Integrating WLANs & MANETs to the IPv6 based Internet

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Abstract— This paper presents a novel approach to integrate Wireless Local Area Networks (WLANs) and Mobile Ad-hoc Networks (MANETs) to the Internet Protocol version 6 (IPv6) based Internet. In the proposed network architecture, the mobiles, connected as a MANET, employ the Optimized Link State Routing (OLSR) protocol for routing within the MANET. Gateways are used to connect MANETs to the Internet. This paper extends the functionality of OLSR to support Mobile IP (MIP). This functionality is essential in a scenario where a node moving into an OLSR MANET needs to auto-configure its care-of-address and to propagate a Binding Update message containing its new care-of-address to its home agent and its correspondent node(s) located on the Internet. Automatic mode-detection and switching capability is also introduced in each mobile node to facilitate handoffs between WLANs and MANETs. Mobility management across WLANs and MANETs is achieved through Mobile IPv6 (MIPv6).

A real test-bed is constructed to demonstrate the viability of the proposed approach. Results from a performance evaluation on this test-bed are presented. Efficiency of handoffs between WLANs and MANETs is measured in terms of delay and packet loss. The impact of OLSR based route discovery and packet propagation, and Mobile IPv6 features such as movement detection and address auto-configuration on the handoff latency and packet loss are quantified. These performance benchmarks and metrics provide an assessment of the impact of the aforementioned system features on the QoS parameters associated with handoffs.

This is, to our knowledge, the first proposal to exploit the salient features of MIPv6 as well as OLSR in a collective fashion.

Keywords-component; Wireless Ad-hoc Networks, OLSR, Mobile Networks, Mobile IPv6.

I. INTRODUCTION

The proliferation of Wireless Local Area Networks (WLANs) in recent years suggests the emergence of a cellular infrastructure in the ISM band. Attempts are being made to connect Mobile Ad-hoc Networks (MANETs) to the Internet infrastructure to fill in the coverage gaps in the areas where WLAN coverage is not available. In the very near future mobiles roaming across multiple WLANs and MANETs while continuously maintaining session connectivity, are envisaged. A mobile may connect to a WLAN and then move into an area where the coverage from the WLAN does not exist. There, it may reconfigure itself into Ad-hoc mode and connect to a MANET. Essential to such seamless mobility is efficient mobility management and handoff support.

Mobile IP (MIP) has emerged as the dominant protocol for supporting mobility in the Internet [1]. However, it only supports the mobility where a mobile node is one hop away from the router. The challenge therefore is to accommodate MANET subnets in such a way that a MANET node, which may be multiple hops away from a router, could be accessed from anywhere from the Internet and the migration of mobile nodes into and out of MANETs is catered to while maintaining connectivity. The key requirements are that the handoff latency and packet loss are within acceptable levels. Excessive handoff delay and packet loss can have adverse impact on TCP based reliable sessions or on real-time multimedia services. A novel network architecture is proposed herein that addresses these concerns and considerations.

In this paper we first describe our approach to integrate MANETs into the Internet and to support mobility across WLANs and MANETs connected to the Internet. In the proposed architecture, the mobile nodes employ the Optimized Link State Routing (OLSR) protocol for routing within the MANET portion of the network [2]. The transfer of information into and out of the MANET is facilitated through a MANET gateway located between the MANET and the Internet. Location management is achieved through Mobile Internet Protocol version 6 (MIPv6). Handoffs between MANETs and WLANs are supported through automatic mode-detection and mode-switching capabilities in the mobiles.

Secondly, we present results for performance benchmarking of a test-bed built jointly by CRC (Communications Research Center), Ottawa and NewMIC (New Media Innovation Center), Vancouver. The motivation behind this performance evaluation is not only to demonstrate the efficiency of our approach but also to quantify the impact of intricate features of MIPv6 and

Optimized Link State Routing (OLSR), on the handoff latency and packet loss. These features include OLSR based route discovery and packet propagation, and IPv6 features such as movement detection and address auto-configuration.

In current research various approaches have been suggested to facilitate Internet connectivity to Ad-hoc networks. The Ad-hoc routing protocols that are proposed, employ on-demand routing protocols such as the Ad-hoc On-Demand Distance Vector (AODV) protocol and the Dynamic Source Routing (DSR) protocol [3][4][8][9][10][11][13]. A gateway acts as a proxy to answer the Route Request (RREQ)/ Route Reply (RREP) messages. The control messages are utilized to detect movement and obtain the global prefix from the Internet gateway as well as to decide if a destination is in the MANET. No route advertisement is provided in the on-demand routing protocols for mobile nodes to detect movement. The on-demand routing protocols do not provide seamless integration between a MANET and the Internet. With Proactive routing protocols, such as OLSR, build-in control messages can provide optimized route advertisement functionality for a mobile node to detect the movement. Moreover, the MANET routing and Internet routing both use a table-driven routing mechanism and the same routing table. This feature makes the process of accessing the Internet and registering with the Mobile IP home agent transparent to a mobile node once it joins a MANET.

The OLSR protocol is a Link State Routing (LSR) based protocol that has also been optimized for MANETs through the use of Multi-Point Relay (MPR) nodes [2][12]. The number of control messages in the network is reduced because only MPRs propagate their MPR selector set instead of every node declaring links to all its neighbors. Only the MPRs retransmit the broadcast messages. The control traffic is thus flooded in the network in a controlled way.

The rest of the paper is organized as follows. In Section II the salient features of the proposed approach are described. Section III provides implementation details of the test-bed and the results of the performance evaluation. Finally, Section IV makes some conclusions and, once again, highlights the main contributions of this work.

II. THE PROPOSED ARCHITECTURE

As illustrated in Fig.1, the network is composed of WLANs and MANETs. Each mobile node has an IPv6 address that corresponds to its home subnet as its identifier in the Internet. Once the mobile node moves into a foreign subnet, it derives its care-of-address (CoA) using the IPv6 auto-configuration mechanism. The new CoA reflects the mobile node's current location and is registered in its Home Agent (HA) so that the mobile node could be accessed for communication. In case the mobile node is already involved in a communications session then the CoA is also propagated to the Corresponding Node (CN) and the previous IPv6 router.

The home subnet as well as the foreign subnet could be a WLAN or a MANET. Within the MANET, the packets are routed based on the OLSR protocol, whereas in the remainder of the network the packet routing follows the MIPv6/IPv6 routing scheme. Central to the proposed architecture are the Mode-Detection and Switching component as well as the MANET Gateway. The Mode-Detection and Switching Component is implemented in each mobile node to facilitate handoffs between WLANs and MANETs. The MANET Gateway is used for connecting MANETs to the Internet. These key constituents of the proposed architecture are elaborated next.

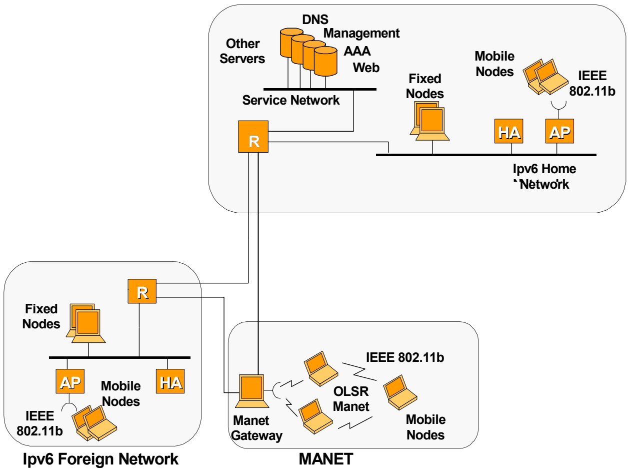

Figure 1. WLANs & MANETs Based Mobile Network.

A. *Mode Detection and Switching*

The 802.11 standard defines two basic modes of operation for wireless networks: the Ad-hoc mode and the Infrastructure mode. The handoff mechanism between two access points (APs) by a mobile node is defined as part of the 802.11 standard; however the 802.11 standard does not define the handoff procedure between the two different modes of operation (i.e. Ad-Hoc mode and Infrastructure mode). Therefore an algorithm was designed to support the handoff between the two distinct 802.11 operational modes. The algorithm, illustrated in Fig. 2, includes the mode-detection and mode-switching procedures which are essential to the mobile node to preserve interoperability with other devices during handoffs between Ad-hoc and Infrastructure networks.

1) *Monitoring the 802.11 Frames*

The 802.11 adapter card is initially set to "Monitor Mode". In "Monitor Mode" it is possible to access the raw data received by the wireless interface and to trace all the 802.11 frames received by the mobile node. The received 802.11 frames are analyzed to identify the Management Frames sent by other wireless devices. If a Beacon Frame is received, then the Capability Field is examined to identify if the Management Frame was generated by an access point (i.e., Infrastructure mode) or by a mobile node (i.e., Ad-hoc mode). In either case, the handoff application will set the appropriate operational mode in the wireless interface in accordance with the information retrieved from the Beacon Frame.

2) *Monitoring the Channel Quality*

During mode-detection the mobile node is able to identify and set the required 802.11 operational mode. The mode-switching procedure is achieved by monitoring the quality of the channel. If the signal quality is satisfactory, then the operational mode of the wireless interface remains unchanged. On the other hand, if the quality of the signal becomes unsatisfactory, then the 802.11 interface is switched to the alternate operational mode. For example, if the 802.11 interface was set to the Ad-hoc mode and later the signal quality degrades, then the wireless interface will be switched to the Infrastructure mode (i.e., the alternate operational mode). The concept of switching to the alternate operational mode is a result of a limitation in the 802.11 wireless adapters in use. This limitation is related to the fact that in "Monitor Mode" the Physical Layer becomes inaccessible to the TCP/IP protocol stack and therefore interconnectivity with other hosts is lost. It is thus preferable to avoid the "Monitor Mode" as part of the mode-switching procedure as it results in unwanted delays while the mobile node scans for the Beacon Frame. In other words, it is preferable to immediately switch to the alternate operational mode so that the mobile node will be ready to communicate with any device that might be operating in that mode. However, if no alternate operational mode is available then the 802.11 adapter is set to operate in "Monitor Mode" and start searching for the 802.11 Beacon Frames, as previously described.

The Channel Quality is measured by monitoring the Signal Strength reported by the 802.11 adapter to the handoff application. The mode-switching procedure is triggered when the Signal Strength drops below the predefined Signal Strength Threshold. It should be noted that the procedure used to monitor the channel quality is achieved in a different way in the Infrastructure mode and in the Ad-hoc mode. In the Infrastructure mode, the 802.11 adapter reports the average signal strength in the associate BSS (Basic Service Set), i.e. the average signal strength between the mobile node and the access point. In this case, the Signal Strength is compared against the Signal Strength Threshold to evaluate if a mode-switch procedure is required. On the other hand, in the Ad-hoc mode, the 802.11 adapter reports the Signal Strength for each 802.11 frame received from neighbouring Ad-hoc devices. Therefore the Signal Strength (as monitored by the handoff application) can fluctuate between small and large values (i.e., from one sample to the next sample) as a result of near and distant mobile nodes, respectively. In this case, the Signal Strength from each sample cannot be compared against the Signal Strength Threshold, as the signal strength from distant nodes can be lower than the Threshold value, thus triggering the handoff procedure, regardless of the fact that there might be Ad-hoc devices nearby with satisfactory signal strengths. As a result, in the Ad-hoc mode, the handoff application waits to gather a number of Signal Strength samples and evaluates if at least one of the samples is greater than the Threshold value. If none of the samples is greater than the Threshold value then a handoff procedure is triggered, otherwise the application keeps monitoring the signal strength.

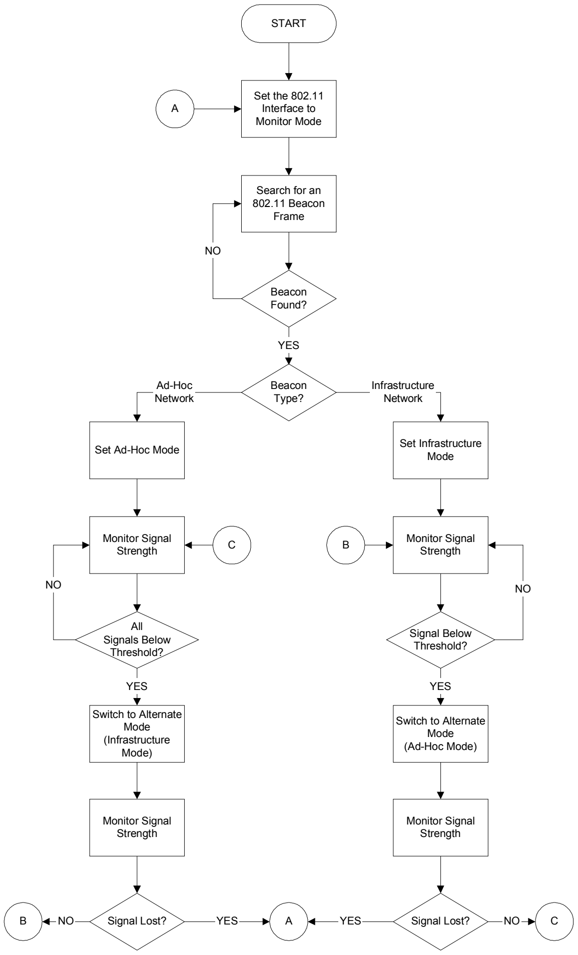

Figure 2. Mode Detection and Switching Procedure

B. *MANET Gateway*

The MANET gateway connects the MANET to the Internet and is responsible for understanding the hierarchical routing scheme of the Internet as well as the OLSR based routing protocol in the MANET. The gateway periodically broadcasts its existence into the MANET using Host Network Association (HNA) messages. HNA messages are used to inject routing information into the MANET of associated hosts/subnets that are not running OLSR thus not participating in the MANET. CNs and the HA can be reached as long as they are located in the subnets that were advertised in the HNA message. Currently there are no distinctions made in the HNA message between subnets attached to the gateway and a connection to the Internet. This paper extends the functionality of HNA messages to support MIP. This functionality has been omitted within OLSR and is very useful in a scenario where a node needs to auto-configure its CoA and to propagate a Binding Update (BU) message containing its new CoA to the gateway and finally to its HA and its CNs located on the Internet.

When an HNA message is received and that one of the network addresses indicates an access point to the Internet (00Hex) the MANET nodes generate an entry in their IPv6 routing table to indicate an access point to the Internet. The OLSR packet includes, the gateway's IP address (the originator address). The address of the sender, that is the next hop to reach the gateway, is located in the IPv6 header (the source address). The gateway's address and next hop address will be used to transfer any packet destined to an IP address that does not have an entry in the routing table. The HNA messages broadcast by the gateway are thus used for gateway discovery, address auto-configuration and for routing packets to the hosts located on the advertised subnets and now anywhere on the Internet.

When a mobile node moves into a MANET, it will use its home address to join the MANET and listen to the HNA message. A mobile node in the MANET, upon receiving an HNA message, can then configure its CoA by using the network address and network mask contained in the HNA message. The CN and the HA can therefore be reached as long as their subnets are advertised in the HNA message.

The IPv6 kernel is modified to ensure that the CoA is computed using the contents of the HNA message, and to enable the IPv6 kernel to differentiate between messages received from the MAC layer as opposed to the OLSR. Once the CoA has been computed, the MIPv6 sends a Binding Update message to the node's HA and to the CNs through the gateway, which is the Internet access point for the MANET nodes. From now, the node will exchange HELLO message with its neighbors by using its CoA instead of its home address. When its one hop and two hop neighbors detect that they have a new neighbor, the nodes in the MANET will recalculate their routing table and include the mobile node's CoA. The gateway's routing table will therefore contain a route to the mobile node's CoA since the mobile node propagates its CoA in the MANET. The gateway acts as a router where the packets are forwarded in a simple manner. The handoff procedure is illustrated in Fig 3.

The rationality behind using HNA messages in place of existing ICMPv6 router advertisements is that the ICMPv6 messages are designed for location detection in a LAN environment where nodes are within the propagation range of the router. The ICMPv6 router advertisements are not propagated further by IPv6 and thus a node moving more than one hop away from the router will not receive these router advertisements. Alterations to the IPv6 kernel are required to accommodate broadcasting of ICMPv6 router advertisement messages beyond single hop and, also, to ensure that the underlying routing protocol is aware of the new CoA computed in the kernel. Besides, the aforementioned broadcast of ICMPv6 router advertisements will incur flooding in the MANET, as opposed to HNA messages that employ OLSR based optimal broadcast involving only a selected set of MPR nodes [2].

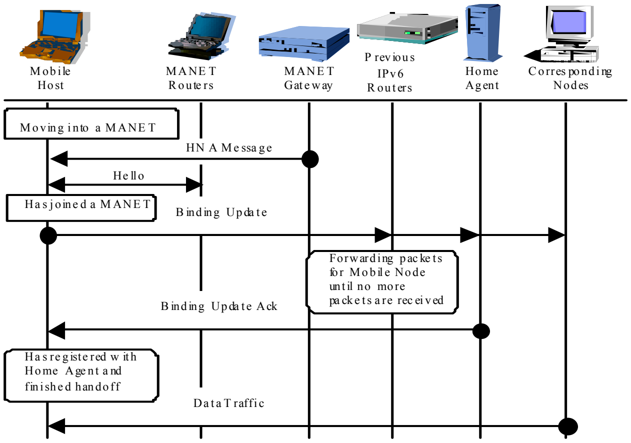

Figure 3. Incoming Handoff to a MANET

III. TEST RESULTS

A test-bed, modeling the network architecture depicted in Fig. 1, has been implemented. It is composed of IEEE 802.11b based Access Points (APs), and Linux laptops and workstations equipped with 802.11b wireless LAN cards. The MIPv6 used in the test-bed was developed at HUT [7]. Using this infrastructure various scenarios were simulated that include initiating a session inside a mobile's home network; initiating a session outside the mobile's home network; handoff from a WLAN to a MANET; and handoff from a MANET to a WLAN. A CN was programmed to send a continuous stream of fixed size UDP packets to the mobile node every 0.1 sec. The frequency of the HNA and HELLO messages was varied. The traffic flow was monitored using Ethereal to measure the performance parameters of interest [5].

The results obtained from the aforementioned scenarios are presented below. The packet loss measured was proportional to the handoff delay and is not shown in the results. The results quantify the impact of intricate features of MIPv6 and OLSR, on the handoff latency. The results also help evaluate various strategies to improve the performance by reducing the handoff delay that include increasing the beacon frequency of Access Points and tune the OLSR parameters such as the frequency of HNA messages, and HELLO messages etc. The overall handoff latency in the proposed setup can be decomposed as follows:

$L_{handoff} = L_{MDS} + L_{BU/A}$, where

$L_{MDS(W\text{->}M)} = L_{LL} + L_{HNA} + L_{MIP} + L_{OLSR}$, and

$L_{MDS(M\text{->}W)} = L_{LL} + L_{MIP}$

$L_{handoff}$ is the overall handoff latency.

$L_{BU/A}$ is the minimum latency for the mobile node in receiving the Binding Update Acknowledgement from the HA and CN and in receiving the first outstanding packet in the new mode. This component of the handoff latency is a function of the hop-count on the routes between the MN and the HA and CNs. In the local test bed where the MN is next to the HA and CN, $L_{BU/A}$ is very small so that we do not count as part of the handoff latency metrics.

L_{MDS} is the component of latency during which a mobile node discovers that it has moved out of its current coverage, switches to the new mode, and re-establishes connectivity under the new mode. $L_{MDS(W->M)}$ denotes the WLAN-to-MANET mode-detection and switching latency whereas $L_{MDS(M->W)}$ corresponds to the MANET-to-WLAN handoffs.

L_{LL} is the latency in detecting that the mobile node has moved out of its current coverage and the time taken by the mode-detection and switching component to switch the 802.11b wireless card from infrastructure mode to the Ad-hoc mode, or vice-versa. Even though, during this phase, the mobile node continues to receive packets over the existing connection, packet loss may occur if there are coverage gaps and the detection is not timely. This component of the handoff latency therefore depends on the signal strength sampling interval as well as the number of signal strength samples to be monitored before initiating the handoff procedure.

L_{HNA} is the latency for the mobile node in capturing the first HNA message in the Ad-hoc mode subsequent to a handoff from infrastructure mode. This component of the handoff latency is a function of the inter-arrival period of HNA messages. The hop-count between the mobile node and the MANET gateway, and the traffic load distribution within the MANET may add to the jitter in the HNA message arrival process.

TABLE I. WLAN-TO-MANET HANDOFF LATENCY METRICS

Handoff Latency	L_{LL}	L_{HNA}	L_{MIP}	L_{OLSR}	Hello Int.	Hop Count
2.12	0.76	0.21	0.18	0.97	0.05	1
2.64	0.79	0.68	0.20	0.97	0.05	2
2.97	0.83	0.90	0.21	1.02	0.05	3
1.99	0.75	0.14	0.18	0.92	0.1	1
2.50	0.76	0.63	0.17	0.94	0.1	2
2.83	0.83	0.84	0.18	0.97	0.1	3
3.27	0.77	0.49	0.26	1.90	0.25	1
4.08	0.80	1.11	0.29	1.88	0.25	2
4.36	0.88	1.26	0.28	1.92	0.25	3
3.63	0.83	0.64	0.27	1.89	0.5	1
4.39	0.83	1.28	0.33	1.95	0.5	2
4.77	0.89	1.49	0.37	1.96	0.5	3

L_{MIP} is the amount of time taken by the MIPv6 function within the mobile node to configure the new IPv6 CoA and delete the old route table. This component of the latency is deterministic.

L_{OLSR} is the latency in establishing the incoming mobile node 's membership to the MANET by using its new CoA. It is the latency for all the MANET nodes to exchange the HELLO messages and update their routing tables, based on the OLSR protocol, to accommodate the incoming mobile node in the MANET. This component of the latency depends on the MANET size, the hop-count from the mobile node to the MANET gateway, and the HELLO message frequency etc.

L_{RA} is the counter-part of L_{HNA} in MANET-to-WLAN handoffs and depends on the transmission frequency of ICMP based Router-Advertisements.

Based on the above decomposition, Table 1 quantifies the WLAN to MANET handoff latency of our proposed network structure. The handoff latency is further decomposed in terms of various parameters and is also shown in Table 1. The delay measurements as well as the HELLO and HNA intervals are expressed in seconds.

The L_{LL} delay presented in Table 1 were obtained by using a forced switch mode capability of the handoff application. A command was given to the handoff application to force the handoff procedure at the link layer. This approach was used so that L_{LL} could be measured more precisely without having to rely on the specific behavior of the 802.11 Linksys card that was being used. (e.g. When the card was in infrastructure mode and the AP was switched off, it would take an unusual long time for the Signal Strength to drop below the predefined Signal Strength.)

The L_{HNA} latency increases when the mobile node moves into the MANET two hops or three hops away from the gateway, as suggested by Table 1. The HNA messages have to travel through the MPRs to reach the mobile node. Therefore it takes more time for the control messages to reach the mobile node. Once the mobile node has received an HNA message, the MIPv6 process configures the mobile node's CoA. The mobile node begins to exchange HELLO messages with its neighbors by using its new care-of address. With information obtained from the HELLO messages, the nodes in the MANET recalculate their routing table and include the mobile node's CoA. When the MIPv6 process configures the new CoA, it sends its first BU to the HA and CNs immediately even though the OLSR process has not completed building its new routing table. As a consequence the MIPv6 process will retransmit the BU because it will not receive an ACK from the HA and CNs before its timer expires. The L_{OLSR} delay shown in Table 1 includes the retransmission time of the BU. The L_{OLSR} delay could be improved by having the OLSR process signal the MIPv6 to send the BU when it has completed calculating its routing table.

Clearly, improvements in the handoff latency and packet loss can be achieved at the expense of bandwidth by reducing inter-arrival periods of HNA and HELLO messages. However, if the inter-arrival period of HNA and HELLO messages is reduced to a very small value, it leads to excessive collisions and/or channel busy conditions as per IEEE 802.11b CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) protocol, resulting in an increase in handoff latency [6]. When the values are large it takes a longer time for the mobile node to receive the HELLO and HNA messages and as a consequence it takes more time to calculate the care-of-address and update the routing table. The handoff latency is, therefore, higher when the inter-arrival period of HNA and HELLO messages is either extremely small or extremely large, as apparent from Fig. 4. An optimum value could be realized that exists somewhere in between the two extremes, for a given traffic load condition.

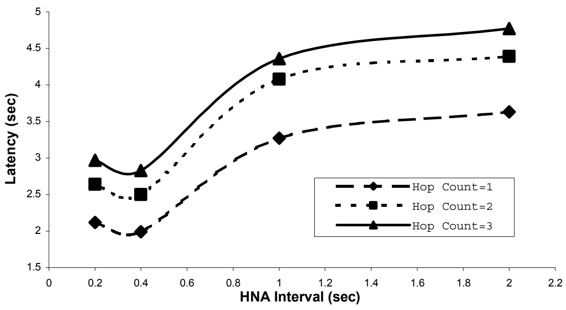

Figure 4. Impact of HNA/HELLO Message Frequency and Hop-Count on Handoff Latency

IV. CONCLUSIONS

A novel approach to integrate MANETs and the Internet is described. The approach supports seamless handoffs between WLANs and MANETs. A test-bed has been constructed and the viability of the proposed approach is demonstrated. The efficiency of the approach is quantified by presenting handoff latency measurements from the test-bed. The benchmarks presented in this paper provide valuable guidelines for tuning MIPv6 & OLSR parameters in a WLAN/MANET based mobile communications infrastructure in the ISM band.

Future extensions of this work will include investigating the impact of the signaling overhead, required to achieve lower handoff latency, on the overall throughput under heavy load network conditions.

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