An IPv6 and OLSR based Architecture for Integrating WLANs & MANETs to the Internet

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Abstract

This paper presents the results from a performance evaluation on a Mobile IPv6 based test-bed composed of WLANs (Wireless Local Area Networks), MANETs (Mobile Ad-hoc Networks) and the Internet. Location management and handoff efficiency is measured in terms of session set-up delay and handoff delay. The mobiles, connected as a MANET, employ the OLSR (Optimized Link State Routing) protocol for routing within the MANET. Location management across WLANs and MANETs is achieved through Mobile IPv6. The impact of OLSR based route discovery and packet propagation, and IPv6 features such as neighbor discovery and address auto-configuration on the session set-up latency, handoff latency and packet loss are quantified.

There are two main contributions reported in this paper. First, a novel approach is proposed to integrate MANETs into the Internet using Mobile IPv6 and OLSR. Secondly, various performance benchmarks and metrics are presented that are obtained using the test-bed developed jointly by CRC, Ottawa and NewMIC, Vancouver. These benchmarks are essential for assessing the impact of the system features listed above.

Keywords

Wireless Ad-hoc Networks, OLSR, Mobile Communications Systems, Mobile IPv6 and QoS.

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 location management and handoff support.

Mobile IP 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 OLSR (Optimized Link State Routing) 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.

The motivation for using OLSR comes from the fact that although a number of routing protocols for the ad-hoc networks have been proposed that include Ad-hoc On-Demand Distance Vector (AODV) protocol, Temporally Ordered Routing Algorithm (TORA), Zone Routing Protocol (ZRP), and Dynamic Source Routing (DSR) protocol, these protocols do not scale well to the global Internet [3]. Furthermore, pro-active routing protocols such as OLSR reduce the route acquisition latency as opposed to on-demand routing protocols. The signaling efficiency is enhanced in OLSR because the messages are propagated in an optimum way where only certain nodes, called multipoint relays, transfer the information through the MANET. Besides, in the proposed approach, a MANET gateway is used and instead of using the multicast or broadcast ICMP routing advertisements for location detection, the built-in gateway advertisement support of OLSR is utilized. All the said features facilitate smooth attachment to the Internet and efficient mobility management support. We demonstrate the effectiveness and viability of our approach by implementing a Mobile IPv6 and OLSR based WLAN/MANET hybrid data network. This is, to our knowledge, the first proposal to exploit the salient features of Mobile IPv6 as well as OLSR in a collective fashion.

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 Mobile IPv6 and OLSR, on the handoff latency and packet loss. These features include OLSR based route discovery and packet propagation, and IPv6 features such as neighbor discovery and address auto-configuration.

THE PROPOSED ARCHITECTURE

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

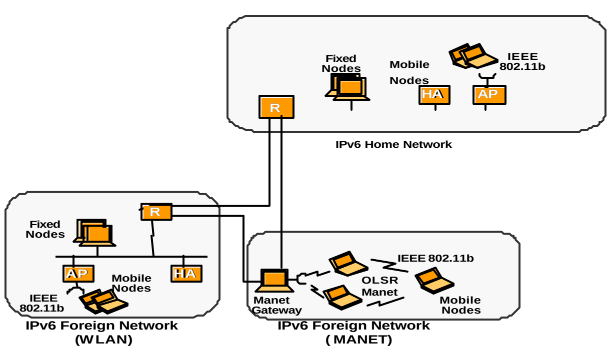

Figure 1. WLANs & MANETs Based Mobile Network.

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.

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 Figure 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.

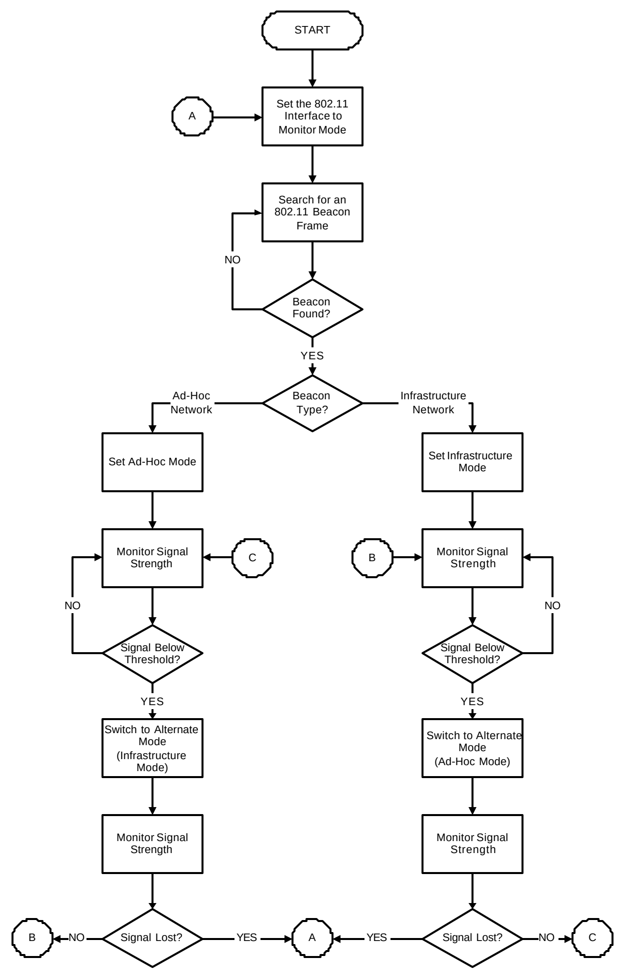

Figure 2. Mode Detection and Switching Algorithm

Monitoring the 802.11 frames

The 802.11 adapter 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.

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.

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 HNA (Host Network Association) messages. A mobile node in the MANET, upon receiving an HNA message, can then configure its care-of-address by using the gateway’s IP address contained in the HNA message. The handoff procedure is illustrated in Figure 3. The HNA messages are also used to propagate the routing information about hosts and/or subnets that are directly connected to the gateway into the MANET. The CN and the HA can therefore be reached as long as their subnets are advertised in the HNA message. A default entry is created in the routing table of MANET nodes to transfer packets, destined to an IP address that does not have an entry in the routing table, to the gateway. 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 or anywhere on the Internet.

The IPv6 kernel is modified to ensure that the care-of-address 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 care-of-address has been computed, the Mobile IPv6 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 care-of-address 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 care-of-address.

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. Significant 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 care-of-address 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 nodes called MPRs (Multi Point Relays) [2].

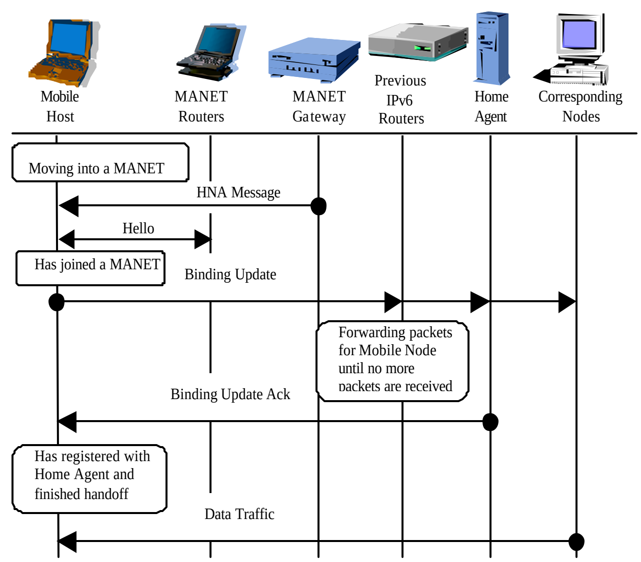

Figure 3. Incoming Handoff to a MANET

TEST-BED CONFIGURATION

A test-bed modeling the network architecture depicted in Figure 1 has been implemented. It is composed of IEEE 802.11b based Access Points, and Linux laptops and workstations equipped with 802.11b wireless LAN cards. The routers between CRC, Ottawa and NewMIC, Vancouver are connected using an ISDN line. The Mobile IPv6 used in the test-bed was developed at HUT [4]. Using this infrastructure various scenarios are 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 is programmed to send a continuous stream of fixed size UDP packets to the mobile node. The traffic flow is monitored using Ethereal to measure the performance parameters of interest [5].

TEST RESULTS

In this section the results obtained from the aforementioned scenarios are presented. The results quantify the impact of intricate features of Mobile IPv6 and OLSR, on the session setup latency and the handoff latency. The results also help evaluate various strategies to improve the performance by reducing mode-detection and switching 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.

Figure 4 illustrate the results obtained by monitoring the UDP packets that are sent every 0.1 seconds and received by a mobile node while performing handoffs. The HNA and HELLO message interval in this sample, are 2.0 sec and 0.5 sec, respectively. The graphs clearly indicate a significant delay before the session is re-established.

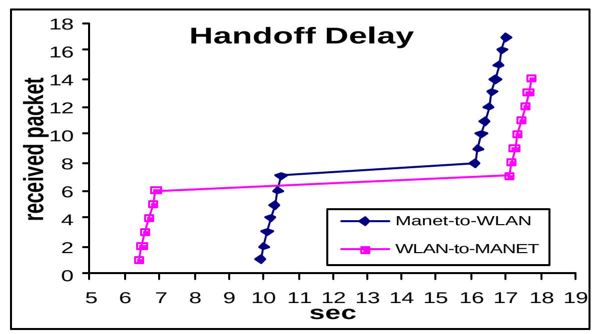

Figure 4. Handoff Delay Illustration

The overall handoff latency in the proposed setup can be decomposed as follows:

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

$L_{MDS(W->M)} = L_{MD} + L_S + L_{HNA} + L_{COA} + L_{OLSR}$, and

$L_{MDS(M->W)} = L_{MD} + L_S + L_{RA} + L_{COA}$

- $L_{handoff}$ is the overall handoff latency.
- $L_{BU/A}$ is the minimum latency for the mobile node to register its new care-of-address, through a Binding Update message, to the previous IPv6 router, and its CNs; and, subsequently, the latency in receiving the Binding Update Acknowledgement and 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 said entities.
- 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 MANET-to-WLAN handoffs.

- L_{MD} is the latency in detecting that the mobile node has moved out of its current coverage. Even though, during this phase, the mobile node continues to receive packets over the existing connection, packet loss may occur if 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. In infrastructure mode the number of samples is equal to one.
- L_S is 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. This component of the handoff latency is deterministic.
- 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.
- L_{COA} is the amount of time consumed in determining the new IPv6 based care-of-address. This component of latency is deterministic.
- L_{OLSR} is the latency in establishing the incoming mobile node 's membership to the MANET. 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 handoff latency of our proposed network structure in terms of various parameters identified above. The latency of handoffs from MANET to WLAN was observed to have an average of approximately 3 sec, with HA and CN being 3 hops apart and the ICMPv6 based Router Advertisement frequency being set to 0.33/sec.

Table 1. WLAN-to-MANET Handoff Latency Metrics

Handoff Latency (sec)	HNA Message interval (sec)	HELLO Message interval (sec)	Hop Count btw. MN and Gateway
5.05	0.2	0.1	1
5.34	0/2	0.1	2
10.73	2.0	0.5	1
15.44	2.0	0.5	2

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 Mobile IPv6 & OLSR parameters in a WLAN/MANET based mobile communications infrastructure in the ISM band.

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

ACKNOWLEDGMENTS

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REFERENCES

[1] D. B. Johnson and C. Perkins, "Mobility Support in IPv6", http://www.ietf.org/internet-drafts/draft-ietf-mobileip-ipv6-15.txt, 2 July 2001

[2] T. Clausen , P. Jacquet et. al. , "Optimized Link State Routing Protocol", http://www.ietf.org/internet-drafts/draft-ietf-manet-olsr-05.txt, October 2001

[3] A. Striegel, R. Ramanujan and J. Bonney, "A Protocol Independent Internet Gateway for Ad-Hoc Wireless Networks", in Proc. of Local Computer Networks (LCN) 2001, Tampa, Florida, Nov. 2001.

[4] Dynamics - HUT Mobile IP Home Page, http://www.cs.hut.fi/Research/Dynamics/.

[5] Ethereal, http://www.ethereal.com.