN. From these experimental results, the 6LoMSN of the proposed PMIPv6-based 6LoWPAN is expected to take a much longer lifetime of the battery.

6 Conclusion

In this paper, we focus on a scheme that supports mobility for 6LoMSNs. We adopt the PMIPv6 protocol to provide mobility for low power 6LoWPAN sensor nodes. Accordingly, we propose an interworking mechanism between the 6LoWPAN and PMIPv6. We define the movement notification of a 6LoMSN in order to support its mobility, based on PMIPv6, as well as to detect the PAN attachment in a multihop-based 6LoWPAN environment. The attachment of 6LoMSNs can minimize the signaling costs by using RS and RA messages.

Performance results show that our proposed scheme can minimize total signaling costs and handoff latency. We also implement the development environment for our proposed interworking mechanism between 6LoWPAN and PMIPv6 to apply to a healthcare system. From the experimental results, the 6LoMSN of the proposed PMIPv6-based 6LoWPAN scheme yield a lifetime at least 34 percent longer than the HMIPv6-based 6LoWPAN scheme. We also verify that the 6LoMSN can maintain connectivity even though it has the freedom of movement between PANs without a mobility protocol stack. In future research efforts, we will evaluate the performance of our proposed scheme under various mobility models.

Acknowledgments

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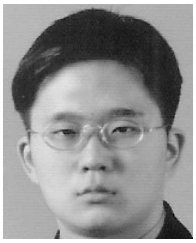

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