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INTER-DOMAIN HANDOVER SCHEME WITH OPTIMAL ROUTE RECOVERY FOR PROXY MOBILE IPV6 PROTOCOL

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Abstract

Proxy Mobile IPv6 (PMIPv6) protocol was standardized to solve the problems associated with MIPv6 protocol including the long handoff latency, packet loss and signalling overhead by excluding the mobile node (MN) from taking part in the mobility process. However, PMIPv6 provides mobility support for MNs moving inside a single domain. Therefore, whenever MN crosses the boundary of its domain, it cannot be reached and the current session is broken down. Several research works have addressed the inter-domain mobility problem for PMIPv6; however, the current proactive handoff methods have reported a high signalling cost due to the redundant multicast messages. In addition, the recovery of the current optimized communication route for the moving MNs has not been considered. Thus, in this paper, a global mobility management scheme, named GRO-PMIPv6, is proposed to provide an effective mechanism to support seamless and fast MN inter-domain handover while maintaining the current optimized communication route for the moving hosts. An analytical model is designed to evaluate and compare the performance of the proposed scheme with the state-of-the art schemes. The numerical results show that the proposed scheme outperforms the current mobility schemes in terms of low handoff signalling cost.

Keywords: Inter-domain mobility, PMIPv6, Route optimization, Signalling cost.

1. Introduction

The rapid growth in the number of mobile devices has increased the challenges to design an efficient mobility management protocols which meet the demand of mobile users to roam freely among different domains with a lower service disruptions.

Proxy Mobile IPv6 (PMIPv6) [1] was standardized by the IETF as a network-based mobility management protocol, to resolve the problems introduced by host-based mobility schemes. In PMIPv6, the mobility functions are relocated to the networks entities which are the Mobile Access Gateway (MAG) and the Local Mobility Anchor (LMA). The MAGs are responsible for detecting the MN attachment and perform the MN registration in the LMA which is considered as the MN’s reachability point. As a network-based mobility protocol, PMIPv6 allows network components to detect the MN attachment and initiate the mobility signalling on behalf of the MNs. Hence, MNs are totally relieved from taking part in the mobility process which leads to reduce the complexity of MNs mobility stack [2]. However, PMIPv6 introduced a single point of failure in the LMA [3, 4], since it is used for maintaining the MNs records and it is involved in all data communication sessions. Also, the data packets go through a long transmission path as it should traverse the far LMA, though the communicating parties are within the same domain [4]. In addition, PMIPv6 protocol was designed to provide mobility service for MNs moving inside the same domain. Thus if MN crosses the boundary of PMIPv6 domain, it cannot be reached and its current session will be broken [5, 6].

Since its emergence, PMIPv6 has been studied from different directions in order to enhance its performance. Yu and Zhou [7], proposed a method to enhance the handoff process by reducing the signalling required for authentication when the MN moves within the same domain. A ‘hitch-on’ group-based handover scheme was proposed by Chiang et al. to reduce the signalling cost required for registering a group of MNs moving at the same time. The ‘hitch-on’ method considered the movement behaviour of MNs to create the MNs groups so that they can be registered using a single set of messages. Another study to register a group of MNs together using single message set was proposed by Ghaleb et al. [9], named, E-CPMIPv6 which grouped MNs according to their mobility patterns in the clustered PMIPv6. Ghaleb et al. [10] proposed a bulk registration method to reduce signalling in the clustered PMIPv6, named BCS PMIPv6, in which the MNs moving at the same time, are grouped together even they belong to different MAGs but reside in the same cluster. Ghaleb et al. [11], proposed a light weight paging scheme to reduce the signalling cost required for idle MNs registration. To balance the load evenly among MAGs, a load balancing method for the clustered PMIPv6 was proposed by Jabir [12], in which the target MAG is determined according to the its current load and the received signal power. When the number of registered MNs becomes large, the management of available resources becomes an issue. Therefore, Jabir [13] proposed a utilization scheme to carefully manage the memory required for saving the MNs context in the LMA.

Recently, several attempts intended to support the inter-domain mobility service for PMIPv6, where the mobile hosts cross their domain boundaries. These studies proposed mobility schemes to keep the ongoing session continue while the mobile host moves outside its domain by transferring the host context in advance to the new PMIPv6 domain. Neumann et al. [14] discussed the possibility of providing a mobility support to MN moves between different PMIPv6 domains, in which the home LMA is responsible for configuring and updating the foreign LMA with the MN address configuration. In this case, the MN keeps the same address and stays totally agnostic for the mobility process. However, the home LMA incurs extra overhead as it keeps records for all MNs even they leave their domain.

In addition, the traffic is still incurs a long path that should traverse the home and foreign LMAs. To reduce the communication path of [14], another method was proposed by Zhong et al. [15], which added an entity named traffic distributer (TD) that connects different LMAs and redirects the traffic to the destination LMA without traversing the home LMA. To provide mobility service for vehicles, Lee et al. [16] proposed a scheme that introduced a new entity called, iMAG, which is placed on the boundary of domains. The iMAG role is to perform the L3 handoff before L2, such that when the MN is attached to the new domain, its address configuration has already been known for the new MAG which leads to reduce the MN location update latency time. The main drawbacks of iMAG are the wrong prediction for the new location of MN, the triangle routing, and the processing overhead required for connecting different domains and maintains mobility support for a large number of MNs crossing different domains [6]. To guarantee a seamless intra- and inter-domain handoff and to reduce the service disruption for MNs moving beyond their domain, a Hybrid Latency Low handover mechanism for PMIPv6 wireless networks (HLL-PMIPv6) scheme was proposed by Al-Surmi et al. [6]. HLL-PMIPv6 introduced a new entity named, iHLMA which connects different LMA domains and coordinates the inter-domain mobility by passing the MNs context to all domains in advance to reduce the handoff latency. In addition, to shorten the traffic route, the data packets are transmitted directly from iHLMA to foreign LMA without visiting the home LMA [15].

The aforementioned schemes are either working in a reactive mode that requires a long time for MN registration in the new domain resulting in a considerable disruption in the MN communication session. In addition, the proactive schemes add extra mobility management signalling to provide inter-domain mobility which increases the network traffic overhead. Moreover, most of the inter-domain mobility schemes have not considered recovering the current optimal route after handoff.

On the other hand, there have been several attempts to maintain an optimal communication path in PMIPv6 domain, which are distinguished by the Route Optimization (RO) initiation entity, RO recovery mechanism and the amount of control messages [17]. For example, the work in [18-21] attempted to maintain an optimal route between MAGs by excluding the LMA from the traffic path. However, these methods incurred long handoff latency due to the involvement of LMA for coordinating the RO process. Boc et al. [22] proposed an Anchor-Based RO (ABRO) scheme which introduced an Intermediate Anchors (IA) which coordinates the communication process to shorten the route path. In ABRO, the IA which is closer to the communicating MNs is selected by LMA to maintain the optimized path. However, ABRO enforced the traffic to go through an IA unit which adds extra delay to the communication cost. Also, ABRO adds extra load on the LMA to update and choose the proper IA entities. Jaber et al. [17] proposed a Cluster-Based RO (CBRO) scheme for the clustered architecture of the PMIPv6 to recover the RO status after handoff for the clustered PMIPv6 (CPMIPv6) architecture. In CBRO, the role of head MAGs (HMAGs), which are placed close to the domain MAGs, is to coordinate the intra- and inter-cluster RO in order to decrease the total handoff signalling cost. However, CBRO has not considered the global mobility scenario for the communicating MNs. To decrease the number of messages needed for resuming the current local RO after handoff, Resam et al. [23] proposed Optimized PMIPv6 (O-PMIPv6) method to minimize the signalling messages required to perform both handoff and route optimization processes by encapsulating the RO context within the handoff messages; however, it was designed for MNs that are moving inside a single domain.

The previous related research work ensures a short communication path for MNs; however, most of them incurred high signalling cost, they depend on LMA which may reside far from MAGs, and they were designed for a single LMA domain. In this paper, an enhanced inter-domain mobility scheme is proposed, named GRO-PMIPv6, based on the work of HLL-PMIPv6 and the O-PMIPv6 to decrease the signalling overhead needed for mobile node location update and RO recovery. Leveraging the fog computing concept, where the computing capabilities and data are brought in the user vicinity to reduce the extensive access to the far cloud system [24], in GRO-PMIPv6 scheme, the signalling cost is minimized by introducing a reference MAG (rMAG) entity for each domain to provide the MN context for other MAGs in the domain. The rMAG is one of the MAGs in each domain that is elected based on its work load to work as an intermediate entity between the far LMA and its connected MAGs. In addition, by leveraging the O-PMIPv6 concept, the MN current RO status is encapsulated in the handoff messages to reduce the total number of signals needed to resume the RO status after MN mobility, which in turn leads to enhance the overall performance for the proposed scheme.

The rest of paper is structured as follows: The related work represented by HLL-PMIPv6 and the conventional inter-domain schemes are presented in Section 2, while a detail description of the proposed GRO-PMIPv6 scheme is given in Section 3. The network model and mathematical description for RO schemes under consideration is shown in Section 4. Section 5 demonstrates the numerical results to show superiority of the proposed GRO-PMIPv6. The conclusion of the paper is given in Section 6 along with some future work suggestions.

2. Related Works

This section gives a details description on the most related research works that are adopted in this paper, including the HLL-PMIPv6 and the conventional global route optimization scheme. HLL-PMIPv6 scheme has studied most of the related works in the field of inter-domain mobility and has outperformed the state-of-the-art inter-domain schemes including the work in [14-16]. Thus, we believe that the comparison against such method emphasizes the potential of our scheme.

2.1. HLL-PMIPv6 scheme

The Hybrid Intra/Inter-domain Handover (HLL-PMIPv6) scheme was proposed by Al-Surmi et al. [6] to provide a seamless handoff for MNs moving within or cross PMIPv6 domains. In addition, HLL-PMIPv6 scheme reduced the data transmission cost by forwarding the income traffic directly to the foreign LMA. The scheme added a new entity called iHLMA which is considered as an intermediate mobility anchor point that connects all PMIPv6 domains together to provide the required inter-domain mobility. HLL-PMIPv6 is a proactive mobility scheme that makes the entire MN context, including the MN-Id, Prefix and Authentication, ready in the new access network before the attachment of the MN to the new MAG. The anchor points, iHLMA and LMAs are working in a cooperative way to allow the MN keeping the same address while it is roaming in different domains. The LMA is responsible for coordinating the intra-domain mobility, while the iHLMA is responsible for transmitting the host context to all LMAs to provide the inter-domain location update.

Figure 1 demonstrates the signalling flow of the HLL-PMIPv6, in which both the intra- and inter-domain location update are presented. In the case of intra-domain, when hMAGm senses the movement of MN, it sends a de-registration message to the hLMA and uses the proper flags to specify the kind of mobility. The hLMA then transmits the MN context to the neighboring MAGs, and when hMAGn detects the MN attachment, it replies by quick RtrAdv to the MN and sends a proxy binding update (PBU) message to the hLMA to complete the registration process.

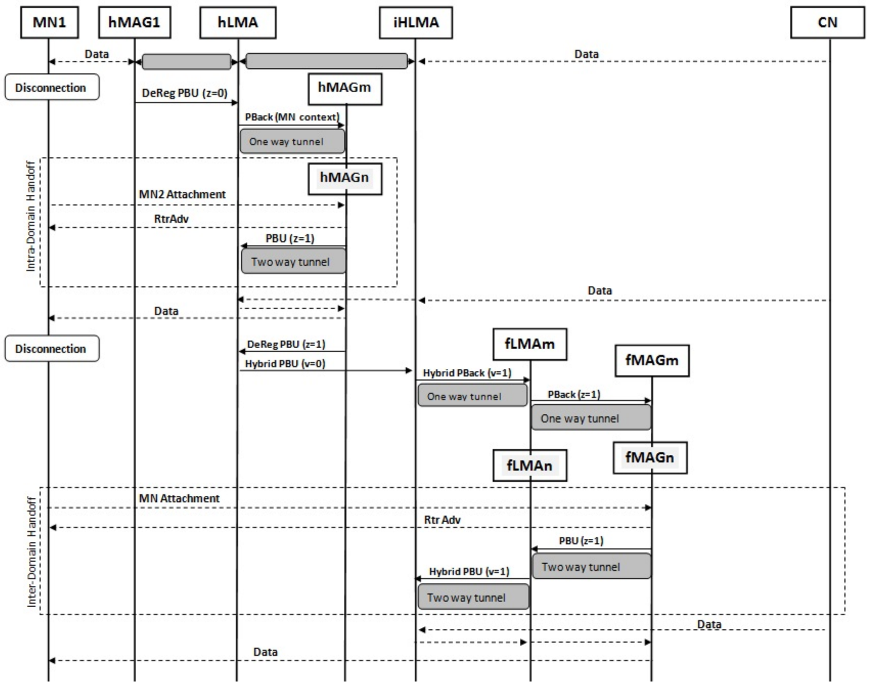

Fig. 1. HLL-PMIPv6 Intra- / Inter-Domain handoff signalling.

On the other hand, when the hMAGn detects that MN intends to cross the domain, it informs the LMA using proper flags, which in turn activates the inter-domain mobility process by sending the MN context to the iHLMA. Upon receiving the MN context, the iHLMA transmits it to all LMAs (fLMAm ... fLMAn) in the connected domains. The foreign LMAs then react by passing the MN context to all their connected MAGs. To this end, all MAGs in all domains are having the MN context and ready to register the MN once it is attached. When the fMAGm senses the MN attachment, it replies by sending a quick router advertisement (RtrAdv) message, and then sends a PBU message to its fLMAm which in turn informs the iHLMA about the MN attachment. The iHLMA then updates the MN entry with the new attachment access point in order to forward the traffic to the MN. The proactive mode of the HLL-PMIPv6 allows the MN to move between different domains while keeping the same address. In addition, the MN can get a fast address configuration, since the MN context is ready before its attachment to the new MAG. HLL-PMIPv6 scheme enhanced the user experience by reducing the service disruption. However, it incurs a very high signalling cost due to the multicasting of the MN context to all MAGs in all connected domains. Also, this method has not considered recovering the current optimal route after handoff.

2.2. Conventional RO scheme

The route optimization means minimizing the communication path by maintaining a direct tunnel between the communicating entities. The conventional global RO mechanism between domains is shown in Figure 2 [25]. When LMA1 receives the first packet from MAG1, it triggers the RO process with LMA2 which initiates the RO process between MAG1 and MAG2. Then MAG2 exchanges the required messages with MAG1 to create the optimal communication tunnel between MAGs. Thus the traffic can be sent directly using the tunnel without the need to go through the far LMAs.

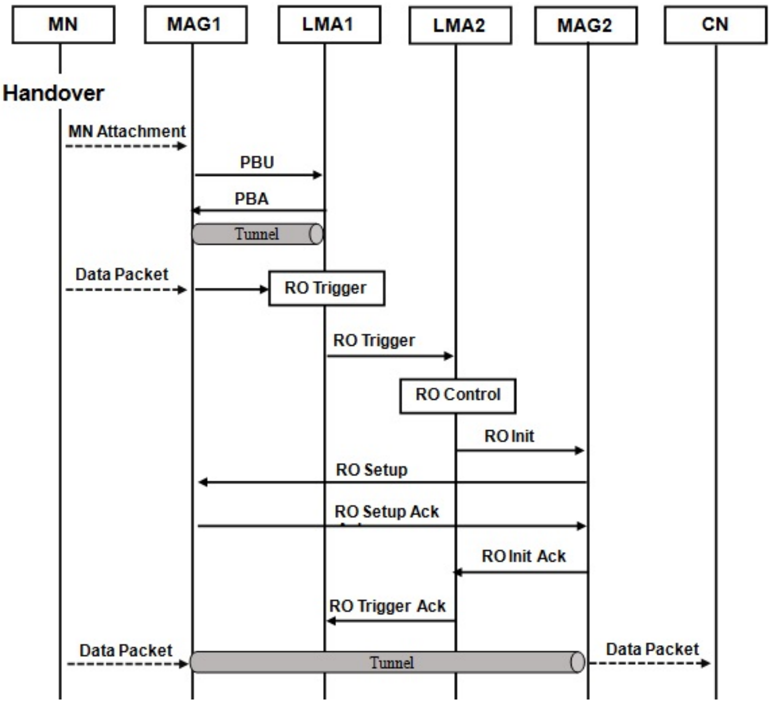

Fig. 2. Conventional Inter-Domain route optimization.

However, when one of the mobile nodes moves either inside its domain or to another domain, this RO status should be quickly recovered. Nevertheless, most of the inter-domain approaches have not considered the RO recovery after handoff. Thus, in this work we proposed an inter-domain mobility scheme that recovers the current RO status when the communicating MNs change their attachment point.

3. Proposed GRO-PMIPv6

The GRO-PMIPv6 scheme is mainly proposed to recover the current RO status for MNs crossing the PMIPv6 boundary. Also, it minimizes the signalling cost required for inter-domain handoff in the HLL-PMIPv6 architecture. The low signalling overhead can be achieved by encapsulating the RO status for MNs in the messages required for handoff, i.e. handoff Initiation (HI), handoff Acknowledgment (HAck), proxy binding update (PBU), and proxy binding acknowledgment (PBA), using a technique similar to that used by O-PMIPv6. In addition, the signalling overhead can be further reduced by utilizing the rMAG to minimize the communication cost between LMAs and their MAGs.

3.1. Protocol architecture

The main entities of the proposed GRO-PMIPv6 scheme is shown in Fig. 3, which consists of one iHLMA unit used to connect a number of LMA domains. The new rMAG entity is used as an intermediate entity between LMA and MAGs to send the control messages on behalf of the far LMA to reduce the signalling cost.

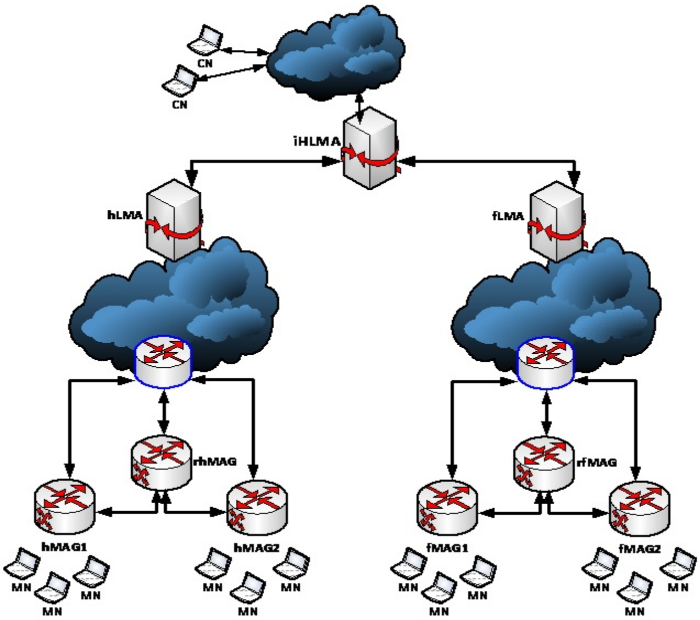

Fig. 3. GRO-PMIPv6 architecture.

3.2. Handoff signalling

In GRO-PMIPv6, the MN context is transferred to the new domain in advance to minimize the handoff time in a similar manner used by HLL-PMIPv6. However, since the HLL-PMIPv6 scheme exchanges a very large volume of signals between LMAs and their connected MAGs, in this work, rMAG entity is introduced in each LMA domain to reduce the signalling cost. The role of rMAG is to receive the MN context from LMA and then forward it to all MAGs in the domain. This will reduce the load on LMA and reduce the time required to get the MN context as it can be obtained from the near rMAG rather than the far LMA. Figure 4 shows the intra-domain mobility, where both MNs are attached and move inside the same LMA domain. It can be seen that the RO status is transmitted along with the registration messages to reduce the handoff signalling cost

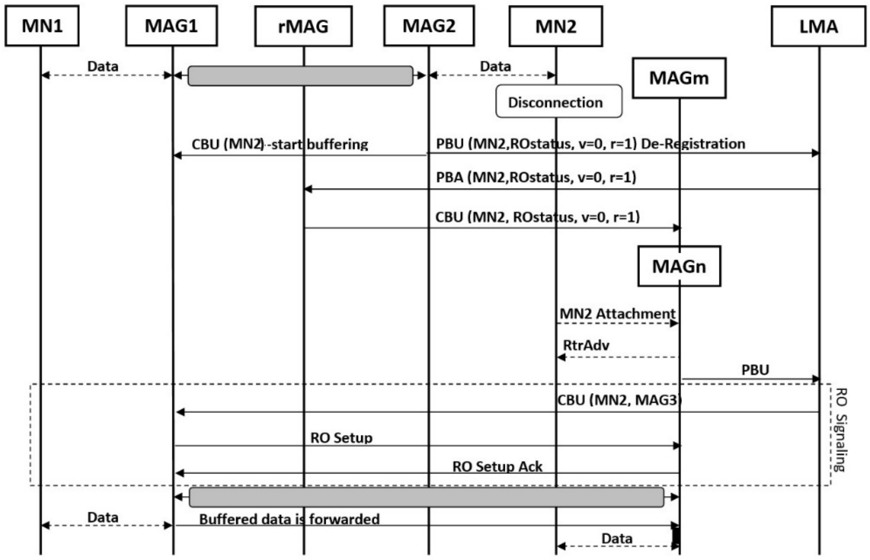

Fig. 4. Intra-domain mobility with RO recovery.

3.3. Inter-domain RO

In this scenario, the MN moves from one PMIPv6 domain to another while it already maintains an optimal route with CN that may reside in the same domain or in another domain.

As shown in Fig. 5, hMAG1 has already maintained an optimized tunnel with hMAG2 to exchange data packets for the communicating MNs. When MN2 moves to fMAGm which is attached to fLMA2, hMAG2 detects the MN2 movement and sends a PBU message with flags (v=1 to indicate an inter-domain mobility, r=1 to indicate an RO status) to its hLMA. At the same time it informs hMAG1, using the corresponding binding update (CBU) message, about the movement of MN2 to start buffering the incoming data from MN1 to MN2. Upon receiving the PBU message, hLMA1 sends a Handoff Initiation (HI) message containing the MN2 route optimization status to the iHLMA which in turn passes the message to all LMAs (fLMAm … fLMAn) in its list. The foreign LMAs send the message to their rMAGs which in turn multicast the message to all MAGs in the domain. To this end, all the information about the MNs RO-status is known for the new domain entities. When MN2 is attached to fMAGm, it sends a PBU message to its fLMA which responds by sending a Handoff Acknowledgement (HAck) message to the iHLMA to complete the registration of the MN in its new domain.

In order to complete the RO operation, the iHLMA sends a HAck message to hLMA1 containing the new location for MN2 in order to pass this information to hMAG1 for exchanging the required messages to create the tunnel with fMAGm. Since the home hMAG1 is used for buffering, the problem of packet out of sequence can be reduced if the home MAG is informed about the MN1 movement in a proper time. Similar signalling is used in the case of both communicating MAGs belong to different domains and one of MNs moves to another domain.

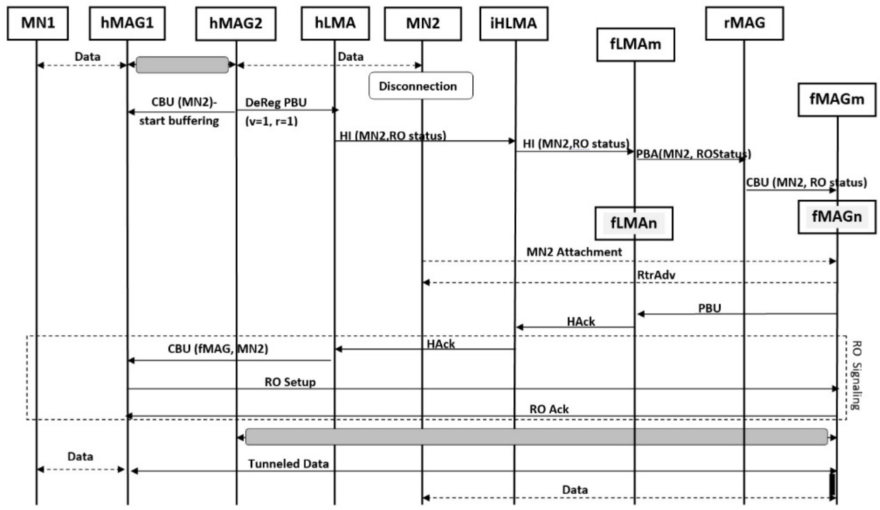

Fig. 5. Inter-domain mobility with RO recovery.

4. Performance Evaluations

This section derives the performance metrics used to evaluate the performance of the schemes under consideration. The network and mobility models are described first followed by deriving the mathematical formulas for calculating the signalling cost metric used in performance comparison for the proposed GRO-PMIPv6, HLL-PMIPv6 without RO support and HLL-PMIPv6 with conventional RO schemes.

4.1. Network and mobility model

The hexagon network model is used for performance evaluation, where each MAG covers a single cell, the LMA domain consists of a set of MAGs, and the LMA domains are connected together by the iHLMA entity. In addition, the Fluid-flow mobility model [26] is used in this paper, where the both mobile node velocity and direction are considered. The mobile node movement direction is uniformly distributed in the range of (0, 2π).

We assume that each domain is represented by a number of rings, *L*, then the total number of MAGs in each domain can be calculated as $M = 3L(L - 1) + 1$. Let *R* represents the radius of the cell (m), the average speed of *MN* is *v* (*m/s*); μ_c is the cell crossing rate, μ_s is the intra-domain crossing rate, and μ_d is the inter-domain crossing rates. They can be expressed as follows [27]:

$$\mu_c = \frac{2.v}{\sqrt{\pi.S}} = \frac{2.v}{\pi.R} \quad (1)$$

$$\mu_d = \frac{\mu_c}{\sqrt{M}} \quad (2)$$

$$\mu_s = \mu_C - \mu_d = \mu_C.\frac{(\sqrt{M}-1)}{\sqrt{M}} \quad (3)$$

Let λ_S be the session inter-arrival time, the average number of intra-domain movements ($E[N_s]$) and inter-domain movements ($E[N_d]$) can be calculated as follows [26]:

$$E[N_s] = \frac{\mu_s}{\lambda s} \quad (4)$$

$$E[N_d] = \frac{\mu_d}{\lambda s} \quad (5)$$

4.2. Analytical model

The performance metric used for performance comparison between the proposed GRO-PMIPv6 method and the HLL-PMIPv6 scheme is derived in this section. Since we are trying to minimize the total handoff signalling cost required for RO recovery, the Signalling Cost (SC) metric is derived for both schemes taking into consideration the required RO recovery signalling. The performance notations used in the performance analysis, are presented in Table 1.

Table 1. Parameters for the performance analysis.

Parameter	Description
$\mathbf{C}_{\mathbf{x\text{-}y}}$	Number of Hops between nodes x and y
t	Wired link transmission cost
$\boldsymbol{SC_x}$	Scheme (*x*) Handoff Signalling Cost

4.3. Signalling cost analysis

The signalling cost is of a significant importance to measure the performance of the mobility schemes as it shows the signalling overhead required for achieving the mobility process. The signalling cost is derived for the intra-/inter-domain handoff without RO recovery, and then the required RO messages are considered for both GRO-PMIPv6 and HLL-PMIPv6 to clearly show the difference between the mobility schemes. To put our mathematical model in a simple form, the authentication and processing cost for all entities are not considered here.

4.3.1. Handoff signalling

In this section, the intra and inter-domain handoff signalling are considered for all mobility schemes without considering the required RO messages.

A. HLL-PMIPv6

In the HLL-PMIPv6 scheme, when an MN moves between MAGs within the same domain, the basic PBU and PBA messages are exchanged between the home MAG and LMA. In addition, the LMA sends a PBA message to all its attached MAGs containing the MN context. The signalling cost required for intra-domain mobility can be derived as:

$$SC_{HLL-PMIPv6}^{Intra} = E[N_s] \times t \times (N_{MAG} + 1) \times \ C_{MAG-LMA}) \quad (6)$$

Whereas in the case of inter-domain mobility, the home LMA sends a Hybrid_PBU messages to the iHLMA which in turn forwards it to all neighboring LMAs (N_{LMA}). Also, all LMAs send PBAck messages to their connected MAGs for preparing the MN's context in advance. Consequently, inter-domain signalling cost can be obtained as follows:

$$SC_{HLL-PMIPv6}^{Inter} = E[N_d] \times \mathrm{t} \times (\mathrm{C}_{\mathrm{LMA-LMA}} \times N_{LMA} + \mathrm{C}_{\mathrm{MAG-LMA}} \times N_{\mathrm{MAG}}) \quad (7)$$

$$SC_{HLL-PMIPv6} = SC_{HLL-PMIPv6}^{Intra} + SC_{HLL-PMIPv6}^{Inter} \quad (8)$$

B. Proposed GRO-PMIPv6

In this section, the intra- and inter-domain mobility signalling costs are derived for the proposed GRO-PMIPv6. To accomplish the intra-mobility process, when LMA is notified about the MN movement, it sends the MN context to its connected rMAG which in turn forwards the context to its attached MAGs. Consequently, intra-domain mobility signalling cost can be expressed as follows:

$$SC_{GRO-PMIPv6}^{Intra} = E[N_s] \times t \times (3C_{MAG-LMA} + (N_{MAG} - 1) * C_{MAG-MAG}) \quad (9)$$

Under other conditions, when the MN crosses its LMA domain, the inter-domain mobility is activated by transmitting the MN context for all connected domains. This is coordinated by the iHLMA which exchanges the HI/HAck messages with its neighbors (N_{LMA}). Also, the home LMA exchanges the CBU/CBA messages with its MAGs involved in the RO status to update their communication tunnel. Thus, inter-domain mobility handoff signalling cost for GRO-PMIPv6 can be expressed as follows:

$$SC_{GRO-PMIPv6}^{Inter} = E[N_d] \times t \times ((C_{LMA-LMA} + C_{MAG-LMA}) \times N_{LMA} + (N_{LMA} - 1) \times (N_{\mathrm{MAG}} - 1) \times C_{MAG-MAG}) \quad (10)$$

$$SC_{GRO-PMIPv6} = SC_{GRO-PMIPv6}^{Intra} + SC_{GRO-PMIPv6}^{Inter} \quad (11)$$

4.3.2. RO signalling

In this section, the signalling cost required to recover the RO status is derived for both schemes when MN crosses its LMA domain.

A. HLL-PMIPv6

In the HLL-PMIPv6 protocol, which follows the conventional inter-domain RO strategy, the current RO is recreated after completing the registration process for MN in the new domain, which can be derived as follows:

$$SC_{HLL-RO} = t \times (4C_{MAG-LMA} + 2C_{MAG-MAG} + 4C_{LMA-LMA}) \quad (12)$$

B. Proposed GRO-PMIPv6

In the proposed GRO-PMIPv6, the RO status has already been sent during the MN registration in the new domain. The extra messages for RO recovery are those required to inform the home MAGs about the new location of MN, i.e. the new MAG, which can be expressed as follows:

$$SC_{GRO-RO} = t \times (C_{LMA-MAG} + 2C_{MAG-MAG} + 2C_{LMA-LMA}) \quad (13)$$

5. Numerical Results

This section demonstrates the numerical results represented by the handoff signalling, which is calculated subject to different parameters settings. The assumptions and the parameter values in [6, 11, 17, 27] have been used in this research as shown in Table 2.

Table 2. Parameters values.

Parameter	Description	Default Value
t	Wired link transmission cost	2
V	MN Velocity	25 (m/s)
R	Cell Radius	500 (m)
λs	Session Inter-Arrival Rate	0.05
$C_{MAG\text{-}LMA}$	Number of Hops between MAG and LMA	16
$C_{MAG\text{-}MAG}$	Number of Hops between two MAGs	$\sqrt{M}$
$C_{LMA\text{-}LMA}$	Number of Hops between two LMAs	20

Figure 6 shows the effect of the velocity of MN on the handoff signalling cost for the HLL-PMIPv6 and GRO-PMIPv6 schemes with and without RO support. The mn velocity is increased from 1 to 50, while other parameters are set to their default values. It can be seen that the handoff signalling cost is increased for all schemes when the MN's velocity is increased. This increment can be attributed to the increment in the cell crossing rate as the velocity is increased, which means exchanging the required signals for MN registration. However, the proposed GRO-PMIPv6 shows the best performance due to the reduction in the number of message between LMAs and their connected MAGs. In addition, GRO-PMIPv6 with RO performs better than HLL-PMIPv6 with and without RO. This is due to the utilization of rMAG and the encapsulation of the RO status with the handoff messages which reduces the total number of signals used for RO recovery. The use of rMAG reduces the distance traversed by the control signals, while the RO encapsulation reduces the number of control messages. Similar performance can be seen in Fig. 7 when changing the radius of the cell. Small cell radius leads to increase the cell crossing rate which in turn increases the number of MN's registration process.

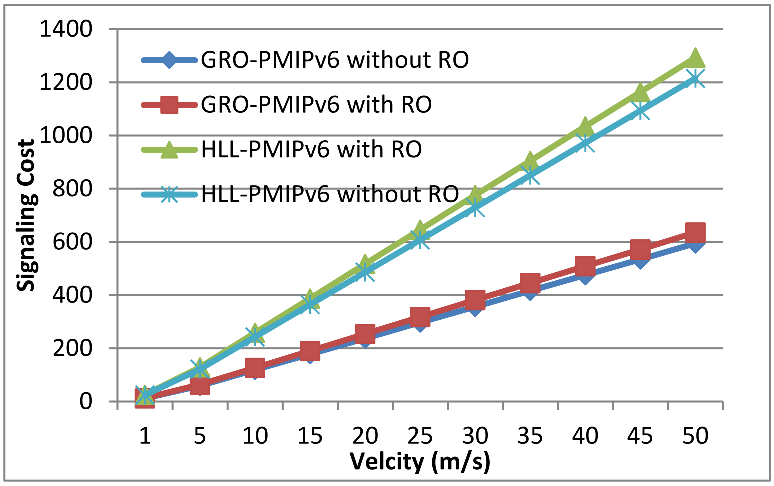

Fig. 6. The impact of node velocity on handoff signalling cost.

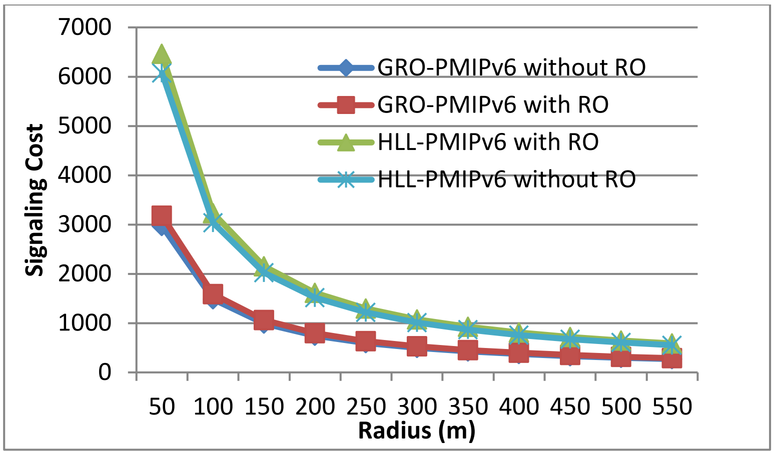

Fig. 7. The impact cell radius on handoff signalling cost.

Figures 8 and 9 show the impact of the wired link delay and the LMA-MAG hop counts, respectively, on the handoff signalling cost. The signalling cost is increased for all schemes with the increment in the wired link delay and the number of hops between LMA and MAG. However, the proposed GRO-PMIPv6 shows the lowest signalling cost when increasing both wired link delay and hops count.

The best performance achieved by the proposed scheme can be contributed to the dependence on the distance between rMAG and its connected MAGs rather than on the distance between MAGs and the far LMA. The use of rMAG reduces the number of hops traversed by the control messages, which leads to reduce the effect of the wired link on the signalling cost.

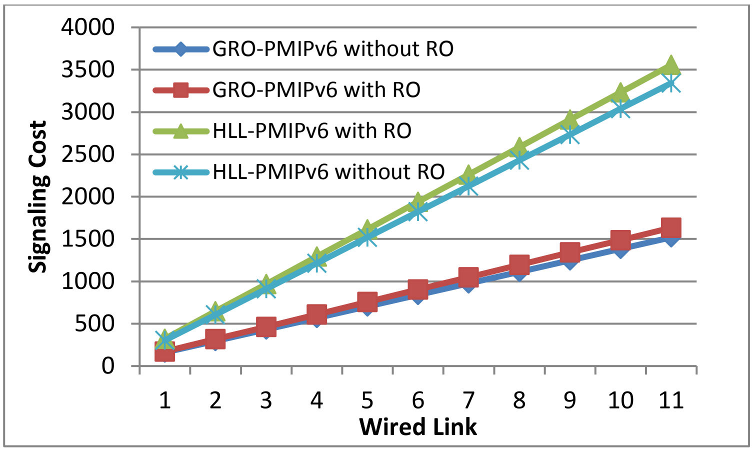

Fig. 8. The impact of wired link delay on handoff signalling cost.

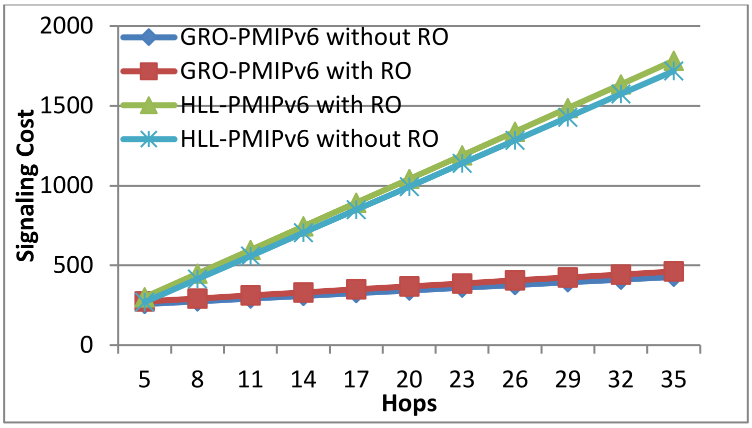

Fig. 9. The impact of LMA-MAG hops on handoff signalling cost.

6. Conclusions

In this paper, we proposed an enhanced inter-domain mobility management for PMIPv6, named GRO-PMIPv6, which supports a seamless and fast handoff for MNs crossing their domains. It provides a fast recovery for the current RO status with minimal signalling cost. The proposed GRO-PMIPv6 has been designed based on the HLL-PMIPv6 and leveraged from the O-PMIPv6 schemes to support the RO service for MNs communicating between different LMA domains. The numerical results revealed the efficiency of the proposed GRO-PMIPv6 in providing the fast registration for MNs crossing their domains while recovering the current RO status with minimal signalling cost. In addition, the use of rMAG entity contributed in reducing the distance traversed by the control messages which makes the GRO-PMIPv6 positioned itself as a good choice for providing the global mobility with or without RO recovery support. Testing the proposed scheme using complex environment and high random mobility scenarios using network simulators is set as future work.

Nomenclatures

$C_{x\text{-}y}$	Total number of Hops between nodes x and y (hop).
$E[Ns]$	Average number of intra-domain movements.
$E[Nd]$	Average number of inter-domain movements.
L	Total number of Rings.
M	Total number of MAGs.
R	Radius of the MAG (m).
SCx	Handoff signalling cost for scheme x.
T	Wired link transmission cost.
V	Velocity of mobile node (m/s)

Greek Symbols

μc	Cell crossing rate.
μd	Inter-domain crossing rate.
μs	Intra-domain crossing rate.
λs	Session inter-arrival rate.

Abbreviations

ABRO	Anchor Based Route Optimization
CBRO	Cluster Based Route Optimization
CPMIPv6	Clustered Proxy Mobile IPv6
fLMA	Foreign LMA
fMAG	Foreign MAG
GRO-PMIPv6	Global Route Optimization PMIPv6
HAck	Handoff Acknowledgement
HI	Handoff Initiation
HLL-PMIPv6	Hybrid Latency Low PMIPv6
hLMA	Home LMA
HMAG	Head-MAG
hMAG	Home MAG
IA	Intermediate Anchor
IETF	Internet Engineering Task Force
iHLMA	Intermediate Hybrid LMA
iMAG	Intermediate MAG
LMA	Local Mobility Anchor
MAG	Mobile Access Gateway
MN	Mobile Node
MN-id	Mobile Node Identifier
O-PMIPv6	Optimized PMIPv6
PBAck	Proxy Binding Acknowledgment
PBU	Proxy Binding Update
PMIPv6	Proxy Mobile IPv6
rMAG	Reference MAG
RO	Route Optimization
RtrAdv	Router Advertisement
TD	Traffic Distributer

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