# PA-NEMO: Proxy Mobile IPv6-aided Network Mobility Management Scheme for 6LoWPAN

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***Abstract*—The IPv6 over Low Power Wireless Personal Area Network (6LoWPAN), a special type of Wireless Sensor Networks (WSNs) with mobility, has a great potential to be deployed for the convenience of people's life. In 6LoWPAN, a group of sensor nodes often move together as a whole subset, guiding by a cluster head. Because of the low-power requirements of mobile devices in 6LoWPAN, seeking low cost schemes to manage the mobility of the whole subset is a very essential problem to be solved. To this end, this paper firstly proposes a Proxy Mobile IPv6 (PMIPv6) Aided Network Mobility (NEMO) management scheme, referred to as PA-NEMO, for 6LoWPAN, by combining traditional PMIPv6 with NEMO Basic Support scheme. In the proposed PA-NEMO scheme, the transmission tunnels are established out of the 6LoWPAN area, so the cost of the devices can be greatly reduced. Then, we formulate and analyse the signalling overhead of the proposed PA-NEMO. Finally, some numerical results are presented to show that our proposed PA-NEMO achieves the lowest signalling overhead among existing mobility management schemes.**

***Index Terms*—Wireless sensor network, 6LoWPAN, NEMO, PMIPv6.**

## I. INTRODUCTION

These years, wireless sensor networks (WSNs) are widely investigated due to its great potential in environmental monitoring, intelligent transportation, healthcare and so on [1], [2]. In WSNs, a large number of small and simple sensor devices communicate over short range wireless interfaces to deliver observations over multiple hops to central sites. In the earliest stage, sensor nodes in WSNs were often assumed static, so the protocols were designed without capability of supporting mobility, which severely constrains the application scenario of WSNs.

Actually, mobile devices can also be used as sensor nodes in WSNs. In many deployment scenarios, such as soldiers in battlefield surveillance applications, animals in habitat monitoring applications, and buses in a traffic monitoring application, mobile platforms are already available in the deployment area. Besides, in other scenarios mobile devices including airborne and ground-based vehicles, also can be incorporated into the WSN [2]. Therefore, it is necessary to extend its functions to support mobility in WSNs.

Low-power wireless personal area networks (LoWPAN) are composed of sensing nodes compliant with standard IEEE 802.15.4 [3] for wireless communications support. The LoWPAN nodes are often with small size, constrained power, limited computing and storage resources, so WSN can be considered as a subtype of LoWPAN.

Nowadays, the Internet of Things paradigm [4] requires that the sensor nodes are natively IP-enabled and Internet connected. Hence, the IPv6 over LoWPAN, i.e., 6LoWPAN, was designed, which is considered as one of the most typical applications of WSN with mobility [5]. Particularly, mobility support also is regarded as the most important reason for the success of 6LoWPAN. However, excessive signalling cost for supporting mobility makes it difficult to implement, which has become a barrier for the application of 6LoWPAN especially in mobility scenarios.

As for network mobility, it can be divided into two classes. One is single node mobility and the other is subnet mobility. Compared with single node mobility, subnet mobility is more difficult to manage. Nevertheless, since subnet mobility can be increasingly found in many practical scenarios including mobile uses on trains, etc., in this paper, we focus on the subnet mobility for 6LoWPAN.

In the subnet mobility scenario of 6LoWPAN, though currently existing subnet mobility management scheme like NEMO-BSP [6] (simply called NEMO) is suggested to manage the whole subnet mobility in 6LoWPAN, it is actually not suitable for WSNs. First, NEMO is a host-based mobility management protocol, but 6LoWPAN itself is made up of resource limited, little memory and low computation power processing ability sensor devices. Second, NEMO has no compressing procession on mobility header, which means a modification must be done on the protocol itself. Therefore, NEMO is not a good choice to manage the whole mobility of 6LoWPAN. Another excellent mobility management protocol, Proxy Mobile IPv6 (PMIPv6 [7]), is a network-based mobility management protocol, but it is designed to support the mobility of single host rather than subnet. Additionally, the separated management leads heavy signalling overhead to PMIPv6. So, PMIPv6 is also not suitable to be employed in the subnet mobility scenario of 6LoWPAN.

Manuscript received April 20, 2013; accepted August 26, 2013.
This work was supported by the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University under Grant no. RCS2012ZT008 and no. RCS2012ZT007, by the National Nature Science Foundation of China (NSFC), no. 61201203 and no. 61171064 and partly by "973" program, no. 2012CB316100(2).

In [8], the authors reviewed the state of the art related with routing and mobility support in 6LoWPAN, and surveyed the available solutions proposed to support routing and mobility over 6LoWPAN mesh networks. As a conclusion, it was pointed out that the design of a new protocol to deal with mobility for 6LoWPAN is still an open issue and challenge.

To this end, in this paper, we design a novel low-cost mobility management scheme for 6LoWPAN. Our contributions are as follows.

– First, we propose a PMIPv6- aided NEMO (PA-NEMO) scheme, which is a network-based subnet mobility management scheme with PMIPv6 for 6LoWPAN;

– Second, we propose an address mapping scheme, which avoids tunnel establishment to reduce the signalling overhead;

– Third, by extensive numerical analysis on the signalling overhead of PA-NEMO scheme, NEMO-based scheme and PMIPv6-based scheme, we show the validity and efficiency of the designed PA-NEMO scheme.

The organization of this paper is as follows. Section II recalls the 6LoWPAN protocol and the existing mobility management researches. Section III presents our PA-NEMO scheme. Section IV analyses the signalling overhead of 6LoWPAN. Section V gives some numerical results, which show that PA-NEMO achieves the lowest signalling overhead among existing mobility management schemes.

## II. RELATED WORKS

For clearly present or proposed PA-NEMO in Section III we shall give a brief review of three typical protocols for supporting the mobility in WSNs.

### A. 6LoWPAN Protocol

6LoWPAN is one of the most typical applications of WSN, which focuses on the IPv6 low power personal area network. 6LoWPAN is made up of two kinds of sensor nodes. One is the cluster head, called gateway. The other is common mobile lower power sensor nodes. In 6LoWPAN, in order to communicate with the outside IP-based network, a modification should be made to the gateway to provide IP fragment reassembly, header compression and decompression, and the intrinsic mesh routing.

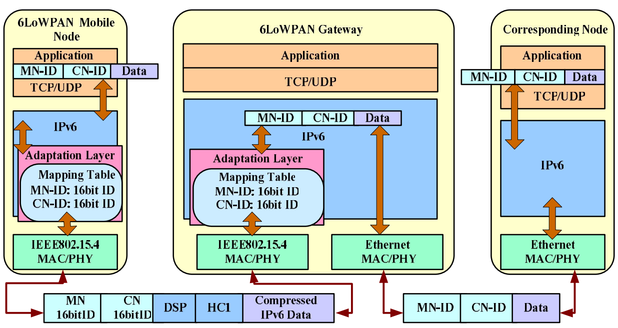


Fig. 1. Data transmission procedure in 6LoWPAN.

Figure 1 presents the data transmission procedure of a 6LoWPAN inside sensor node with a normal IPv6 node through a modified gateway.

### B. NEMO-based Mobility Management Scheme

NEMO is composed of two main mobile entities. One is the mobile router (MR), which processes the mobility signaling and supplies the transparent mobility for mobile nodes (MN) accessed to it. The other is the home agent (HA), which manages the mobility signaling and allocates the home address for MN.

As the current 6LoWPAN gateway has no compression method on mobility header, a modification should be made to the NEMO protocol to meet the low weight requirements of 6LoWPAN. After the procession, a new low weight NEMO (LoWNEMO [4]) can be used to fulfill the subnet mobility management. The handoff procedure is shown in Fig. 2.

Though LoWNEMO can be used to manage the whole mobility of 6LoWPAN, it is not a suitable alternate scheme because: first, changes should be made on protocol itself. Second, as shown in Fig. 2 the bi-direction tunnel spreads into 6LoWPAN, which increases the signalling overhead of 6LoWPAN simultaneously.

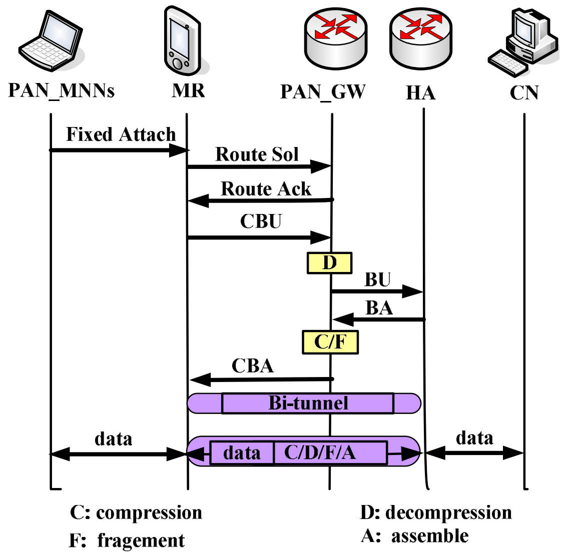


Fig. 2. NEMO-based Mobility Management Scheme for 6LoWPAN.

### C. PMIPv6-based Mobility Management Scheme

PMIPv6 is also featured with two main entities. One is the Localized Mobility Anchor (LMA) and the other is the Mobile Access Gateway (MAG). LMA maintains the binding items for each node that registered with it, periodically advertises prefix information and intercepts packets destined to it. MAG always emulates the MN's home link, detects the activities of MN and handles overall mobility-related signalling on behalf of MN. Figure 3 presents the procedure of PMIPv6-based mobility management scheme for 6LoWPAN [9].

As shown in Fig. 3, the mobility management signaling is processed outside of the 6LoWPAN region and the problem exists in the NEMO-based scheme disappears. But PMIPv6 can only manage the mobility for hosts, which cannot manage the subnet mobility. So the total signaling cost inevitably linearly increases with the expansion of the subnet scale.

## III. THE PROPOSED PA-NEMO

In this section, we introduce the proposed PA-NEMO. As shown in Fig. 4, there are two types of handoff scenarios in 6LoWPAN, where move1 and move2 represent the intra-PAN handoff and the inter-PAN handoff, respectively.

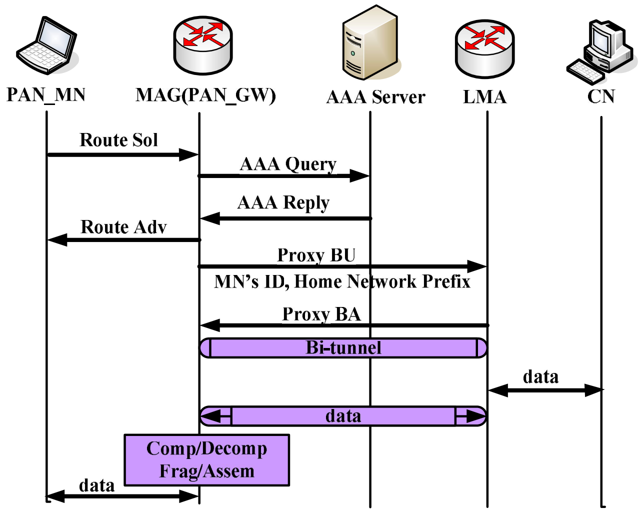


Fig. 3. PMIPv6-based Mobility Management Scheme for 6LoWPAN.

In conventional PMIPv6, MAG only detects the single-hop handoff. To break through the limit, in PA-NEMO, MR actively notifies MAG about its attachment by the interaction of route solicitation (RS) and route advertisement (RA). Furthermore, an address mapping approach is proposed to decrease overall signalling overhead.

In the section, we will separate the analysis on the mobility management procedure into three aspects. They are the address mapping, the mobility management and the packet transmission, respectively.

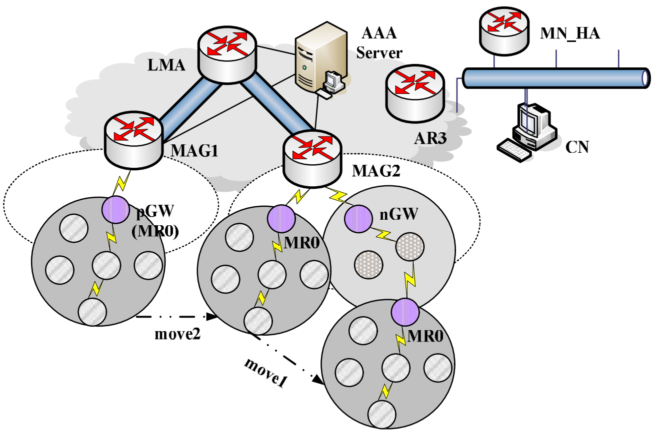


Fig 4. PA-NEMO supported subnet handoff scenario.

## A. Address Mapping

PA-NEMO is an integration mobility management scheme of PMIPv6 and NEMO, and address mapping scheme is one of the creations. According to the address mapping approach, the Mapping Cache List (MCL) is maintained synchronously by MR and MN-HA. In this way, packets destined to MN are transmitted firstly to MN-HA executing address mapping, then go through the bi-tunnel between LMA and MAG, which arrive at MR running address anti-mapping, and finally reach MN. The address mapping procedure is illustrated in Table I.

Each MN that participates in the subnet movement will carry out the address mapping procedure instead of tunnel establishment, which reduces the overall overhead in packet transmission by restricting the length of the packet header. In the address mapping scheme, all MN as long as they stay obediently within the subnet will enjoy a fixed locator, even if subnet handoff takes place. When an inter-PAN subnet handoff occurs, neither MR nor MN-HA has to update the MCI, which is an inevitable procedure in the common mobility management scheme.

***Address mapping Algorithm***
***If*** *a* ***new MobileNode*** *(nMN) wants to become a member of a subnet*
*nMN sends access solicitation to MR*
*MR checks whether the MCL about the nMN stored on it*
***If*** *there is already an item about the nMN on MR*
*MR sends access reply to nMN*
***Exit***
***Else***
*MR builds a mapping relation between the HoA of the nMN and the address of the MR*
*Everytime packets transmit passing through MR, an address mapping procedure is triggered.*
***End***

## B. Mobility Management

The mobility management procedure of PA-NEMO in 6LoWPAN can be presented as Fig. 5. At the beginning, the two end hosts are communicating with each other through a data link. And then one host moves into another PAN area guiding by a MR.

For the subnet inter-PAN handoff, if one moves into the broadcasting domain of MAG, MAG can directly detects its entertain. If one moves out of the broadcasting domain, MR first executes RS/RA to discover MAG, and then repeats the conventional PMIPv6 procedure.

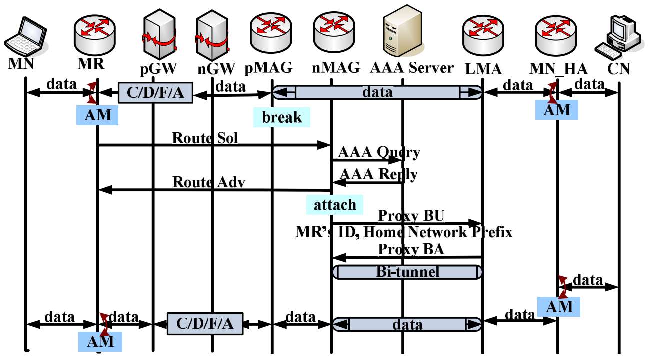


Fig. 5. 6LoWPAN working mode based PA-NEMO.

## C. Packets Transmission

Here we take the subnet handoff scenario described in Fig. 4 as the analysis model. Packets to and from MN are transmitted hop-by-hop through 6LoWPAN sensor nodes, MR, MAG, LMA, MN-HA and so on. The procedure of the packet transmission can be presented as shown in Fig. 6.

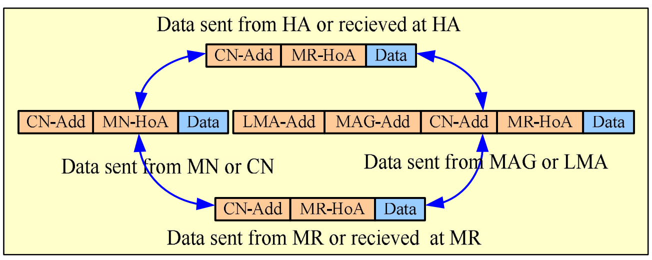


Fig. 6. Packet transmission procedure.

For the packet transmitted from CN to MN, the source and destination addresses are the CN-Add and MN-HoA. The packet is first forwarded to MN-HA according to the longest prefix matching mechanism, then the MN-HoA is mapping to

MR-Add and the CN-Add remain unchanged. After that, the packet arrives at LMA based on the previous prefix matching principle. Passing through the bi-tunnel between LMA and MAG, it reaches MR executing an address anti-mapping. Finally, the packet is delivered to MN, and vice versa.

## IV. Signalling Cost Analysis

In this section, we analyse the signalling cost of PA-NEMO scheme of 6LoWPAN. For comparison, the signalling cost of NEMO-based scheme and PMIPv6-based scheme are also presented. As in the intra-PAN handoff procedure, no mobility signalling is required and just route updating or route re-establishing is enough， thus in the following analysis, we assume the signalling cost for intra-PAN mobility management to be zero. For clarity, we define some notations as follows:

TABLE I. NOTATIONS.

| | |
|---|---|
| $C_{Tot}$: | The total signaling cost |
| $C_H$: | The subnet handoff management cost |
| $C_F$: | The packet forwarding cost |
| $N$: | The number of mobile network nodes |
| $H_{MM}$: | The number of hops between MR and MAG/AR |
| $H_{MA}$: | The number of hops between MAG/AR and AAA |
| $H_{ML}$: | The number of hops between MAG/AR and LMA/MR_HA |
| $H_{LH}$: | The number of hops between LMA/MR_HA and MN_HA |
| $H_{HC}$: | The number of hops between MN_HA and CN |
| $H_{NM}$: | The average number of hops between MN and MR |
| $\delta_{LMA}$: | The processing cost of binding update or packet at HA/LMA |
| $\delta_{MAG}$: | The processing cost of binding update or packet at MR/MAG/GW |
| $p_t$: | The proportional coefficient that means average transmission cost on tunneled path per hop |
| $p_{nt}$: | The proportional coefficient that means average transmission cost on no tunneled path per hop |
| $p$: | The probability of subnet moving outside of a given domain |
| $T$: | The average resident time that a subnet stays in the same PAN |

### A. Signaling Cost of NEMO-based Scheme.

We assume the total signalling cost composing of location management cost, handoff management cost and packet forwarding cost as depicted in (1)

$$C_{Tot}^{(\mathrm{NEMO})} = C_L^{(\mathrm{NEMO})} + C_H^{(\mathrm{NEMO})} + C_F^{(\mathrm{NEMO})}. \quad (1)$$

So the analysis of the total signalling cost $C_{Tot}^{(\mathrm{NEMO})}$ turns into the analysis of the location management cost $C_L^{(\mathrm{NEMO})}$, the handoff management cost $C_H^{(\mathrm{NEMO})}$, and the packet forwarding cost $C_F^{(\mathrm{NEMO})}$. For simplicity, we assume that the binding update cost is proportional to the distance in terms of the number of hops between the source and destination mobility entities such as MR, MN-HA, AR(MAG), MR-HA(LMA). Then location management cost $C_L^{(\mathrm{NEMO})}$ in (1) can be rewritten as follows

$$C_L^{(\mathrm{NEMO})} = \left[(4H_{MM} + 2H_{ML})p_{nt} + \delta_{LMA} + 2\delta_{MAG}\right]\frac{P}{T}. \quad (2)$$

The first term is the registration cost when a subnet moves into a new PAN area.

In NEMO-based scheme, the handoff cost can be expressed as the sum of movement detection (MD) cost and duplicate address detection (DAD) cost. Therefore, we can rewrite the handoff management cost $C_H^{(\mathrm{NEMO})}$ as follows

$$C_H^{(\mathrm{NEMO})} = (C_{MD} + C_{DAD}) \cdot \frac{p}{T}. \quad (3)$$

In NEMO-based scheme of 6LoWPAN, the packet transmission is either through a tunnelled path or not. We assume the cost is proportional to the numbers of hops between one another. So the final packet forwarding cost $C_F^{(\mathrm{NEMO})}$ can be written in (4)

$$C_F^{(\mathrm{NEMO})} = \left[(H_{MM} + H_{ML}) \times p_t + H_{NM} + H_{LH}\right] \times p_t + H_{HC} \times p_{nt} + \delta_{LMA} + 2\delta_{MAG}. \quad (4)$$

### B. Signaling Cost of PMIPv6-based Scheme

Adopting the same analysis method above, the total signalling cost in the PMIPv6-based subnet mobility management scheme can be expressed as follows

$$C_{Tot}^{(\mathrm{PMIPv6})} = C_H^{(\mathrm{PMIPv6})} + C_L^{(\mathrm{PMIPv6})} + C_F^{(\mathrm{PMIPv6})}. \quad (5)$$

When an inter-PAN handoff occurs, the location management cost $C_L^{(\mathrm{PMIPv6})}$ can be presented as (6). The first term is the registration cost of the mobile subnet

$$C_L^{(\mathrm{PMIPv6})} = \left[\left(2H_{MM} + 2(H_{MM} + H_{NM})N + 2H_{ML}(N+1)\right) \times p_{nt} + (N+1)(\delta_{LMA} + 2\delta_{MAG})\right]\frac{p}{T}. \quad (6)$$

In the conventional PMIPv6 protocol, the per-MN-prefix principle must be observed, which means the DAD procedure is unnecessary. But an authentication procedure is needed to validate the identities of the moving entities. Therefore, we can rewrite the handoff management cost $C_H^{(\mathrm{PMIPv6})}$ as below

$$C_H^{(\mathrm{PMIPv6})} = \left[\left(3H_{MM} + 3(H_{MM} + H_{NM})N + 2H_{MA}(N+1)\right) \times p_{nt} + (N+1)C_{MD}\right]\frac{p}{T}. \quad (7)$$

Similarly, the packet transmission cost $C_F^{(\mathrm{PMIPv6})}$ between CN and MN can be written in the equation below

$$C_F^{(\mathrm{PMIPv6})} = H_{ML} \times p_t + \left(H_{NM} + H_{MM} + H_{LH} + H_{HC}\right)p_{nt} + \delta_{LMA} + \delta_{MAG}. \quad (8)$$

### C. *Signaling Cost of PA-NEMO.*

According to the analysis above, the total signalling cost in the proposed PA-NEMO scheme is also made up of three parts, as shown in the (9).

$$C_{Tot}^{(PA-NEMO)} = C_{H}^{(PA-NEMO)} + C_{L}^{(PA-NEMO)} + \\ + C_{F}^{(PA-NEMO)}. \quad (9)$$

As the total signalling cost consists of the location management cost $C_L^{(PA-NEMO)}$, the handoff management cost $C_H^{(PA-NEMO)}$ and the packet forwarding cost $C_F^{(PA-NEMO)}$, we will analyse the terms in (9) one by one in the following content. $C_L^{(PA-NEMO)}$ describes the location updating cost when an inter-PAN movement occurs

$$C_{L}^{(PA-NEMO)} = [2(H_{MM} + H_{ML})p_{nt} + \text{¢}_{LMA} + \\ + \text{¢}_{MAG}] \times \frac{p}{T}. \quad (10)$$

For the same reason given in PMIPv6-based scheme, no duplicate address detection procedures are required. So the total handoff management cost $C_H^{(PA-NEMO)}$ is as follows

$$C_{H}^{(PA-NEMO)} = [3H_{MM} + 2H_{MA})p_{nt} + C_{MD}] \times \frac{p}{T}. \quad (11)$$

Similarly, the packet transmission cost $C_F^{(PA-NEMO)}$ between CN and MN can be written in the equation below

$$C_{L}^{(PA-NEMO)} = (H_{MM} + H_{NM} + H_{LH} + H_{HC})p_{nt} \\ + H_{ML} \times p_t + \text{¢}_{LMA} + 2\text{¢}_{MAG}. \quad (12)$$

According to the equation listed above, no matter NEMO-based scheme, PMIPv6-based scheme or PA-NEMO supported scheme, the total signalling cost $C_{Tot}$ all involves the location management cost ($C_L$), the handoff management cost $C_H$ and the packet forwarding cost $C_F$. Comparing (2) and (6) with (10), as can be concluded that $C_L$ in PA-NEMO supported scheme is the least. Similarly, compared $C_F$ in (4) and (8) with (12), we can see $C_F^{(PA-NEMO)}$ equals $C_F^{(PMIPv6)}$, but is less than $C_F^{(NEMO)}$. As in PMIPv6-based scheme, the mobility management procedure of the subnet members is carried out separately, so the parameter N is introduced. Therefore, $C_H$ in PMIPv6 grows linearly with N, while in the other two schemes, which maintains the same. Finally, we can see the PA-NEMO enjoys the best comprehensive performance. In the following section, we will give a direct display on the analysis above.

## V. Numerical Results

In this section, we shall present some numerical results to show the performance of the proposed PA-NEMO scheme. In order to give a direct display about the theoretical analysis results above, we take the topology in Fig. 7 as the simulation environment.

For quantifying the theoretical analysis results in the previous section, we use the parameters in Table II to do the performance emulation. The parameters refer to papers [10]–[12].

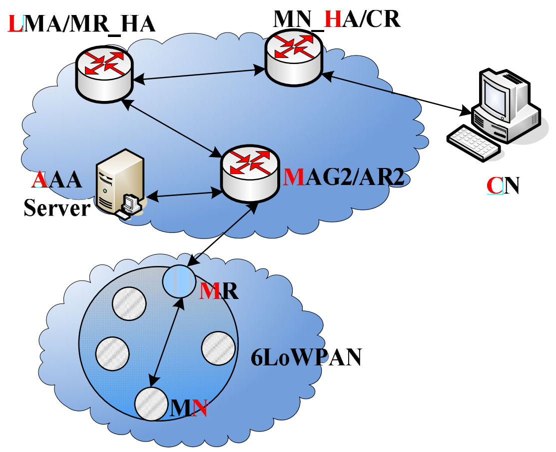


Fig. 7. Simulation network topology.

TABLE II. PERFORMANCE ANALYSIS PARAMETER.

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $T$(s) | 0~10 | $p$ | 0~1 |
| $\delta_{LMA}$ | 20 | $\delta_{MAG}$ | 10 |
| $p_{nt}$ | 0.2 | $p_t$ | 0.4 |
| $H_{MM}/H_{MA}/H_{NM}$(hops) | 1-10 | $H_{ML}$(hops) | 3 |
| $H_{LH}$ / $H_{HC}$(hops) | 10 | $N$ | 1~100 |
| $C_{MD}$ | 12 | $C_{DAD}$ | 24 |

### A. *Signaling Cost Related to Mobility*

The location management cost related to mobility composes of the location management cost and the handoff management cost as shown in (13), the emulation result is shown in Fig. 8

$$C_M = C_L + C_F. \quad (13)$$

As shown in Fig. 8, with the increasing of the residence time $T$, the signalling cost decreases. As depicted before, intra-PAN mobility management signalling cost is zero, which means the signalling cost is determined by inter-PAN mobility. As $T$ means the frequencies of intra-PAN mobility, so the total signalling cost is reduced as $T$ increases. Though the change trend is similar in the three schemes, the PA-NEMO enjoys the rapidest decline in signalling cost with the increase of $T$.

### B. *Signaling Cost Related to the Scale of the Subnet*

The signalling cost related to the scale of the subnet is shown in (14), while the scale is defined as the number of sensor nodes in the subnet. The simulation result is shown in Fig. 9, as can be seen that only in the PMIPv6-based scheme, the handoff management cost and the location management cost increase with the number of sensor nodes in the subnet. While the signalling cost in the NEMO or PA-NEMO based scheme remain unchanged when the scale of the subnet expands and PA-NEMO remains the lowest signalling cost.

$$C_{scale} = C_H + C_F. \quad (14)$$

The total signalling cost related to mobility is shown in Fig. 10. According to the theoretical analysis, the PMIPv6 related scheme as PMIPv6 and PA-NEMO, can decrease the packet forwarding cost by shortening the length of the tunnel.

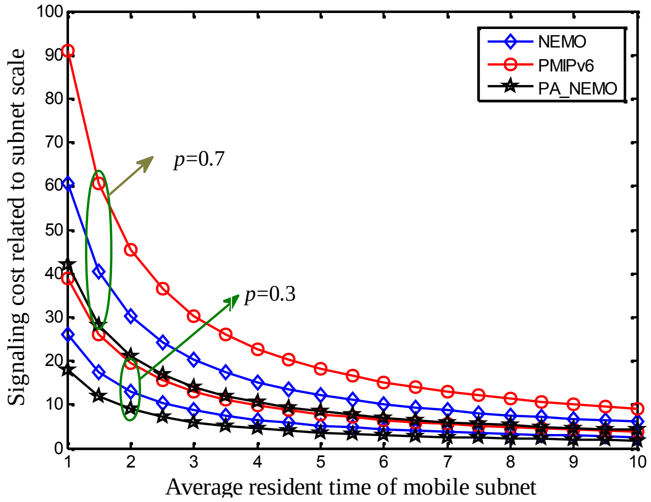


Fig. 8. Signaling cost related to the resident time of the subnet.

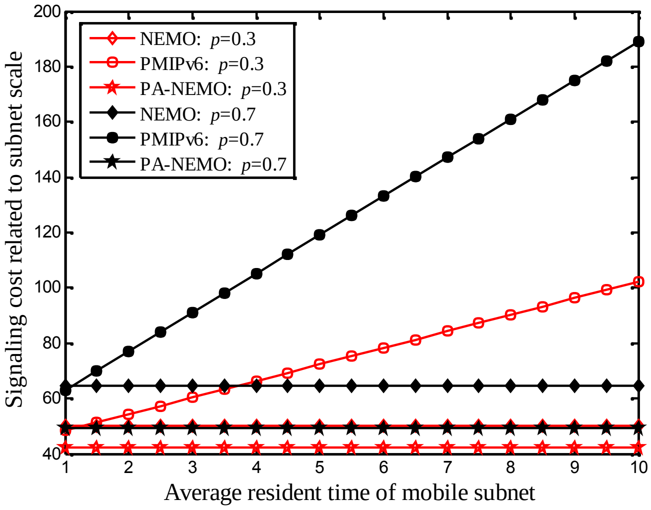


Fig. 9. Signalling cost related to the number of sensor nodes in the subnet.

## C. *Total Signaling Cost*

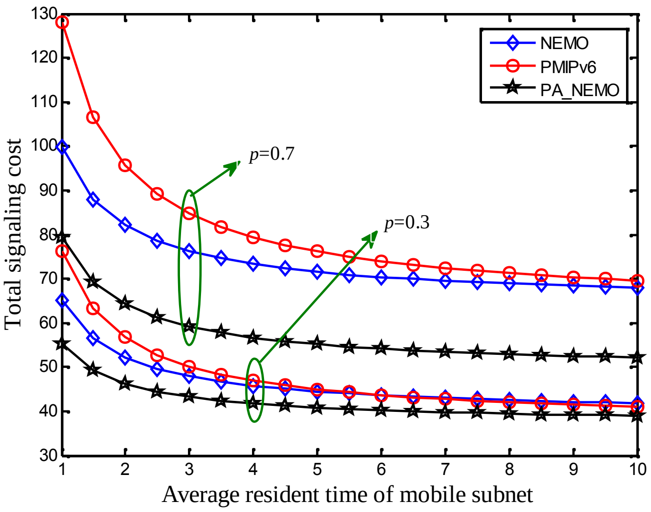


Fig. 10. Total signalling cost related to mobility of subnet.

Furthermore, compared to NEMO-based scheme, no matter the PMIPv6-based scheme or PA-NEMO, both avoid DAD procedure. For NEMO, with the increase of the inter-PAN probability *p*, the total signalling cost increases the most. That is because the packets should be encapsulated by multiple tunnels. However, the PA-NEMO communication incurs lower signalling cost and the mobility related signalling is transmitted through the shortest tunnel path for PA-NEMO, then the total cost increases slowest with the increase of *p*. In conclusion, PA-NEMO has predominant performance with optimized packet transmission path and mobility management process.

## VI. CONCLUSIONS

In this paper, we proposed a complete network-based mobility management scheme for 6LoWPAN, called PA-NEMO, which combines the network-based management of PMIPv6 and the subnet mobility of NEMO. In PA-NEMO, a novel approach called address mapping is proposed to provide efficient mobility supports even in the nested scenario. According to the theoretical analysis and the numerical results, PA-NEMO achieves the lowest signalling overhead among existing mobility management schemes.

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