An Enhanced Group Mobility Protocol for 6LoWPAN-Based Wireless Body Area Networks

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***Abstract*— The IPv6 over low power wireless personal area network (6LoWPAN) has attracted lots of attention recently because it can be used for the communications of Internet of things. In this paper, the concept of group-based network roaming in proxy mobile IPv6 (PMIPv6) domain is considered in the 6LoWPAN-based wireless body area networks. PMIPv6 is a standard to manage the network-based mobility in all-IP wireless network. However, it does not perform well in group-based body area networks. To further reduce the handoff delay and signaling cost, an enhanced group mobility scheme is proposed in this paper to reduce the number of control messages, including router solicitation and router advertisement messages as opposed to the group-based PMIPv6 protocol. Simulation results illustrate that the proposed handoff scheme can reduce the handoff delay and signaling cost. The packet loss ratio and the overhead can also be reduced.**

***Index Terms*— Wireless body area networks, proxy MIPv6, handoff delay, signaling cost, 6LoWPAN.**

I. Introduction

VARIOUS wireless sensor nodes can be attached to the human body or clothes and hence can form a wireless network named as the Wireless Body Area Networks (WBAN) [1]. These tiny sensors are used to measure particular parameters of the human body, such as the body temperature, blood glucose, pulse rate and heart-beat. These sensing values can be gathered and transmitted to the monitoring server for healthcare applications or surveillance systems.

IPv6 is the latest IP version which has large address spaces and better auto-configuration mechanisms and thus it can overcome the IP shortage problem; while Low-power Wireless Personal Area Networks (LoWPANs) can support the communications of the Internet of Things (IOTs) and thus it has attracted lots of attention recently. Hence, the Internet Engineering Task Force (IETF) has set up a working group for IPv6 over Low power Wireless Personal Area Network (6LoWPAN) [2], which is carried out over IEEE 802.15.4 interfaces. Since the maximum packet size of IEEE 802.15.4 [3] is 127 bytes, the sensors are unable to hold the complete IPv6 address. The limitation of the packet size is to maintain the low power consumption of sensors, which are powered by batteries only. As a result, 6LoWPAN adds an adaption layer to implement the seamless connection of MAC and network layer. Taking the characteristics of 6LoWPAN into account, the host-based mobility approach is unsuitable to be applied in IP based Wireless Sensors Networks (IP-WSN) since there are huge amount of tunneling, especially in the case of the WBAN mobility scenario. All of the sensors should have a mobility stack, such as Mobile IPv6, FMIPv6 [4], HMIPv6 [5]. However, the sensors should actively participate in mobility-related signaling that the above protocols are not suitable for them. The network-based mobility protocol would be more suitable for this situation. Proxy Mobile IPv6 (PMIPv6) [6] currently is being standardized by the working group of IETF's Network-based Localized Mobility Management protocol (NetLMM). PMIPv6 can be considered as the most suitable manner to manage the mobility of the 6LoWPAN-based WBAN.

The sensors' signaling the mobility related message to the agent themselves is a heavy burden. Hence, reducing the signaling cost becomes an important issue because most of the sensors are powered by battery only. Using network-mobility scheme for mobile sensors is a proper solution because it can reduce signaling cost. When the sensors change the point of attachment, there is a delay time before obtaining the IP configuration. Therefore, how to decrease the times of exchanging the control messages in case that a number of sensors attach on one MAG is also an important issue.

To solve the above problem, a new format of control messages for carrying many other identifiers in one message is proposed in this paper so as to reduce the numbers of the control messages and shorten the handoff delay. An enhanced group-based handoff scheme, which adopts the new formatted control messages, is proposed. The proposed handoff scheme contains three phases, namely the registration, up-link handoff, and down-link handoff phases. Simulation results have shown that the proposed protocol can reduce the signaling cost and handoff latency for mobile sensors and it can also decrease the overhead of the Mobile Access Gateway (MAG) in PMIPv6.

The rest of this paper is organized as follows: Section II describes the related works and motivation. In section III, the system model and basic idea are described. Section IV

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describes the proposed group-based protocol in 6LoWPAN-based WBAN. Section V demonstrates the performance analysis results. Section VI presents the simulation results. Section VII concludes this paper.

II. Related Works

In this section, related works are described first followed by the motivation of this paper.

A. Related Works

A survey on body area networks (BANs) is proposed in [7], which provides an investigation of sensor devices and protocols on physical layer, data link layer, and radio technology aspects of BANs. This paper also highlights some of the design challenges and open issues on BANs that still need to be addressed.

Several researches [8]–[10] focus on the security issues of WBSN. He et al. [8] propose an attack-resistant and lightweight trust management scheme for WBSN named ReTrust based on a two-tier architecture. The Collection Tree Protocol is implemented on the proposed system. Experiment results have shown that ReTrust not only can detect malicious/faulty behaviors, but can also improve the network performance. A distributed trust evaluation model, which uses simple cryptographic techniques, for medical sensor networks (MSNs) is proposed in [9]. Relevant node behaviors, such as transmission rate and leaving time, is introduced into trust evaluation to detect malicious nodes. Zhang et al. propose a key agreement scheme that a common key is generated by electrocardiogram (ECG) signals and shared by neighboring nodes in BANs. To set up the key agreement for the message authentication, an improved Jules Sudan (IJS) algorithm is proposed. Without causing any key distribution overheads, the proposed ECG-IJS key agreement can secure data communications over BANs in a plug-and-play manner.

Istepanian et al. [11] indicates that 6LoWPAN is quite suitable for WBSN because the sensors are based on IEEE 802.15.4 standard which is low power and low data rate. The mobility of 6LoWPAN has been an important solution in wireless communication particularly in WBSN. Most of the existing mobility protocols [12], [4], [5] for IPv6 are not suitable for 6LoWPAN because they are the tunnel-based mobility protocols, which indicates that the mobile sensor nodes need to send lots of control message in order to ensure the continuity of communications. PMIPv6 [6], [13] network-based mobility protocol is a solution to handle the mobility management of the body sensors. The network side performs the mobility-related signaling of the sensors and there is no need to perform Duplicate Address Detection (DAD) of the IP address. The control message is exchanged between the Localized Mobility Anchors (LMA) and Mobile Access Gateway (MAG) and then establishes the tunnel for data transmission to maintain the communication. This manner reduces the signaling cost and handoff latency of each mobile sensors.

From the single mobile node's perspective, Oliveira et al. [14] has pointed out that the requirements and resources for adapting the existing solutions to 6LoWPAN is still a challenge and further researches on 6LoWPAN mobility are required. Therefore, Islam et al. [15] propose a scheme to support IP-WSN. The packet format for communication in ingress interface to deal with the handoff procedure is proposed in this paper. Oliveira et al. [14] also indicates that multi-hop communications cannot be used in PMIPv6 protocol. Hence, Haw et al. [16] propose a multi-hop communication scheme in the ingress interface by using mesh routing to increase the coverage range. But this scheme only focuses on one mobile node. If there are several nodes move around, this scheme has no effective solution for this situation. Bag et al. [17] propose a 6LoWPAN mobility supported scheme, which depends on the dispatch types of the 6LoWPAN. But this scheme does not have an obvious improvement on reducing handoff delay.

From the network-based perspective, some related works are described as follows: Kim et al. [18] proposed a 6LoWPAN mobility scheme based on Network Mobility (NEMO) [19], which uses a mobile router to support the handoff and modify the dispatch of 6LoWPAN, but the loading of the mobile router is heavy. Since the issue of maintaining the sessions meanwhile reducing the handoff delay and signaling cost of group-based mobility in 6LoWPAN-based WSBN is important, Li et al. [20] provided a scheme for PMIPv6 environment. This scheme considered the case of many correlated sensor nodes moving together and taking handoffs at the same time. The LMA calculates the SNR value of each sensors and classify the sensors with similar value into groups. This protocol can reduce the handoff signaling cost by sending the PBA (Proxy Binding Ack) message per group. PBU (Proxy Binding Update) and deregistration PBU can decrease the handoff delay by simplifying the procedure. However, the control message of router solicitation (RS) and router advertisement (RA) can not be reduced in case that body sensors move in the PMIPv6 domain. Besides, this scheme is not suitable for the 6LoWPAN-based WSBN. Chai et al. [21] propose a group mobility management in 6LoWPAN based WSN. A network architecture that integrates NEMO and 6LoWPAN is proposed. The group mobility management mechanism and the corresponding signaling flow including the registration at the home network, association, negotiation, handoff between different ARs, and packet routing are discussed. The handoff signaling required for the proposed NEMO protocol is nearly $\frac{1}{n}$ times than that required for MIPv6, where n is the number of nodes. However, it increases the burden of the sensor router, which needs to provide connection and routing support for other normal sensor nodes inside the group and it is designed for MIPv6, not for PMIPv6.

B. The L2 and L3 Handoffs

The reduction of the handoff delay is a critical issue for the mobility protocol. The L2 delay contains the channel scanning, authentication, and association delays; while the L3 delay contains the movement detection, CoA (Care of Address) configuration, DAD (Duplicate Address Detection), and registration delays [22]. Many researches [23]–[26] try to improve the L2 handoff by reducing the channel scanning delay because channel scanning is the most time consuming part of the L2 handoff. The neighbor graph is used in both [23] and [25] so as to confine the probing scope to the potential handoff targets and thus reduces the channel scanning delay. Pre-registration is used in [25] so as to further reduce the handoff delay. In [24], caching is used first so that the STA can associate with the caching AP fast. If the first two caching AP cannot be associated successfully, the selective scanning is performed. A Deuce-Based Fast Handoff Scheme (named as DeuceScan) is proposed in [26]. Deduce scheme uses a spatiotemporal graph to provide spatiotemporal information for accurately and correctly making the handoff decision. A prescan approach is also adopted in the DeduceScan scheme so as to further reduce the L2 handoff latency.

In [27], when an MN is waiting for the DHCP server to assign a new IP address, a temporary IP address is assigned for the MN to resume the communication immediately after the handoff. The pre-handoff route discovery (PRD) concept for AODV is proposed in [28]. PRD enables MNs to set up routes in the handoff-target network before handoff. The FMIPv6 [4] uses L2 triggers for anticipation and initiation of L3 handoff. The duplication of the new CoA is validated before the MS's movement and thus the FMIPv6 can reduce the movement detection and CoA configuration delays. The L3 delay (around 2300ms) is much longer than the L2 delay (around 50 $\sim$ 250ms) [22] and hence there is more potential to greatly reduce the handoff delay by reducing the L3 delay. The proposed group handoff protocol can not only reduce the signaling cost (L2 handoff) but also reduces the registration cost (L3 handoff).

C. Motivation

In WBANs, the sensors always move together and take handoff at the same time. For example, a patient may walk around in the hospital for inspections or surgeries. Hence, how to achieve the seamless handoff scheme with less delay time is an important issue. The existing group-based protocol [20], [21] relies on the first newly attaching node to carry the rest of nodes' binding information to reach the goal of reducing the signaling cost and handoff delay. However, the sensors equipped on the human body always attach to the newly access link at the same time. Hence, it is better to use one control message (RS and RA) to carry the whole body sensors' information for reducing the signaling cost. Grouping the body sensors to enhance handoff procedure is also a feasible solution. To achieve the goals of reducing the delay time and signaling cost during the handoff procedure, the enhanced group mobility scheme and a new format of RS and RA message is proposed in this paper to solve those problems.

III. PRELIMINARIES

This section introduces the system model first follows by describing the basic idea.

A. System Model

The proposed protocol is designed for a WBAN consists of 6LoWPAN sensors and a Personal Area Network (PAN) coordinator. Fig 1 illustrates the 6LoWPAN protocol stack of the proposed protocol. 6LoWPAN uses the IEEE 802.15.4 standard as the link-layer protocol. The adaption-layer is used to compress the IPv6 packet header (40 bytes) into 2 bytes for incoming communication (6LoWPAN) and decompress for the outgoing interface (PMIPv6). The 6LoWPAN domain contains full-function devices (FFDs), which support all IEEE 802.15.4 functions and features. The Mobile Body Sensors (MBSs) send the packet through the FFDs to the Mobile Access Gateway (MAG), which has two interfaces for end-to-end communication. The MAG receives the packet, and then decompresses the packet in adaption layer to follow the IPv6 packet format. Thus, the Local Mobility Anchor (LMA) set the binding state for the MBSs after receiving the packet from the MAG. When an MBS attaches to an MAG via wireless link, it sends a Router Solicitation (RS) message which includes the Mobile Node-Identifier (MN-ID) for using an address from its home network prefix (HNP). The MAG emulates the home link of MBS by replying the Router Advertisement (RA) message to the MBS. Thus, the MBS can configure the same address through the HNP in PMIPv6 domain. There is a centralized LMA in the PMIPv6 domain, which acts like a home agent for all mobile nodes. For increasing the coverage of one MAG scope, 6LoWPAN is in beacon-enable mode and equips with the FFDs to support multi-hop communications. Hence, the packet can successfully send to the MAG through multi-hop communications and vice versa.

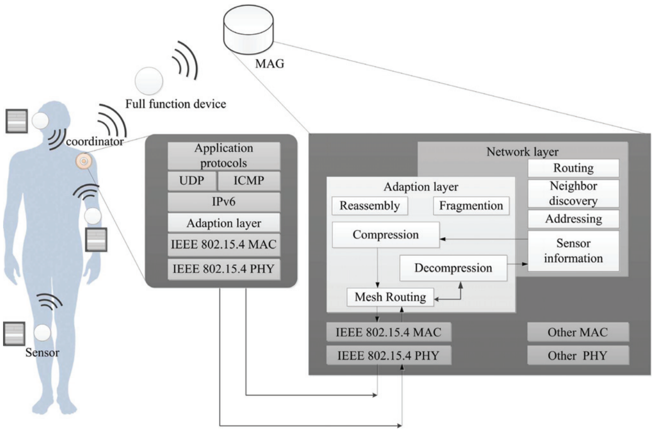

Fig. 1. The protocol stack and system model of Mobile Access Gateway (MAG) and sensors in WBAN.

The RS and RA control message of the conventional PMIPv6 protocol can be represented as $<Header, ICMP, MN\_ID, LL\_ID>$, where $Header$ contains the addresses of the source and destination, $ICMP$ is a protocol for TCP/IP layer, MN_ID and LL_ID contain mobile node-identifier and link-layer identifier, respectively. The link-layer identifier can be represented as $<Header, ICMP, HNP>$, where HNP contains the home network prefix of the sensor that assigned by the LMA.

B. Basic Idea

The basic idea of this work is to reduce the handoff delay and signaling cost for WBAN roams in PMIPv6. A new format of control message is proposed to combine the necessary information of the sensors into one message and thus the number of control messages can be substantially reduced. Besides, an enhanced group-mobility scheme is proposed to further reduces the handoff delay time between the LMA and the MAG. The signaling cost can also be reduced due to the group management. Fig. 2 illustrates the difference of signaling cost among three protocols. Fig. 2(a) is the original protocol and the protocol showing in Fig. 2(b) is proposed in [19]. The enhanced group protocol is shown in Fig. 2(c). Assuming that there are n sensors attached on a human, who enters or roams in PMIPv6 domain. Fig. 2(a) shows that every types of control message have to send n times in the original protocol. Fig. 2(b) illustrates that the group-based protocol reduced $n-1$ times of sending deregistration of PBAs and PBUs. But it still causes high signaling costs while the first node does not contain the rest nodes information.

Fig. 3 shows the traffic flow among the original protocol, the group-based protocol, and the proposed protocol. It illustrates the difference on delay time among the three protocols. The vertical axis represents the delay time during handoff process. The proposed group-based protocol can reduce the times of sending control messages and thus decreases the delay time.

IV. An Enhanced Group-Based Handoff Scheme

To achieve the goal of reducing the signaling cost and delay time, three phases are proposed, namely the registration, up-link handoff, and down-link handoff phases. The proposed group-based handoff scheme works as follows: When a group of body sensors enter a PMIPv6 domain and attaches to an access link, the registration phase starts. One of the body sensors in the group needs to act as a coordinator and only the coordinator needs to exchange the control messages with the MAG. During the registration phase, only one RS_{EG}, RA_{EG}, PBU_{EG}, and PBA_{EG} messages are sent and thus reduces lots of signaling and registration cost. The body sensor performs an active scan periodically by sending a beacon request to the nearby FFDs. The nearby FFD, that receives the beacon request from the body sensor, advertises a beacon message including their MAG-IDs. Upon receiving the beacon messages, the body sensor decides whether itself is still in the same MAG or has moved to another MAG by comparing the current MAG-ID with the previous MAG-ID. If the body sensor has detected that it has moved to the new MAG, it then associates with the new MAG by performing the up-link handoff phase. After the up-link handoff phase, the down-link handoff phase starts.

The details of the new packet format, the registration, up-link handoff, and down-link handoff phases are shown in the following subsections.

A. The New Packet Format

The enhanced mobility protocol mainly simplifies the procedure of home registration and handoff. To achieve this goal, new formats of RS and RA messages are proposed in this paper to reduce the signaling cost and handoff delay. RS_{EG} and RA_{EG} are used to represent the proposed new format of

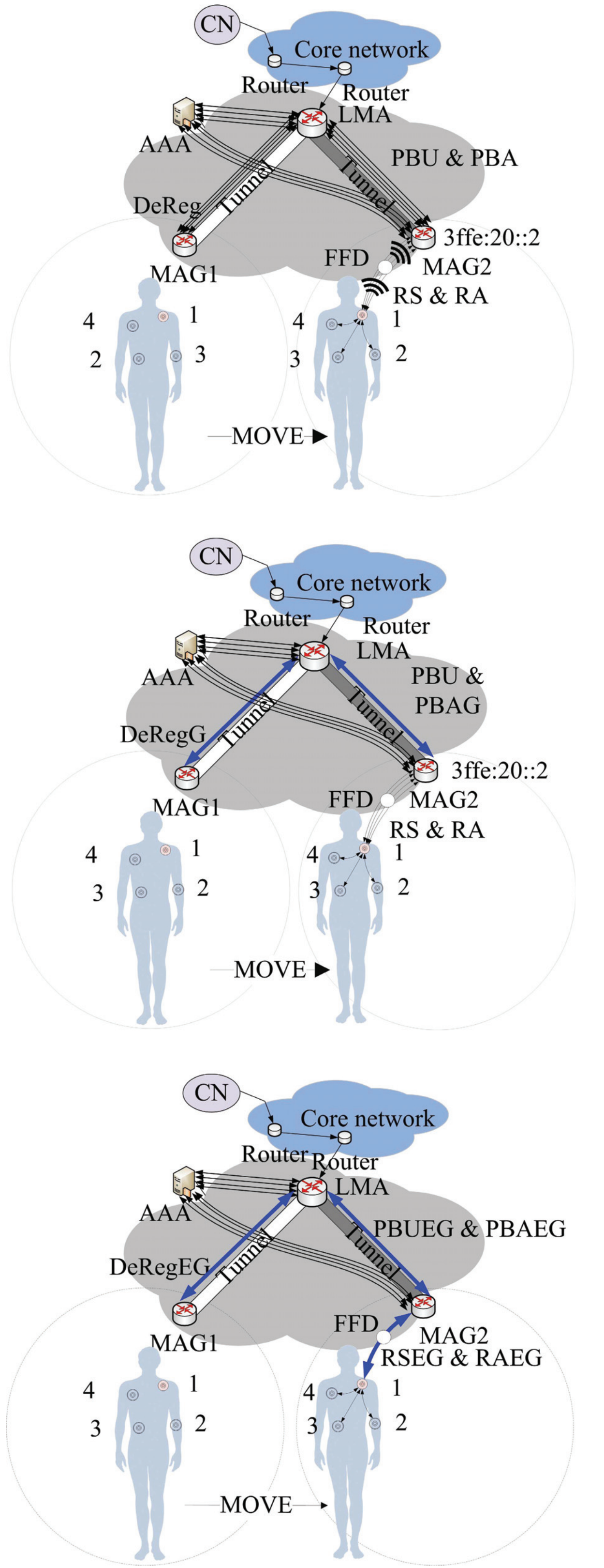

Fig. 2. The comparison among three protocols: (a) original protocol; (b) group-based protocol; and (c) proposed protocol.

the RS and RA messages, respectively. The RS_{EG} message contains the following components: <Header, ICMP, Body number (BN), MN_ID_1,LL_ID_1, MN_ID_2,LL_ID_2, ...,

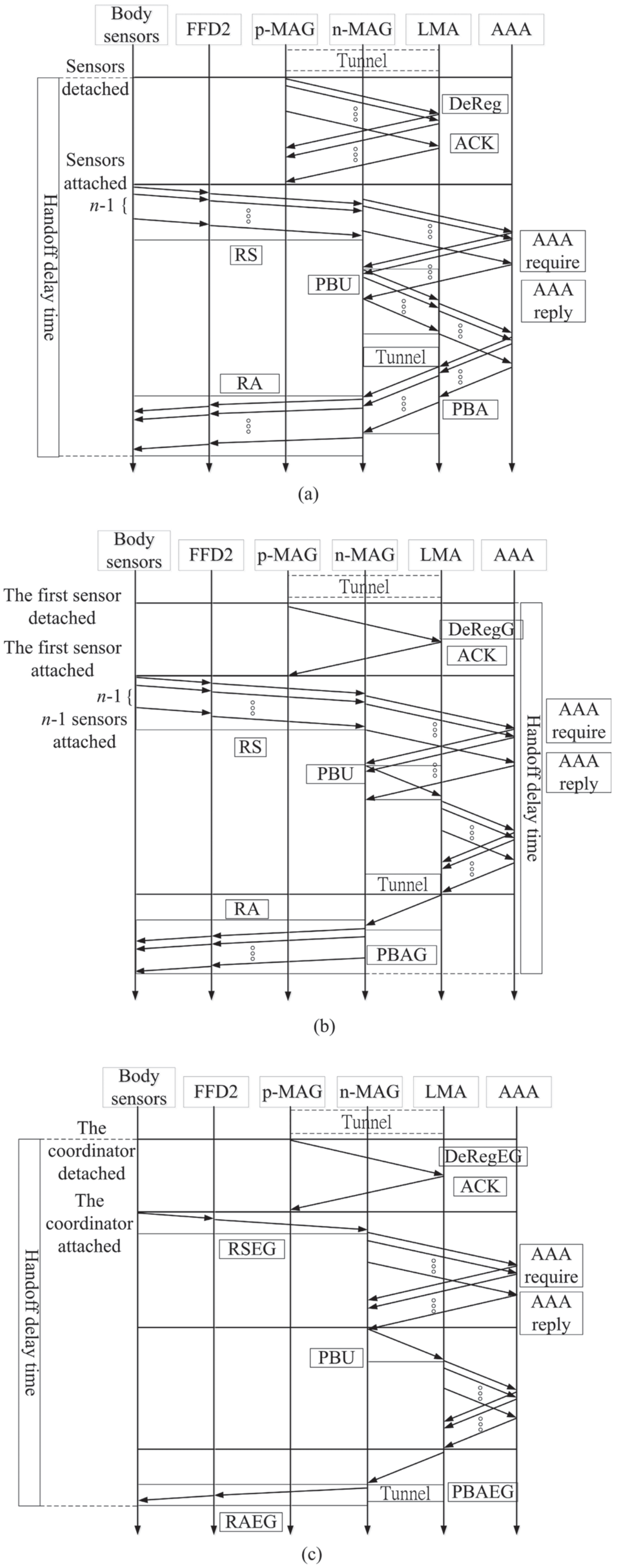

Fig. 3. The comparison of the traffic flow among three protocols: (a) original protocol; (b) group-based protocol; and (c) proposed protocol.

MN_ID_n,LL_ID_n>, where MN_ID_i,LL_ID_i indicates a set of mobile node-identifiers and link-layer identifiers of S_i and S_i denotes the i-th sensor attached on the human body.

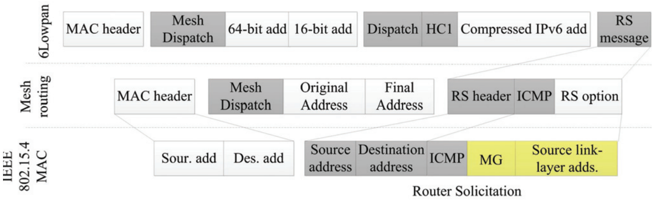

Fig. 4. The packet format of the proposed RS_{EG} message.

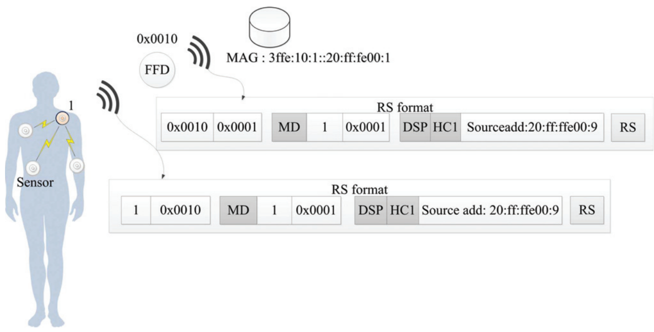

Fig. 5. The forwarding process of the RS_{EG} message.

The RS_{EG} message contains the following components: <Header, ICMP, B_j, HNP_1, HNP_2, HNP_3, ..., HNP_n>, where B_j indiccates the j-th body and HNP_i indicates a set of home network's prefixes of sensor S_i. The PBU_{EG} message contains the following components: <flag(p), B_j, MN_ID_1,LL_ID_1, MN_ID_2,LL_ID_2, ..., MN_ID_n,LL_ID_n>. The PBA_{EG} message contains the following components: <flag(p), B_j, HNP_1, HNP_2, HNP_3, ..., HNP_n>. The packet format of the proposed RS_{EG} message is shown in Fig. 4.

Assumes that the body node (BN) option can be identified by the MAGs and the LMAs. The BN option initially set as ALL_ZERO (0x00). The MAG can identify the BN option and record the identifier of MN in the binding cache if the BN option is already assigned a value. The LMA has two types of behavior to deal with the BN option.

- If the value of BN option is ALL_ZERO, the LMA allocates a value to the BN option that has not been assigned in the binding cache.
- If the value of BN option is already being assigned previously, the LMA searches the binding cache and uses the value of BN to update the information. The RA_{EG} message is used to response the RS_{EG} message and the option is used to carry all the HNPs.

Examples of the forwarding processes for messages RS_{EG} and RA_{EG} are illustrated in Figs. 5 and 6, respectively. The coordinator unicasts the RS_{EG} message instead of broadcasting when S_i attaches on the access link. The FFD is used for supporting the multi-hop communication. Assume that the 16-bit short address is 0x0010, which is assigned by the MAG. S_i can recognize the FFD address by a beacon message. If S_i registers or handovers in the PMIPv6 domain, the coordinator sends the RS_{EG} and RA_{EG} messages to the MAG. Hence, S_i

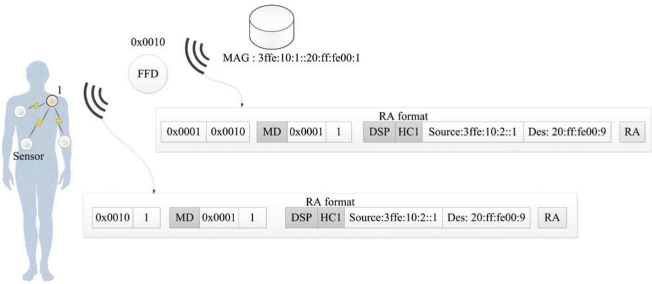

Fig. 6. The forwarding process of the RA_{EG} message.

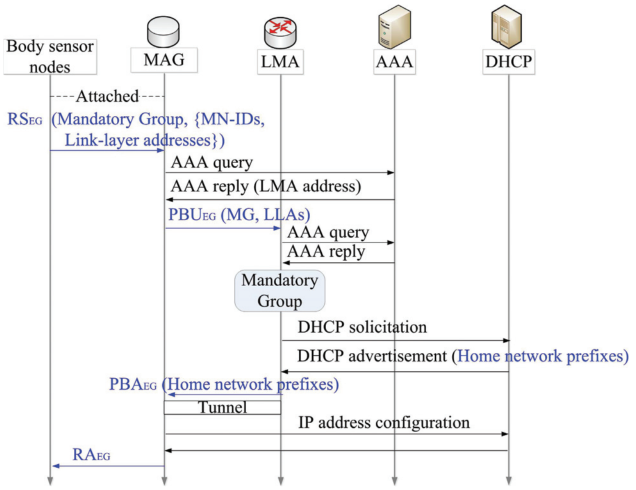

Fig. 7. The signaling call flow for the proposed registration scheme.

can reduce sending $n - 1$ times of the original RS and RA messages.

B. The Registration Phase

The registration phase aims to reduce the amount of control messages. Fig. 7 illustrates the signaling call flow. One of the body sensors needs to act as a coordinator, which can interact with other sensors in 6LoWPAN environment. All the sensors use DHCP-based address configuration. The procedure of the group-based registration is given as follows:

- S1 When a group of body sensors enter a PMIPv6 domain and attaches to an access link, the body sensor sends an RS_{EG} message by multi-hop transmissions to the MAG.
- S2 Upon the MAG received the RS_{EG} message, the MAG uses all the LL_ID_i one by one for authentication by sending the AAA query. After a successful authentication, the AAA server sends a reply which includes the LMA's address and the MN's profile.
- S3 After the MAG gets the LMA's address, MAG then sends a PBU_{EG} message, which contains all the identifiers, to the LMA.
- S4 Once the LMA receives the PBU_{EG} message, LMA performs access authentication to verify whether PBU_{EG} message is genuine or not.
- S5 If the PBU_{EG} message is trustworthy, the LMA initiates the DHCP solicitation procedure to request HNPs for the body sensors one by one. After the delegating router replies the unique HNPs for the body sensors (still one by one), the LMA creates the binding cache entry, stores the prefixes information, and assigns a BN, which is also added in the binding cache for classifying the body sensors into one group. Then, the LMA replies a PBA_{EG} message, which includes all of the body sensors' HNPs and BN, to the MAG. The LMA also sets up its endpoint of the bidirectional tunnel to the MAG.
- S6 After the MAG received the PBA_{EG} message, the MAG stores the BN and requests the addresses from the DHCP server on behalf of the body sensors. The DHCP server then configures the respective Home of address (HoA) from those prefixes and sends it to the MAG.
- S7 Upon received those messages, the MAG stores the IP address and sent an RA_{EG} message back.

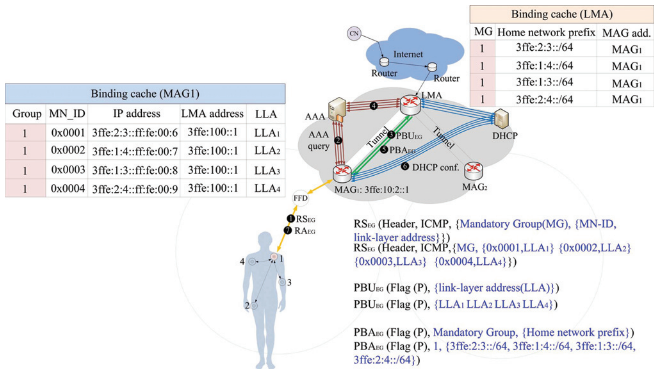

Fig. 8. An example of the registration phase.

Fig. 8 illustrates an example of the home registration scenario for a group of body sensors enter a PMIPv6 domain. Assume that sensor node 1 is the coordinator of the group of body sensors. In the first step, the group of body sensors are attached to an access first, S_i then sends the RS_{EG} (<Header, ICMP, 00, 0x0001, LL_ID_1, 0x0002, LL_ID_2, 0x0003, LL_ID_3, 0x0004, LL_ID_4>) message to the MAG. After the MAG gets the LMAs address, MAG then sends a PBU_{EG} (<flag (P), 0x00, NAI_1, LL_ID_1, NAI_2, LL_ID_2, NAI_3, LL_ID_3, NAI_4, LL_ID_4>) message which contains all the identifiers to the LMA on behalf of the group of the body sensors. In the 5th step, the LMA replies a PBA_{EG} (<flag (P), B_1, 3ffe:2:3::/64, 3ffe:1:3::/64, 3ffe:2:3::/64, 3ffe:1:4::/64>) message including all the HNPs and BN number of the body sensor group to the MAG. The LMA also sets up its endpoint of the bi-directional tunnel to the MAG. Upon receiving the DHCP advertisement messages, the MAG stores a set of home network prefixes 3ffe:2:3::ff:fe:00:6, 3ffe:1:4::ff:fe:00:7, 3ffe:1:3::ff:fe:00:8, 3ffe:2:4::ff:fe:00:9 and sends RA_{EG} message, which contains B_1 and the function of ACK, to the group of body sensors.

C. The Up-Link Handoff Phase

The body sensor performs an active scan that searches a list of the available channels by periodically sending a beacon request to the nearby FFDs. The nearby FFD, that receives

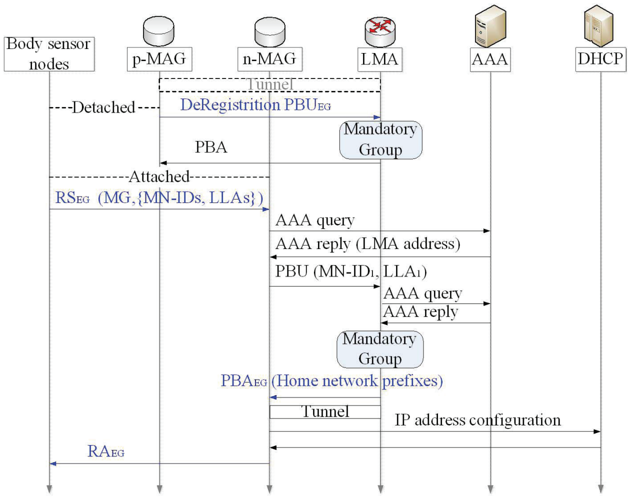

Fig. 9. The signaling call flow for the proposed handoff scheme.

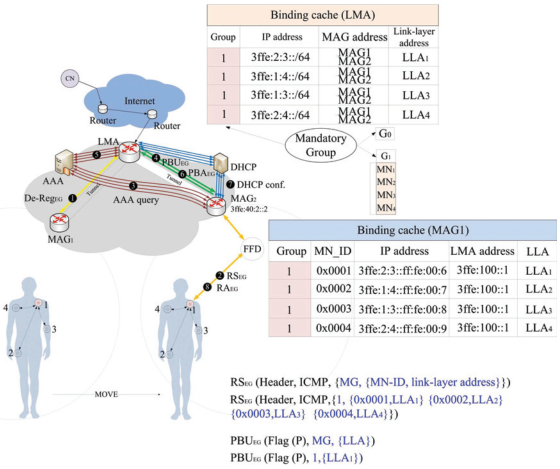

Fig. 10. An example for down-link handoff scenario.

the beacon request from the body sensor, advertises a beacon message including their MAG-IDs. Upon receiving the beacon messages, the body sensor decides whether itself is still in the same MAG or has moved to another MAG by comparing the current MAG-ID with the previous MAG-ID contained in the beacon message. If the comparative results of all the MAG-IDs in the received beacon messages are the same, the movement represents intra-PAN mobility, and the body sensor has moved within the same PAN area. On the other hand, if the body sensor moves from the previous MAG (p-MAG) to the next MAG (n-MAG), the body sensor is able to detect its movement since the current MAG_ID is different from the previous MAG_ID, as contained in the received beacon messages. The body sensor can then be associated with the new MAG.

Fig. 9 shows the detail of signaling call flow for the handoff procedure. The proposed protocol is able to reduce $(n-1)$ RS messages because it replaces per identifier per RS message with a set of all identifiers. Furthermore, by using the assigned BN, it can also save $(n-1)$ handoff messages such as deregistration PBU, PBU, and PBA. The proposed group-based handoff scheme is described as follows.

S1 When the previous link on MAG (p-MAG) detects the detachment event from the body sensor, the MAG will signal the LMA by sending the deregistration PBU. Instead of all nodes sending the deregistration PBU respectively (as the original protocol did), here the MAG sends only one LL_ID from the body sensor. Upon the LMA receives this message, LMA can obtain the rest sensors' information due to previously assigned BN, which is stored in the binding cache. After the LMA has confirmed all the information of sensors, the LMA will remove the binding and routing states if the LMA does not receive any PBU message within the given amount of time. Then, the LMA replies a PBA message and informs the MAG not to send other unnecessary deregistration PBU message. This way, the proposed scheme can reduce $(n-1)$ times of sending deregistration PBU to advertise the LMA.

S2 In order to let the n-MAG obtains the assigned group value of the body sensor, once the body sensor has attached to the new MAG (n-MAG), the coordinator of the body sensor sends the RS_{EG} message on behalf of all sensors to the n-MAG by unicast.

S3 Upon the n-MAG received the RS_{EG} message, MAG stores the BN, all the MN_ID_i and LL_ID_i in the binding cache. Then the n-MAG uses all the LL_ID_i one by one for authentication by sending the AAA query. After a successful authentication, the AAA server sends a reply which includes the LMA's address and the MN's profiles.

S4 This step aims to enhance the handoff performance by using the assigned group value in the LMA. Therefore, After the n-MAG obtaining the LMAs address, n-MAG sends a PBU_{EG} message. Compare to the original PMIPv6 protocol, the PBU_{EG} message can reduce $(n-1)$ times of binding message. The reason is that the LMA can obtain the other sensorsâŁ™ binding information by using the previously assigned BN.

D. Down-Link Handoff Phase

Fig. 10 illustrates an example of the down-link handoff procedure scenario for a group of body sensors enter a PMIPv6 domain. Assume that the sensor node 1 is the coordinator of the body sensor group. In the first step, the MAG sends only LL_ID_1. Upon the LMA receives this message, LMA knows the rest sensors' information due to the assigned B_1 value, which is stored in the binding cache. Once the group of body sensors attaches to the new MAG (denoted as n-MAG), the body sensor in B_1 sends the RS_{EG} (<Header, ICMP, 0x01, 0x0001, LL_ID_1 0x0002, LL_ID_2 0x0003, LL_ID_3 0x0004, LL_ID_4>) message and the value 0x01 of B_1 to the n-MAG.

The details of this phase are described as follows:

S1 Once the LMA received the PBU_{EG} message, the LMA still needs to perform authentication to verify whether the PBU_{EG} message is genuine or not.

S2 For obtaining the whole assigned prefixes information of the body sensor, the LMA uses the classified group ID to search for the necessary data from the binding cache. Hence, if the PBU_{EG} is trustworthy, within the given amount of time, the LMA replies a PBA_{EG} message, which includes all the body sensor's unique HNP_i. The LMA also changes the bidirectional tunnel from the p-MAG to the n-MAG and stores in the binding cache entry.

S3 After the n-MAG received the PBA_{EG} message, the n-MAG stores the information of HNPs and then sends the DHCP requests. Thus, the DHCP server identifies the client from the client-DUID and identifies that link from the link-address. After that, the DHCP server allocates the same addresses of all the body sensors' prefixes respectively to the n-MAG one by one.

S4 Upon received IP configuration messages, the n-MAG stores the IP address and sends an RA_{EG} message to the coordinator of the body sensor. After the coordinator receives the RA_{EG} message, the coordinator broadcasts the ACK to the rest of the body sensors.

As shown in Fig. 10, after the n-MAG gets the LMA's address, n-MAG then sends a PBU_{EG} ($<$ flag (P), 01, NAI_1, $LL\_ID_1>$) message, which contains only the coordinator's identifier and the B_1 (0x01). Hence, in the second step, the n-MAG receives the PBA_{EG} ($<$ flag (P), 3ffe:2:3::/64, 3ffe:1:3::/64, 3ffe:2:3::/64, 3ffe:1:4::/64$>$) message. Upon receiving those messages, the MAG stores the home network's pre-fixes 3ffe:2:3::/64, 3ffe:1:3::/64, 3ffe:2:3::/64, 3ffe:1:4::/64 on the binding cache and sends the RA_{EG} message, which has only the function of ACK, to the body sensors in B_1.

E. The Creation and Maintenance of Tunnels

When a group of body sensors enter a PMIPv6 domain and attaches to an access link, the body sensor sends an registration message (i.e. RS_{EG}) to the MAG. The MAG and the corresponding LMA exchange control messages (i.e. PBU_{EG} and PBA_{EG}) and then may establish a bidirectional tunnel between the MAG and LMA with IPv6-in-IPv6 encapsulation if the tunnel between the MAG and LMA does not exist. If the body sensor has detected that it has moved to the new MAG, it registers to the new MAG and may trigger a new tunnel between the new MAG and the corresponding LMA to be established if the tunnel does not exist. A timer is used for managing the tunnel lifetime and a counter for keeping a count of all the groups of body sensors that are sharing the tunnel. When the tunnel lifetime expires or there are no group of body sensors sharing the tunnel, the tunnel should be deleted.

V. PERFORMANCE ANALYSIS

In this section, the analysis of the handoff latencies of PMIPv6 and the proposed enhanced group mobility scheme ($PMIPv6\_EG$) in WBANs are provided. The handoff latency is defined as the period from the moment when the body sensor cannot receive the packet from the p-MAG (e.g. the body sensor has detached from the p-MAG) to the moment when the body sensor receives the first packet from the n-MAG (e.g. the body sensor has completed address configuration and received the RA_{EG} message). The signaling cost is defined as the total number of packets transmitted in the handoff procedure.

TABLE I
NOTATIONS USED IN THE ANALYSIS

n	number of body sensors in a human body
T_{PMIPv6}	Total delay time of the original protocol in PMIPv6 domain
T_{PMIPv6_G}	Total delay time of the group-based protocol in PMIPv6 domain
T_{PMIPv6_EG}	Total delay time of the proposed protocol in PMIPv6 domain
$\bar{T}_{PMIPv6}$	Average delay time of the original protocol in PMIPv6 domain
$\bar{T}_{PMIPv6\_G}$	Average delay time of the group-based protocol in PMIPv6 domain
$\bar{T}_{PMIPv6\_EG}$	Average delay time of the proposed protocol in PMIPv6 domain
T_{DHCP}	DHCP address configuration delay
T_{RS}	RS message transmission delay
T_{RA}	RS message transmission delay
T_{PBU}	PBU message transmission delay
T_{PBA}	RBA message transmission delay
T_{PBA_G}	RBA message transmission delay of the group-based protocol
$T_{RS_{EG}}$	RS_{EG} message transmission delay of the proposed protocol
$T_{RA_{EG}}$	RS_{EG} message transmission delay of the proposed protocol
$T_{PBU_{EG}}$	PRU_{EG} message transmission delay of the proposed protocol
$T_{PBA_{EG}}$	PBA_{EG} message transmission delay of the proposed protocol

To simplify the analysis of the handoff delay, the following assumptions are assumed:

- A group of body sensors in a human body move from p-MAG to n-MAG.
- The AAA access delay is not considered in the handoff procedure.
- All the body sensors use DHCP address configuration through the MAG.

For the ease of describing the analysis results, the notations used in the analysis are defined in Table I.

As shown in Fig. 3(a), the total handoff delay of the original protocol that the body sensor changes the point of attachment from p-MAG to n-MAG in PMIPv6 domain is denoted as:

$$T_{PMIPv6} = \sum_{i=1}^{n} i\,(T_{RS}+T_{PBU}+T_{DHCP}+T_{PBA}+T_{RA}) \quad (1)$$

Equation 1 can be simplified as:

$$T_{PMIPv6} = n(T_{RS} + T_{PBU} + T_{DHCP} + T_{PBA} + T_{RA}) \quad (2)$$

Hence, the average delay time is denoted as:

$$\bar{T}_{PMIPv6} = \frac{1}{n} T_{PMIPv6} = T_{RS}+T_{PBU}+T_{DHCP}+T_{PBA}+T_{RA} \quad (3)$$

As shown in Fig. 3(b), the total handoff delay of the group-based protocol that the body sensor changes the point of attachment from p-MAG to n-MAG in PMIPv6 domain is denoted as:

$$T_{PMIPv6\_G} = \sum_{i=1}^{n} i\,(T_{RS}+T_{DHCP}+T_{RA})+T_{PBU}+T_{PBA_G} \quad (4)$$

Equation 4 can be simplified as:

$$T_{PMIPv6\_G} = n(T_{RS}+T_{DHCP}+T_{RA})+T_{PBU}+T_{PBA_G} \quad (5)$$

Hence, the average delay time is denoted as:

$$\begin{aligned}\bar{T}_{PMIPv6\_G} &= \frac{1}{n}T_{PMIPv6\_Q} \\ &= T_{RS}+T_{DHCP}+T_{RA}+\frac{T_{PBU}+T_{PBA_G}}{n} \quad (6)\end{aligned}$$

As shown in Fig. 3(c), the total handoff delay of the proposed protocol that the body sensor changes the point of attachment from p-MAG to n-MAG in PMIPv6 domain is denoted as:

$$\begin{aligned}&T_{PMIPv6\_EG} \\ &= \sum_{i=1}^{n} iT_{DHCP}+T_{RS_{EG}}+T_{RA_{EG}}+T_{PBU_{EG}}+T_{PBA_{EG}} \quad (7)\end{aligned}$$

Equation 7 can be simplified as:

$$\begin{aligned}&T_{PMIPv6\_EG} \\ &= nT_{DHCP}+T_{RS_{EG}}+T_{RA_{EG}}+T_{PBU_{EG}}+T_{PBA_{EG}} \quad (8)\end{aligned}$$

Hence, the average delay time is denoted as:

$$\begin{aligned}\bar{T}_{PMIPv6\_EG} &= \frac{1}{n}T_{PMIPv6\_EQ} \\ &= T_{DHCP}+\frac{T_{RS_{EG}}+T_{RA_{EG}}+T_{PBU_{EG}}+T_{PBA_{EG}}}{n} \quad (9)\end{aligned}$$

In the proposed protocol, only the coordinator needs to connect to the FFD for carrying out the handoff process. The RS_{EG} message is sent from the coordinator to the MAG once. The PBU and PBA messages also can be reduced to one message respectively by using the PBU_{EG} and PBA_{EG} messages instead. After the MAG received the PBA_{EG} message, the MAG still has to carry out the DHCP configuration process for each of the body sensors one by one. Therefore, the DHCP configuration process still needs to be performed n times. After the DHCP configuration completing, the MAG sends a unicast RA_{EG} message once to the coordinator of the body sensors. Then the coordinator sends a broadcast RA_{EG} message to the rest of sensors. According to the results of Equations 3, 6, and 9, since $\frac{T_{RA_{EG}}}{n} < T_{RA}$, $\frac{T_{RB_{EG}}}{n} < T_{RB}$, $\frac{T_{PBU_{EG}}}{n} < T_{PBU}$, and $\frac{T_{PBA_{EG}}}{n} \le \frac{T_{PBA_G}}{n} < T_{PBA}$, we have $\bar{T}_{PMIPv6} > \bar{T}_{PMIPv6\_Q} > \bar{T}_{PMIPv6\_EG}$. Hence, the handoff delay of the proposed protocol is the smallest followed by the group-based protocol and the original protocol.

VI. Simulation Results

To evaluate the proposed enhanced group mobility protocol and the group-based handoff scheme [29], the Network Simulator-2 (NS2) with 6LoWPAN and PMIPv6 modules [30], [31] is used to simulate these protocols. The group mobility protocol proposed in [21] is not compared because it is based on MIPv6, while the proposed protocol is based on PMIPv6. The networks size is 150 × 150 m^2, the packet size is 1000 bytes and the data rate is 250 kbps. The initial delay value of the wireless link delay is 10ms and the delay link between the corresponding node and LMA is set as 10ms. The simulation scenario is that a human, who has attached several sensor nodes (from 1 to 10), moves from left to right. In this situation, the sensors implement the handoff process at the same time. The packet is forwarded from p-MAG to n-MAG. The performance metrics to be observed are shown as follows:

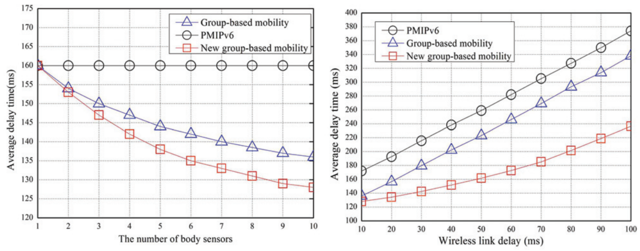

Fig. 11. Performance of average delay time vs. (a) The number of sensors. (b) Wireless link delay.

- The average delay time (ADT) is defined as the total delay time divided by the total number of sensor nodes.
- The packet loss ratio (PLR) is defined as the total number of lost data packets divided by the total number of transmitted data packets.
- The average signaling cost (ASC) is defined as the total number of control messages divided by the total number of sensor nodes for performing the handoff procedure.
- The packet overhead (PO) is defined as the total number of control packets and all data packets which includes retransmitted packets.

The simulation results for the average delay time (ADT), packet loss ratio (PLR), average signaling cost (ASC), and packet overhead (PO) are discussed from several aspects in following subsections.

A. Average Delay Time (ADT)

The simulation results of Average Delay Time (ADT) vs. the number of body sensors and wireless link delay are illustrated in Fig 11. Fig. 11(a) shows the average handoff latency (ADT) vs. the number of body sensors (from 1 to 10 sensors). In general, the ADT drops as the number of body sensors increases. This is because that the amounts of the RS and RA messages for each handoff of the group-based and the propose schemes are constants no matter what is the number of the body sensors and hence each body sensor needs to transmit less amount of messages and incurs lower average latency as the number of body sensors increases. Fig. 11(b) provides the simulation result of the average handoff latency (ADT) vs. the wireless link delay (ranging from 10 ms to 100 ms). The ADT increases as the wireless link delay increases because higher link delay incurs higher handoff and transmission latencies. The ADT of the proposed scheme is the lowest followed by the group-based and the PMIPv6 schemes. The results match with the analysis results in section V.

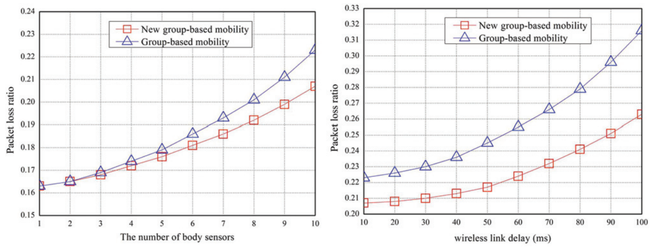

Fig. 12. Performance of packet loss ratio vs. (a) The number of sensors. (b) Wireless link delay.

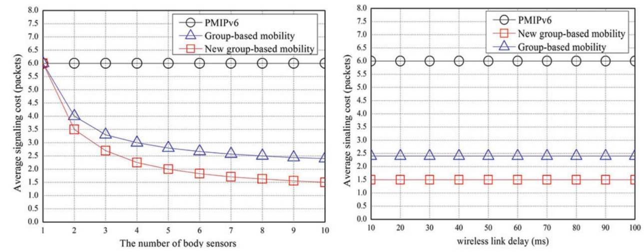

Fig. 13. Performance of average signaling cost vs. (a) The number of sensors. (b) Wireless link delay.

B. Packet Loss Ratio (PLR)

The simulation results of the packet loss ratio (PLR) vs. the number of body sensors and wireless delay time are illustrated in Fig 12. Fig. 12(a) shows the simulation result of PLR vs. the number of body sensors (ranging from 1 to 10 sensors). In general, the PLR increases as the number of body sensors increases because more number of body sensors incurs more handoff and more handoff incurs more packet losses. The PLR of our protocol is smaller than that of the group-based protocol with the increasing number of body sensors. Fig. 12(b) shows the simulation result of the PLR vs. the wireless link delay (ranging from 10 ms to 100 ms). In general, the PLR increases as the wireless link delay increases. The PLR of our protocol is smaller than group-based protocol with wireless link delay increasing. The reason is that the number of exchanged control messages in our enhance group mobility protocol is smaller.

C. Average Signaling Cost (ASC)

Fig. 13 shows the simulation results of the average signaling cost of handooff (ASC). Fig. 13(a) shows the simulation result of the ASC vs. the number of body sensors (ranging from 1 to 10 sensors). The ASC indicates the number of control messages exchanging between sensor nodes and MAG. The ASC of the proposed scheme is smaller than that of the group-based scheme because the proposed protocol can reduce the control message by using one message to carry other sensors nodes' information. In general, the ASC decreases as the number of body sensor increases. The reason is that the total signaling costs of the group-based and the proposed schemes do not increases much as the number of body sensors increases because the amounts of the RS and RA messages for each handoff of the group-based and the proposed schemes are constants no mater what is the number of the body sensors.

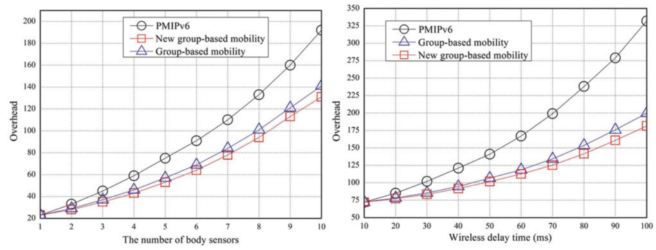

Fig. 14. Performance of overhead vs. (a) The number of sensors. (b) Wireless link delay.

The proposed scheme has the lower ASC than that of the group-based scheme, because the amount of the PBU and PBA messages for each handoff of the proposed scheme is a constant as opposed to the group-based scheme. Fig. 13(b) offers the simulation result of the ASC vs. the wireless link delay (ranging from 10 ms to 80 ms). In general, the ASC increases but does not have the direct relationship with the wireless link delay.

D. Packet Overhead (PO)

The simulation results of Packet Overhead (PO) vs. the number of sensors and wireless delay time are illustrated in Fig. 14. Fig.14(a) shows the PO vs. the number of body sensors (ranging from 1 to 10 sensors). In general, the PO increases as the number of body sensors increases. This is because more number of body sensors incurs more packet losses and more retransmissions of data. Fig.14(b) provides the simulation results of the packet overhead (PO) vs. the wireless link delay (ranging from 1 to 10 sensors). The PO increases as the wireless link delay increases. This is because longer wireless delay incurs more packet losses and more retransmissions of data.

VII. Conclusion

In this paper, an enhanced group mobility protocol is proposed. A new format of control message is proposed to combine the necessary information of the sensors into one message and thus it can reduce the number of control messages. Besides, an enhanced group-mobility scheme is proposed to further reduces the handoff delay time between the LMA and the MAG. The signaling cost can also be reduced due to the group management. Simulation results have shown that the handoff delay and signaling cost can be reduced by using the proposed enhanced group handoff scheme. In the future, we will study the security issues in wireless body area networks

References

[1] J. Xing, "A survey on body area network, networking and mobile computing," in *Proc. Int. Conf. Wireless Commun.*, Sep. 2009, pp. 1–4.

[2] (2013). *Ipv6 Over Low Power Wpan (active wg)* [Online]. Available: http://tools.ietf.org/wg/6LoWPAN

[3] *Wireless Medium Access Control and Physical Layer Specifications for Low-rate Wireless Personal Area Networks*, IEEE Standard 802.15.4-2003, Sep. 2006.

[4] D. Saha, A. Mukherjee, I. S. Misra, and M. Chakraborty, “Mobility support in IP: A survey of related protocols,” *IEEE Network*, vol. 18, no. 6, pp. 34–40, Nov. 2004.
[5] H. Soliman and C. Castelluccia, *Hierarchical Mobile IPv6 Mobility Management*, British, Royal Flying Corp., Aug. 2005.
[6] (Aug. 2008). *Proxy Mobile IPv6* [Online]. Available: http://merlot.tools.ietf.org/html/rfc5213
[7] M. Chen, S. Gonzalez, A. Vasilakos, H. Cao, and V. C. M. Leung, “Body area networks: A survey,” *Mobile Netw. Appl.*, vol. 16, no. 2, pp. 171–193, 2011.
[8] D. He, C. Chen, S. Chan, J. Bu, and A. Vasilakos, “Retrust: Attack-resistant and lightweight trust management for medical sensor networks,” *IEEE Trans. Inf. Technol. Biomed.*, vol. 16, no. 4, pp. 623–632, Jul. 2012.
[9] D. He, C. Chen, S. Chan, J. Bu, and A. Vasilakos, “A distributed trust evaluation model and its application scenarios for medical sensor networks,” *IEEE Trans. Inf. Technol. Biomed.*, vol. 16, no. 6, pp. 1164–1175, Nov. 2012.
[10] Z. Zhang, H. Wang, A. Vasilakos, and H. Fang, “Ecgcryptography and authentication in body area networks,” *IEEE Trans. Inf. Technol. Biomed.*, vol. 16, no. 6, pp. 1070–1078, Nov. 2012.
[11] R. Istepanian, E. Jovanov, and Y. Zhang, “Guest editorial introduction to the special section on mhealth: Beyond seamless mobility and global wireless health-care connectivity,” *IEEE Trans. Inf. Technol. Biomed.*, vol. 8, no. 4, pp. 405–414, Dec. 2004.
[12] G. Kushalnagar, G. Montenegro, J. Hui, and D. Culer, *Transmission of IPv6 Packets Over IEEE 802.15.4 Networks*, IETF Standard RFC 4944, 2007.
[13] M. Shin, T. Camilo, J. Silva, and D. Kaspar, “Internet-draft-6LoWPAN-mobility,” *Internet-Draft*, vol. 2, pp. 5–10, Nov. 2007.
[14] L. M. L. Oliveira, A. F. de Sousa, and J. P. C. Rodrigues, “Routing and mobility approaches in IPv6 over LoWPAN mesh networks,” *Int. J. Commun. Syst.*, vol. 24, no. 11, pp. 1445–1466, 2011.
[15] M. M. Islam and E. N. Huh, “Sensor proxy mobile IPv6 (SPMIPv6)—A novel scheme for mobility supported IP-WSNs sensors,” *Sensors*, vol. 11, pp. 1865–1887, Feb. 2011.
[16] R. Haw, E. Cho, C. Hong, and S. Lee, “A 6LoWPAN sensor node mobility scheme based on proxy mobile IPv6,” *IEEE Trans. Mobile Comput.*, vol. 11, no. 12, pp. 2060–2072, Dec. 2012.
[17] G. Bag, M. T. Raza, K. H. Kim, and S. W. Yoo, “Lowmob: Intra-pan mobility support schemes for 6LoWPAN,” *Sensors*, vol. 9, pp. 5844–5877, Jul. 2009.
[18] J. H. Kim, C. S. Hong, and T. Shon, “A lightweight nemo protocol to support 6LoWPAN,” *ETRI J.*, vol. 30, no. 5, pp. 685–695, 2008.
[19] V. Devarapalli, R. Wakikawa, A. Petrescu, and P. Thubert, *Network Mobility (NEMO) Basic Support Protocol*, IETF Standard RFC 3963, 2005.
[20] Y. Li, Y. Jiang, H. Su, D. Jin, L. Su, and L. ZengA, “A group-based handoff scheme for correlated mobile nodes in proxy mobile IPv6,” in *Proc. IEEE Global Telecommun. Conf.*, Dec. 2009, pp. 1–6.
[21] R. Chai, Y.-L. Zhao, Q. Bin Chen, T. Dong, and W.-G. Zhou, “Group mobility in 6LoWPAN-based wsn,” in *Proc. Int. Conf. WCSP*, Oct. 2010, pp. 1–5.
[22] F. Anwar, M. H. Masud, S. Bari, and S. A. Latif, “Enhanced hand-off latency reduction mechanism in layer 2 and layer 3 of mobile IPv6 (MIPv6) network,” *Austral. J. Basic Appl. Sci.*, vol. 7, no. 6, pp. 658–671, 2013.
[23] H.-S. Kim, S.-H. Park, C.-S. Park, J.-W. Kim, and S.-J. Ko, “Selective channel scanning for fast handoff in wireless lan using neighbor graph,” in *Proc. Int. Conf. Pers. Wireless Commun.*, Sep. 2004, pp. 194–203.
[24] S. Shin, A. G. Forte, A. S. Rawat, and H. Schulzrinne, “Reducing MAC layer handoff latency in IEEE 802.11 wireless lans,” in *Proc. Int. Workshop Mobility Manag. Wireless Access Protocols*, 2004, pp. 19–26.
[25] P.-J. Huang, Y.-C. Tseng, and K.-C. Tsai, “A fast handoff mechanism for IEEE 802.11 and IAPP networks,” in *Proc. IEEE Veh. Technol. Conf.*, May 2006, pp. 966–970.
[26] Y.-S. Chen, M.-C. Chuang, and C.-K. Chen, “Deucescan: Deuce-based fast handoff scheme in IEEE 802.11 wireless networks,” *IEEE Trans. Veh. Technol.*, vol. 57, no. 2, pp. 1126–1141, Mar. 2008.
[27] A. G. Forte, S. Shin, and H. Schulzrinne, “Improving layer 3 handoff delay in IEEE 802.11 wireless networks,” in *Proc. Int. Workshop Wireless Internet*, 2006, pp. 1–8.
[28] S. Speicher and C. H. Cap, “A fast handoff mechanism for IEEE 802.11 and IAPP networks,” in *Proc. Int. Symp. Wireless Commun. Syst.*, Sep. 2006, pp. 233–237.
[29] M. M. Islam and E. N. Huh, “A novel addressing scheme for PMIPv6 based global IP-WSNs,” *Sensors*, vol. 11, pp. 5844–5877, Aug. 2011.
[30] (2010). *Ns2 6LoWPAN Module* [Online]. Available: http://sourceforge.net/projects/LoWPAN/
[31] (2012). *Ns2 PMIPv6 Module* [Online]. Available: http://commani.net/pmip6ns/download.html

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Chih-Shun Hsu, photograph and biography not available at the time of publication.

Hau-Kai Lee, photograph and biography not available at the time of publication.