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# NETWORK-BASED MOBILITY WITH PROXY MOBILE IPV6

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## ABSTRACT

This paper presents a handover delay analysis of network-based handovers with Proxy Mobile IPv6 and compares its performance to Mobile IPv6. Recommendations are given to avoid excessive handover delays due to timer and configuration mechanisms in the IPv6 specification. Furthermore, extensions are proposed to make Proxy Mobile IPv6 applicable to make-before-break handovers in multi-interface scenarios. Finally, by leveraging functions of a Multi-Radio Resource Management, handover execution can be adapted to the actual radio conditions on the terminal.

## I. INTRODUCTION

The future landscape of mobile communication networks will consist of heterogeneous radio access technologies, different kinds of mobile terminal equipment and will entail a wide range of applications. In such networks, there is a need for a sophisticated resource and mobility management to decide which radio access technology shall be used to serve a particular mobile terminal and to be able to cope with mobility across different radio technologies in a non-disruptive way [1].

In the past, the focus of mobility management research for IP-based networks was on client-based solutions such as Mobile IP [2]. While Mobile IP is still considered to be the solution for global mobility across administrative domains, network-based approaches have gained momentum for localized mobility management within an operator's network. The IETF NETLMM working group [3] is developing such a network-based localized mobility management solution and has recently decided to adopt a proposal called Proxy Mobile IPv6 (PMIPv6) as the basis for further development [4]. One application is expected in future 3GPP networks, where PMIPv6 is being actively discussed to handle mobility between Evolved RAN and the GERAN/UTRAN systems [5, 6]. However, the current PMIPv6 specification does not cover handovers involving multiple interfaces, as for example from a cellular system to a WLAN 3GPP IP Access network [7].

In this article, the performance of PMIPv6 is examined and compared to Mobile IPv6 (MIPv6). An extension to PMIPv6 is proposed and evaluated, which allows for efficient handover execution on terminals with multiple interfaces. We further suggest an integration with a Multi-Radio Resource Management, in order to optimize handover decision and to exert a higher degree of control over the handover sequence.

The remainder of this paper is structured as follows: Section II. explains PMIPv6 and provides a qualitative comparison to MIPv6. In section III., the performance is analyzed for handovers involving a single interface only. Section IV. extends this analysis towards handovers over multiple interfaces.

## II. PROXY MOBILE IPV6

At the time of writing, there were two PMIPv6 drafts available [4, 8]. This analysis is based on PMIPv6 as specified in [4], which has recently become official WG document of the NETLMM WG. Contrary to the PMIPv6 specification, our analysis only covers stateless address autoconfiguration [9].

### A. Mode of Operation

PMIPv6 is based on MIPv6 signaling messages [2]. A basic network scenario showing the principal elements involved in PMIPv6 signaling is depicted in the lower part of Fig. 1. The Local Mobility Anchor (LMA) is a modified MIPv6 Home Agent (HA), which maintains the address bindings for mobile nodes (MN) in the PMIP domain. The Mobile Access Gateway (MAG) is an additional device, which takes part in mobility-related signaling on behalf of the mobile node. Mobile nodes themselves are not required to provide any additional function compared to basic IPv6 specifications [9, 10].

The PMIPv6 specification assumes a home network prefix to be exclusively assigned to each MN. The MAG imitates the MN's home network, such that the MN always sees its home prefix and always configures the same address, irrespective of its current location within the PMIP domain. By this mechanism, mobility can effectively be hidden from the terminal. While it is allowed that multiple MNs share the same address prefix, this comes with the restriction that stateless address autoconfiguration is not allowed anymore. Therefore, our analysis is restricted to the per-MN prefix case.

Fig. 2 shows the message flow for network attachment and handover procedures. Whenever an MN attempts to enter the operator's network, it performs a layer 2 network entry procedure, during which it is authenticated by a AAA server in the operator's network. If the MN is authorized to receive mobility services, the MAG retrieves the MN's profile from a repository, which contains the MN's home network prefix and permitted address configuration modes. After reception of this profile, the MAG sends a Proxy Binding Update to the LMA, containing the MN identifier and its home network prefix. The MAG's IP address is set as the Care-Of-Address. The LMA sets up a bind-

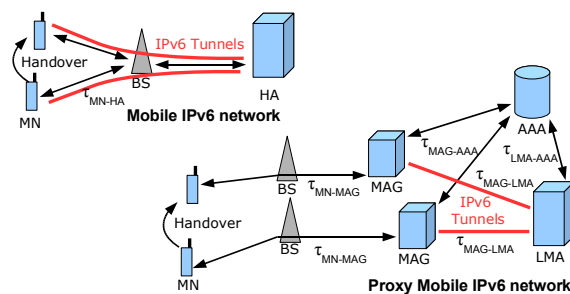


Figure 1: MIPv6 and PMIPv6 scenario

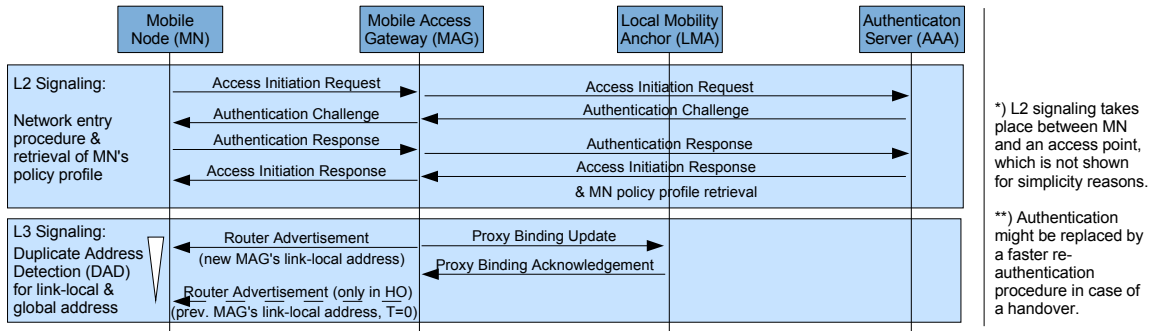


Figure 2: Proxy Mobile IPv6 bootstrapping and handover sequence

ing for the MN’s home network prefix to the MAG’s IP address. To emulate the MN’s home network, the MAG starts sending Router Advertisements (RA) advertising the MN’s home network prefix. Alternatively, the MN might have solicited an RA by sending a Router Solicitation message.

After having completed access initiation, the MN starts configuring a link-local IP address with an interface identifier which is either derived from the interface’s link layer address, or generated randomly according to [11]. The MN also configures its global address according to the home prefix extracted from the RA. According to the IPv6 specification, the MN then performs Duplicate Address Detection (DAD) for both, link-local and global address [9].

The LMA sends a Proxy Binding Acknowledgment to the MAG, once it has created a routing table entry for the MN’s home prefix towards the Mobile Access Gateway. After reception of the Proxy Binding Acknowledgment, the MAG completes the bidirectional tunnel establishment and configures its routing table accordingly. All traffic from and to the MN can now be forwarded through the tunnel between MAG and LMA.

When the MN roams through the network, the procedure as depicted in Fig. 2 takes place every time a handover occurs. Whether or not the MN performs DAD for its addresses in the handover case depends on several factors and will be further discussed in section III. Because the respective MAG emulates the MN’s home link, the MN continuously detects its home network and keeps its global address. However, the MN will detect that the link-local address of the router sending the RA messages has changed and interpretes this as a change of the default router on this link. IPv6 procedures require the MN to add a new entry for this router to its Default Router List [10]. The old entry to the previous MAG will still be used until it eventually times out, or is removed after Neighbor Unreachability Detection, which has proven that the old router is no longer reachable. For handover performance, it is crucial that the MN quickly times out the old router entry. This can be achieved by either adjusting the respective timers in the MN’s IPv6 stack, or by requiring the new MAG to send an additional RA with the link-local address set to the previous MAG and with a Router Lifetime field set to zero (see Fig. 2) [4].

**B. Comparison to Mobile IPv6**

A MIPv6 handover consists of router discovery, movement detection and address configuration. While router discovery also exists for PMIPv6, it does not require movement detection.

There is also no need to configure a new address, given that the advertised prefix does not change. If the mobile can be prevented from going into an unnecessary DAD, handover latency can be greatly reduced as compared to MIPv6.

Another advantage of PMIPv6 is the support of both MIP-capable and non-MIP-capable devices, which largely reduces deployment problems for mobility services. It also helps in reducing security issues as trust relationships are only required between MAG and LMA. For mobile terminals, PMIPv6 fully relies on authentication procedures of the radio access network.

As illustrated in Fig. 1, IPsec tunnels are set up only between LMA and MAG, avoiding tunneling overhead for data sent over the air interface. Furthermore, tunnels can be shared by several MNs, further reducing overhead on the link between MAG and LMA. Especially in non-3GPP access scenarios, such as in I-WLAN [7], tunneling overhead introduced by MIPv6 implying two stacked IPsec tunnels is considerable.

**III. HANDOVER IN SINGLE INTERFACE CASE**

The PMIPv6 specification is targeted towards handovers performed on a single interface only. Depending on various design factors and on the radio technology involved, handover delay can largely vary. In this section, handover delay of PMIPv6 handovers *on a single interface* is analyzed and compared to the delay of MIPv6 handovers. In the following,  $\tau_*$  represents total transmission time and  $t_{p,*}$  reflects the respective processing delays, as it can be seen from Table 1 and Fig. 1.

**A. Handover Delay Analysis for Mobile IPv6**

For handover performance of MIPv6, it is referred to the analysis in [12]. With the time required for L2 access,  $T_{L2}$ , the back-off time for Neighbor Solicitation,  $t_{Wait,NS}$ , and the duration of DAD,  $t_{DAD}$ , the overall handover delay without considering route optimization can be given to:

$$T_{HO,MIPv6,DAD} = T_{L2} + t_{Wait,NS} + t_{DAD} + T_{BU} \quad (1)$$

where  $T_{BU}$  constitutes the time for the Binding Update:

$$T_{BU} = 2 \cdot \tau_{MN-HA} + t_{p,HA} \quad (2)$$

In case of a MN performing Optimistic DAD [13], the handover delay is reduced. In the following equation,  $t_{MD}$  represents the Movement Detection delay, which in (1) was hidden by the time required for NS and DAD:

$$T_{HO,MIPv6,oDAD} = T_{L2} + t_{MD} + T_{BU} \quad (3)$$

Table 1: Symbols and parameters

Description	Symbol	Value
Transmission time MN-MAG	$\tau_{MN-MAG}$	1 ms
Transmission time MAG-LMA	$\tau_{MAG-LMA}$	10 ms
Transmission time MAG-AAA	$\tau_{MAG-AAA}$	10 ms
Transmission time MN-HA	$\tau_{MN-HA}$	11 ms
Processing time AAA	$t_{p,AAA}$	1 ms - 5 ms
Processing time LMA	$t_{p,LMA}$	1 ms - 5 ms
Processing time HA	$t_{p,HA}$	1 ms - 5 ms
Backoff Router Solicitation	$t_{Wait,RS}$	0 s - 1 s
Backoff Neighbor Solicitation	$t_{Wait,NS}$	0 s - 1 s
Backoff solicited RA	$t_{Wait,sRA}$	0 s - 0.5 s
Backoff unsolicited RA	$t_{Wait,uRA}$	30 ms - 70 ms
Duplicate Address Detection	$t_{DAD}$	1 s
Movement Detection	$t_{MD}$	200 ms - 270 ms

### B. Handover Delay Analysis for Proxy Mobile IPv6

The following analysis distinguishes between different handover cases for solicited and unsolicited RAs, as well as between handovers with and without DAD. In all cases, the overall handover delay  $T_{HO}$  consists of (1) the time  $T_{L2}$  for access initiation, (2) the time  $T_{sRA}$ , respectively  $T_{uRA}$  for router and prefix discovery, (3) the time  $T_{DAD}$  for address configuration and (4) the time  $T_{PBU}$  required for the Proxy Binding Update and the routing table update of the MN. The first part,  $T_{L2}$ , can be expressed as:

$$T_{L2} = 4 \cdot \tau_{MN-MAG} + 4 \cdot \tau_{MAG-AAA} + 2 \cdot t_{p,AAA}. \quad (4)$$

For router or prefix discovery, it has to be distinguished between solicited and unsolicited RAs. In the case of a MN actively soliciting a RA, the transmission of the Router Solicitation has to be delayed for a random time  $t_{Wait,RS}$  between 0 and 1s, given that it is the first message to be sent on this interface [10]. The RA sent in response is also delayed by a random time  $t_{Wait,sRA}$  between 0 and 0.5s. The time  $T_{sRA}$  for reception of the first RA is thus:

$$T_{sRA} = t_{Wait,RS} + t_{Wait,sRA} + 2 \cdot \tau_{MN-MAG} \quad (5)$$

The delay introduced by these back-off timers can be substantial. However, adjusting these timer values is difficult, as this would modify the default behavior of the MN's IPv6 stack and might create problems when the MN roams outside the PMIPv6 domain. Instead of solicited RAs, we suggest to configure the MAG such that unsolicited RAs are sent. Unlike for MIPv6, unsolicited RAs don't need to be sent at a high rate, given that there is no movement detection. An interval time of several seconds is considered sufficient. However, the first RA issued by the MAG should be sent as soon as the MN's profile has been received. Because the RA is destined towards a single MN only, a back-off timer is not strictly necessary, but adding a small delay is still recommended to leave enough time for the MN to complete its L2 configuration and to ensure that the RA can actually be received. We choose this initial delay  $t_{Wait,uRA}$  to 30-70ms. An unsolicited RA is then received by the MN after  $T_{uRA} = t_{Wait,uRA}$ .

Whether the MN initiates address configuration after having received the RA message depends on the underlying link layer

technology, the way the link layer handover was carried out and whether the MN is DnAv6-capable [14]. For a handover from one WLAN cell to another, the interface only needs to be tuned to a new ESSID, which can be fully transparent to the IP layer. However, for a handover from UTRAN to Evolved RAN, the disruption is much more severe, given that the radio interface needs to be shut down and be reconfigured. Such an interface reinitialization is probably not transparent to the IP layer anymore. An IPv6 host therefore initiates a new address configuration procedure, which leads to a DAD being triggered for all unicast addresses on this interface. Given that the uniqueness of the global address in PMIPv6 is guaranteed by the per-MN prefix model and further given that the link between MN and MAG is a point-to-point link, there is actually no need to perform DAD on the home address. For the link-local address, a collision with the link-local address of the MAG might occur when the MN changes its point of attachment. Anyhow, a DAD procedure for the link-local address does not affect communication over the home address and thus has no impact on handover delay. The time required to perform DAD on an address is  $t_{DAD}$ , to which an additional back-off timer  $t_{Wait,NS}$  needs to be added if the Neighbor Solicitation is the first message to be sent on this link. An alternative is in requiring MNs to perform Optimistic DAD, which allows addresses to be used while configuration is still ongoing [13]. However, Optimistic DAD cannot be expected to be supported by every MN.

The last contribution to the overall handover delay is the time needed for the Proxy Binding Update and to remove stale entries from the MN's Default Router List. As it has been outlined in section II. the latter can be enforced by sending another RA message with the link local address set to the previous MAG's address and with the Router Lifetime field set to zero. The PBU is sent by the MAG  $\tau_{MN-MAG}$  before the MN receives the Access Initiation Response. From the MN's point of view, the time required for the PBU and the subsequent RA to flush the MN's routing table then is:

$$T_{PBU} = 2 \cdot \tau_{MAG-LMA} + t_{p,LMA} \quad (6)$$

To sum up, the overall handover delay for PMIPv6 handovers in case of solicited RAs, DAD for the global address and flushing stale routing table entries can be given to:

$$T_{HO,sRA,DAD} = T_{L2} + \max\{T_{sRA} + t_{DAD}; T_{PBU}\} \quad (7)$$

In case of unsolicited RAs and DAD, this changes to:

$$T_{HO,uRA,DAD} = T_{L2} + \max\{T_{uRA} + t_{Wait,NS} + t_{DAD}; T_{PBU}\} \quad (8)$$

In the cases without DAD for the global address, handover delay in uplink and downlink direction have to be distinguished, given that packets can already be received although the routing table on the MN is not yet properly configured. For solicited RAs, the overall delay in uplink direction is:

$$T_{HO,sRA,noDAD,UL} = T_{L2} + \max\{T_{sRA}; T_{PBU}\} \quad (9)$$

In downlink direction, the total interruption time is:

$$T_{HO,uRA,noDAD,DL} = T_{L2} + T_{PBU} \quad (10)$$

For the unsolicited RA case,  $T_{sRA}$  in equations (9) and (10) just need to be replaced by the expression for  $T_{uRA}$ .

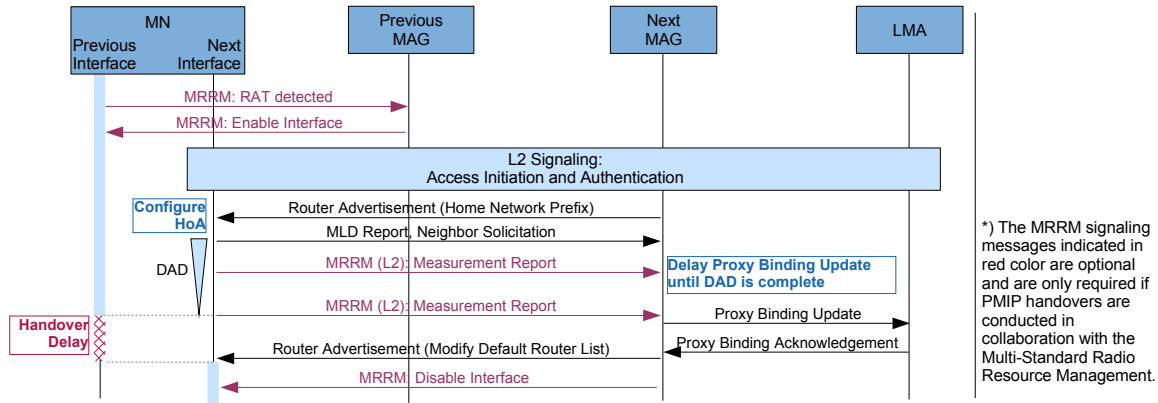


Figure 3: Proxy Mobile IPv6 extension for handover with multiple interfaces

C. Results and Comparison

The resulting handover latencies in uplink and downlink direction for MIPv6 and PMIPv6 according to the parametrization in Table 1 are depicted in Fig. 4. It can be seen that timers within the IPv6 specification play a significant role with respect to handover delay. For PMIPv6, avoiding DAD or doing Optimistic DAD and using unsolicited RAs yields a performance gain of one order of magnitude. Considering ideal configuration as in the two rightmost scenarios, PMIPv6 performs better due to the Movement Detection delays in MIPv6.

IV. HANDOVER IN MULTIPLE INTERFACES CASE

During vertical handovers, the delay can be much reduced, when the MN can use the old and the new interfaces in parallel. This allows to perform make-before-break (MBB) handovers, where the address configuration can be done while the old interface is still in use. This is particularly important under the constraint that IPv6 specifications require DAD for the home address on the new interface, which leads to substantial delays as it has been shown in section III.

A. Make-Before-Break Handover in Mobile IPv6

In MIPv6, MBB handovers avoid the latency of DAD. Assuming further that Movement Detection can be replaced by link-layer triggers, the handover delay corresponds to the time needed to do a binding update on the new interface:

$$T_{HO,MIPv6,MBB} = 2 \cdot \tau_{MN-HA} + t_{p,HA} \quad (11)$$

In [12], it has been proposed to send the binding update from the old interface, which is not fully conform to [2], but has the potential to further reduce handover delay.

B. PMIPv6 Extension to Multiple Interfaces

The PMIPv6 specification does not deal with handovers involving multiple radio access technologies. Obviously, such a vertical handover could be performed in a break-before-make manner. However, this would not allow to leverage the benefits of having two operational interfaces in parallel.

In standard PMIPv6, the Proxy Binding Update would be performed too early for a proper MBB handover, given that the PBU is triggered by the access initiation on the new interface.

The message flow in Fig. 3 depicts the PMIPv6 signaling in this multi-interface case. After the MN has detected a new radio access network, the interface is enabled and the network entry procedure is started. Meanwhile, the previous interface can still be used for communication. The next MAG then sends a RA containing the MN’s home network prefix, which leads to stateless address autoconfiguration being started on the MN.

The same global address has to be configured on the new interface as the one used on the old interface. This implies that the home address cannot be built from a link-layer identifier as suggested in [4], but the suffix has to be manually configured. In this case, the specification does not allow to use Optimistic DAD [13]. The new interface will thus be blocked for  $t_{DAD}$ , plus an additional back-off time  $t_{Wait,NS}$ .

Here, sending the PBU has to be delayed until address configuration is complete, which is different from the standard PMIPv6 procedure. Otherwise, the PBU would immediately lead to tunnel establishment from the LMA towards the new MAG and the LMA would thus remove the routing table entry to the old MAG, which effectively tears down connectivity on the old link. The problem here is for the MAG to determine the end of the MN’s address configuration procedure. There are two possibilities to solve this problem: The first solution we propose is to start a timer on the MAG for  $t_{DAD}$  seconds, immediately after the Neighbor Solicitation from the MN has been received. When the timer expires, DAD on the MN can be expected to be complete and the PBU can be sent to the LMA.

The other more advanced solution we propose is to complement PMIPv6 by a Multi-Radio Resource Management (MRRM) [15]. The MRRM consists of measurement and mobility control components in the MN and another control unit in the operator’s network, e.g. on the MAG, between which signaling messages are exchanged (see Fig. 3). For a detailed description of MRRM, it is referred to [1, 15]. The network side MRRM continuously receives measurements on candidate radio access networks and may command the MN to activate a certain interface. Once the network entry procedures are complete, the new MAG starts sending router advertisements, but not yet the PBU. The MN now sends measurement reports to the new MAG. Only after the MN has finalized DAD, PBU is performed and a RA with lifetime zero for the previous default router is sent to the MN to remove the old route from the MN’s Default Router List. The correct timing in this case can be ac-

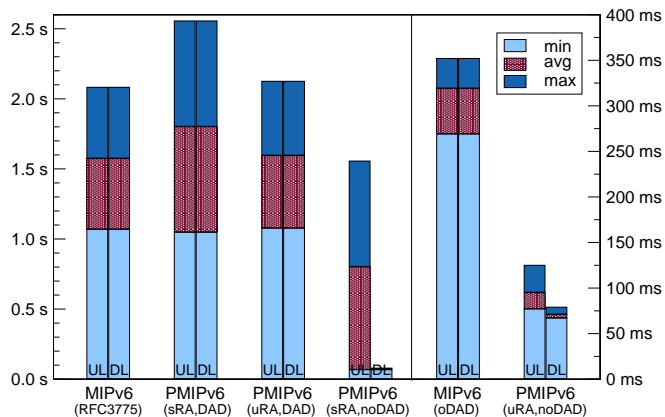


Figure 4: Handover latencies in single interface case

accomplished by indicating the completion of DAD in one of the measurement reports. The MRRM scheme further allows to monitor the current signal quality levels on both interfaces and thus deduce the optimum time to switch to the new interface. The measurement reports are either sent as L2 frames over the new link, or they are relayed by the previous MAG.

The resulting overall handover delay in the uplink direction for make-before-break handovers with PMIPv6 for either of the proposed extensions is then given by the time from processing of the PBU in the LMA until the update of the MN's Default Router List:

$$T_{HO,MBB,UL} = T_{PBU} + 2 \cdot \tau_{MN-MAG} \quad (12)$$

In the downlink direction, there is no interruption at all, as long as the path to the LMA via the old MAG is equal to or shorter than the transmission time over the new MAG.

### C. Results for Make-Before-Break handovers

The resulting handover delays for MBB handovers for the scenario given by Fig. 1 and Table 1 are shown in Fig. 5. It is again distinguished between interruption time in downlink and in uplink direction. It can be seen that the handover delays are significantly reduced compared to the single interface case and effectively correspond to the time required for the binding update. The PMIPv6 handover delay now equals a MBB handover in MIPv6.

## V. CONCLUSION

We have analyzed the performance of PMIPv6 for network-based handovers on a single interface and compared the results to terminal-based handovers with MIPv6. For a single interface, Duplicate Address Detection dominates the handover latency and MIPv6 and PMIPv6 perform similarly. To avoid excessive delays from back-off timers in the IPv6 specification, a PMIPv6 implementation should use unsolicited RAs and replace DAD by Optimistic DAD for non-DNAv6 capable hosts. As stated in [4], actions have to be taken to quickly age out stale routing table entries, otherwise communication in the uplink direction stalls until Neighbor Unreachability Detection completes. With these optimizations, PMIPv6 handover latency is around 100 ms, which is three times faster than MIPv6.

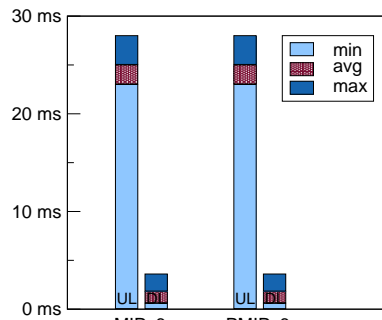


Figure 5: Handover latencies in multiple interfaces case

For the multiple interfaces case, the standard PMIPv6 procedure needs to be interrupted in order to delay the Proxy Binding Update until DAD on the new interface is complete. This can be achieved using a timer on the MAG. PMIPv6 latency then equals the latency of MBB handovers in MIPv6.

We have further proposed a combination of PMIPv6 with Multi-Standard Radio Resource Management. MRRM provides a mean to detect and choose the best instant in time to switch to the new interface and allows operators to exert a higher degree of control over the handover sequence than it is the case in MIPv6 or standard PMIPv6.

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