Efficient Mobility Management in 6LoWPAN Wireless Sensor Networks

Abdelwahed Berguiga, Habib Youssef
PRINCE Research Unit, ISITCom, Hammam Sousse
University of Sousse, Tunisia
abdelwahed.berguiga@infcom.rnu.tn, habib.youssef@fsm.rnu.tn

***Abstract*—Wireless Sensor Networks (WSNs) represent one of the most exciting today's research areas. Their utility ranges from causal sensing and data collection to mission critical applications such as battle field control, medical assistance, and natural disaster forecasting. With all the constraints related to WSNs, and with the urgent need to provide connectivity between sensor networks and the Internet, a new IETF Working Group, namely 6LoWPAN, was created. This group opens up a wealth of application opportunities as well as a number of difficult challenges. One of these challenges is the efficient support of sensor mobility. This paper proposes a mobility management scheme for IPv6 over Low power Wireless Personal Area Network (6LoWPAN) sensor nodes. We propose FPMIPv6-S (Fast handover Proxy Mobile IPv6 for Sensor networks), an improved version of the protocol PMIPv6, a protocol recently adopted as an RFC to support mobility in IPv6 based networks. We present a performance comparison of FPMIPv6-S with PFMIPv6, a recently proposed modification to PMIPv6 using an analytical approach. Performance results show that FPMIPv6-S exhibits a significantly lower number of messages exchanged and handoff latency, thus extending the network lifetime.**

***Keywords*—Wireless Sensor Networks; 6LoWPAN; FPMIPv6-S; PFMIPv6; Binding update cost; Packet delivery cost.**

I. INTRODUCTION

The emergence of low cost technologies in wireless communication has enabled the development of small wireless sensors. Characterized by their low cost, low power consumption and their implementation in different applications, wireless sensors have attracted attention in the academic field as well as in industry. Indeed, wireless sensors can be used in various applications such as remote control, health, and military applications. The distinguishing characteristic of sensors is their limited resources (memory and processing) and autonomous, but usually limited power supply.

Although it is a part of the domain of ad hoc networks, sensor networks and ad hoc networks differ in many ways. A WSN is composed of simple nodes. Applications require a few bytes sent periodically or on demand, generally triggered by an external event. Each node can be either a source or a destination of information. A sensor network may consist of hundreds of mobile nodes which can move from one place to another. These mobile nodes can communicate with each other or with external networks such as the Internet. So far, sensor networks use non-IP protocols such as the ZigBee 802.15.4 protocol stack [1]. Besides the fact that the ZigBee protocol is incompatible with the Internet Protocol, it introduces several constraints such as resource usage, energy consumptions, limited bandwidth, etc.

With all the constraints related to WSNs, and with the urgent need to provide connectivity between sensor networks and the Internet, a new IETF Working Group, namely 6LoWPAN [2], was created. The 6LoWPAN working group proposed two RFCs: RFC 4919 [2], which provides an overview, assumptions, problems, and goals for improving IPv6 over low power wireless PAN; and RFC 4944 [3], which specifies the transmission of IPv6 packets over IEEE 802.15.4 protocols. The integration of IPv6 in LoWPAN is expected to facilitate the introduction of new applications such as information sharing with other networks as well as the ability to provide cell-based mobility so that a session can be maintained while the device moves.

Indeed, providing IP connectivity to mobile 6LoWPAN devices may suggest that the devices can use traditional mobility related IP protocols such as Mobile IPv6 (MIPv6) [4], Hierarchical Mobile IPv6 (HMIPv6) [5], and Proxy Mobile IPv6 (PMIPv6) [6]. However, mobility using traditional mobility related IP protocols poses several challenges. First, the signaling overhead triggered by a sensor move can deplete sensor battery. Second, mobility always results in energy consumption due to the messages exchanged to synchronize with the new channel and also degrades the performance of the network due to packet loss. In addition, the connection discontinuity during handover can increase the delay and packet loss. Further, 6LoWPAN nodes are not equipped with a mobility protocol. Special proxy agents such as 6LoWPAN gateways are responsible for maintaining connectivity between 6LoWPAN mobile node and the Internet. The 6LoWPAN gateway is responsible for managing mobility-related functions on behalf of the 6LoWPAN sensor devices.

The objective of this work is to introduce a new IP-based related mobility protocol named Fast handover PMIPv6 for Sensor networks (FPMIPv6-S). We analyze and compare the binding update cost and packet delivery cost of our proposed scheme with PFMIPv6. This performance evaluation shows the most suited protocol to manage mobility in a wireless sensor network.

The remainder of the paper is organized as follows. Section II reviews background data related to IEEE 802.15.4 and mobility in WSNs. Section III presents an overview of Fast handover for PMIPv6. In Section IV, the proposed mobility scheme is described and discussed. Section V evaluates the location update cost and packet delivery cost using analytical model. Experimental results are given in Section VI. Finally, conclusions and future work are given in Section VII.

II. RELATED WORKS

Many proposals have been reported for wireless sensor networks to increase the lifetime of mobile sensors and thus improve their performance. The idea presented by David Kiyoshi Goldenberg et al. [7] is to have the nodes move to predetermined positions that minimize energy consumption to transmit the sensed data toward a static sink. Howard et al. [8] proposed an algorithm to be implemented on sensor guided by mobile robots. The main objective of this algorithm is to maximize the coverage area in order to increase the line-of-sight between robots. Rajesh Rao et al. [9] proposed distributed algorithms for mobile sensors. In this work, the proposed algorithms enable the sensor to move to new areas to optimize the transmitting power needed to send collected data toward the static sink. The new position of sensors is determined by distributed simulated annealing algorithms.

Chatzigiannakis and Nikoletseas [10] explore the possibility of using a small number of mobile coordinators for efficient communication between any pair of nodes in the network. These nodes act as mobile relays and they carry packets from source to destination. Indeed, the packets are exchanged when the source node and the relay are in the radio vicinity of each other. Then, the mobile relay forwards packets to the sink. With this approach, the energy required to transmit a packet from a node to the sink is reduced significantly. However, the problem of energy has been replaced by the delay because the sensor has to wait for the mobile relay to pass nearby. Also, this solution is feasible only in the so-called delay tolerant networks.

Most of the above proposed approaches do not take into account the connectivity between IEEE 802.15.4 based-network and existing IP-based infrastructure. Further, the majority of the proposed solutions provide mobility within the same IEEE 802.15.4 network. However, with the introduction of the *Internet of Things* (IoT), a wireless sensor network can be composed of several sub-networks (or clusters) that are interconnected via an existing transport network, e.g., the Internet. Communication across subnets is likely to be multi-hops.

Interconnecting a Wireless Personal Area Network (WPAN) such as a WSN to the Internet presents several challenging tasks. To overcome this problem, a 6LoWPAN protocol has been proposed to insure internetworking between ZigBee/802.15.4 and TCP/IP. Given the limited packet size of 802.15.4, the 6LoWPAN protocol describes methods and assumptions for improving IPv6 over low power wireless PAN. Providing IP connectivity to mobile 6LoWPAN devices may suggest that the devices can use traditional mobility related IP protocols such as Mobile IPv6 (MIPv6), Hierarchical Mobile IPv6 (HMIPv6), and Proxy Mobile IPv6 (PMIPv6). Unfortunately, deploying HMIPv6 and MIPv6 in the sensor networks requires the modification of the protocol stack of the mobile nodes. However, with sensors characterized by limited resources in terms of processing capacity and memory, it is difficult to modify the structure of their protocol stack. The PMIPv6 protocol provides network-based mobility management. With PMIPv6, a Mobile Node (MN) is exempt from participating in any mobility-related signaling. In fact, all messages signalling are supported by the proxy mobility agents namely Local Mobility Anchor (LMA) and Mobility Access Gateway (MAG). The main idea of PMIPv6 is that the MN is not involved in any IP layer mobility-related signaling. The problem with PMIPv6 in that all data traffic between the mobile and correspondent nodes is forwarded through the LMA. This presents two main drawbacks:

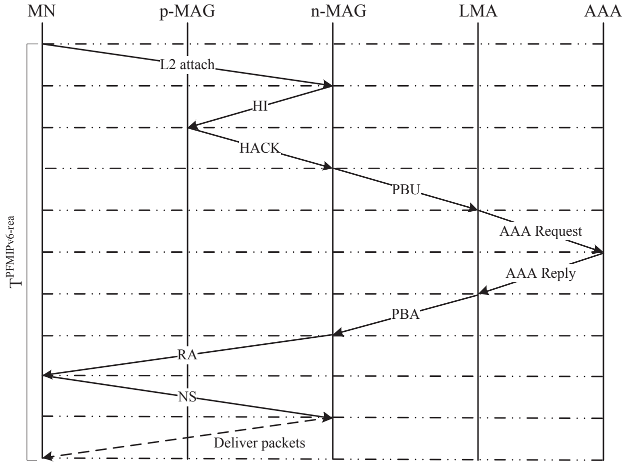

Fig. 1. PFMIPv6 handover procedure

1) Besides its mobility management role, the LMA will get overburden with data forwarding task between the communicating nodes.
2) Packets delivery delay will get increased because of the imposed transfer through the LMA.

Some efforts have recently been reported to adapt this protocol for WSNs. Islam et al. [11] have proposed a new scheme called Sensor Proxy Mobile IPv6 (SPMIPv6). SPMIPv6 is an adaptation of the PMIPv6 standard. However, SPMIPv6 inherits the centralized approach of PMIPv6 which has some limitations such as non-optimized routing path, single point of failure, packet loss, and long handoff latency which result degradation of mobility performance. In order to reduce packet losses during the handover latency, MIPSHOP working group [12] has standardized the Fast Handover for Proxy Mobile IPv6 (PFMIPv6). However, PFMIPv6 reduces only packet loss by creating, during the handover, a bi-directional tunnel between the previous MAG that is currently serving the MN and the new MAG to which the MN is most likely to move. However, handover latency is longer than PMIPv6, because of increased signalling during PFMIPv6 handover. Also, PFMIPv6 requires that a mobile node is capable of reporting lower-layer information, as stated in [12], which may also require a modification of the mobile node.

III. OVERVIEW OF FAST HANDOVERS FOR PMIPV6

The overall PFMIPv6 signaling flow includes two modes of handover: the first mode is reactive and the second is predictive. For simplicity, the terms MAG, LMA, and MN will be used here-in-after to unify the terms among PFMIPv6. Each step of the first mode, as shown in Figure 1, is described as follows [12]:

1) When a MN detects that a handover is imminent, it reports its identifier (MN ID) and the previous Access

Point Identifier (AP ID) to the new MAG (n-MAG) to which the MN is about to move.

2) Based on its neighbor local table, n-MAG can determine the previous MAG (p-MAG) address according to the tuples (AP-ID, MAG) of the context information. Then, the new MAG initiates the exchange of the handoff information by sending the Handover Initiate (HI) message to the previous MAG.
3) The p-MAG sends a Handover Acknowledge (HAck) message back to the n-MAG. The HAck message contains MN related context such as MN-HNP, and the LMA address that is currently serving the MN.
4) Once the n-MAG receives the HAck message, it establishes a bi-directional tunnel with the p-MAG and packets destined for the MN are forwarded from p-MAG to the n-MAG over this tunnel. This kind of routing may increase the end-to-end delay.
5) After that, n-MAG sends a Proxy Binding Update (PBU) message to the MN's LMA, whose address is provided in HAck message, to update the MN's new location.
6) The LMA sends a request message to the Authentication Authorization Accounting (AAA) server for the MN's access authentication.
7) After successful authentication, the LMA will reply by sending back a Proxy Binding Acknowledgment (PBA) message. In addition, the LMA establishes a bidirectional tunnel with the n-MAG. From this time, the packets to/from the MN go through the n-MAG instead of the p-MAG. In addition, n-MAG sends a RtrAdv message to the MN to advertise MN-HNP as the hosted on-link prefix.
8) Finally, after completing the address configuration procedure the MN is able to use the new address to continue sending/receiving data to/from corresponding node (CN).

However, although in PFMIPv6 the MN is exempt from any participation in any mobility related signaling, additional HI/HAck messages are required to be exchanged between p-MAG and n-MAG requesting buffered packets. Nevertheless, it is not defined based on which criteria and when n-MAG has to request the buffered packets from p-MAG. Also, another problem that may arise is a neighbor queue overflow at new MAG, as well as the long handoff latency, and non-optimized communication path.

IV. PROPOSED SCHEME (FPMIPV6-S)

A. FPMIPv6-S protocol architecture

In this section, we present our proposed scheme: Fast handover Proxy Mobile IPv6 for Sensor networks (FPMIPv6-S). FPMIPv6-S is an enhanced architecture of PFMIPv6 and its main objective is to reduce the handover latency of MN while moving and changing the attachment point to the new network. The FPMIPv6-S architecture consists of the following entities:

- **Sensor Mobile Access Gateway (SMAG)**: Sits on the network border and it acts like an access gateway router between MN and external network. Its main role is to detect the MN's movement and perform the mobility-related signaling with SLMA on behalf of the MN. Packets sent/received to/from the MN are routed through a tunnel created between the SMAG that is currently serving the 6LoWPAN MN and the SMAG whose the corresponding node is attached.

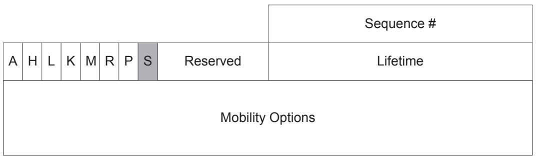

Fig. 2. FPMIPv6-S SBU Message Format

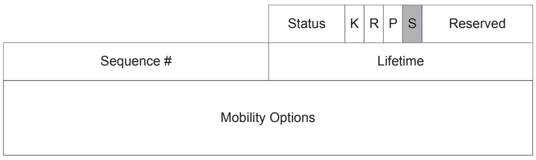

Fig. 3. FPMIPv6-S SBA Message Format

- **Sensor Local Mobility Anchor (SLMA)**: Acts like a Home Agent in MIP. SLMA is responsible of maintaining reachability with MN while it moves within a PMIPv6 domain.
- **6LoWPAN Mobile Node (MN)**: A device that changes its point of attachment from one network to another. The MN may change its location without changing its home address.

B. Message format for FPMIPv6-S

This section gives the message formats exchanged to perform the binding, and communication processes in the sensor PMIP domain. These messages include Sensor Binding Update (SBU), Sensor Binding Acknowledgement (SBA), Localized Routing Initiation (LRI), and Localized Routing Acknowledgment (LRA).

For binding query operation in FPMIPv6-S, we define the two new messages, SBU and SBA, by adding the 'S' flag bit into the existing PBU and PBA messages of PMIPv6, respectively, as shown in Figures 2 and 3. The SBU and SBA messages are exchanged between SMAGs and SLMA to update the current location of the 6LoWPAN MN. The definition and description of the other flags are beyond the scope of this study and are described in [6].

To perform the communication process, SLMA and SMAGs exchange localized routing (LR) messages to request local forwarding for a pair 6LoWPAN MN-CN which locates the MAG who's the CN is attached for delivery data packets. The key idea of the LRI and LRA messages is to introduce the route optimization process and reduce end-to-end delay [13]. Hence, all data packets can travel between 6LoWPAN MN and CN through a tunnel that is created between SMAGs without being intercepted by the SLMA. Therefore, this allows better routing of data packets between the 6LoWPAN MN and CN which results in the reduction of network load and end-to-end delivery delay.

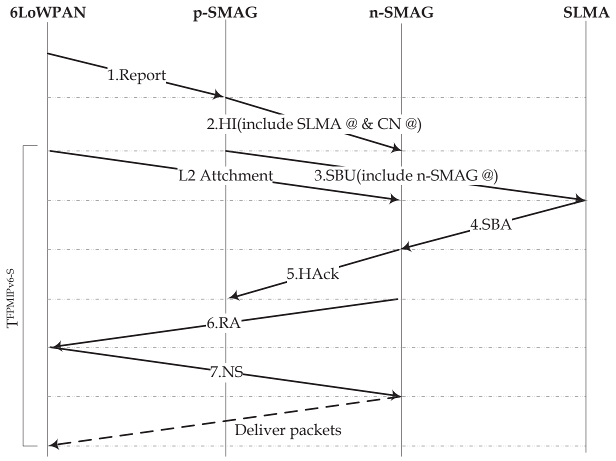

Fig. 4. FPMIPv6-S handover procedure

The procedure of sending data packets from 6LoWPAN MN to CN can be described as follows. First, given that the communicating MN and CN are anchored to the same SLMA, this latter initiates LR by sending two separate LRI messages to the two SMAGs. Each LRI message contains the IP address of the counterpart SMAG. When the SMAGs receive the LRI, each SMAG creates a local forwarding entry and a bi-directional tunnel is established between the two SMAGs such that all data packets, for which the destination is CN, are sent from the 6LoWPAN MN over this tunnel without being intercepted by the SLMA.

C. Message Flow in FPMIPv6-S

The steps of the sequence diagram of the message flow are shown in Figure 4. There are seven steps:

- **Step 1 and 2**: When a MN detects that it is entering a new sensor network, it sends a Report message to the previous SMAG (p-SMAG) that is currently serving the MN. The Report message contains the MN Identifier (MN ID) and the New Access Point Identifier (New AP ID). The p-SMAG sends a Handover Initiate (HI) message to the new SMAG (n-SMAG). The HI message MUST include both SLMA and CN addresses.
- **Step 3**: The p-SMAG sends the SBU message to the SLMA on behalf of the n-SMAG. The SBU message contains the default information like the PBU message on PFMIPv6 plus the n-SMAG address. From this moment, n-SMAG will wait for a SBA message from SLMA.
- **Step 4**: In response to the SBU, SLMA which includes both the authentication (AAA) and network information sends back a Sensor Binding Acknowledge (SBA) message.
- **Step 5**: Once n-SMAG receives SBA, it replies by sending HAck to p-SMAG, configures the required routing information needed to reach 6LoWPAN MN, and registers the requesting 6LoWPAN MN in its BUL table.

TABLE I. Performance evaluation related parameters

Parameter	Description
T_{x-y}	Transmission cost of a packet between nodes x and y
P_C	Processing cost of node C for binding update or lookup
N_{MAG}	Number of MAGs in the PMIP domain
$N_{MN/MAG}$	Number of active MNs per MAG
C_{x-y}	Hop count between nodes x and y
S_{ctrl}	Size of control packet (byte)
S_{data}	Size of data packet (byte)
a	Unit cost of binding update with LMA
b	Unit cost of lookup for MN at LMA
t	Unit transmission cost of a packet per hop (wired link)
k	Unit transmission cost of a packet per hop (wireless link)

- **Step 6**: n-SMAG sends a RtrAdv message to 6LoWPAN MN. When the 6LoWPAN MN receives this RtrAdv message, it will configure its IP address using either a stateful or stateless address configuration.
- **Step 7**: Once the MN performs address configuration, it sends a Neighbor Solicitation (NS) message to n-SMAG, and accordingly the MN is connected to the n-SMAG. From this moment, the sensor node is able to communicate with the CN through SMAGs.

V. PERFORMANCE EVALUATIONS

In this section, we analyze the performance of PFMIPv6 and FPMIPv6-S in terms of binding update cost (BUC) and packet delivery cost (PDC). We define the total cost (C_{total}) as the sum of binding update cost and packet delivery cost, i.e.,

$$C_{total} = BUC + PDC \tag{1}$$

Table I gives notations used in this work [14] [15] [16]. For simplicity, we consider that all costs are symmetric, i.e., T_{x-y}=T_{y-x}.

A. PFMIPv6 cost analysis

The binding update process of PFMIPv6 is performed as follows: When MN enters a new MAG (n-MAG) region, it performs the channel scanning which corresponds to the handover latency at L2 (T_{MAG-MN}). Then, there is an exchange of HI and HAck messages between the new MAG and the previous MAG (p-MAG). This operation takes 2$T_{MAG-MAG}$.

After that, n-MAG performs the binding update operations by exchanging the PBU and PBA control messages with LMA which takes 2$T_{MAG-LMA}$+P_{LMA}. The n-MAG, on receiving the PBA message, sends back a Router Advertisement (RA) message to the MN which takes T_{MN-MAG}. After receiving RA and configuring its IP address using either a stateful or stateless address configuration, the MN sends a neighbor solicitation message to n-SMAG and performs the Layer 2 attachment which corresponds to 2T_{MN-MAG}.

We noted that the authentication process to be done by LMA via Authentication, Authorized and Accounting server (T_{AAA}) will be simply expressed as the delay to exchange

TABLE II. Parameter values

Parameter	Default value
N_{MAG}	20
$N_{MN/MAG}$	200
$C_{MAG-LMA}$	5
$C_{MAG-MAG}$	$\sqrt{N_{MAG}}$
S_{ctrl}	50 bytes
S_{data}	1024 bytes
a	3
b	2
t	2
k	4

messages between LMA and AAA server [17]. Hence, the binding update cost can be expressed as follows:

$$\begin{aligned} BUC^{PFMIPv6} &= S_{ctrl}(4T_{MN-MAG} + 2T_{MAG-LMA} \\ &+ 2T_{MAG-MAG} + T_{AAA}) + P_{LMA} \\ &= S_{ctrl}(4kC_{MN-MAG} + 2tC_{MAG-LMA} \\ &+ 2tC_{MAG-MAG} + T_{AAA}) \\ &+ alog(N_{MAG} \times N_{MN/MAG}) \end{aligned} \tag{2}$$

It is assumed that the processing cost for binding update with LMA (P_{LMA}) is proportional to the total number of active MNs in the LMA domain (N_{MAG}x$N_{MN/MAG}$) in the log scale by using a tree-based data structure to implement the database. Therefore, the processing cost at the LMA can be expressed as follows:

$$P_{LMA} = alog(N_{MAG} \times N_{MN/MAG}) \tag{3}$$

In PFMIPv6, the packet delivery process consists of sending data packet from MN to CN. First, a packet is sent from the MN to the LMA via its MAG, which is equal to T_{MN-MAG} + $T_{MAG-LMA}$. Then, the LMA will look for CN address in its binding cache which requires P_{LMA}. Finally, LMA sends the packet to MAG of CN ($T_{MAG-LMA}$), and further to CN (T_{MAG-CN}). Therefore, the PDC for PFMIPv6 can be expressed as follows:

$$\begin{aligned} PDC^{PFMIPv6} &= S_{data}(T_{MN-MAG} + 2T_{MAG-LMA} \\ &+ T_{MAG-CN}) + P_{LMA} \\ &= S_{data}(kC_{MN-MAG} + 2tC_{MAG-LMA} \\ &+ kC_{MAG-CN}) \\ &+ blog(N_{MAG} \times N_{MN/MAG}) \end{aligned} \tag{4}$$

B. FPMIPv6-S cost analysis

As we have already mentioned in Section IV-C, in FPMIPv6-S the p-SMAG sends SBU message to the SLMA on behalf of the n-SMAG, which corresponds to $T_{SMAG-SLMA}$. On receiving the SBU, SLMA will perform the needed authentication and registration processes which take $2P_{SLMA}$. After that, SLMA replies by sending back the SBA that contains the MN's home network prefix ($T_{SLMA-SMAG}$). Once the n-SMAG gets SBU message, it will directly reply by sending HAck to the p-SMAG and RA to the MN, which takes $T_{SMAG-SMAG}$+$T_{SMAG-MN}$. After receiving RA and configuring its IP address using either a stateful or stateless address configuration, the MN sends a neighbor solicitation message to n-SMAG and performs the Layer 2 attachment which corresponds to $2T_{MN-SMAG}$.

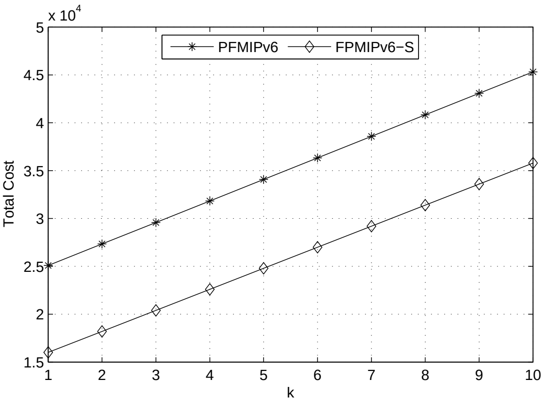

Fig. 5. Total cost versus *k*

$$\begin{aligned} BUC^{FPMIPv6-S} &= S_{ctrl}(3T_{MN-SMAG} + 2T_{SMAG-SLMA} \\ &+ 2T_{SMAG-SMAG}) + 2P_{SLMA} \\ &= S_{ctrl}(3kC_{MN-SMAG} \\ &+ 2tC_{SMAG-SLMA} + 2tC_{SMAG-SMAG}) \\ &+ 2alog(N_{SMAG} \times N_{MN/SMAG}) \end{aligned} \tag{5}$$

We note that, from Figure 4, the handover delay is equal to the period from the moment that 6LoWPAN MN starts L2 attachment to the moment that 6LoWPAN MN receives the first packet from n-SMAG.

In the case of data packet delivery, we analyze the communication between two MNs that belong to different MAGs in the same domain. As we mentioned earlier, when the MN is attached to the n-SMAG, SLMA exchanges localized routing messages with n-SMAG and p-SMAG to request local forwarding for a pair 6LoWPAN MN-CN. When the SMAGs receive the LRI, each MAG creates a local forwarding entry and a bi-directional tunnel is established between two SMAGs such that all data packets, in which the destination is CN, are sent from the MN over this tunnel. Accordingly, the packet delivery cost for FPMIPv6-S can be expressed as follows:

$$\begin{aligned} PDC^{FPMIPv6-S} &= S_{data}(T_{MN-SMAG} + T_{SMAG-SMAG} \\ &+ T_{SMAG-CN}) + S_{ctrl}4T_{SMAG-SLMA} \\ &= S_{data}(kC_{MN-SMAG} \\ &+ tC_{SMAG-SMAG} + kC_{SMAG-CN}) \\ &+ S_{ctrl}4tC_{SMAG-SLMA} \end{aligned} \tag{6}$$

VI. NUMERICAL RESULTS

In this section, we show numerical results based on the analysis derived in the previous section. To simplify our analysis, we only focus on analyzing the handover latency within a same domain. The other possible scenarios [18] for interdomain movement are not considered in the present document, and they are set as future work. The parameter

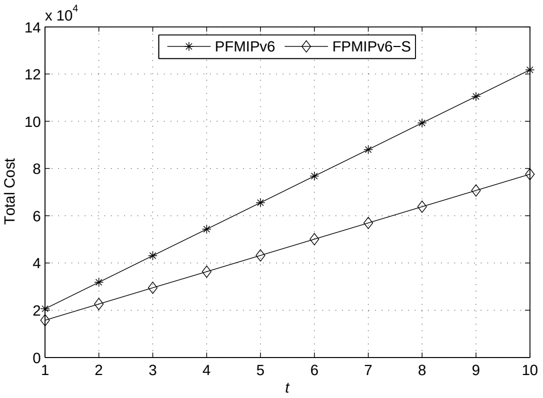

Fig. 6. Total cost versus *t*

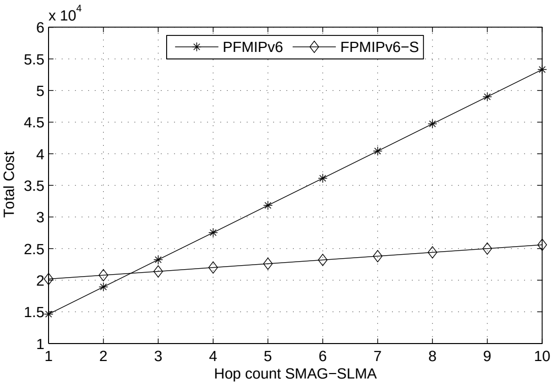

Fig. 7. Total cost versus hop count SMAG-SLMA

values are taken from [14] [15] [16]. They are shown in Table II.

Figure 5 shows the total cost with respect to the wireless link delay. In this analysis, we have changed the parameter (*k*) and setting all other parameters to their default values. We see that the total cost for the two protocols increases linearly with the increment in the wireless link delay. The proposed scheme FPMIPv6-S gives better performance than PFMIPv6 scheme. This is due to the protocol properties. Indeed, as shown in Section IV-C, the handover latency is reduced since the L2 attachment is not taken into account during the exchange of Sensor Binding Update/Acknowledge messages.

Figure 6 shows the impact of wired link delay on total cost. For all of the mobility protocols, it can be observed that the total cost considerably increases as the wired link delay increases. FPMIPv6-S results in a lower total cost latency than PFMIPv6. As mentioned earlier with PFMIPv6, when a MN wants to send a data packet to a CN, all data packets get routed to the LMA through a tunnel between the MAG and the LMA. Then, LMA forwards the packet to the destination MAG. Thus, when the data packet size is increased, the cost to send it is also increased. Also, this can create the triangle routing problem. However, with FPMIPv6-S, we don't need to send a data packet to SLMA. Indeed, control messages must be exchanged between SMAGs and SLMA. As a result, a tunnel between SMAGs is established, and all packets exchanged between 6LoWPAN mobile and correspondent nodes are tunneled through this optimized routing path.

Figure 7 illustrates the variation in the total cost as the distance between the SMAGs and SLMA (MAGs and LMA) is changed. From the Figure, it is clear that the total cost increases for all the mobility protocols schemes. However, when the hop count is larger than 3 hops, PFMIPv6 has higher total cost than FPMIPv6-S. This is because sending a data packet from MN to CN must include intermediate nodes such as SLMA (LMA). However, with FPMIPv6-S, only control packets must be exchanged between SMAGs and SLMA to find the CN's location.

VII. CONCLUSION AND FUTURE WORK

In this paper, we studied the problem of mobility management for 6LoWPAN mobile sensor nodes. We presented PFMIPv6-S , a new fast proxy-based mobility management protocol, which is an improved version of PFMIPv6. We have conducted a comparative analytical study for two mobile protocols, PFMIPv6 and FPMIPv6-S. We compared the total cost which is expressed as the sum of binding update cost and packet delivery cost. The performance analysis and the numerical results presented in this work shows that our proposal significantly outperforms PFMIPv6. We are in the process of building NS3 simulation models of PFMIPv6 and FPMIPv6-S protocols in order to validate our analytical results and to perform a more thorough evaluation.

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