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Abstract. This paper examines the handover process of Mobile IPv6 in a real wireless testbed, based on IEEE 802.11b and extracts information on the actions taken by network entities during the movement of a mobile node. This work focuses on the decomposition and analysis of all the initiated events and exchanged signals and measures, in a real-life scenario, the delays associated with them. Particular attention is given to the period leading to the L3 registration part of the handover, since this has been identified by many as the "choking point" of the whole process. Experimental results help in understanding the effect of Duplicate Address Detection, Router Advertisement Intervals and Wireless Beacon Intervals on the handover delay.

Keywords: Mobile IPv6, Handovers, L2 Delays, Router Advertisements, Beacon Intervals.

1 Introduction

Mobility is seen as an integral part of future networks, where the initiatives for next generation networks (NGN) will meet more traditional and established networks to form heterogeneous architectures. IPv6 is the networking technology of choice in the effort to move to an all-IP 4G environment. In order to effectively support the integration of Cellular (3G), Wireless LAN and Wireless Broadband (WiMax) technologies to the core networks, IPv6 and Mobile IPv6 will be required to provide transport and mobility solutions over different access technologies.

Mobility in IPv6 is therefore an enabler for future services and as such, all actions associated with it need to be thoroughly understood. One such action is the handover process. A handover (HO) is the process during which a mobile node (MN) creates a new connection and disassociates from its old one. The decision for a new association may be initiated due to movement, if we are moving away from the old connection point and we are approaching a new one; low signal quality, because of interference or other impairments in the wireless path; quality of service decision, trying to effect a balanced load among neighboring or overlapping cells; better service, if we recognize a network with services that we require; or policy and cost decision, where the network or the user decide that it is more appropriate, or advantageous to relate to a different location.

Handovers can be characterized as Horizontal if they are performed between connection points using the same access technology, or Vertical if they are performed between access points of different technologies, a case which will be more common in future heterogeneous networks.

In addition Handovers are considered Link Layer (L2) if they are performed between connection points belonging to the same subnet, or Network Layer (L3) if they are performed between different subnets and require the configuration of a different IPv6 address.

In this paper we examine the handover process of Mobile IPv6 in a real wireless testbed, based on IEEE 802.11b, and extract information on the actions taken by network entities during the movement of a mobile node. This work focuses on the decomposition and analysis of all the initiated events and exchanged signals and measures, in a real-life scenario all the delays associated with them, both in the Link and the Network layer.

Our work is important because it provides real-implementation results for significant parts of the handover process which cannot be obtained through simulation. We consider that simulators, though useful to some extent from an analytical point of view, either introduce unnecessary uncertainty into the network, or strictly specify significant parameters. Therefore there is always a margin of error in simulation results.

The rest of the paper is structured as follows: In Section 2 the mobility management, address resolution and other protocols related to MIPv6 handovers are presented. The handover process is analyzed in Section 3 and related work is outlined. The experimental evaluation of MIPv6 handovers in IEE802.11b is described in Section 4. Concluding remarks and items for future work are given in Section 5.

2 Protocol Overview

2.1 Mobile IPv6

Mobile IP version 6 is the mobile extension to IP version 6 [1]. The MIP fundamental principle is that a mobile node should use two IP addresses, a permanent address (the home address, assigned to the host and acting as its global identifier) and a temporary address (the care-of address -CoA, providing the host's actual location).

MIPv6 retains the general ideas of home network, encapsulation, home agent, and care-of address from MIPv4 [2]. However, it has a slightly different philosophy and a much-improved design than its predecessor.

While a mobile node is attached to its home network, it is able to receive packets destined to its home address, and being forwarded by means of conventional IP routing mechanisms. When the mobile node moves into a new network (visited/foreign network) its movement is detected and a new association is made with mobility agents (foreign agents) in the new domain. In MIPv6 a mobile node is more "independent" and does not have to rely on an access point to obtain a CoA and register with the home agent. To obtain its CoA, a mobile node uses the IPv6 protocols for Address Autoconfiguration [3] and Neighbor Discovery [4].

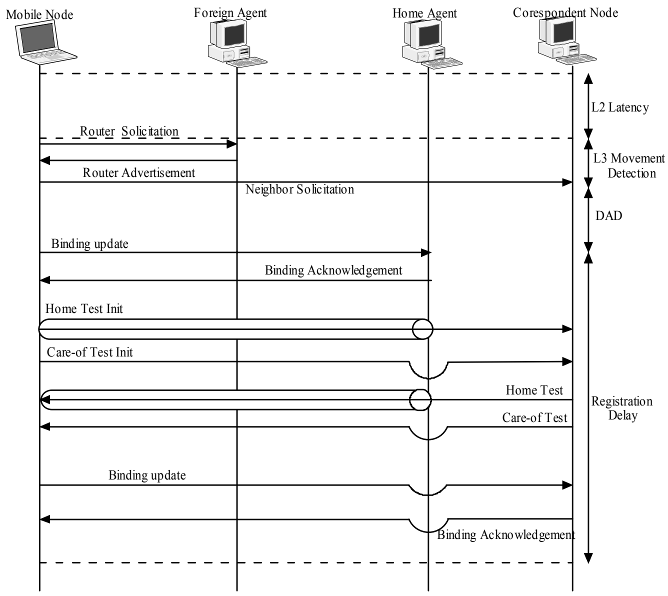

Figure 1 MIPv6 Handoff Signaling

Once configured with a CoA, the MN needs to send a Binding Update (BU) message to its Home Agent (HA) to register its current primary CoA. The first time a correspondent node (CN) needs to communicate with the MN, it sends the packets to the mobile node's home address. The HA is then encapsulating the packets and forwards them to the MN's CoA, where they are de-capsulated by the corresponding mobility agent and forwarded to the mobile node.

Upon a new association, the MN transmits BUs to its HA and the communicating CNs for them to associate the MN's home address with the new CoA. From then on, CNs will use IPv6 Routing headers for forwarding the packets to the MN. These packets have as destination address the MN's CoA. The 'home address' information is also included in the routing header to preserve transparency to upper layers and ensure session continuity. In the reverse direction, datagrams sent by the mobile node can be delivered to their destination using standard IP routing, without having to go through the home agent. Packets have as a source address the host's CoA while the home address is also included for the same reasons as above.

When the home agent discovers that the mobile node has moved, it uses techniques from Neighbor Discovery to indicate the new MAC address for the mobile node to all the correspondent nodes on the mobile node's home network.

Two well-known approaches in reducing the MIP handoff latency have been proposed in the literature. One aims to reduce the (home) network registration time through a hierarchical management structure, while the other tries to minimize the lengthy address resolution delay by address pre-configuration through what is known as the fast-handoff mechanism.

Hierarchical mobility management protocols, like Hierarchical MIPv6 (HMIPv6) [5] decide *when* to perform an action (registration in this case), whereas fast handover protocols, like Fast MIPv6 (FMIPv6) [5], address the problem of *how* to perform L3 actions in a faster way.

2.2 Stateless Address Autoconfiguration and Duplicate Address Detection

The stateless address autoconfiguration mechanism [3] allows a host to generate its own addresses in the following way. Access routers advertise prefixes that identify the subnet(s) associated with a link, while hosts generate an 'interface identifier' that uniquely identifies an interface on each subnet. A global address is formed by combining the two. The formation of an address must be followed by the Duplicate Address Detection (DAD) procedure in order to avoid address duplication on links where stateless address autoconfiguration is used. The address autoconfiguration is composed of the following steps:

The host generates a link-local address for its interface on a link. When in handoff, the host can use the same interface identifier as the one used in the previous link. It then performs DAD to verify the uniqueness of this address, i.e. the interface identifier on the new link. It uses the prefix(es) advertised by routers for forming a global address so as to be able to communicate with hosts other than the neighboring ones. During DAD, the host transmits a Neighbor Solicitation for the tentative linklocal address and waits for some specified delay (RetransTimer) [4] till it considers the address unique. DAD only fails if in the mean time, the host receives a Neighbor Advertisement for the same address, meaning that another host is using the being questioned address or if another host is in the progress of performing DAD for the same address and has also transmitted a Neighbor Solicitation.

2.3 Layer 2 handover

The IEEE 802.11 handover procedure is composed of three distinct phases: scanning, authentication, and reassociation phase During the IEEE 802.11 handoff procedure the MN performs a channel scanning to find the potential APs to associate with. In the passive scan mode, each MN listens for beacon messages which are periodically sent by APs. In addition to the passive scan, each MN may broadcast a probe frame on the channel and receive probe responses from APs in the active scan mode. Regardless of scanning modes, all possible channels defined by the IEEE 802.11 standard (11 or 13 channels) are examined during a scan.

The scanning results in a list of APs that have been detected and it includes the related information for each detected AP, such as ESSID, the AP's MAC address, and the measured signal strength of each AP. Based on the scan result, the MN chooses an AP to associate with (usually the one with the highest signal strength). After that, the MN initiates the authentication procedure by transmitting the frames related to it. If the authentication phase is successfu1, the MN tries to re-associate with the AP by sending a reassociation request message to the AP. Then, the AP responds with a re-association reply message which contains the results of the reassociation. If everything is successful, this phase becomes the last step of the handover. The length of the scanning procedure may vary from one implementation to the other but is generally considered to be the heaviest part of a Wireless LAN handover [7][8].

3 Handover Latency Analysis

A mobile node is unable to receive IP packets on its new association point until the handover process finishes. The period between the transmission (or reception) of its last IP packet through the old connection and the first packet through the new connection is the handover latency. The handover latency is affected by several components:

- ***Link Layer Establishment Delay (D_{L2}):*** The time required by the physical interface to establish a new association. This is the L2 handover between access routers.
- ***Movement Detection (D_{RD}):*** The time required for the mobile node to receive beacons from the new access router, after disconnecting from the old AR.
- ***Duplicate Address Detection (D_{DAD}):*** The time required to recognize the uniqueness of an IPv6 address.
- ***BU/Registration Delay (D_{REG}):*** The time elapsed between the sending of the BU from the MN to the HA and the arrival/transmission of the first packet through the new access router.

The overall handover process as well as the component delays identified above are presented in Figure 1. The handover delay for MIPv6 can analytically be computed as:

$$D_{MIPv6} = D_{L2} + D_{RD} + D_{DAD} + D_{REG} \tag{1}$$

The delays can be further broken down to:

$$D_{MIPv6} = (T_{PRB} + T_{AUTH} + T_{RASS}) + (T_{RSOL} + T_{RADV}) + D_{DAD} + (T_{HBU} + T_{HBA} + 2T_{HOTI} + 2T_{HOT} + T_{CBU} + T_{CBA}) \tag{2}$$

Where:

D_{L2}, D_{RD}, D_{DAD}, D_{REG} as described above, T_{PRB}, T_{AUTH}, T_{RASS} : probe, authentication and reassociation delays at L2, T_{RSOL}, , T_{RADV} : Router solicitation and Router Advertisement, T_{HBU} ,T_{HBA} : BU and Back with HA, $2T_{HOTI}$, $2T_{HOT}$: HoTi and HoT process and T_{CBU} ,T_{CBA} : BU and Back with CN.

Due to the differences in access networks, hardware, implementation versions and traffic, there can be no single value for the overall MIPv6 delay. Related values found in the literature vary from 1.3 sec in [9][10] to 1.9 sec in [11] [13], and 2.6 sec in [12]. It should be noted that only the last three refer to real implementations.

As it can been seen from Figure 1 and equation (2), the overall MIPv6 handover latency can be reduced by direct manipulation of a number of parameters. Solutions like HMIPv6 and FMIPv6 manage to reduce the BU/Registration Delay. In our work we focus on the other three delay components: the D_{L2}, D_{RD}, and $D_{DAD.}$

3.1 L2 delays

The values measured or considered in the literature for the D_{L2} delay are between 50ms [9] and a few hundred milliseconds [6]. In [14] and [15] the value is at 100ms. In [16] the range is from 100-300ms. In [11] the range is from 50-400ms. L2 delays are however very dependent on the physical medium and always exhibit great variations. Since the scanning, or probing, delay is the most prevalent one during an L2 handover, we believe that it merits special attention. In this work we shorten the wireless beacon interval to values below 100ms in an effort to reduce $D_{L2.}$

3.2 Router Advertisements

Router Solicitations (RSol) and Router Advertisements (RA) help the MN identify that it has changed subnets and provide it with the necessary information for the creation of the new CoA. While in traditional IPv6, the values for RAs were in the order of 3 to 5seconds, for Mobile IPv6 these values need to be significantly lower. In this work, we change the RA interval in an effort to deduce the effect of it on D_{RD}.

3.3 Duplicate Address Detection

Once the MN discovers a new router and creates a new CoA it tries to find out if the particular address is unique. This process is called Duplicate Address Detection and it is a significant part of the whole IPv6 process, with very little room for improvement. In this work we evaluate MIPv6 HOs with this feature either enabled or disabled.

3.3 Related Work

Reducing the L2 probe delay is not a protocol issue, but an implementation issue. In [13] the authors examine different IEEE802.11-based network cards and propose the reduction of the MaxChannelTime to 100ms in order to reduce the effect of the probing procedure. In addition they suggest that another possible way to reduce L2 handovers is to extend the protocol with new IEEE 802.11 specific options that allow access routers to send to mobile nodes, all details that they might need for rapidly associating with a new Access Point, such as frequency, ESSID, and authentication info.

In [9] they recognize that the DAD time is significant during a handoff and they propose a scheme for HMIP in order to reduce the DAD time on handoff delay. The scheme is called Stealth-time HMIP (SHMIP) and assigns a unique on-link care-of address (LCoA) to each mobile node and switches between one-layer IPv6 and two-layer IPv6 addressing. In this mechanism when a mobile node sends a local BU, it also sends Bus to its home agent and correspondent nodes at the same time, using LCoA instead of RCoA. To further reduce packet losses, they also adopt pre-handoff notification to request previous mobility anchor points (MAP) to buffer packets for the mobile node.

In [17] they work specifically on the registration delay component. They make the assumption that the link layer delay can he considered equal to zero for link layer technologies supporting soft handover. They also consider the movement detection delay depends upon the frequency of router advertisement and could be large in a bandwidth constraint environment.

In [18] the total handover latency MIPv6 is found to be 5 seconds. Based on the author's assumptions, if the L2 handover takes about 1 second, then the remaining 4 seconds are used for the L3 handover. This happened because the minimum period of *RA* (Router Advertisement) was 3 seconds and the maximum period was 5 seconds which corresponds to the default setting in *wired* IPv6. In MIPv6 these values are expected by the RFC to be smaller. In a subsequent paper [19] the same authors consider that the router advertisement (RA) message is sent to wireless link in every 1-3 seconds which is a better interval, but as we will show in Section 4 is can also be considered large.

In [20] the authors use analytical models to evaluate MIPv4, MIPv6, FMIPv6, and HMIPv6 and compare their performances in terms of handover delay for VoIP services. They propose an adaptive timer for the retransmission of router solicitations, binding updates and other control signals, to replace the backoff timer usually found in MIP implementations. The results obtained using the adaptive timer technique show a 50% improvement compared to the fixed-timers option. However, these results are purely analytical and make specific static assumptions on the values of the different L2 and L3 component delays.

In [10] they do similar comparisons, utilizing a simulator instead of mathematical analysis. They compare Standard MIP, HMIP, FMIP, FHMIP and FFHMIP focusing on L3 HO values, and ignoring L2 and DAD delays.

The authors in [21] claim that none of the Fast or “assisted” methods of handover can be applied in IEEE 802.11 systems since such systems are based on the fact that the APs involved in a MN's reassociation can “anticipate" the handover before it is actually performed. However the 802.11 APs become aware of a MN's movement only after real occurrence of a reassociation event at the new AP. Other methods of shortening the movement detection delay are: (a) the MN pre-caches the IP information needed to perform the IP movement detection, without depending on the MIP advertisements for this purpose and (b) the APs are either pre-configured with information useful to perform movement detection for a newly connected MN, or obtain this information via periodic announces or other similar methods (centralized caching of the necessary information in each subnet).

We believe that the results of our research work can be of benefit to the work of others trying to characterize mobility management protocols, since it can help them utilize real-life values in their simulations, emulations, or equations.

4 Experimental Evaluation

The work items identified in Sections 3.1, 3.2 and 3.3 are evaluated experimentally in this Section. The testbed setup is explained in Section 4.1 and the results of each evaluation are analyzed separately afterwards.

4.1 Testbed Setup

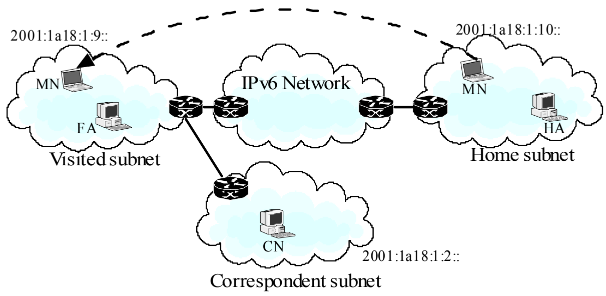

Figure 2 Testbed Topology

The experimental testbed consists of three wireless LANs connected through an IPv6 cloud as shown in Figure 2. This setup topology provides the simplest configuration for a realistic study of L2 and L3 handover components. Twenty experiments were run for each configuration and the average times are computed and analyzed. The devices used in the testbed have the specifications shown in Table 1.

Table 1 List of Equipment and Software

Mobile Node	Home Agent	Foreign Agent	Corresponded Node
IBM ThinkPad T42p	Acer Veriton 9100	Dell Optiplex GX1	Dell Optiplex GX1
Intel Pentium M 1.86GHz	Intel Pentium 4 1500MHZ	Intel Pentium III 50OMHz	Intel Pentium III 500MHz
2048 cache	256 cache	512 cache	512 cache
Atheros AR5212 802.11abg NIC	D-Link, PCI IEEE802.11b card, GWL-520, Atheros chipset		
Auto channel	Channel 1	Channel 6	
LINUX, Fedora Core 5, kernel 2.6.16			
MIPL v2.02			

Table 2 contains some of the configuration parameters in our testbed: Autoconfiguration is enabled, Forwarding is enabled only on the IPv6 routers and not on the MN, the MTU is 1500 bytes and the backoff timers for router solicitations, BU and Home / Co Test Initialization are set to the default values. The parameters on the right hand side are those changed in our experimental evaluation. The values in brackets are the default values.

Table 2 MIPv6 Testbed Parameters

Parameter	Value
mtu	1500
autoconf	1
forwarding	1 (MN=0)
Home / Co Test Init	1
Rt. Solicitation	1
BU	1.5

Parameter	Value
MinRouterAdv	0.03 - 1s (0.5)
MaxRouterAdv	0.07 - 1.5s (1.5)
DAD	On / Off (On)
Beacon Interval	50-100 ms (100)

4.2 Results

Based on the default values of Table 2, the total MIPv6 handover latency recorded in our setup was D_{MIPv6} = 3.68 sec. This delay is broken down as follows: $D_{L2}+D_{RD}$[1]=0.612s, D_{DAD} = 1.414s and D_{REG}= 1.651s

The major share in the handover latency goes to D_{REG} as expected. The BU and registration functions account for 45% of the total delay. The DAD function takes another 38% and the movement detection (including the L2 delay) accounts for the rest 17%. Compared to values recorded or computed by other researchers, the outcome of our measurements is higher by about one second. We believe that this is caused by slightly higher delays in all components, but especially in D_{REG} which contains the most transitions through the IPv6 cloud. It is important to mention that, to the best of our knowledge, no other work has taken this feature into account. Similar evaluations are made with the visited network directly connected to the home network and sometimes the visited/foreign router directly connected to a different interface of the HA.

4.2.1 Duplicate Address Detection

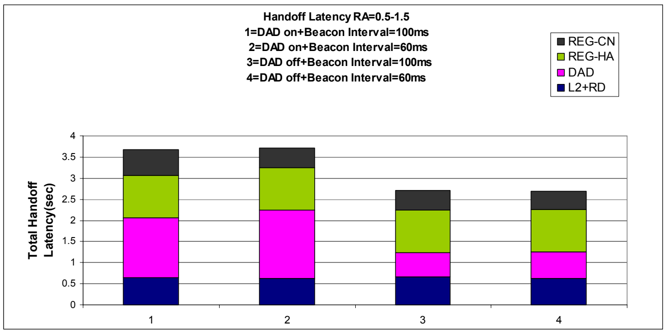

Figure 3 DAD component contribution to the MIPv6 Handover Latency

In Figure 3 we observe that when the DAD function is switched off the respective delay is reduced by almost 1sec which is the default timer value for this operation. In

[1] Due to the setup configuration, it was not possible to obtain separate values for D_{RD} and D_{L2}.

reality D_{DAD} is reduced on average by 0.835 and 0.979 sec for L2 wireless beacon intervals of 100ms and 60ms respectively.

Based on these results we can safely conclude that if we operate in a controlled environment where the probability of duplicate addresses is negligible, then we can discard the DAD function and achieve a decrease in the total MIPv6 delay of at most one second.

4.2.2 Router Advertisement Interval and Beacon Interval

The discovery of a new router is affected by two factors: the probe/scanning delay on L2 and the router discovery on L3. In this section we will examine the effect of the latter on the overall and component latencies in MIPv6.

Typical values for the min and max router advertisements are of the order of a few seconds in wired IPv6 networks. In MIPv6 these values are usually lowered and are usually centered around 1sec. We have started with our default values of 0.5 – 1.5 sec and lowered the intervals down to 0.03-0.07 sec.

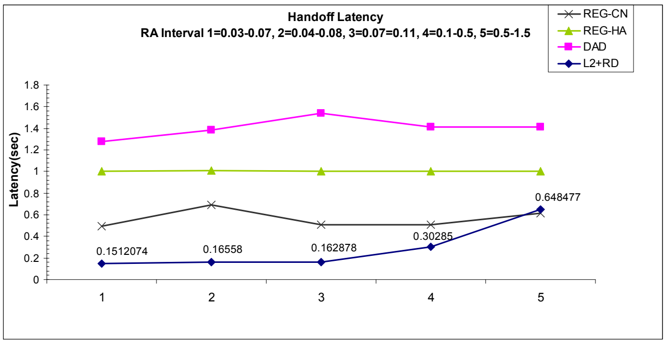

Figure 4. Router Advertisement Interval effect on handover component latencies.

In Figure 4 we recognize that the change in the RA interval only affects the combined $D_{L2} + D_{RD}$. We observe a 200-400% reduction in the corresponding delay between the default and lower values. This dramatic reduction is significant in terms of the handover delay, but may have other repercussions in the network which are not visible in these results. In this work we cannot comment yet on the effect of a lower interval on the overall network traffic and on the processing load of the routers.

Even though the change in RA intervals has reduced by a significant percentage the router discovery time, the effect on the overall handover delay is not as dramatic as it can be seen from Figure 5. This is expected since the contribution of the D_{RD} delay to the total is only 17%.

Based on the standards MaxRouterAdv needs to be at least three times larger than the MinRouterAdv interval. In Figure 6 we adjust the ranges using MinRouterAdvintervals between 0.1 and 0.5sec. The result is again a 300% reduction in an almost linear manner. The figure is appended with plots of different Beacon Intervals, which do not provide any insight to their importance.

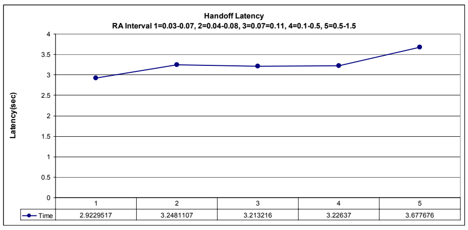

Figure 5. Router Advertisement Interval effect on overall handover latency.

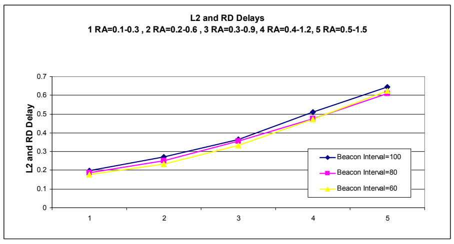

Figure 6. Router Advertisement and Beacon Interval

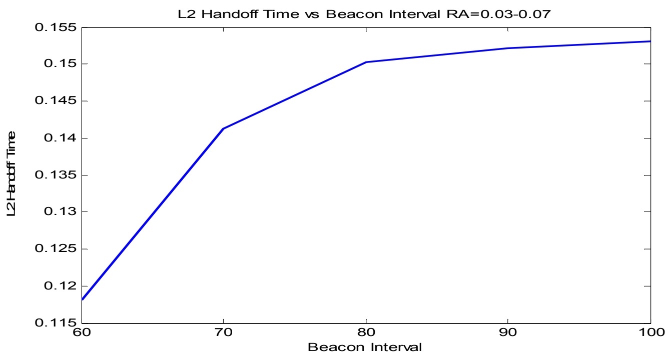

Figure 7. L2 delay vs Beacon Interval

The Wireless Beacon Interval does make a change in the delay of the lower layer. Based on Figure 7 we see that a reduction of the Beacon Interval from 100ms to 60ms corresponds to an almost equal reduction in the L2 delay, with the steepest drop at 70 ms.

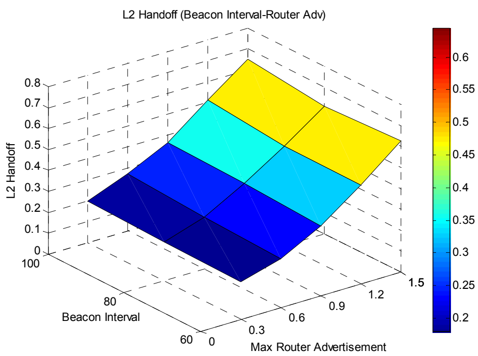

Figure 8. L2 handover delay vs Router Advertisement and Beacon interval

The combined contribution of RA interval and Beacon interval on lower layer delays is illustrated in Figure 8.

5 Conclusions and Future Work

The existing L2 handoff schemes in technologies such as IEEE 802.11, 3GPP, and 3GPP2 do not consider the L3 handoff. In addition the L3 handoff like Mobile IPv6 does not consider the L2 handoff. Although the HMIPv6 and FMIPv6 protocols and their extensions can reduce the L3 handoff latency, they cannot reduce the L2 handoff latency. In these networks, the L2 handoff scheme in newly defined wireless access network technologies should be designed carefully and should consider the L3 handoff scheme to reduce the handoff latency.

In this paper we have examined the handover process of Mobile IPv6 in a real wireless testbed, based on IEEE 802.11b. This work has performed a detailed decomposition and analysis of the handover delay, with a focus on the pre-registration phase.

Our work is important because it provides real-implementation results for significant parts of the handover process which cannot be obtained through simulation. The testbed setup is considered to reference a very realistic topology and all the results were obtained with no optimizations on the L3 part of the implementations used. Our results illustrate how the link layer detection, the movement detection, and the address autoconfiguration parts of the handover can be reduced.

In addition, the outcome of this work can be utilized in recognizing further items for future research. Our future work will include the evaluation of the effect of the identified changes to the overall performance of the network. It also remains to be seen if the same delay reductions are present when the number of users in the network increases.

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