FHMIPv6-based Handover for Wireless Mesh Networks

Zimani Chitedze and William D. Tucker
Department of Computer Science
University of the Western Cape, Private Bag X17, Bellville 7535
Tel: +27 21 9592461, Fax: +27 21 9593006
email: 2834180@uwc.co.za, wdtucker@gmail.com

Abstract- This paper shows that mobility management protocols for infrastructure Internet may be used in a wireless mesh network environment. Mesh topology tends to be an unplanned graph and routes change dynamically and in this research Mobile IPv6 and Fast Handover for Hierarchical Mobile IPv6 are successfully implemented in a wireless mesh network environment. Horizontal handover simulation with ns2 involved Mobile IPv6 and Fast Handover for Hierarchical Mobile IPv6 applied to wireless mesh networks. Mobile IPv6 was used as a baseline to compare the performance of the two protocols. The results show that in mesh networks, Fast Handover for Hierarchical Mobile IPv6's performance is superior to Mobile IPv6. Fast Handover for Hierarchical Mobile IPv6 generates more throughput and less delay than Mobile IPv6. Furthermore, Fast Handover for Hierarchical Mobile IPv6 drops fewer data packets than Mobile IPv6. Even though MIPv6 and its extensions are for infrastructure networks, they can be used effectively in mesh networks.

Index Terms—Mobility, handover, MIPv6, FHMIPv6, wireless mesh networks.

I. INTRODUCTION

This paper demonstrates that mobility management protocols for infrastructure Internet such as Mobile IPv6 (MIPv6) and Fast handover for Hierarchical Mobile IPv6 (FHMIPv6) can be used in a wireless mesh network (WMN) environment. Mobility management in WMNs has still not been researched thoroughly, although a significant amount of research on wireless and cellular network mobility management has been addressed [1]. Fourth generation (4G) networks will include all-IP (Internet Protocol) wired and wireless networks interworking together as heterogeneous networks [2]. WMNs can be connected to other wireless communication networks such as generic wireless fidelity (Wi-Fi), worldwide interoperability microwave access (WiMAX), cellular and sensor networks but the challenge is MIPv6-based mobility management. MIPv6 and its extensions rely on the good performance of an infrastructure-based network but a typical WMN topology tends to be an unplanned graph and routes change dynamically [3].

Mobility management provides seamless support of real-time and non-real-time services for mobile subscribers and facilitates the maintenance of connections for subscribers on the move when they change points of attachment. Mobility management involves location management and handover management [4]. Location management allows the network to keep track of the location of a mobile client and handover management is the procedure by which a mobile node keeps its connection active when it moves from one point of attachment to another. Handover can be classified as horizontal or vertical. Horizontal handover refers to the move from one access point to the other within the same technology. Vertical handover refers to the ability to roam between heterogeneous wireless technologies.

MIPv6 [5] is intended to deal with mobile nodes (MNs) in motion between IPv6 networks. When an MN is on the move and connects to a new access router (AR) in another subnet, its home address is not valid any longer; therefore it requires a new address in the visiting subnet. The MN obtains a new address called care-of-address (CoA) to register with its home agent (HA) and the corresponding node (CN) whilst the MN is away from its home network. MIPv6 supports Route Optimization which results in an effective route formation between the MN and the CN. Nevertheless, sometimes it takes too long to send binding updates (BUs) after handover in MIPv6 which results in packets destined for the MN being dropped [6].

FHMIPv6 [7] is a proposal that combines Hierarchical MIPv6 (HMIPv6) and Fast handover for MIPv6 (FMIPv6) extensions to MIPv6. Fast handover for hierarchical mobile IPv6 reduces signaling overhead and BU delay during handover by using HMIPv6 procedures. Furthermore, movement detection latency and new CoA configuration delay during handover are reduced by utilizing FMIPv6 processes. When the MN associates with a new MAP domain, HMIPv6 procedures are performed with the HA and the Mobility Anchor Point (MAP). If the MN moves from a previous AR (pAR) to a new AR (nAR) within the domain, it follows the local BU process of HMIPv6. Packets sent to the MN by the CN during handover are tunneled by the MAP en route for the nAR [8]. However, when FHMIPv6 is applied in WMN, the good performance is no longer guaranteed. Multiple wireless hops in WMN makes it difficult for a protocol designed for infrastructure networks.

The remainder of this paper is arranged as follows. Section II presents work related to handover. Section III details the experimental design to learn how MIPv6 and FHMIPv6 perform for handover between mesh networks. Section IV presents and discusses handover results. Section V concludes the paper and also points toward future work.

II. RELATED WORK

MIPv6 and its extensions have been studied in numerous publications, all for infrastructure rather than ad-hoc networks [9] [10] [11] [12] [13]. Gwon *et al.* [10] investigated handover performance of MIP and its extensions (see Table 1). The investigation involved simulating 100,000 mobile subscribers across a large scale experimental network consisting of WLANs. The results indicated that HMIPv6 suffers considerably less handover signaling overhead than FMIPv6. FMIPv6 achieves the best handover performance exhibiting the lowest latency and data loss. FHMIPv6 achieves similar handover performance to that of FMIPv6 but with improved handover signaling overhead. FHMIPv6 is also more robust to AR and HA failures.

Table 1: *Handover latency presented by Gwon et al.[10].*

Protocols	Handover latency in ms
MIPv6	1300
HMIPv6	300 - 500
FMIPv6	200
FHMIPv6	200 - 400

Hsieh and Seneviratne [13] also compared MIPv6 and its extensions (see Table 2). The authors use the topology and link delays shown in Figure 1.The results show that S-MIP performs best under both ping-pong and linear movement during handover. All other protocols suffer from packet loss and performance degradation. Optimization of S-MIP is proposed to improve performance. Chow *et al*. [9] proposed a protocol for both macro and micro mobility management in mobile broadband wireless access networks. The mobile-initiated handovers are based on Signal-to-Noise-and-Interference-Ratio (SNIR). The proposed protocol is similar to FHMIPv6, although the terminology used is different, for example, the MAP is replaced by a domain AR. The experiments are conducted in the OPNET simulator. The topology used is similar to Figure 1 but uses the 802.16e standard. In the results, the handover latency is defined as the delay incurred for obtaining a new CoA. It is not the communication between the MN and the CN. The proposed scheme experiences 128 milliseconds (ms) delay while obtaining a new CoA.

Table 2: *Handover latency presented by Hsieh and Seneviratne [13].*

Protocol	Handover latency in ms
MIPv6	814
HMIPv6	326
FMIPv6	358
FHMIPv6	270
S-MIP	100

Figure 1 shows the topology used in both [9] and [13]. Both CN and HA are connected to an intermediate node (N1) with 2ms link delay and 100 Mbps links. The link between N1 and the MAP is a 100 Mbps link with 50 ms link delay. The MAP is further connected to the intermediate nodes N2 and N3 with 2 ms link delay over 10 Mbps links. N1 and N2 are connected to PAR and NAR with 2 ms link delay over 1 Mbps links.

III. EXPERIMENTAL DESIGN

Our task is to examine handover latency when incorporating WMNs. We constructed a simulated environment in which MIPv6 and FHMIPv6 are applied within a WMN. MIPv6 is used as a baseline to study the performance of FHMIPv6 in WMNs. The simulation experiment for this prototype is carried out in network simulator 2 (ns2) version 2.32.

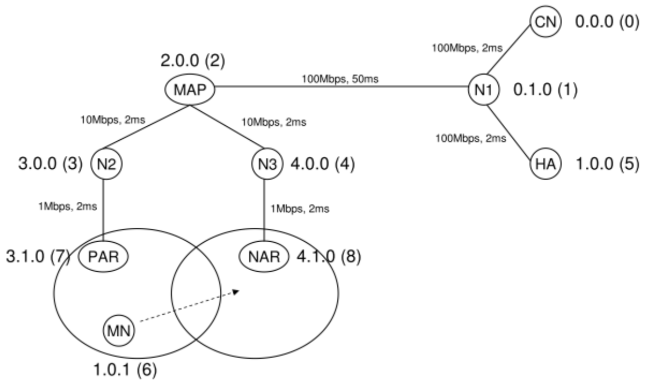

Figure 1: *Topology used in [9] and [13].*

We used an extension developed by Hsieh and Seneviratne that supports MIPv6, HMIPv6, FMIPv6 and FHMIPv6. S-MIP is not supported although it was proposed by the same people who developed this extension. The FHMIPv6 extension was developed by extending a special MAP Agent and fast handover functionality to the standard mobile IP and NOAH (no ad hoc routing agent) extensions. The MAP Agent is attached to a wired node to make a MAP, which behaves as a hop between the HA and the pAR. The packets destined for the MN are encapsulated by the HA and tunneled to the MAP. The MAP decapsulates packets and encapsulates them again, by using the address of the FA. Finally, the FA decapsulates the packets and delivers them to the MN.

Originally, the FHMIPv6 patch did not support ad hoc routing. To handle this problem, a new routing agent called Ad Hoc Routing Agent (AHRA) is introduced to the patch. AHRA enables the FHMIPv6 patch in ns2 to support ad hoc multi-hop routing and this is made possible by making modifications to the NOAH routing agent. FHMIPv6 with AHRA (FHAMIPv6) was proposed by Ortiz *et al.* [14]. AHRA involves two operational stages. The first, *routing discovery*, takes place during the registration process where the modified NOAH learns about the available routes by taking each mesh node's registered message's address. MIP agents exchange registration messages and the NOAH agent takes the information. The second stage is *sending of data through defined routes*, which happens after establishing the TCP connection. The modified NOAH uses the captured information and forwards the TCP packets until they arrive at their destination.

This experiment was planned to produce realistic results and at the same time make sure ns2 is able to handle the simulation resourcefully. The simulation setup consists of nodes in a wireless mesh network. The mesh nodes include the MN, within the vicinity of the HA in the home network. It also includes the CN, intermediate routers (N1, N2 and N3), the pAR, the nAR and the MAP. All mesh nodes possess a hierarchical address and the nodes are distributed in 5 domains.

In the simulations, the performance metrics are studied as observed by the MN, which is communicating with the CN. The MN follows a pre-determined path from position t1 to position t2, then to position t3 (see Figure 2). The simulation duration is 30 seconds. This setup permits full control of the MN and the handover while the interruption from the other mesh nodes is still realistic as a result of the mesh nodes fighting for resources. When the MN moves towards the vicinity of the nAR (see Figure 2), different handover scenarios behave in different ways:

MIPv6 scenario: The MN does not respond to advertisements from the nAR when it is receiving advertisements from the pAR. As soon as the MN loses its connection to the pAR, it sends a registration request to the nAR and changes its CoA. In the scenario of MIPv6 with priority handover, priorities are allocated to the base stations (pAR and nAR). If the nAR possess a higher priority than the pAR, then the handover is triggered right away.

FHMIPv6 scenario: combines FMIPv6 functionality of the extension and the FHMIPv6 draft. The MN sends RtSolPr message to the pAR once receiving an advertisement from the nAR. Instead of sending the message to the MAP (to imitate FHMIPv6), pAR and nAR construct a HI-HACK conversation like in FMIPv6. The MN receives the PrRtAdv message from the pAR and sends a request to register with the nAR. The MAP receives a request from the nAR and the MAP begins sending packets to nAR. This does not really create a bi-directional tunnel that minimizes packet loss since packets are sent after the registration is completed. FHMIPv6 was chosen to compare with MIPv6 because it is a combination of HMIPv6 and FMIPv6, which adds up the advantages of the two protocols and provides additional improvements.

When the simulation starts, the MN is positioned at t1 in the home network and begins to communicate with the CN right away. At 3 seconds into the simulation, the MN starts moving towards the pAR passing nodes N1, the MAP and N2 on its way, until it reaches position t2 in the network of the pAR. 15 seconds into the simulation the MN starts to move towards the nAR. At this point in time the registration process is complete and the MN has already registered its CoA with the HA.

The main objective of this simulation experiment is to observe and compare the effects of FHMIPv6 in the WMN on the QoS parameters described in the previous section. There are two different scenarios simulated using the same simulation setup. The first scenario uses MIPv6, as a baseline for this experiment, and the second scenario uses FHMIPv6. For this experiment, the independent variables are the protocols (MIPv6 and FHMIPv6), while the dependent variables are throughput, delay and packet loss.

IV. RESULTS

The results of the horizontal handover simulations are presented in this section and focus on delay, throughput, and packet loss. The studied MN performs horizontal handovers within the WMN roaming from the home network moving towards the pAR and then to the nAR during the 30 sec of the simulation (see Figure 2). The MN starts moving towards the pAR 3 sec into the simulation, then at 20 sec, it moves towards the nAR. The MN communicates with the CN using UDP-CBR throughout the simulation. The CN is connected to the UDP-CBR agent and the MN acts as a sink of the UDP-CBR agent. After the simulation, a trace file (*.tr file) and an animation file (*.nam file) are produced. The trace file is used to trace the performance metrics being studied. AWK is used to filter the trace file to construct a graph in Microsoft Excel.

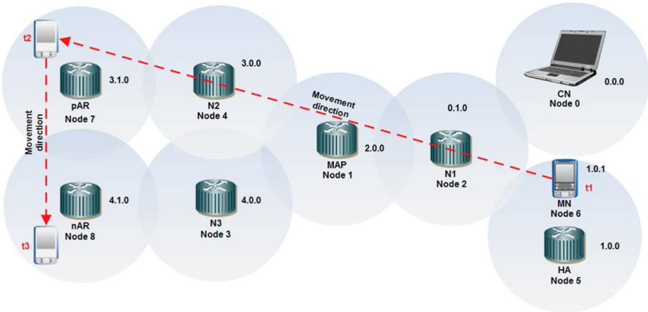

Figure 2: *Horizontal handover topology consists of nodes in a WMN. The MN follows a pre-determined path from position t1 to position t2, then to position t3.*

A. Delay

Figure 3 shows the delay for MIPv6 and FHMIPv6 scenarios incurred during the experiment. The blue line in the graph indicates delay for MIPv6 and the red line indicates delay produced with FHMIPv6. 3 seconds into the simulation, when the MN starts moving, MIPv6's delay begins to increase peaking at 8 seconds with 1000 ms. The delay remains at 1000 ms up to the end of the simulation except at 21 sec when delay decreases to 790 ms. In contrast, FHMIPv6's delay is at its peak (460 ms) at 5 sec into the simulation. Throughout the simulation, its delay stays at around 200 ms. The only time delay is at 350 ms is when horizontal handover occurs.

Figure 3 illustrates that FHMIPv6 experiences less latency than MIPv6. Less latency shows that communication between the MN and the CN will have a better quality than communication with higher latency.

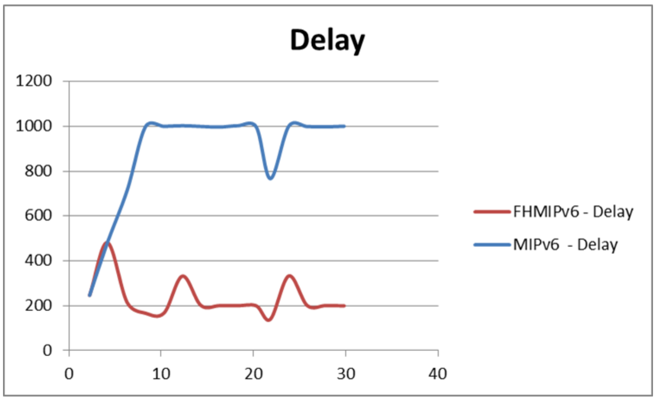

Figure 3: *Delay (Latency) is the time period that passes between the last data packet received by the MN through the previous point of attachment and the first data packet received by the MN through the new point of attachment during handover.*

B. *Throughput*

Figure 4 shows throughput incurred during this experiment. MIPv6's throughput is indicated in blue and FHMIPv6's throughput is shown in red in the graph. MIPv6's throughput shows that as soon as the MN starts moving, throughput begins to go down until 5 sec into the simulation and it stabilizes at 0.5 kbps. The throughput goes up briefly when the MN starts moving from the pAR to the nAR and goes down back to 0.5 kbps up to the end of the simulation. In contrast, FHMIPv6's throughput begins to rise up to 3.1 kbps when the MN starts moving towards the pAR. As soon as the MN reaches the pAR and begins to associate with it, the throughput drops to 0.5 kbps. After finalizing pAR association, the throughput goes up again to 2.4 kbps. The MN starts moving from the pAR to the nAR at 20 sec into the simulation, which causes throughput to shoot up to 4.5 kbps then begins to drop to 0.5 kbps. After association with the nAR completes, the throughput goes back to 2.4 kbps.

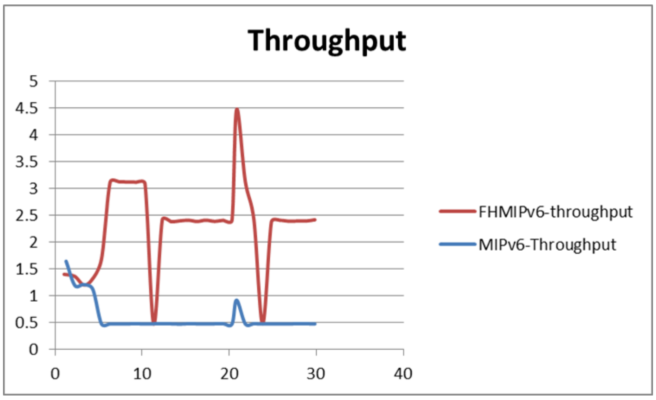

Figure 4: *The throughput is measured in kilobit per second (kbps) and corresponds to the amount of data that is transmitted between the MN and the CN per period of time. CBR packets are the only data considered; the rest are filtered out, including the overhead in the network.*

C. *Packet loss*

We can represent packet loss as a ratio of the number of packets lost to the total number of packets transmitted between the MN and the CN. Packet loss is a consequence of packets that are sent by the nodes but not received by the final destination. 712 UDP data packets are sent by the CN during the simulations, but in the MIPv6 scenario, only 638 packets are received by the MN and in FHMIPv6, the MN receives 686 packets. MIPv6 incurs 10.3933 percent packet loss while FHMIPv6 experiences 3.6517 percent packet loss (see Figure 3).

Table 3: *Packet loss statistics of horizontal handover.*

Protocol	Sent data	Received data	% loss
MIPv6	712	638	10.3933
FHMIPv6	712	686	3.6517

D. *Discussion*

Comparing throughput of MIPv6 with throughput of FHMIPv6, it can be seen that FHMIPv6 scenario has higher throughput than MIPv6 scenario. Even though FHMIPv6's throughput drops twice during the simulation, its throughput is still better than MIPv6's throughput, which remains mostly at 0.5 bits/sec. FHMIPv6's throughput also illustrates the drop of throughput when the MN is on the move and associates with a new mesh router. For example, when the MN is associating with the pAR, throughput drops. Another drop occurs when the MN moves from the pAR to the nAR at 20 sec into the simulation. Figure 4 clearly shows that FHMIPv6 is better than MIPv6 at handling throughput in a WMN.

Table 4 shows that FHMIPv6 has higher average rate of successful message delivery than MIPv6 during simulation. FHMIPv6 produces 2.300405 average throughput, compared to MIPv6 with 0.613884. This is so because FHMIPv6 experiences lower latency than MIPv6. FHMIPv6's latency outperforms MIPv6's latency since the distance in order to update the node that is forwarding packets to the MN is always shorter. A MAP is used to send updates locally, which reduces latency. FHMIPv6 also uses the FMIPv6 mechanisms by preparing the handover in advance. After handover, there is no wait for the old AR to be updated to start receiving packets again. When the MN receives the Fast Binding Acknowledgement (FBAck) from the MAP indicating that the handover should be performed, the re-directed packets are already waiting in the nAR.

Table 4: *Average statistics of the handover simulation.*

Protocol	Average delay	Average throughput	Average packet loss
MIPv6	0.613884	880.26	10.3933
FHMIPv6	2.300405	231.92	3.6517

When packets are experiencing delay during handover, the FBAck acts as a synchronization packet informing the mechanism that new packets are already waiting or about to arrive to the nAR. This way handover latency is reduced or removed. FHMIPv6 waits as long as possible for the FBAck at the old point of attachment to start handover. If the MN performs the handover right after sending the FBU, it will not immediately receive any redirected packets, which increases the handover latency and packet loss. FHMIPv6 assures that when FBAck is received, no packets lost sent to the old CoA and the packets redirected to the new CoA are buffered. This result in reduced or no packet loss at all. Table 4 summarizes the performance of the two protocols. FHMIPv6 achieves better results than MIPv6 in all three performance metrics that are studied.

Table 5: *Handover latency - mesh vs non-mesh.*

Protocol	Non-mesh related work		Mesh
	Gwon *et. al*	Hsieh and Seneviratne	Our experiment
MIPv6	1300	814	880.26
FHMIPv6	200 - 400	270	231.92

Mobility management studies are based on different assumptions about the experiment environment, the topology, the network links, as well as the definition of QoS metrics being involved. Although the numerical results might be available, it is not possible to compare the results with related work directly. Latency is the main factor that affects how much throughput is delivered and how much packet loss is experienced. Low latency means better performance. Table 5 illustrates handover latency comparison of mesh and non-mesh experiments. Gwon *et al*. [10] and Hsieh and Seneviratne [13] experiments involved non-mesh network infrastructure. This research is mesh-based experiment. The mesh handover delay results show a better performance against Gwon *et al*.'s results, in both MIPv6 and FHMIPv6. It also achieves better against Hsieh and Seneviratne's FHMIPv6 handover delay, but their MIPv6 delay is lower.

V. CONCLUSION AND FUTURE WORK

This paper addressed how mobility management protocols such as MIPv6 and FHMIPv6 behave during handover with wireless mesh networks. A wireless network was constructed in ns2 simulator in which MIPv6 and FHMIPv6 were applied within a WMN. As expected, FHMIPv6 performed better than MIPv6 in all three focus areas of throughput, delay and packet loss. FHMIPv6 experienced higher throughput, less delay and less packet loss than MIPv6. FHMIPv6 benefits from the help of HMIPv6 procedures and FMIPv6 processes. HMIPv6 procedures in FHMIPv6 allows the MN to register locally, which reduces network overhead because the MN does not require sending BUs to the CN and the HA as in MIPv6. The FMIPv6 mechanism in FHMIPv6 enables the MN to send or receive packets from the period of time the MN de-associates with one point of attachment in a subnet to the period of time the MN associates with a new CoA from the new point of attachment. These extensions help to reduce handover delay and packet loss while maximizing throughput. Comparing mesh's MIPv6 and FHMIPv6 with non-mesh handover delays, it is clear that MIPv6 and its extensions can behave the same way whether in mesh or non-mesh environment. Considering that these protocols are meant for infrastructure-based networks with wireless nodes at the edge and rely on the good performance of the network infrastructure, our mesh simulation produced results similar to non-mesh related work. MIPv6 and its extensions can be used effectively in mesh networks.

For future work, it will be good to simulate and compare all MIPv6 extensions to see their performance in mesh networks. Even though FHMIPv6 is a hybrid of HMIPv6 and FMIPv6, it will be interesting to see individual performance of the two in mesh networks.

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Zimani Chitedze received his Honours degree in Computer Science from the University of the Western Cape (UWC) in 2009 and is presently studying towards his MSc degree with the Bridging Applications and Networks Group (BANG) at the same institution. His research interests include wireless mesh and Next Generation Networks.

William D. Tucker is a Senior Lecturer of Computer Science at UWC and leads BANG research there. His research interest includes Internet Protocol (IP) networks and their applications in developing regions.