Integrating Mobile Ad Hoc Network to the Internet

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Abstract  A novel scheme is presented to integrate mobile ad hoc networks (MANETs) with the Internet and support mobility across wireless local area networks (WLANs) and MANETs. The mobile nodes, connected as a MANET, employ the optimize d link state routing (OLSR) protocol for routing within the MANET. Mobility management across WLANs and MANETs is achieved through the hierarchical mobile IPv6 (HMIPv6) protocol. The performance is evaluated on a HMIPv6 based test-bed composed of WLANs and MANETs. The efficiency gain obtained from using HMIPv6 in such a hybrid network is investigated. The investigation result shows that the use of HMIPv6 can achieve up to 27% gain on reducing the handoff latency when a mobile roams within a domain. Concerning the reduction of the signaling load on the Internet, the use of HMIPv6 can achieve at least a 54% gain and converges to 69%.

Key words  mobile ad hoc network (MANET);  optimized link state routing (OLSR);  wireless networks;  mobile IPv6;  hierarchical mobile IPv6

With the popular use of mobile devices, the desire for mobile access to the Internet is increasing. An important area of IP research is mobile wireless networking. There are currently two variations of mobile wireless networks. The first type of mobile wireless network is known as an infrastructure network, i.e., a network with fixed and wired gateways. Typical applications of this type of network include wireless local area networks (WLANs). The second type of wireless network, which lacks an underlying infrastructure mobile network, is commonly known as a mobile ad hoc network (MANET). MANETs have no fixed infrastructure, and all nodes are capable of movement and can be connected dynamically in an arbitrary manner. All nodes in a MANET serve as routers to discover and maintain routes to other nodes in the network.

MANETs are often put into the Internet to fill the coverage gap where WLANs are not available. Since nodes in MANETs are inherently mobile, some of these mobile nodes roam between MANETs and other parts of the Internet. To achieve seamless mobility for Internet mobile users who travel across multiple WLANs and MANETs, one must consider a mechanism for efficient mobility management and handoff support in such an environment. Recent research has focused on achieving this purpose. Most of the research on this topic concentrates on the integration of Ad hoc on-demand distance vector (AODV) routing protocol with Mobile IP presented in Ref.[1], MIPMANET as well as the integration of the dynamic source routing (DSR) protocol with mobile IP, etc[2-3]. On the other hand, some researchers explore the use of table-driven MANET routing protocols as a way of integrating MANETs with the Internet. MEWLANA-TD proposed in Ref.[4] employs a table-driven MANET routing protocol, the destination sequenced distance vector (DSDV) protocol. An integration approach of combining Mobile IP with the optimized link state routing (OLSR) protocol is presented in Ref.[5]. Different type of integration method has different performance features. However, all existing methods exploit and extend Mobile IP or Mobile IPv6 to achieve location management.

The motivation of our work is to reconsider the use of Mobile IPv6 in the existing integration proposals. In such an environment where mobile nodes (MNs) roam frequently across MANETs and WLANs within the same domain, the use of Mobile IPv6 could result in long handoff latency and high signaling load over the Internet. Hierarchical Mobile IPv6 (HMIPv6), an extension of the basic Mobility support in IPv6, is presented in Ref.[6] to handle micro-mobility. The protocol proposes a hierarchical scheme that differentiates local (intra-site) mobility from global (inter-site) mobility in the Internet. Based on the hierarchical network architecture, HMIPv6 employs...
different network servers as mobility management agents to manage different levels of mobility of a mobile node. Can we employ HMIPv6 to manage the mobility between WLANs and MANETs? To integrate HMIPv6 protocol with a MANET routing protocol, what extensions and modifications need to be done in HMIPv6 and the MANET routing protocol? How much efficiency gain is obtained in the use of HMIPv6? Our work focuses on these problems.

In this paper, we first describe a novel scheme to integrate MANETs with the Internet and support mobility across WLANs and MANETs. In our approach, HMIPv6 protocol is employed to support the mobility management across MANETs and WLANs; optimized link state routing (OLSR) protocol is chosen as the internal routing protocol within a MANET\(^7\). To the best of our knowledge, this is the first proposal to exploit the salient features of HMIPv6 in a hybrid network architecture of integrating MANETs with the Internet. Secondly, we present results for a performance evaluation of our approach based on a real test-bed. A set of performance benchmarks are designed and exploited to assess the effect of various factors on the integration scheme. Especially, efficiency gains obtained in the use of HMIPv6 over basic MIPv6 in the integration scheme are investigated.

1 HMIPv6 and OLSR Overview

1.1 Hierarchical Mobile IPv6

Hierarchical Mobile IPv6 (HMIPv6) is an extension of Mobile IPv6\(^6\). Mobile IPv6 provides mobility management by using two IP addresses for an MN: a fixed home address to identify the MN, and a changeable care-of-address (CoA) to associate with the MN’s current location. HMIPv6 as an extension of the basic MIPv6 protocol proposes a hierarchical scheme that differentiates local (intra-site) mobility from global (inter-site) mobility in the Internet. Based on the hierarchical network architecture, HMIPv6 employs different network servers as mobility management agents to manage different levels of mobility of a mobile node. A MN’s CoA is split into two care-of-addresses: regional CoA (RCoA), local CoA (LCoA). The two CoAs are used to handle global mobility and local mobility respectively. The RCoA identifies the domain where an MN is visiting. The LCoA identifies the MN’s access point within the domain. A new entity called a mobile anchor point (MAP) is introduced. The MAP functionality is installed on a domain MAP server. An MN configures its LCoA with the access router prefix and its RCoA with the MAP prefix. An MN registers its LCoA with the MAP and only registers its RCoA with its HA and CNs. So, when an MN moves within a domain, it does not need to re-register its local access point with its HA and CNs outside the domain. During local movement, the MN’s RCoA, known by its HA, remains unchanged so that global travel of the registration signal is avoided. HMIPv6 reduces signaling latency; since signaling messages travel only up to the MAP for local handoff, therefore local mobility performance is improved. It also reduces signaling overhead; since mobility control messages are limited to a local scope, the signaling load on the whole Internet is reduced.

1.2 Optimized Link State Routing Protocol

OLSR is a table-driven routing protocol standing for optimized link state routing in MANETs\(^7\). Compared with on-demand routing protocols, OLSR has the advantage of having the routes available immediately as needed. To reduce the bandwidth cost in exchanging frequent periodic control messages in the pure link state protocol, OLSR introduces multipoint relays (MPRs). Each node selects a set of nodes from its one-hop neighbors, which retransmits its broadcast packets. These selected neighbors consist of an MPR set of the node. Based on the idea of MPRs, OLSR protocol achieves an optimization over the pure link state routing protocol as a result of two features. First, it reduces the size of control messages since it only declares the link with its MPR selectors instead of all links with its neighbors. Second, it minimizes flooding of the control messages as it only uses its MPRs to retransmit the broadcast messages in a MANET.

2 Proposed Architecture

The proposed network consists of WLANs and MANETs connected to the Internet, as illustrated in Fig.1. In the hierarchical network architecture, a MANET is viewed as a basic unit of mobility management. MANETs and WLANs may belong to the same domain or different domains. Besides the entities introduced in HMIPv6: mobile anchor point (MAP), access router (AR), a new entity is introduced in a MANET: the MANET gateway (GW). GW as a bridge connecting a MANET to the Internet, is responsible for transferring messages into or out of the MANET. The MANET GW is also used to propagate
location information to facilitate mobility management. An MN traveling in the proposed network has three IP addresses:

1) Home address, to correspond to its home subnet and work as an identifier;
2) Regional care-of-address (RCoA), to identify the domain region;
3) Local care-of-address (LCoA), to specify its location in the domain.

Fig.1  Architecture of an OLSR with HMIPv6 network

Within the MANET, OLSR protocol is chosen to handle the internal mobility of mobile hosts within the MANET; HMIPv6 protocol is employed to support local mobility across MANETs and WLANs within a single domain or global mobility between different domains. Similar to the behavior of basic MIPv6, HMIPv6 is designed to support mobility where an MN is one hop away from the router. In our scheme, the challenge is to accommodate MANETs in such a way that an MN, which may be multiple hops away from a router, can be accessed from anywhere on the Internet. The hierarchical architecture of MN location management in HMIPv6 makes CoA autoconfiguration technique and joining MANET mechanism more complicate. The key constituents of the proposed architecture are elaborated next

2.1 CoA Autoconfiguration Technique

When an MN moves into a new domain, it should autoconfigure its new RCoA according to the MAP prefix. During a movement within the same domain, an MN keeps its RCoA. When the MN moves into a new basic unit area (either a WLAN or a MANET), it should autoconfigure its new LCoA according to the subnet’s prefix.

In MANETs, the MANET GW is used to receive and propagate the MAP option from the domain MAP. On the other hand, the GW broadcasts its existing network prefix periodically to MNs arriving in the MANET. However, MNs that are more than one hop away from the GW cannot receive the general RA message which can only be sent by link-scope multicast address. So, a new technique needs to be defined that allows a multi-hop distanced MN to receive the MAP option and GW address.

A new message type, the auto configuration message (ACM), is designed in OLSR. The ACM messages are flooded into the MANET through MPRs. A new arriving MN in a MANET uses the ACM message to detect its movement and configure its RCoA and LCoA instead of using the ICMP6 RA message.

IPv6 kernel and ICMP6 kernel are extended to support the interaction of ACM functionality with HMIPv6. HMIPv6 kernel implementation is modified to ensure the synchronization between the OLSR operation and HMIPv6 operation.

2.2 Binding Updates to CNs

After arriving in a MANET, an MN receives the ACM message from the MANET GW and configures its RCoA and LCoA. The MN has an option to use its home address, RCoA or LCoA to join the MANET. The choices depend on a MN’s communication partner — CN nodes. We refer to a CN located outside the MANET as an external CN and a CN located inside the MANET as an internal CN. Different registration operations to the two different types of CNs, i.e. internal CNs and external CNs, are employed in our solution. An MN registers its RCoA with external CNs by sending binding updates (BUs) with its home address and RCoA. Unlike external CNs, the MN can register its LCoA with those internal CNs, i.e. send BUs binding its home address and its LCoA to those
internal CNs. The routes to both external and internal CNs are optimal.

2.3 Handoff Process

During a MN’s handoff process from a WLAN to a MANET, nodes outside the MANET, including MAP, HA, and CN, and nodes within MANET, including MANET GW, MPR and MN, could be involved. Fig. 2 shows the control message flows among different components when an MN moves into a MANET.

Fig. 2 Message flows during the handoff process

3 Test-Bed Configuration and Performance

A testbed has been designed and built. It is composed of Linux laptops and workstations equipped with IEEE 802.11b based access points and 802.11b wireless LAN cards. Five subnets are involved in the test: the home network with an HA, a correspondent network with a CN, two wireless foreign networks with wireless access points (FN1 and FN2), and a MANET network with gateway access. To simulate local movements and regional movements of the MN, the FN1 and the MANET are put into the same domain (Domain #1); FN2 is put into another domain (Domain #2). The WAN emulator machine is used to insert artificial WAN delays between the HMIPv6 domains and the rest of the network, using NIST Net application[8]. NIST Net has not yet been updated to support IPv6 and therefore we use IPv6 over IPv4 tunnels to route IPv6 packets through the delay emulator.

Using this infrastructure various scenarios are simulated to demonstrate the efficiency of our approach. The performance tests focus on the handoff latency and signaling load during a handoff between a MANET and a WLAN in a domain or in different domains. According to the results of performance tests, a performance comparison between our implementation and CRC OLSR with MIPv6 implementation is done. The gain from employing HMIPv6 over MIPv6 in the hybrid network of MANETs and WLANs is assessed.

3.1 Gain on Handoff Latency

To quantify the benefit of OLSR with HMIPv6 on reducing the handoff latency, we calculate the gain achieved by our approach over CRC OLSR with MIPv6. We denote GLO as the gain in handoff latency when the MN is roaming within a domain, and GREG as the gain in handoff latency when the MN is roaming from one domain to another domain. GLO and GREG are defined as follows:

\[
G_{LO} = \frac{L_{LO}}{L_{OLSRRMIP}} - \frac{L_{LO}}{L_{OLSRRMIP}}
\]

\[
G_{REG} = \frac{L_{REG}}{L_{OLSRRMIP}} - \frac{L_{REG}}{L_{OLSRRMIP}}
\]

where \(L_{OLSRRMIP}\) is the handoff latency for CRC OLSR with MIPv6 implementation, \(L_{LO}\) and \(L_{REG}\) are the local handoff latency and regional handoff latency for our implementation respectively.

\(G_{LO}\) values for different WAN channel delays computed from the test results are presented in Tab.1. \(G_{REG}\) values for different WAN channel delays computed from the test results are presented in Tab.2.

Tab.1 \(G_{LO}\) in local handoff

<table>
<thead>
<tr>
<th>Hop count</th>
<th>Channel delay/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.30 0.60 1.00</td>
</tr>
<tr>
<td>One hop</td>
<td>0.11 0.19 0.27</td>
</tr>
<tr>
<td>Two hops</td>
<td>0.12 0.18 0.25</td>
</tr>
</tbody>
</table>
These results presented in Tab.1 and Tab.2 show that our approach achieves a gain in handoff latency over CRC OLSR with MIPv6. The $G_{LO}$ and $G_{REG}$ are larger for larger WAN channel delays.

### 3.2 Gain on Signaling load

One of the most important criteria that affect the scalability property of a mobility management scheme is its signaling load. The signaling load is measured using the number of BUs and ACKs during each handoff. Local resources are not the most critical[6], we only quantify the signaling load introduced with our approach on the Internet backbone, which is emulated using the NISTNet tool in our testbed.

We denote $SL_{LO}$ as the signaling load when the MN is roaming within a domain, $SL_{REG}$ as the signaling load when the MN is roaming from one domain to another domain, and $SL_{OLSR&MIP}$ as the signaling load of each handoff with CRC OLSR with MIPv6 implementation. We refer to the number of CNs as $N_{CN}$. The values of $SL_{LO}$, $SL_{REG}$, and $SL_{OLSR&MIP}$ are the following:

$$SL_{OLSR&MIP} = 2(N_{CN} + 1)$$  
$$SL_{LO} = 0$$  
$$SL_{REG} = 2(N_{CN} + 2)$$

Based on the signaling load on the Internet backbone for each of these schemes, we can calculate the gain achieved by our approach over CRC OLSR with MIPv6. We denote $G_{SIG,LO}$ as the gain in signaling load when the MN is roaming within a domain, and $G_{SIG,REG}$ as the gain in signaling load when the MN is roaming from one domain to another domain. $G_{SIG,LO}$ and $G_{SIG,REG}$ are defined as follows:

$$G_{SIG,LO} = (SL_{OLSR&MIP} - SL_{LO}) / SL_{OLSR&MIP}$$  
$$G_{SIG,REG} = (SL_{OLSR&MIP} - SL_{REG}) / SL_{OLSR&MIP}$$

We also evaluate $G_{SIG,AV}$, the weighted average of $G_{SIG,LO}$ and $G_{SIG,REG}$. By making use of the results established in Ref.[9] that 69% of a host’s mobility is local, it is defined as follows:

$$G_{SIG,AV} = 0.69G_{SIG,LO} + 0.31G_{SIG,REG}$$

According to the above formula, we attain the gain $G_{SIG,AV}$ for different amounts of CNs, displayed in Fig.3.

The gains computed from the test results show that $G_{SIG,AV}$ is a function of the amount of CNs. The average gain is always larger than 54% and converges to 69%. With the growth of the size of the network and the amount of CNs, the gain in the signaling load achieved by our approach over CRC OLSR with MIPv6 becomes larger.

### 4 Conclusions

A novel approach to integrate MANETs with the Internet and support mobility across WLANs and MANETs is described. This approach employs and extends HMIPv6 and OLSR to support the MANET global connectivity and mobility management. A testbed modeling the hybrid network architecture was constructed. The performance tests have addressed two tasks: first, the impact of various factors on the handoff latency was quantified; second, the efficiency gains from our scheme over CRC OLSR with MIPv6 on reducing handoff latency and signaling load are assessed. Regarding the reduction of local handoff latency, our scheme achieves at least an 11% gain and increases to up to 27%. Regarding the reduction of regional handoff latency, our scheme achieves a 17% gain when the WAN channel delay is 1 second. The average gain in reducing signaling load is a function of the number of corresponding nodes. Concerning the reduction of signaling load on the Internet, the average gain achieved by our scheme is at least 54% and...
converges to 69%. From the significant gain attained by our scheme in reducing signaling load, we conclude that our scheme improves the scalability of CRC OLSR with MIPv6.

Future extensions of this work will include implementing different registration operations to internal CNs and external CNs, combining other MANET routing protocols with HMIPv6 in such a hybrid network of MANETs and the Internet.

References


Brief Introduction to Author(s)

WANG Mao-ning (王茂宁) graduated from Sichuan university, China in 1995. She received the first Master degree of Electrical and Electronic Engineering from Electrical Power Department, Sichuan University. In 2000, she entered the Department of Computer Science, Carleton University in Ottawa, Canada. After receiving her second Master degree of Computer Science, she worked in Communication Research Center, Canada in 2002. In 2004, she came back to Sichuan University for taking research and teaching work. Her current research interest is IPv6, Ad hoc network and sensor networks.