Enabling Network Based Local Mobility With Cooperative Access Points

Yang Xia, Chai Kiat Yeo
School of Computer Engineering, Nanyang Technological University, Singapore

***Abstract*—In this paper, we propose a network based local mobility management scheme for 802.11 wireless networks. The scheme does not require modification on the mobile node and the mobility management is entirely handled by the network. Our scheme makes use of a cooperative DHCP service to ensure mobile node always obtains the same IP address within the mesh network. In addition, 802.11s is used to forward traffic to the correct location after mobile nodes moving to a different access point. We developed an analytical model to study the performance of proposed scheme and show that it can enable transparent node mobility in 802.11s networks. It can serve as an alternative to the existing proxy mobile IPv6 protocol when access points are under different domains.**

I. INTRODUCTION

Mobility management has been an active research area in recent years. The objective is to enable seamless handover when a Mobile Node (MN) moves from one network to another network. The issues involved in this handover process mainly caused by two sources: the change of IP address after MN moving to a new network and the redirection of traffic to the new IP address of MN. In Mobile IPv6 (MIPv6) [1], a Home Agent (HA) at MN's home network will help to tunnel the traffic from the communicating Correspondent Node (CN) to the new Care-of Address (CoA) of MN. In addition, MIPv6 also proposed a Route Optimization (MIPv6-RO) mode to tunnel the traffic from CN to MN directly such that traffic from CN does not have to be relayed by MN's HA, which is commonly referred to as triangular routing. However MIPv6 requires modification of network stack on the mobile nodes. This hinders the large scale deployment of MIPv6.

Proxy Mobile IPv6 (PMIPv6) [2] was proposed to address this issue. In PMIPv6, the mobility management is handled by the network and it is transparent to MN provided the movement of MN is within the PMIPv6 domain. PMIPv6 allows MN to roam among different wireless networks under the same administrative PMIPv6 domain. The requirement of under the same domain is feasible if considering roaming between different networks provided by the same service provider. However, when there are multiple service providers, neighboring networks might not be under the same domain. For example, shopping malls often provides free WiFi networks, but they may subscribe to different service providers. Then PMIPv6 will not work when a MN roams from one shopping mall to another. Research effort [3], [4] has been made to mitigate this problem. However, the proposed schemes require extension to original PMIPv6 scheme to enable collaboration between PMIPv6 domains.

On the other hand, it is observed that it is very common to have handover between WiFi hotspots. Neighboring 802.11 Access Points (APs), probably under different administrative domain, can form wireless mesh networks. Thus, it is desirable to enable transparent roaming of MN within such mesh networks. To facilitate easy deployment, it should not require modification on MN. In addition, APs should be independent and have equal role in the mesh since they are under different administrative domains. Some schemes [5], [6] have been proposed for mobility support in wireless mesh networks. However, they assume a different scenario where each nodes having different roles. For example, [6] requires one of the mesh nodes to act as location server.

802.11s [7] is an emerging standard for 802.11 wireless mesh network. 802.11s enables the mesh network appear as a single broadcast domain. Besides the normal mesh node which only participating in traffic forwarding, the mesh node can also collocate with an AP and becomes a Mesh Access Point (MAP). Each MAP serves as a proxy to the mobile clients attached under its AP interface. Each MAP will maintain proxy information regarding to the mobile client in the mesh network and this proxy information is dynamically updated. In addition, Mesh Portal (MP) are nodes with connectivity to other external networks.

In this paper we propose a network based local mobility scheme based on Cooperative AP (COAP) for 802.11 wireless networks. COAP is proposed as an alternative to PMIPv6 for network based handover in 802.11 networks. Similar to PMIPv6, COAP does not require modification on MN. In addition, COAP does not require APs under the same administrative domain. The basic idea of COAP is to use cooperative DHCP server to ensure that wherever MN roams to in the mesh, it will acquire the same IP address. Furthermore, COAP utilizes 802.11s for traffic forwarding within the mesh. The movement of MN is concealed within the network and transparent to external nodes. We developed an analytical model to study the performance of COAP and show that it can enable transparent node mobility in 802.11s networks. In next section, the design of COAP is presented. In section III, the proposed scheme is evaluated and compared with MIPv6-RO. Section IV concludes this paper.

II. DESIGN

A. Network Model and Overview

In this paper, we focus on mobility management for 802.11 based networks under different administrative domains. Refer to Fig. 1, each cell represents the coverage of an Access Point (AP) and the corresponding router. It is assumed each AP also participates in 802.11s mesh operation and acts as a MAP. In addition, since MAPs are assumed to be under different administrative domains, each of them will be collocated with a Mesh Portal (MP) to provide Internet connectivity to mobile users. In this way, each MAP is independent of others and has equal role in the formed mesh network.

The fundamental idea of the proposed COAP scheme is simple. Upon startup, each MAP will communicate with other MAPs within its vicinity to form a mesh network according to 802.11s standard. MAPs provide Internet connectivity to the attached MNs and on the other hand, participate the packet forwarding within the mesh network. When a MN enters the network, it will attach to one of the MAPs. The initial MAP that MN attaches to is referred to as the *Home MAP* and the subsequent MAPs it attaches to as *Foreign MAP*. To tackle the problem caused by change of IP address, COAP proposes a cooperative extension to Dynamic Host Configuration Protocol (DHCP) service such that the address assigned to MN remains the same wherever MN roams to within the mesh network. In addition, to conceal the movement of MN within the mesh network, traffic to or from a MN always enters or leaves the mesh network via the home MAP of the MN. MAPs will take care of the redirection of traffic within the mesh network.

B. Cooperative Extension of DHCP

When a MN joins a network, it uses DHCP service to acquire an IP address. In our scenario, since MAPs are independent of each other, the address pool of the DHCP server on each MAP are also configured independently. In IPv6 networks, each network will have a globally unique network prefix and thus there will not be any duplicate addresses in their address pools. On the other hand, in IPv4 networks, it is common to see private addresses used in conjunction with Network Address Translation (NAT). In such scenario, it is possible that the address pool configured for DHCP servers collide.

To avoid duplicate address assignments, COAP requires the address pools of DHCP servers to be disjoint. Upon startup, each cooperative DHCP server will broadcast their address pool in the mesh to detect overlapping address ranges. When an overlap is detected, only one of the server may keep the overlapping portion, others will give up on this portion and use other address ranges. Simple heuristics can be applied to decide which MAP to keep the overlapping portion. For example, the overlapping portion can be kept by the MAP with the IP address of the smallest decimal value. The IP addresses of MAPs can be extracted from the previous address pool broadcast and no additional message exchange is required. Furthermore, since address duplication only happens when private IPv4 addresses are used, it is possible to introduce an auto-configuration mode to DHCP server such that the network administrator only specifies the size of the address pool and the DHCP servers will determine the exact address range cooperatively. Note that this procedure only takes place

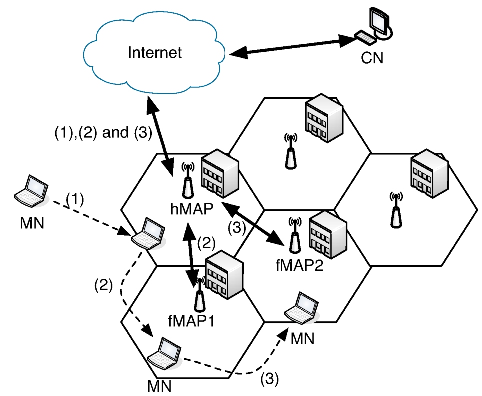


Fig. 1. An example illustrating the movement of MN in 802.11s mesh network. Dashed lines represents the movements of MN. Solid lines represents the forwarding path of inbound and outbound traffic when MN attaches to different MAPs.

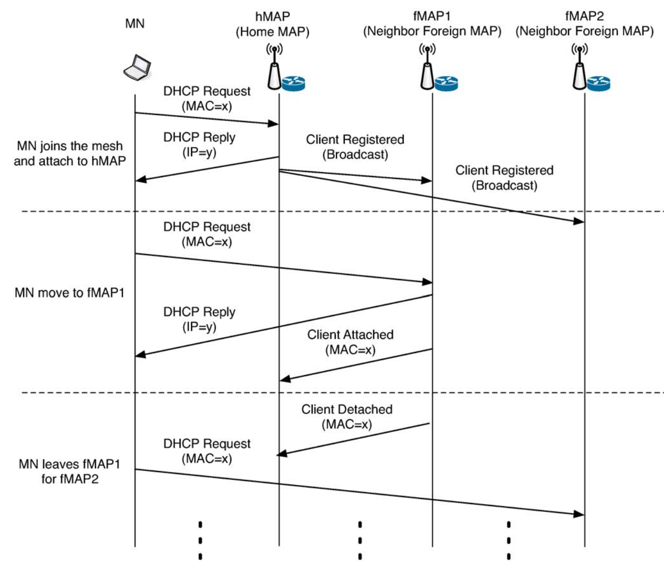


Fig. 2. An illustration of handover signaling.

during the formation of the mesh network and it does not impact the normal operation of the network.

C. Handover Procedure

To keep track of node mobility, each MAP maintains a *Mesh Client Table* recording the information about roaming MNs within the mesh network. Each Mesh Client Entry (MCE) in the table includes the MAC address of MN, the IP address of MN and the IP address of MN's home MAP. In addition, each MAP will maintain a *Registered Client Table*, which records information about the nodes who uses this MAP as home MAP. Each entry in *Registered Client Table* includes the MAC address of MN, the IP address of MN and the MAP MN currently attaches to. The *Registered Client Table* is used to track the address usage and reclaim address leased when MN leaves the network.

To explain the handover procedure, refer to Fig. 1 for an example. The dashed lines represents the movements of MN. Initially, MN enters the network and attaches to its home MAP hMAP, then it moves to a foreign MAP fMAP1. Subsequently, it leaves fMAP1 and enters another foreign MAP fMAP2. The signaling of the handover is illustrated in Fig. 2. Upon the attachment to a MAP, hMAP, MN will initiate the DHCP procedure to acquire an IP address from hMAP. When hMAP receives the DHCP request from MN, it will first look up its Mesh Client Table and determine whether this MN is new to the network or is an existing roaming MN from other cells. If the MN is found to be new to the network, this MAP becomes MN's home MAP and it will assign an IP address to MN from its address pool. Then MN can start communication. hMAP will also broadcast a *Client Registered* message to other MAPs, indicating the MAC address of MN, IP address assigned and the corresponding Home MAP. Other MAPs will record this information in their *Mesh Client Table* together with the IP address of the announcing MAP.

If MN later roams to a neighboring foreign MAP, fMAP1, when MN requests IP address from fMAP1, fMAP1 will look up its *Mesh Client Table* and assign the same IP address to MN as recorded in the table. In addition, it will notify hMAP, the Home MAP of MN, by sending a *Client Attached* (CA) message. hMAP will then update its *Registered Client Table* accordingly. As soon as hMAP detects MN has left its coverage, it will cache the inbound traffic destined to MN until it receives *Client Attached* message from fMAP1. When hMAP receives the notification from the fMAP1, it will release the cached packets to the network. Upon MN moving to fMAP1, underlying 802.11s will update the proxy information automatically. Then the packets will be forwarded to the correct MAP by 802.11s and no special handling is needed. For outbound traffic, the fMAP1 will forward them back to hMAP such that the outbound traffic of MN leaves the mesh network from the same MAP despite the movement of MN. This can be achieved by policy routing at network layer. This is required because otherwise it could leave the mesh network from the local MP at fMAP1 and cause NAT failure and issues with egress filtering. When MN continues to roam to fMAP2 from fMAP1, fMAP1 will send a *Client Detached* (CD) message to hMAP to notify the movement of MN. hMAP will update its *Registered Client Table* accordingly.

Note that with 802.11s, the mesh network appears as a single broadcast domain to the upper layers and the broadcast packets will be relayed to throughout the mesh automatically. On the flip side, when a MAP receives a DHCP request, it should only serve the request if the request comes from the AP interface serving the clients.

D. Address Tracking

In order to keep track leased addresses, hMAP will start a timer whenever it detecting MN has detached from one of the MAP. The detection can be carried out by local MAC detection if MN was attached to hMAP itself or by *Client Detached* (CD) message if MN was attached to other MAPs. If there is no *Client Attached* message received within *MaxHandoverDelay* seconds, hMAP assumes the MN has left the network. It will reclaim the address previously leased to MN and broadcast a *Client Deregistered* to all MAPs. Other MAPs will then remove the corresponding entry in their *Mesh Client Table* accordingly.

III. EVALUATION

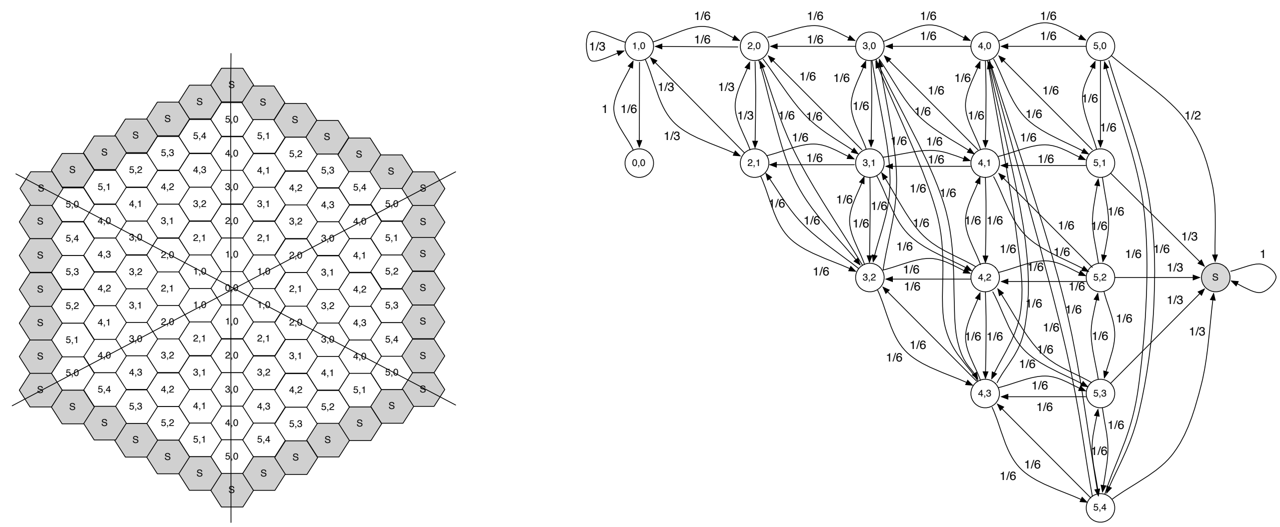
In this section, we evaluate the performance of the proposed scheme. Specifically, since each MAP holds information about a roaming MN in their *Mesh Client Table*, the number of entries in the table, i.e. the maximum number of MCE is of interest to study to provide an estimation on the resource requirement of MAPs. In addition, we are also interested in the handover delay. We first developed an analytical model to model the movement of MN and then present the numerical results. For comparison, since in the scenario under study neighboring MAPs are assumed to be under different administrative domain, therefore PMIPv6 is not applicable. Hence, we use MIPv6-RO for comparison.

A. Analytical Model

Inspired by [8], we model the movement of MN as 2D random walk over hexagonal cells as illustrated in Fig. 3(a). The unshaded cells represents cells in the mesh network and each cell represents the coverage of a MAP. The surrounding shaded cells are the area beyond the coverage of the mesh network. The movements of MN in the mesh network follows a random walk and it is deemed to have left the network once it enters the shaded cells. Each cell in the mesh is labeled (x, y) where x being the hop count from the center cell and y being the type of the cell. Together (x, y) identifies a cell's relative location within the mesh. Note that there are cells with identical (x, y) label. These cells are considered equivalent because they have the same set of neighbors. For example, cells labeled with $(3, 1)$ has common neighbors of $(3, 0)$, $(3, 2)$, $(2, 0)$, $(2, 1)$, $(4, 1)$ and $(4, 2)$. Therefore the total number of cells can be simplified and reduced. Refer to [8] for the algorithm to label the cells.

Since with random walk, a MN can move to any of the neighboring cells with equal probability, i.e. 1/6 in the case of hexagon, the state transition diagram of the random walk over the reduced set of cells can be derived as illustrated in Fig. 3(b). A state (x, y) represents MN in a cell of type (x, y). Because we only interest in the movements of MN within the mesh network, we considers the movement ends once MN leaves the networks, i.e. reaching one of the S cells. Correspondingly, state S is an absorbing state, it indicates that MN has leaved the network.

Based on Fig. 3(b), the transition matrix $\mathbb{P}$ of the random walk can be written as (1). The order of elements in the rows and columns of the matrix follows the order of (0,0), (1,0), (2,0), (2,1), $\cdots$, (5,3), (5,4) and S. Each element p_{ij} of $\mathbb{P}$ represents the probability that MN will move to state j in the next transition when currently in state i. Based on Chapman-



(a) An illustration of cell classification in 6-subarea mesh network. Each hexagon represents the coverage of a MAP. Cells are labeled (x, y) where x being the hop count from the center cell and y being the type of the cell.

(b) A state transition diagram illustrating the transition probability between states.

Fig. 3. This figure illustrates the cell classification and the state transition diagram.

Kolmogorov equation, the k-step transition matrix $\mathbb{P}^{(k)}$ can be written as (2).

$$\mathbb{P} = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 1/6 & 1/3 & 1/6 & 1/3 & 0 & \cdots & 0 & 0 & 0 \\ 0 & 1/6 & 0 & 1/3 & 1/6 & \cdots & 0 & 0 & 0 \\ 0 & 1/3 & 1/3 & 0 & 0 & \cdots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 1/6 & 1/3 \\ 0 & 0 & 0 & 0 & 0 & \cdots & 1/6 & 0 & 1/3 \\ 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 1 \end{pmatrix} \quad (1)$$

$$\mathbb{P}^{(k)} = \mathbb{P}^k \quad (2)$$

Each element $p_{ij}^{(k)}$ in $\mathbb{P}^{(k)}$ is the probability of MN moves from state i to state j in k transitions. Then we can define the probability that MN moves state j from state i at kth transition, $p_{k,ij}$, as follow,

$$p_{k,ij} = \begin{cases} p_{ij} & \text{if } k = 1 \\ p_{ij}^{(k)} - p_{ij}^{(k-1)} & \text{if } k > 1 \end{cases}$$

The expected number of transitions W_i made by a MN starting in state i before leaving can be computed as (3).

$$W_i = \sum_{k=1}^{\infty} k p_{k,iS} \quad (3)$$

Let the probability of MN initially in state i ($i \neq S$) be q_i. If the number of states is c and it is equally likely for MN to start from any cell in the network, then $q_i = 1/c$. Then, W, the expected number of transitions made by a MN before leaving the network starting in any cell, is written as (4).

$$W = \sum_{i=1}^{c} W_i q_i \quad (4)$$

$$L = \lambda W \quad (5)$$

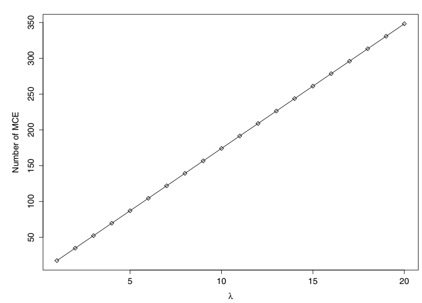


Fig. 4. A plot of the number of MCE for different λ.

Now if we consider the mesh network a queuing system where MNs arrives at the network at the rate of λ and on average MNs stays in the system for W time units, then by Little's formula, the expected number of MNs in the system, L, is given by (5).

B. Expected Number of MCE

Since each MAP keeps a Mesh Client Entry (MCE) for every roaming MN in the network, thus the expected number of MCE in each MAP is just L, the number of nodes in the network. To compute L, we use the first 200 terms of $p_{k,iS}$ to estimate W_i. Then L can be computed using (3), (4) and (5). The number of MCE against different λ is plotted in Fig. 4. It can be seen that the number of MCE increases linearly with λ and it is about 17 times of λ. This gives an estimation on the amount of resources required to handle the mesh client table for different arrival rate of MN and it can be used as one of the guideline when deciding the required capability of MAP.

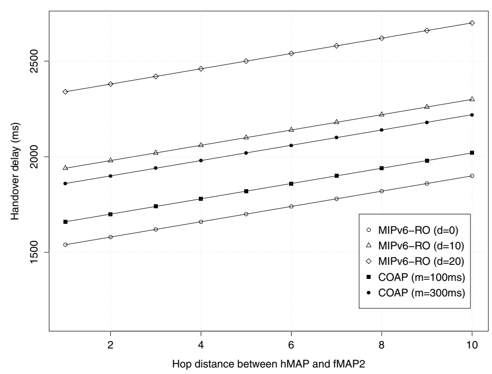


Fig. 5. A plot of handover delay for MIPv6-RO and COAP.

C. Handover Delay

To compute the handover delay, let's consider the handover process when MN moves from fMAP1 to fMAP2. We define the handover delay as the period from the time MN is detached from fMAP1 until it attaches to fMAP2 and starts receiving the data traffic from CN.

For MIPv6 with Route Optimization (MIPv6-RO), it will need to send BU to CN to notify its new CoA so that CN can forward the traffic directly to its new CoA. Let the time taken to perform layer 2 association be T_{L2} and the time taken to acquire IP address through DHCP be T_{DHCP}. If $T^{BU}_{MIPv6-RO}$ represents the time taken for the Binding Update (BU) to reach CN and $T^{Data}_{MIPv6-RO}$ represents the delay for the data from CN to be forwarded to the new CoA of MN, then the handover delay of MIPv6-RO, $T_{MIPv6-RO}$, can be computed as the (6). Let H^A_B represents the hop distance between two nodes A and B. If the expected per hop delay is τ, we can write (7) and (8).

$$\begin{aligned} T_{MIPv6-RO} &= T_{L2} + T_{DHCP} + T^{BU}_{MIPv6-RO} \\ &\quad + T^{Data}_{MIPv6-RO} && (6) \\ T^{BU}_{MIPv6-RO} &= H^{MN}_{CN}\tau && (7) \\ T^{Data}_{MIPv6-RO} &= H^{CN}_{MN}\tau && (8) \end{aligned}$$

Similarly, we can derive the handover delay for COAP as shown in (9), (10) and (11), where T^{CA}_{COAP} is the time for fMAP2 to send *Client Attached* message to hMAP and $T_{MeshUpdate}$ is the delay taken for 802.11s to update the proxy information about MN. Note in COAP, the data is cached at hMAP during handover and therefore the we can write (11).

$$\begin{aligned} T_{COAP} &= T_{L2} + T_{DHCP} + T_{MeshUpdate} + \\ &\quad T^{CA}_{COAP} + T^{Data}_{COAP} && (9) \\ T^{CA}_{COAP} &= H^{fMAP2}_{hMAP}\tau && (10) \\ T^{Data}_{COAP} &= (H^{hMAP}_{fMAP2} + H^{fMAP2}_{MN})\tau && (11) \end{aligned}$$

Let $T_{L2} = 500ms$, $T_{DHCP} = 1000ms$, $\tau = 20ms$. Since MN is attached to fMAP2, $H^{fMAP2}_{MN} = 1$. To plot the numerical result, Let $m = T_{MeshUpdate}$ and $d = H^{MN}_{CN} - H^{fMAP2}_{hMAP}$, then handover delay can be plotted as shown in Fig. 5. It can be seen that as H^{hMAP}_{fMAP2} increases, the handover delay of COAP increases accordingly. On the other hand, the handover delay also increases as the time taken to update the Mesh Proxy information increases, which is in turn depends on the size of the mesh network. MIPv6 shows lower handover delay when H^{MN}_{CN} is the same as H^{fMAP2}_{hMAP} and it is expected to show similar performance if H^{MN}_{CN} is smaller. This happens when the CN is also in the local mesh network. Although 802.11s will also update the proxy information to redirect the traffic, it would take shorter time for MN to update CN directly since the mesh proxy update will need to inform all MAPs in the network. As d increases, H^{MN}_{CN} becomes larger than H^{fMAP2}_{hMAP}, the handover of MIPv6-RO is observed to take longer time than COAP. This suggests that COAP can incur lower handover delay unless both MN and CN are in the same mesh network. On the flip side, MIPv6 requires modification on the protocol stack of MN. COAP removes such requirement with this slightly longer handover delay in rare scenarios, which justifies the trade-off.

IV. CONCLUSIONS

In this paper, we proposed a network based local mobility scheme to enable mobile node to roam transparently among different APs. The proposed scheme uses a cooperative DHCP service to ensure MN's IP address remain unchanged in the mesh network and utilizes 802.11s for traffic redirection and forwarding. The proposed scheme does not require MN to participate in the signaling and the mobility management is carried out entirely by the network. In addition, it does not require APs under the same domain as PMIPv6 does. This makes it a suitable alternative to PMIPv6.

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