Proxy Mobile IPv6 for Cluster based Heterogeneous Wireless Mesh Networks

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Abstract

This work extends Proxy Mobile IPv6 to support mobility to Mobile Nodes having standard IPv6 stack in Cluster Based Heterogeneous Wireless Mesh Architecture. We also propose an enhanced network-based IP-layer movement detection mechanism which allows the network to detect the attachment and the movement of each Mobile Node independently from the access technologies without any special support from Mobile Nodes. We implemented and evaluated the extensions in a virtual IPv6 wireless testbed using User-mode Linux ad Ns-2 Emulation. Some qualitative results are also provided to prove the correctness and the advantages of the proposals.

1. Introduction

Wireless Mesh Networks (WMNs) are multi-hop wireless networks with self-healing and self-configuring capabilities. These features, plus the ability to provide wireless broadband connectivity, make WMNs a promising solution for ubiquitous Internet access and a wide range of applications [1]. A WMN generally consists of a set of mesh nodes that interconnect with each other via wireless medium to form a wireless backbone. Some or all of the mesh nodes also serve as access points for mobile users under their coverage. One or more mesh nodes have wired connections to the Internet and function as the gateway. Compared to traditional wireless LANs, the main feature of WMNs is their multi-hop wireless backbone.

We consider a Cluster Based Heterogeneous Wireless Mesh Architecture in which the WMN is divided into clusters. Each cluster containing a CH that has complete knowledge about group membership and link state information in the cluster. The Cluster Head (CH) is often elected in the cluster formation process. Other routers within a cluster, called Mobile Routers (MRs), are minimal mobile and control heterogeneous radio access technologies. This architecture is considered advantageous over other existing Wireless Mesh Architecture as it can reduce the flooding signaling traffic during the dynamic route discovery process and the registration process.

We extend Proxy Mobile IPv6 (PMIPv6) to support mobility of MN having standard IPv6 stack in such a Cluster Based Heterogeneous WMN. To support a heterogeneous environment composing of different access technologies, we introduce an enhanced network-based IP-layer movement detection mechanism. It allows the network to detect the attachment and the movement of each MN independently from the access technologies and requires no special support from the MN. Upon any attachment or detachment of a Mobile Node (MN), the MR informs the CH on behalf of the MN to maintain the reachability of the MN while it is moving. Here, MNs are expected to maintain their IPv6 addresses allocated from their home link while moving within the mesh network.

The paper is organized as follows: Section 2 describes related work including Cluster Based WMN, PMIPv6, and existing movement detection mechanisms. Section 3 introduces our framework with an extended PMIPv6 and an enhanced network-based IP-layer movement detection. Section 4 describes Eurecom's implemented software architecture of PMIPv6 and the virtual IPv6 wireless testbed using User-mode Linux (UML) and Ns-2 Emulation. It also provides some qualitative. Finally, section 5 concludes the paper and provides perspectives for future work.

2. Related Work

2.1. Cluster Based Wireless Mesh Network

We consider a Cluster Based Heterogeneous WMN Architecture in which the WMN is divided into clusters as in Figure 1. A cluster is a group of nodes located within close physical proximity, typically all within range of one another, which can be grouped together for the purpose of limiting the production and propagation of routing information.

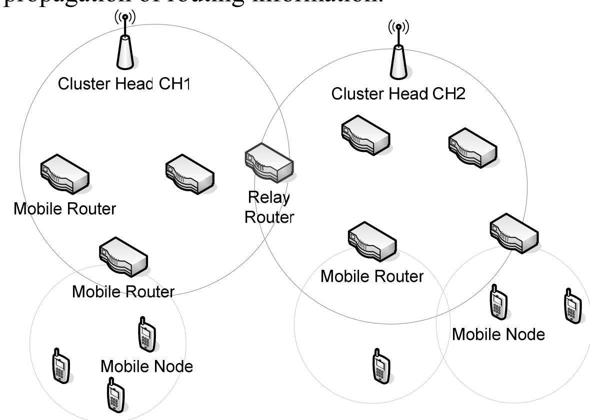

Figure 1. Cluster Based WMN

Each cluster containing a CH that has complete knowledge about group membership and link state information in the cluster. The CH is often elected in the cluster formation process. Each cluster should have one and only one CH. MRs are minimal mobile and control heterogeneous radio access technologies and provide network access to MNs. A relay router connects two adjacent clusters. The MN, which attaches to the MR, can be connected through the mesh structure to all other routers in the mesh. The MN therefore can communicate with other mobile Correspondent Nodes (CNs) through MRs as well as with CNs on the Internet through CHs.

The architecture can minimize the updating overhead during topology change due to mobility of mesh nodes.

2.2. Proxy Mobile IPv6 (PMIPv6)

PMIPv6 is designed to provide network-based mobility management to MNs having standard IPv6 stack [2][3][4]. The new principal functional entities of PMIPv6 are the Mobile Access Gateway (MAG) and Local Mobility Anchor (LMA). The main role of the MAG is to detect the MN's movements and initiate mobility-related signaling with the MN's LMA on behalf of the MN. The serving network assigns a unique home network prefix to each MN, and conceptually this prefix always follows the MN wherever it moves within a PMIPv6 domain. From the perspective of the MN, the entire PMIPv6 domain appears as its home network. The MN can configure an address using any address configuration mechanism that is allowed in the network. Here we assume a Stateless Address Configuration.

Figure 2 shows a typical PMIPv6 handover process of an IPv6 MN. Once a MN enters the PMIPv6 domain and attaches to a MAG, the MAG must identify the MN and acquire the Mobile Node Identifier (MNID). If the MAG determines that the MN is authorized for the network-based mobility management service, it must start the Location Registration procedure on behalf of the MN to maintain the reachability of the MN. The MAG sends Proxy Binding Update (PBU) message to the LMA and waits for the Proxy Binding Acknowledgement (PBA) message from the LMA. At the end of this Location Registration procedure, the MAG and the LMA establish a bidirectional tunnel and update the routing entry to forward the MN traffic through the bidirectional tunnel. The soft state of a MN at LMA ad MAGs is maintained in a Binding Cache entry which can be accessed using the MNID as search key. Such information associates a MN with its serving MAG, and allows the relationship between the MAG and LMA to be maintained.

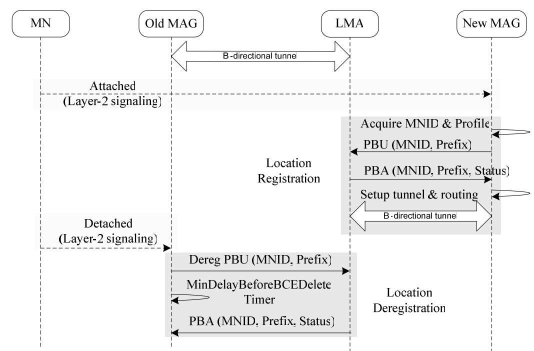

Figure 2. PMIPv6 Sequence Diagram

At any point, the MAG detects that the MN has moved away from its access link, or if it decides to terminate the MN's mobility session, it should start the Location Deregistration procedure by sending a Proxy Binding Update message to the LMA with the lifetime value set to zero.

The standard PMIPv6 provides a natural solution for intra-cluster mobility and communication. However for inter-cluster mobility and communication, one fundamental issue is that of locating the serving MAG or serving LMA of the CN.

2.3. Movement Detection Mechanisms

An important aspect of any mobility protocol is the movement detection. Different movement detection mechanisms have been proposed for Mobile IP. However these are host-based and require special supports from the MN. For PMIPv6, the MAG must be responsible for the movement detection; this requires a network-based movement detection mechanism. The hints for movement detection can be the Link-Layer

Event Notifications, Traffic Monitoring Events or DNAv6 [5]. Table 1 compares advantages and the drawbacks of different approaches:

Table 1. Comparison of Movement Detection Approaches

Hints	Advantages	Drawbacks
Traffic Monitoring Events	Independent from access technologies.	Processing overhead at MAGs.
Link-Layer Events	Accurate and Rapid.	Dependent on access technologies.
DNAv6	Independent from access technologies.	Dependent on how MN detect the attachment

A traffic monitoring based mechanism only works fine when there is uplink traffic from the MN to the network. The mechanism can be independent from the access technology but causes processing overhead at MAGs because MAGs must inspect every packet on the link. A link-layer event notification mechanism can be accurate and rapid. However in a heterogeneous environment, it depends on particular access technologies, requires a lot of modifications either on the network side or on the terminal side and therefore the deployment becomes difficult. DNAv6 also provides an IP-layer movement detection independent from access technology. DNAV6 uses the fact that the MN will send ICMPv6 message, e.g. Neighbor Solicitation (NS), and/or Router Solicitation (RS), when it move to a new link, which depends on how the MN detect the attachment and detachment.

An enhanced network-based IP-layer movement detection is a must to complement existing mechanisms.

3. Framework

This framework extends PMIPv6 to support mobility in Cluster Based WMNs. In this architecture, the MAG typically runs on the MR and the LMA runs on the CH. Therefore MR and CH can be interpreted as MAG and LMA.

3.1. Extended PMIPv6

The standard PMIPv6 provides a natural solution for communication between the MN and the CN outside the PMIPv6 domain. It also works fine for intra-cluster communication between two MNs in the same cluster and intra-mobility. However for inter-cluster communication, when the MN and the CN belong to different clusters in the same PMIPv6 domain, one fundamental issue is that of locating the serving MAG or the serving LMA of the CN. As for inter-cluster mobility, when the MN moves from one cluster to a new cluster, it is necessary to activate the Location Deregistration procedure in the old cluster to maintain up-to-date routing information.

When establishing the communication between a MN and a CN belonging to different clusters, the serving MAG of the MN needs to know the serving MAG or the serving LMA of the CN. This issue is expressed as the problem of mapping a CN address into its serving MAG address or serving LMA address. This issue also arises in the case of route optimization in which the traffic could be forwarded directly from a source MR to a destination MR without passing through CHs.

We propose a new couple of messages: Proxy Binding Request and Proxy Binding Response and a new mobility header option, named Serving MAG Address option (see Figure 3).

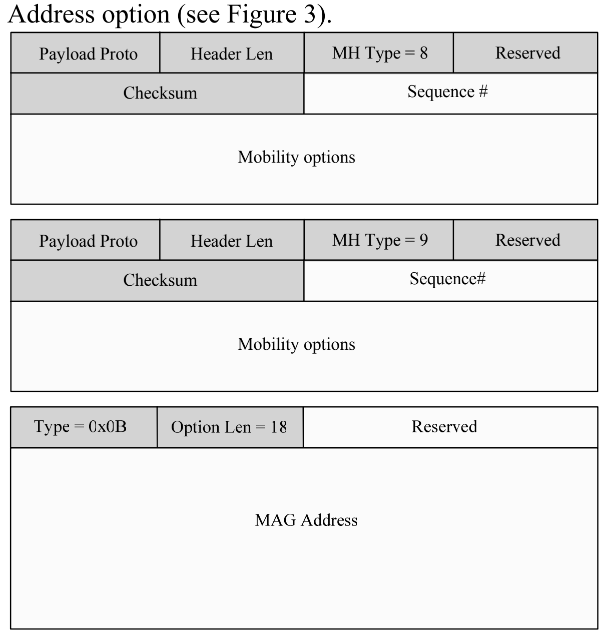

Figure 3. New messages and options

The Proxy Binding Request message structure is similar to that of Binding Request of Mobile IPv6 [6] except that the MH Type takes a value of 8 instead of 0. The value should be registered at IANA. This message is sent by the LMA to an All-LMA multicast group, an All-MAG multicast group, or to a centralized super LMA to find which MAG is serving a mobile CN. The Proxy Binding Response message has similar structure as that of Proxy Binding Request. It responses to a Proxy Binding Request except that the MH Type takes a value of 9 instead of 5. Serving

MAG Address option is a mandatory option of these two messages.

3.2. Enhanced Network-based IP-layer Movement Detection

We propose here an algorithm for network-based IP-layer movement detection in heterogeneous wireless environment.

3.2.1. Precondition. In standard PMIPv6, the MN maintains an IP address that is unchanged within the PMIPv6 domain and is used for communications. This address is a global IP address and is referred in this paper as PMIPv6 address.

In our proposal, each MR broadcast two prefixes: (i) a global prefix P which is assigned to each MN (per-MN prefix) or is shared by all MNs (multi-link subnet) and (ii) a site-scope (or equivalent) prefix P*. The global PMIPv6 address is configured from the global prefix P while the temporary site-scope IP address is configured from the site-scope prefix P*.

Whenever the MN moves to a new link, it configures a new temporary address and deletes the previous temporary address when its preferred lifetime is expired. The NS message for this new temporary address, in Duplicate Address Detection (DAD) process, is used as a hint for the network attachment detection. The following assumptions are taken into account:

Assumption 1: the MAG could extract the MNID, e.g. the MAC address, from any ICMPv6 messages sent by the MN, e.g. NS, RS, and Neighbor Advertisement (NA). Besides, there exists a bidirectional conversion between the MNID and the PMIPv6 address. Given a PMIPv6 address, we can infer the MNID and vice versa.

Assumption 2: If multiple addresses are active for the same interface, depending on the destination address, the source address of the communication is selected according to the Source Address Selection algorithm [7].

The first assumption allows the MAGs to detect the hints for network attachment of a MN when the MAG receives an ICMPv6 message. The second assumption ensures that the MN always prefer the PMIPv6 address for communications even when multiple addresses co-exist and therefore global prefix P and temporary site-scope prefix P* could be broadcasted by the MR on the same link without causing conflicts.

3.2.2. Algorithm description. With the above precondition, each MN will have two IPv6 addresses: one is PMIPv6 address, which is a global IPv6 address and is unchanged within the PMIPv6 domain; another is the temporary address, which is a site-scope IPv6 address and is reconfigured whenever the MN moves from the old MR to a new MR.

Thanks to the temporary site-scope prefix P* in Router Advertisement messages, sent periodically by the MR, the MN configures temporary site-scope address and activate DAD procedure by sending an NS message. This message will be used as a hint for the new MR to verify if the MN is really attached to it. The new MR activates the Unreachability Detection procedure by sending NS for address resolution with the target set to PMIPv6 Address. It also creates a temporary binding cache entry for the MN with a short life time and waits for the NA. If the MN has really moved inside the coverage of the new MR and associate with the new MR at the link layer, it must be able to answer this NS with an NA as the default behavior of Neighbor Discovery for IP Version 6 (NDPv6) [8]. The NA message, with the PMIPv6 address as the target, confirms the attachment of the MN and activates the Location Registration procedure.

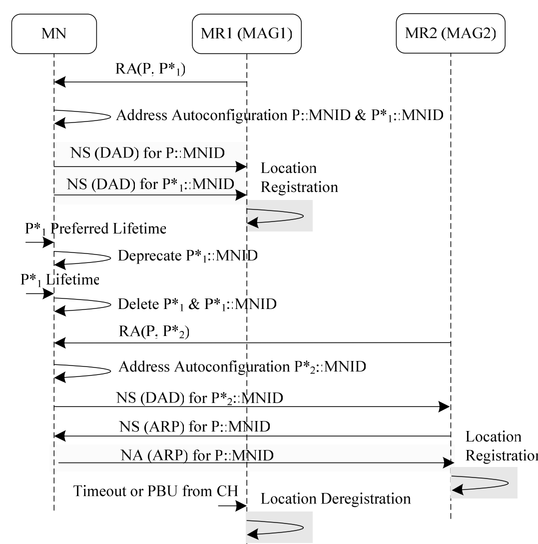

Figure 4. Example of Enhanced Network-based IP-Layer Movement Detection

The Figure 4 shows a sequence diagram of a typical handover scenario, with enhanced network-based IP-layer movement detection, in which the MN first comes to the PMIPv6 domain, using a shared prefix, and attaches to the MR1. Later, the MN moves away from MR1 and attaches to the MR2.

4. Implementation and Evaluation

To evaluate the PMIPv6 in Cluster Based Heterogeneous WMN, we implemented the PMIPv6 under linux kernel 2.6.20, and setup a virtual wireless mesh IPv6 testbed using UML [9][10] and Ns-2 Emulation [11].

4.1. PMIPv6 Implementation

We implemented PMIPv6 on top of Mobile IPv6 for Linux (MIPL) v2.0 [12]. All the basic bricks of MIPL are reused in an efficient way as shown in Figure 5. In MIPL v2.0, Mobile IPv6 is implemented using multi threads: One thread for handling the ICMPv6 messages, one thread for handling Mobility Header messages, one thread for handling tasks and time events, etc.

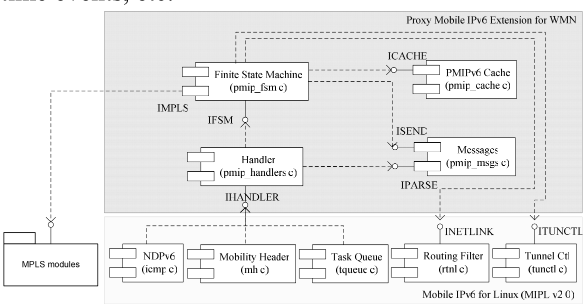

Figure 5. PMIPv6 Software Architecture

To support PMIPv6, we extend these elements and implement handlers for all necessary messages and events. All ICMPv6 messages or Mobility Header messages are parsed as the input to the finite state machine, which is the heart of the system. This finite state machine makes appropriate decisions and controls all other elements to provide a correct predefined protocol behavior. As PMIPv6 implementation is built on top of MIPL version 2, it could be later integrated in MIPL easily and grows inline with the standards as well as MIPL source code.

4.2. Virtual IPv6 WMN

In order to keep the results closest to the real experiment, we used a virtualization based testbed, using a combination of User-mode Linux (UML) and Ns-2 Emulation, which would allow migrating to the real testbed with just insignificant efforts.

UML is a Linux kernel which is compiled to run as a virtual machine on a Linux host. The virtual machine, called the guest to distinguish with the real host machine, can be assigned a guest root file system and other virtual physical resources different from the host machine. A UML virtual machine requires a guest kernel and a guest root file system. The guest root file system of an UML is stored in a file on the real host machine.

The Ns-2 Emulation feature is used to emulate the wireless environment. It can grab packets from a virtual machine with real IPv6 stack, pass them through a simulated wireless network, and then inject them back into the destination virtual machine.

The virtual testbed in this early phase composes of one cluster with one CH, two routers MR1 and MR2. A CN, positioned in the Internet, is connected directly with the CH. There are two MNs which don't have any specific software to support the mobility. Initially, MN1 is attached to MR1 and MN2 is attached to MR2. IEEE 802.11 is used for the virtual wireless link.

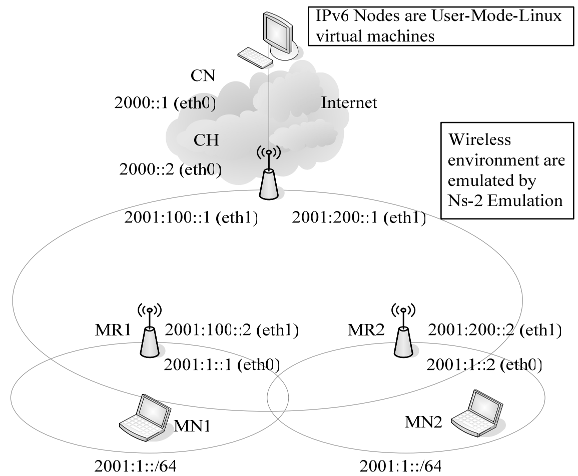

Figure 6. Virtual Wireless Mesh Testbed

Figure 6 shows the virtual Wireless Mesh testbed. The topology is defined and generated using Virtual Network User-ode Linux (VNUML) [13]. Scenarios are defined and automated with Tcl language which is a part of Ns-2 Emulation.

4.3. Qualitative Results

Different test scenarios are defined and carried out to verify the correctness of the framework. Table 2 shows important scenarios which have been tested.

Table 2. Test Scenarios

Scenarios	Descriptions	Results
Attachment Detection	MN1 and MN2 come inside MR1 coverage	Successful registration of MN1/MN2 in both MR1& CH
Detachment Detection	MN1 or MN2 turns down the interface (or moves away from MR1).	The cache entry is deleted in both MR1 and CH.

Intra-link Communication	MN1, MN2 are attached to MR2. Traffic between MN1 and MN2	MN1 can communicate with MN2
Intra-cluster Communication	MN1 is attached to MR1. MN2 is attached to MR2. Traffic between MN1 and MN2	The traffic is encapsulated through MR1-CH and MR2-CH tunnels.
Mobility and Movement Detection	MN1 moves from MR1 to MR2. The PMIPv6 address of MN1, which is configured with the PMIPv6 prefix, is kept unchanged. MN1 configures new temporary address, and deletes the old temporary address.	MR2 detects the attachment and starts the registration procedure. MR1 detects the detachment and starts the deregistration procedure. Session continuity is assured. On-going sessions can continue

5. Conclusion and perspectives

We extended PMIPv6 for Cluster Based Heterogeneous WMNs. The framework can support network-based mobility to MNs having standard IPv6 stack. A new enhanced network-based IP-layer mechanism was proposed. This movement detection mechanism allows detecting the attachment and the movement of each MN independently from the access technologies and requires no special support from the MN. We implemented and deployed the PMIPv6 protocol in a virtual IPv6 wireless mesh testbed and provide some qualitative results to prove the correctness and the advantages of the framework.

The proposed framework is suitable for different applications. One of current applications is to deploy rapidly a mobile and wireless communication environment in Integrating Communications for enhanced environmental risk management and citizens safety (CHORIST) project [14] which proposes solutions to increase rapidity and effectiveness of interventions following natural hazards and industrial accidents, in order to enhance citizens' safety and communications between rescue actors. The framework combines different hot trends in mobile networking to form a realistic and practical platform for future advanced mobile networking researches. Our future work will concentrate on inter-cluster communication, on route optimization as well as on QoS support. We also foresee the use of MPLS instead of IP-in-IP. Performance evaluation with quantitative results will also be realized.

6. Acknowledgements

Eurecom Institute's research is partially supported by its industrial members: BMW, Bouygues Télécom, Cisco Systems, France Télécom, Hitachi Europe, SFR, Sharp, STMicroelectronics, Swisscom, Thales. Authors are also thankful to Hussain Ahmed, Paul Marie Joseph Venmani Daniel Philip, Lamia Romdhani (Eurecom Institute) and Hirokazu Naoe (SHARP) for help and valuable advices.

7. References

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