

# Mobile Vertical Handover between Wireless LAN and Wireless Mesh Network

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**Abstract—This paper addresses mobility management issues in an environment with both wireless LAN and wireless mesh networks. We first examine wireless mesh network client side transparency within mesh mobility management protocols and then look at standard mobility management protocols. The client side transparency scheme enables mobile nodes to support mobility in heterogeneous and homogeneous networks. However, they are not necessarily compatible with mobile IP protocols. Although a typical mesh topology tends to be an unplanned graph and routes change dynamically, standard mobility management protocols such as MIPv6, HMIPv6, and FMIPv6 may be used for mobility management in wireless mesh networks. To learn how MIPv6 operates, we used the OPNET 16.0 MIPv6 model to simulate a heterogeneous wireless environment comprising both WLAN and WMN. The simulation results show that MIPv6 is able to manage vertical handover between WLAN and WMN. However, in our opinion, its performance with both route optimization and tunneled traffic mechanisms is not effective enough. MIPv6 suffers from handover latency and packet loss which can combine to compromise delay-sensitive applications such as video conferencing.**

**Index Terms—Fixed/Mobile Handover protocols  
Mobile/wireless protocols**

## I. INTRODUCTION

Fourth generation (4G) networks will include all-IP (Internet Protocol) wired and wireless networks interworking together as heterogeneous networks [1]. 4G promises to provide higher data rates up to a hundred times faster than the current networks. Its high capacity will be beneficial as it is projected that by 2015 overall global data traffic will grow up to 6.3 exabytes per month [2]. This is due to the introduction of more and more laptops, tablets and high-end handsets on to mobile networks. These devices generate much higher traffic than a basic feature phone, e.g. a laptop can generate as much traffic as 515 basic-featured phones and a smartphone can generate as much as 24 [2].

It is suggested that operators may be able to offload this traffic onto other IP networks such as Wireless Mesh Networks (WMNs) by offering subscribers dual-mode mobile phones. WMNs are attracting attention because of their characteristics such as ease of installation and scalability, low cost network deployment, ease of network reconfiguration, reduction in wired links, robust communication, spectrum reuse efficiency and network capacity improvement [3].

WMNs can be connected to other wireless communication networks such as generic wireless fidelity (Wi-Fi) networks, worldwide interoperability microwave access (WiMAX), cellular and sensor networks (see Fig. 1). Even though WMNs have turned out to be attractive and hold a great potential for 4G networks due to their capability to integrate with other wireless networks, there are still challenges that need to be addressed.

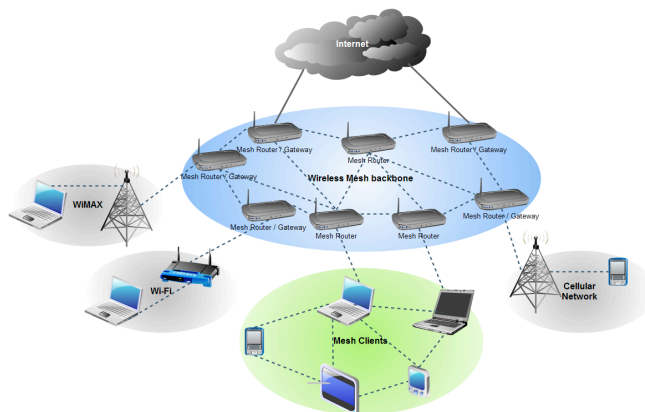


Fig. 1: Hybrid WMN

One well-known challenge is IP-based mobility management in WMN environments. A typical WMN topology tends to be an unplanned graph and routes change dynamically. Mobility management in WMNs has still not been researched thoroughly, although a significant amount of research on Wi-Fi, cellular and mobile ad hoc mobility management has been addressed [4].

As the world progress towards all-IP next generation heterogeneous networks, mobility management becomes an important ingredient in ubiquitous wireless networking. 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* [5]. Location management allows the network to keep track of the location of mobile clients 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.

Several protocols and mechanisms have been developed to support handover for multimedia services. Depending on the movement of the mobile node, the handover can be classified as horizontal or vertical handover. Horizontal handover (see Fig. 2) refers to the ability to handover from one access point to another within the homogeneous

technology, for example handover from one 802.11n network to another 802.11n network [5].

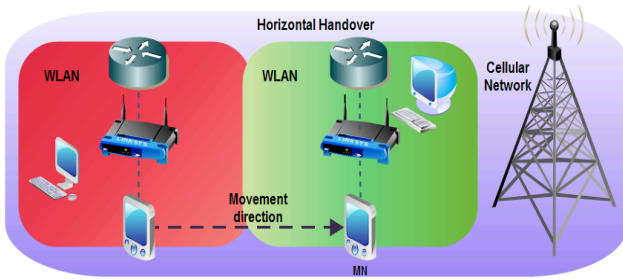


Fig. 2: Horizontal handover from one 802.11n WLAN to another 802.11n WLAN.

On the other hand, vertical handover (see Fig. 3) refers to the ability to handover across heterogeneous wireless technologies, for example, handover from a Wi-Fi wireless local area network (WLAN) technology to GPRS/UMTS. Vertical handover in heterogeneous networks is a much more complex matter. That is why it has been researched on different levels of the OSI reference stack.

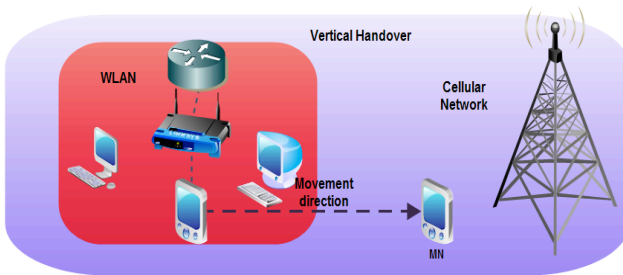


Fig. 3: Vertical handover from WLAN to a cellular network.

Although, there is no specific solution for the mobility management issues in WMN environment, protocols for wired networks such as mobile IP may be used as guidelines to tailor and evaluate strategies for wireless mesh mobility management. The aim of this paper is to examine vertical handover between WMN and WLAN using mobile IP version 6 (MIPv6) and compare the performance of its signaling mechanisms: route optimization and bi-directional tunneling. MIPv6 is studied and evaluated with the OPNET 16.0 simulator. The remainder of this paper is arranged as follows. Related work is presented in Section II. Section III details the experimental design. Results are presented and discussed in Section IV. Section V concludes the paper and also points toward future work.

## II. RELATED WORK

One of the objectives of mobility management is seamless support for real-time communication. This seamless support refers to achieving a low latency and packet loss during handover. This section presents related work toward attaining these objectives for WLANs and WMNs. First we examine WMN client side transparency mobility management protocols. Then we look at standard mobility management protocols.

### A. WMN Client-side Transparency mobility protocols

*SMesh* [6] was developed at John Hopkins University by the Distributed System and Networks Lab. *SMesh* provides

seamless mobility and fast handover without a client pre-installing anything. Any 802.11 mobile device which supports DHCP (Dynamic Host Configuration Protocol) will be able to connect to an *SMesh* network. *SMesh* is a wireless mesh network that allows unmodified clients to connect and roam freely between access points on a wireless coverage area. The wireless clients perceive the wireless mesh as a single omnipresent AP (access point). All nodes have the same SSID (service set identifier) using IBSS (independent basic service set), or ad hoc, mode. Mesh Internet gateways nodes provide access to the Internet. As a client moves, the mesh nodes continuously monitor the mobile client connectivity to decide the best access point to service the client. *SMesh* uses a DHCP server to allow mesh routers to rapidly locate and manage a mobile client's connectivity. An *SMesh* client is associated with a client control group (CCG) and a client data group (CDG) which are multicast groups. CCG consists of a group of access points which communicate among each other to determine the best set of access points to serve a client. CDG consists of a group of access points from CCG which have the best connectivity to the client. Although handover performance is acceptable using this multicast approach, bandwidth usage is heavy.

*iMesh* [7] is another WMN architecture, used for community networking applications. *iMesh* uses 802.11b technology for its access mesh routers and aims to provide seamless network services to mobile clients. Like *SMesh*, *client side transparency* is an essential objective of the design of this architecture. Mesh clients are not aware of the mesh backbone. Hence they view they whole network as a single AP. When a mesh client is on the move and associates with a different AP, a Layer 2 handover mechanism initiates routing updates in the mesh backbone. The handover procedure involves both Layer 2 and Layer 3 mechanisms. When implementing *iMesh*, [7] used two solutions: *transparent mobile IP*, which is similar to mobile IP and a flat routing scheme, which according to [7] is much better than a traditional Layer 3 handover technique.

*Ant* [8] is a another WMN mobility management scheme which also employs client side transparency like *SMesh* and *iMesh*. It creates bi-directional tunnels between previous mesh nodes and a new mesh node during handover, similar to fast handoff [RFC 4068]. This scheme is used to reduce handover latency and packet loss. A location server on a neighborhood mesh node is used by the new mesh node to determine the previous mesh node's IP address. The previous node decreases packet loss by buffering the packets when the MAC layer de-association event is triggered.

Even though *SMesh*, *iMesh* and *Ant* WMN mobility management protocols are implemented differently, they all use a *client side transparency* scheme. This transparency feature enables mesh nodes to support mobility in any heterogeneous network because the mobility management protocol is not incorporated into a mesh node's (MN) stack. However there will be limitations to a MN trying to roam between a 4G network and these client side transparency networks. This is because these networks will be using different mobility management mechanisms. 4G networks will be a combination of wired and wireless networks interworking together. Therefore, mobility management

protocols for wired networks such as MIPv6, HMIPv6 and FMIPv6 will be essential for future seamless mobility in 4G networks. These are discussed in the next section.

### B. Standard Mobility Protocols

In the past, several mobility management protocols have been proposed. These protocols can be categorized as *micro-mobility* and *macro-mobility* protocols. In micro-mobility, the MN moves within a given domain between subnets and engages in *intra* domain handovers. Micro-mobility solutions include Cellular IP and Handoff-Aware Wireless Access Internet Infrastructure (HAWAII) [9]. Cellular IP, from Columbia University and Ericsson Research, supports paging and several handover techniques and optimization. Host location information is updated regularly using packets, to minimize signaling. However, Cellular IP relies on MIP to support global mobility. Hence, there is a limitation to support heterogeneous mobility between different domains. HAWAII, from Lucent Technologies, also relies on MIP for inter-domain mobility. HAWAII is not a standalone solution but extends Mobile IP to provide intra-domain mobility with Quality of Service (QoS) support. HAWAII leverages Mobile IP to enable QoS mobility [9].

In macro-mobility, the MN moves from one administrative domain to another, and engages in *inter* domain handovers. Mobile IP is the most widely used protocol for macro-mobility management [10]. MIPv6 is able to support seamless mobility more efficiently than MIPv4 because of its robustness, easiness and reliability. MIPv6 also supports Route Optimization which results in effective route formation between an MN and a corresponding node (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 [11].

HMIPv6 and FMIPv6 were proposed by the IETF as extensions to MIPv6 to enhance its benefits. HMIPv6 concentrates on localizing the mobility management by minimizing signaling load within a network. FMIPv6 offers anticipated handovers by using layer 2 triggers to initiate the handover process beforehand.

MIPv6 is intended to deal with MNs in motion between IPv6 networks. When an MN is on the move and connects to a new access router 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 the care-of-address (COA) to register with its home address (HA) and the CN whilst the MN is away from the home network. The mapping of the home address and COA of the MN so that the HA can always recognize the communication of the MN is called *binding* [11].

In MIPv6, the handover procedure occurs when a MN examines router advertisements sent by the access router (AR) from time to time or the MN requests the AR to send router advertisements (router solicitation) and realizes that it is no longer in the home network. The COA is created using information in the router advertisements. The MN confirms that the link-local address is unique, and then creates the new COA by auto-configuring a either a stateful or stateless address. The process of verifying the address if it

is unique is called *duplication address detection* (DAD) and it involves sending a neighbor solicitation to the new address. DAD takes some time which results in an increase of handover latency. To deal with DAD's additional time during handover, the MN carries out DAD at the same time of its communications. The MN sends *binding updates* to the HA and CN when the assembling of COA is finalized [10].

## III. EXPERIMENTAL DESIGN

Now that we understand how MIP operates in general, we want to learn how to apply it in a heterogeneous wireless environment comprising WLAN and WMN. We used an OPNET MIPv6 model to do this. This section describes the MIPv6 OPNET model, and then presents the simulation setup that involves a mobile node moving from one network to the other so we can example vertical handover delays.

### A. MIPv6 Model

The MIPv6 model in OPNET has been designed and developed with a lot of standard MIPv6 features. The OPNET MIPv6 model supports features such as router optimization, MN-HA bi-directional tunneling, IP extension headers which include mobility, routing and destination option extension headers. It also supports neighbor discovery, duplicate address destination modeled as a delay and router advertisements for movement detection, address auto-configuration (stateless) and home agent address detection.

In OPNET, a WLAN workstation or server node can be configured as MIPv6 MN or CN with route optimization either enabled or disabled. Yet all regular workstation nodes behave as CNs with no route optimization support. If the MN is initially away from home and more than one AP exist, the HA needs to be specified. Otherwise, this can be learned from the HA's router advertisements when the MN is at home. Furthermore, the global address of the MN should also be specified and use the same network prefix as the HA.

WLAN roaming capability should be enabled on the node to allow the MN to scan and switch to other APs when the signal from the connected AP becomes weak. A router can have many wired or wireless interfaces that act as HAs but each interface needs to be configured individually. HAs and FAs also need to have router advertisements enabled so that MNs can learn of the closest HA.

### B. Simulation Setup

The simulation topology was designed to produce realistic results in the OPNET simulator. The topology (see Fig. 4) is composed of WMN (BSS\_2) that is connected to the Internet (depicted as a cloud) via a gateway using a point to point (PPP) duplex link. The gateway has two interfaces, one running Router Information Protocol next generation (RIPng) and the other running Ad-hoc On-Demand Distance Vector (AODV) routing protocol. The interface running RIPng is connected to the Internet while the interface running AODV communicates with the rest of the WMN. AODV is the ad-hoc routing protocol in the WMN.

WLAN subnets (BSS\_0, BSS\_1 and BSS\_3) are each connected to the internet via a router in their basic service

sets (BSS) running RIPng routing protocol. BSS\_0 is the home network of the MN and BSS\_3 is the home network of the CN. The nodes in the simulation are positioned in a way to provide a total coverage to an area of approximately 200 square meters after considering a transmission range of the 802.11b standard which is being used by all nodes in the scenario. The nodes' transmission power is set to 0.005 watts and the data rate is set to 11Mbps. This is the data rate that will be used by the MAC for transmission of data frames via the physical layer. The routers also act as APs for the BSSs.

MN, CN and HA are configured as explained in the previous section. We analyze the degradation of the performance metrics from the point of view of a single MN that follows a deterministic path, roaming through two WLAN subnets (BSS\_0 and BSS\_1) to the WMN (BSS\_2). All simulations have a duration of five minutes. During this simulation time, a MN communicates with a CN using a video conferencing application.

There are two simulation scenarios in this setup. The first setup has the route optimization signaling mechanism enabled while the second setup has the route optimization signaling mechanism disabled and uses the tunneling signaling mechanism only. Route optimization allows MN to communicate directly with its CN instead of tunneling the traffic via the HA node. If enabled, an MN tries to establish an optimized route with the CN it is communicating with. On the other side, the CN accepts the request from MN to establish route optimization only if it is also enabled for this attribute. When disabled, the MN will not try to start the route optimization procedure at any time. The alternative mechanism used instead of route optimization will be tunneling traffic via a HA.

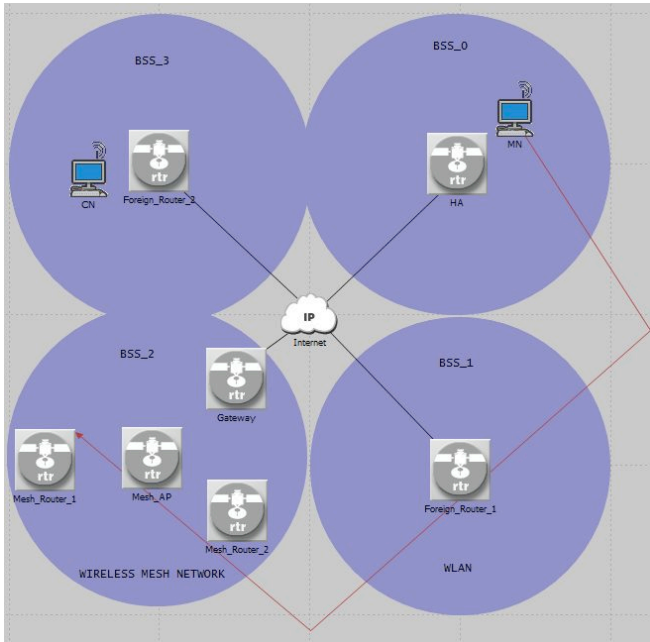


Fig. 4: Simulation Topology

#### IV. RESULTS AND DISCUSSION

This section discusses the performance of handover in our evaluation. Running the simulation in OPNET, we were able to analyze the following metrics: network load, traffic received by MN, end-to-end packet delay, packet loss, and handover delay are analyzed. These metrics are addressed in turn, below. The impact of MIPv6 signaling mechanisms (route optimization and bi-directional tunneling) are measured and compared with respect to these metrics.

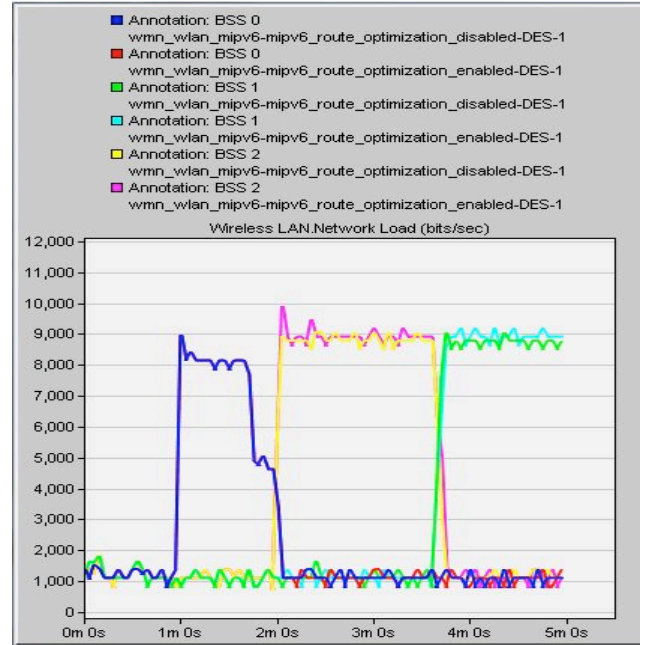


Fig. 5: Network load

Fig. 5 shows network load that represents the total traffic in bits per second received by the entire BSS at Layer 2 that are accepted and queued for transmission. This illustrates that the MN managed to roam from the home network, BSS\_0 (1m 0s – 2m 0s), to another WLAN network, BSS\_1 (2m 0s – 3m 40s), and finally to the foreign WMN network, BSS\_2 (3m 40s – 5m 0s).

Fig. 6 shows traffic received by the MN which represents the average number of packets per second forwarded to all video conferencing applications at the transport layer in the network. Fig. 6 also shows gaps in the communication at 2m 0s and 3m 40s. Each gap is created when the MN changes its current AP. This initiates MIPv6 binding procedures to report to the HA about the MN's new COA. All traffic directed to the MN is lost while the binding procedure updates HA and CN. The video conferencing application response time is directly affected by the MIPv6 mechanism used by the MN in order to communicate with the CN. Fig. 6 also illustrates that the route optimization scenario application delay at 3m 40s is slightly less than the tunneled traffic scenario. This is so because the route taken by the route optimization scenario to communicate with the CN is shorter than tunneling. The MN communicates directly with the CN.



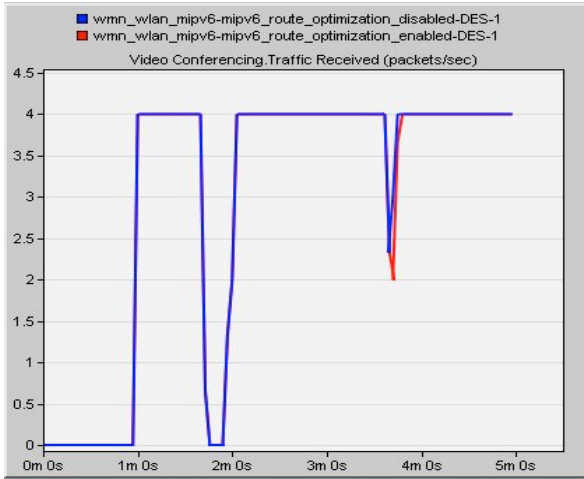


Fig. 6: Traffic Received by MN

Fig. 7 shows the time taken to send a video application packet to a destination node application layer. These statistic record data from all nodes in the network. The statistics in Fig. 7 show that the route optimization scenario is slightly lower than the tunneled traffic scenario. The route optimization mechanism uses routing and destination IPv6 extension headers to directly transport the traffic between the MN and the CN. On the other hand, the tunneled traffic mechanism uses tunnels via the HA, producing two times the data traffic.

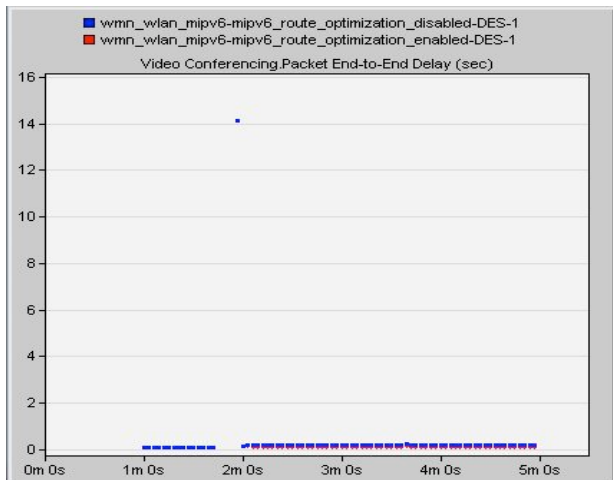


Fig. 7: Video conferencing packet end-to-end delay

Fig. 8 shows total higher layer data traffic in bits per second dropped by wireless nodes in the network as a result of consistently failing retransmissions. This diagram reports the number of higher layer packets that are dropped because the MAC Layer could not receive any acknowledgements (ACKs) for the (re)transmissions of those packets and their fragments. Comparing Fig. 8 with Fig. 9, we can see that data dropped is not directly proportional to delay. In this case, data is dropped in two separate occasions: the time period between 1m 40s and 2m 0s, and between 3m 40s and 3m 50s. Handover is triggered at these times. Delay of 3.55s (see Fig. 9) takes place at 1m 50s which is during handover between BSS\_0 and BSS\_1. Fig. 9 illustrates no delay during WLAN and WMN handover. Although, the tunneled traffic scenario fairs slightly better than route optimization scenario, the data loss is still high during handover.

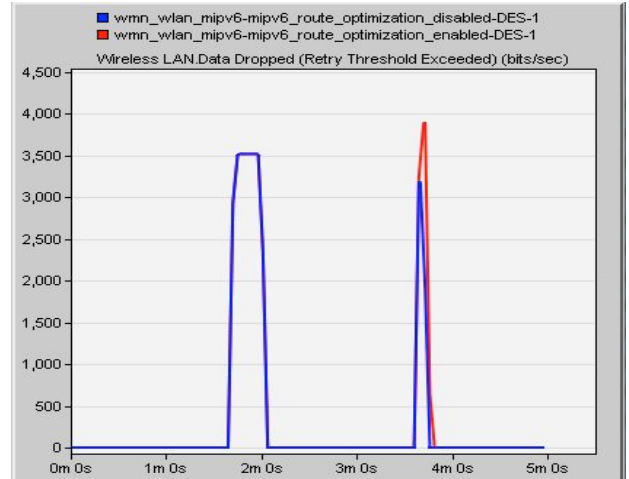


Fig. 8: Data dropped

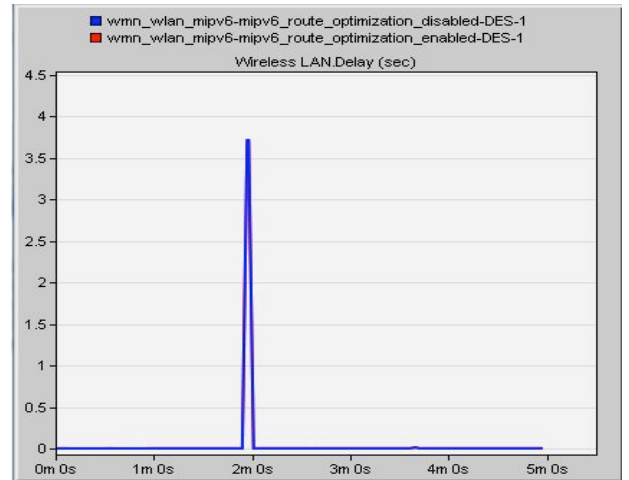


Fig. 9: Delay

## V. CONCLUSION AND FUTURE WORK

This paper addressed mobility management issues in an environment with both WLAN and WMN. We examined WMN client side transparency within mesh mobility management protocols and then looked at standard mobility management protocols. The client side transparency scheme enables MNs to support mobility in heterogeneous and homogeneous networks. However, they are not necessarily compatible with mobile IP protocols. Although a typical WMN topology tends to be an unplanned graph and routes change dynamically, standard mobility management protocols such as MIPv6, HMIPv6, and FMIPv6 may be used for WMN mobility management. To learn how MIPv6 operates, we used the OPNET 16.0 MIPv6 model to simulate a heterogeneous wireless environment comprising WLAN and WMN. The simulation results show that MIPv6 is able to manage vertical handover for WLAN and WMN. However, in our opinion, its performance with both route optimization and tunneled traffic mechanisms is not effective enough. MIPv6 suffers from handover latency and packet loss which can combine to compromise delay-sensitive applications such as video conferencing.

For future work, we are considering enhancements to MIPv6 for better performance. According to [5], HMIPv6 has better performance than MIPv6 in the wireless domain. Handover latency and packet loss is minimized when

HMIPv6 is implemented. However, to improve handover performance even more, Fast Handover for Hierarchical Mobile IPv6 (FHMIPv6) could be incorporated to the MIPv6 handover mechanism. FHMIPv6 combines the outstanding features of FMIPv6 and HMIPv6, which could result in even more minimized handover latency and packet loss.

## VI. ACKNOWLEDGMENTS

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