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Performance evaluation of Mobile IPv6 handover

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Abstract

This paper gives a performance evaluation of Mobile IPv6 handover. Primary focus is placed on Layer 3 (L3) factors which cause handover delay. Several distinct scenarios were worked out in order to make those factors clear. With different combination of scenarios, 3 experiments were made. The results showed that the handover delay varies in different scenario. In the experiment with different type of Correspondent Node, impact of the Return Routability procedure to the handover delay became clear. It was also confirmed that the proportion of Duplication Address Detection (DAD) process to the handover delay is considerably large.

1. Introduction

This paper aims to evaluate handover performance of Mobile IPv6 protocol [1] focusing on end-to-end packet loss when the Mobile Node (MN) is communicating with Correspondent Node (CN). We simply tried to examine how well the base specification of the Mobile IPv6 performs handover. We intend that the experimental result given in this paper to become guidance information on Mobile IPv6 operation. And we also regard this work as a preliminary study of further improvements in the Mobile IPv6 such as enhancement for performing fast handover.

Mobile IPv6 is under process of becoming a standard going through intense discussions in the Mobile IP working group of IETF [2]. There is high demand for the Mobile IPv6 to become a standard and start its commercial services. During the last several revisions of the draft, there have been significant changes made in its base design due to security considerations. Return Routability (RR) procedure was added to the base specification to authorize Binding Update message sent to the CN. Some of these modifications may affect protocol performance since the number of signaling has been increased. This made us motivated to comprehend handover performance of Mobile IPv6 based on the experimental result.

2. Experimental system

In this section, we will give an introduction to the experimental system. Brief information about Mobile IPv6 will be given followed by the experimental system overview.

2.1. Introduction to Mobile IPv6 implementation

We have developed Mobile IPv6 protocol on NetBSD operating system [4]. Most of the functionalities are developed inside kernel as an extension to the original IPv6 protocol stack. It is a prototype implementation of Mobile IPv6 and conforms to the version 19 of the specification[3]. The implementation has gone through an interoperability test in January 2003 [3]. Relatively high level of interoperability has been confirmed with other implementations.

IPsec protection for the BU/BA exchanged between MN-HA which is mandated in the specification is omitted for simplicity in the experiment. Overhead of IPsec protection should also be examined but it is out of focus in this paper. Movement detection algorithm of the MN is rather simplified in our implementation. The MN detects movement when its default router and available care-of address (CoA) change. With respect to router behavior there is a small modification to the Router Advertisement mechanism used in our experiment. Since the movement detection relies on Router Solicitation/Advertisement exchange in our case, it will be influenced

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[3] The latest specification of the Mobile IPv6 is version 20, however this work has been started in prior to the release of the current draft.

by behavior of the router sending Router Advertisements. The Neighbor Discovery Protocol (NDP) [5] specifies that router should calculate random delay when it receives Router Solicitation in order to avoid collision. There is also a constraint in sending multicast Router Advertisement, which should be rate limited. Since our focus is on delay factors mainly due to Mobile IPv6 protocol itself, we simplified behavior of the router. Modification to the Router Advertisement daemon program[4] was made in a way that it immediately sends Router Advertisement responding to Router Solicitation message.

2.2. Experimental system overview

Figure 1 shows the network topology of the experimental system. There are 4 Ethernet LANs, Home Network, Foreign Network 1, Foreign Network 2 and Foreign Network 3. We have introduced an intelligent switching hub which has port-based VLAN functionality. The switching hub can be managed by SNMP messages when making changes on its configuration. Based on the request, the switching hub creates association of ports. MN sends a request to the switching hub to simulate L2 handover to certain networks, which can be regarded as handover initiation. Thus MN can move around among Home Network, Foreign Network 1, 2, and 3. The intension of introducing the port-based VLAN technology is to make handover easy and measurable. Handover measurement cannot be done precisely with manual operation.

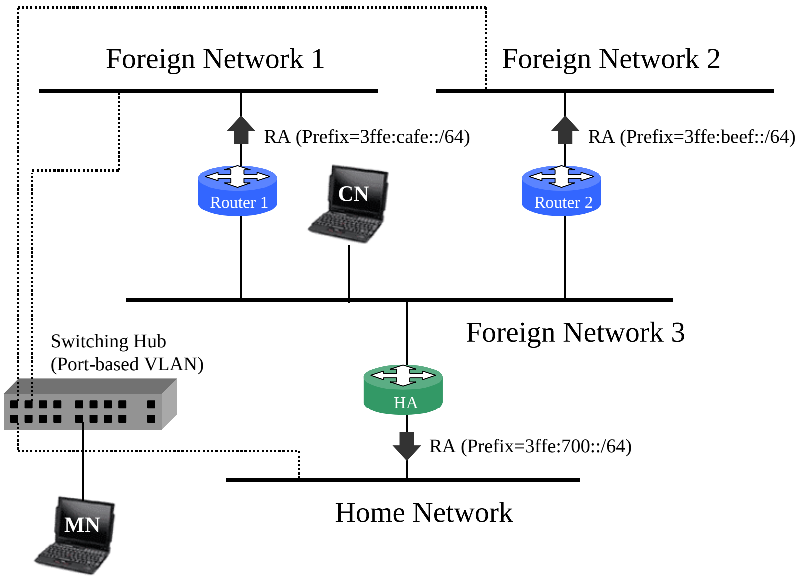

Figure 1: Network topology of the experimental system

Router 1 and Router 2 advertises variant prefix to the Foreign Network 1 and Foreign Network 2 respectively carried by the Router Advertisement message. Similarly the HA advertises home prefix to the Home Network carried by Router Advertisement message. Router Advertisement sent by the Home Agent indicates that the router is serving Home Agent functionality of Mobile IPv6. Foreign Network 1 and Foreign Network 2 both consist of completely same sets of switching hub and router. Therefore network latency among each other is considered to be symmetric. Correspondent Node is a stationary node which is attached to the Foreign Network 3. The network is designed with an intention that network latency between the CN and MN attached to either network becomes nearly equal, so that end-to-end delay between MN-CN will not be affected by the location of the MN.

2.3. Handover sequence

Figure 2 shows flow of the MN performing handover in our experimental system. When the MN performs handover, it first sends a SNMP request message to the switching hub. This is a request for the switching hub to make change in its port association. When the port association is changed, the MN loses L2 connectivity to the network. Then the switching hub sends a SNMP response to the MN. After MN detects completion of L2

[4] rtadvd (8) – router advertisement daemon of NetBSD-1.5.2 Release

handover, it immediately sends Router Solicitation to the visited network, and will receive RA from the router. Duration between the time MN sends SNMP request and the time MN receives Router Advertisement is described as *T1* in Figure 2. *T1* includes disruption of L2 connectivity and round-trip time between the MN and the router for exchange of Router Solicitation/Advertisement. Disruption of the L2 connectivity is colored in dark gray in the figure and it is not measurable due to mechanism of the switching hub. However, experience shows that it takes about 180-200 milliseconds for the switching hub to complete port switching in most cases. The MN detects movement when it receives Router Advertisement from the router and it also configures CoA associated with the prefix advertised by the router. When the binding at the HA is updated, the HA starts tunneling packets to the MN's CoA. Consequently MN starts receiving packets from the CN. This is an indication that MN obtains L3 connectivity to the network. *T2* represents a period in which MN drops inbound/outbound packets from/to the CN. Difference between *T2* and *T1* should include delay caused by L3 related factors. We regard this value as a handover delay in this paper. During this period, MN should complete movement detection, CoA assignment and binding registration to acquire L3 connectivity to the network.

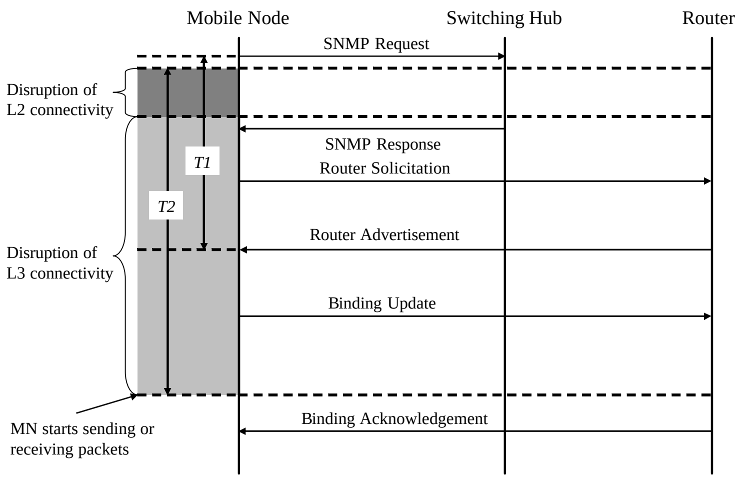

Figure 2: Handover sequence

2.4. Method for measuring handover delay

In the experiment, handover delay is derived from the number of packet loss during the handover. The CN (or the MN) keeps sending UDP packets to the MN (or the CN) at 20 milliseconds of regular intervals. UDP packet contains sequence number and timestamp to keep track of packet flow. For instance, if the receiver drops 10 sequential packets, it means that there should have had been at least 180 milliseconds disruption during the handover. Since we put primary focus on delay derived from L3 factors, we tried to get rid of delay derived from L1 and L2 factors. Therefore we got rid of delay caused by loss of L2 connectivity and a time required for exchanging Router Solicitation/Advertisement.

3. Contributing factors in handover delay

In this section, categorization of the contributing factors in handover delay is discussed. Handover delay is mainly due to the loss of MN's connectivity to the network. As stated already this paper focuses on connectivity at the network layer (L3). We categorized L3 factors into three: CoA availability, link layer address resolution, and routing information consistency. Description of each categorized factors is given below.

I. CoA availability

When the MN visits foreign network, it should start using new CoA at the network. In Mobile IPv6, source address of the packet sent by the MN that is away from home must be its CoA. Since CoA is topologically correct IPv6 address, this prevents the packets from being dropped by the ingress filtering. Thus when the MN visits another network, it must assign new IPv6 address to its interface and use it as source address in the IPv6 header when sending packet. IPv6 specifies several ways for nodes to assign IP address to their interfaces and Mobile IPv6 MN can choose any from those alternatives. This is rather implementation or operation dependent issue but in many cases MN will be affected by DAD mechanism when it starts using new CoA. IPv6 specification requires IPv6 node to verify uniqueness of the IPv6 address when the node newly assigns the address to its interface [6]. CoA availability will affect both inbound and outbound traffic handled by the MN.

II. Link layer address resolution

In Mobile IP, the MN frequently moves from one network to another. Upon movement, MN should delete its neighbor cache since it is no more valid after the movement. At least the MN needs to have default router's link layer address in its neighbor cache to start sending packets. Similarly the router on the visited network needs to be aware of MN's link layer address so that it can forward packets destined to the MN. Link layer address resolution is unidirectional factor which may affect MN's inbound and outbound traffic separately.

III. Routing information consistency

When the MN moves to different network and its CoA changes, it must update corresponding binding at the HA and possibly at the CN. If the peer node sends packet towards MN's home address via HA, duration between the MN's movement and the time when BU arrives at the HA will become disruption of L3 connectivity. During the period, packets destined to the MN's home address will be misrouted by the HA to the previous CoA and lost. If there is binding at the CN, MN must update it after movement. Otherwise, CN will keep sending packets towards MN's previous CoA with route optimized manner. This factor is directly influenced by signaling mechanism of Mobile IPv6 protocol including authorization mechanism such as RR procedure. It should also be noted that this factor is affected by the network latency between the MN and the HA or the CN. Routing information consistency affects separately inbound and outbound traffic handled by the MN. Inbound traffic will come under the influence of inconsistency of routing information while outbound will not be affected by the inconsistency.

4. Experimental Result and Analysis

In this section, experimental results of handover delay are presented. We analyzed the results in line with contributing factors given in Section 3. Section 4.1 gives scenarios in each experiment which makes it possible to extract delay due to different factors. 3 experiments and their results, analysis are given in Section 4.2, 4.3, and 4.4.

4.1. Experiment scenarios

In order to observe handover precisely, we have worked out several scenarios in handover experiment. We prepared following 4 scenarios. By trying combination of the each scenario, we can examine L3 factors which influence handover delay.

A) Type of movement

When the MN attached to Home Network moves to a different network, we call this movement "Home-to-Foreign" movement. In Figure 1, Home-to-Foreign movement occurs when the MN moves from Home Network to Foreign Network 1 or 2. In "Home-to-Foreign" movement, MN first detects movement at visited network by receiving Router Advertisement message from the router. Then it detaches home prefix which has been considered to be on-link, and assigns it on virtual interface. When the MN moves from certain Foreign Network to another, it is called "Foreign-to-Foreign" movement in this paper. In this movement, the MN should detach previously used prefix and delete corresponding neighbor cache entries. The last movement is "Foreign-to-Home" movement. It is a movement that the MN returns Home Network from certain Foreign Network. Foreign-to-Home movement is the most complicated situation comparing to the others. MN needs to de-register its binding at the HA by sending BU and should not be respond to NS targeted to its home address until it receives BA from the HA. During the process, HA must protect MN's home address on MN's behalf. This scenario is mainly for ascertaining how much does the factor related to routing information consistency affect handover delay. However, it is still useful to work out other factors related to CoA availability and link layer address resolution.

B) Type of the CN

We also introduced different scenarios related to CN type. We prepared various CNs which differ in its capability of handling bindings of the MN. There are three types of CNs introduced in the experiment: (1) non Mobile IPv6 aware CN, (2) Mobile IPv6 aware CN without RR capability, and (3) Mobile IPv6 aware with RR capability. The first type of CN is a normal IPv6 node which cannot handle any kinds of Mobile IPv6 signaling. Since the CN cannot understand Binding Update message nor create binding cache, it never sends packets towards the MN in Route Optimized manner. The packets from the CN will be tunneled by the HA and packet from the MN will be reverse tunneled by the HA as well. The second type of node is Mobile IPv6 aware CN without RR capability, which can handle Mobile IPv6 signaling and store binding cache but never performs RR procedure between the MN. According to the specification, RR procedure is suggested to be used in securing BU. But there can be a case where the MN and CN have pre-configured secret key and thus omit the RR procedure when sending/receiving BU. The last type of CN is Mobile IPv6 aware node with RR capability. This node is a Correspondent Node in the Mobile IPv6 terminology which is capable of receiving and processing Binding Updates. The CN can activate route optimization when it has binding of the MN. The CN will receive BU when it completes RR procedure between the MN. This scenario is used to examine factors related to routing information consistency.

C) Direction of the traffic

We have showed that contributing factors in handover delay may affect MN's inbound and outbound traffic separately. Therefore we prepared scenario related to direction of traffic handled by the MN. In this scenario, there are simply two conditions: inbound and outbound. In former case, MN keeps receiving packets from the CN. In latter case, MN keeps sending packets to the CN. In both cases, handover delay is derived from the number of packet loss as described in Section 2.4. This scenario may be related to all of the given factors except CoA availability.

D) DAD handling

When the MN moves to foreign network, it obtains CoA by certain method. Before MN assigns CoA to its interface, it should perform Duplicate Address Detection process in accordance with IPv6 specification. IPv6 specifies that DAD must take place on all unicast addresses, regardless of whether they are obtained through stateful, stateless or manual configuration. IPv6 autoconfiguration specification defines two variables with respect to DAD processing. Variable DupAddrDetectTransmits is the number of Neighbor Solicitations to be sent when a node performing DAD. Variable RetransTimer is the time in milliseconds for a node to wait so that uniqueness of the IPv6 address can be verified. The default value for the DupAddrDetectTransmits is set to 1 and 1000 for RetransTimer. According to these values, the time needed for the IPv6 node to complete DAD is 1 second in normal case. This scenario is exclusively related to CoA availability factor.

4.2. Comparison based on CN type

In the first experiment, we tried to monitor the handover delay between the MN and different type of CN. Primary focus is placed on how much handover delay differs in each scenario with 3 different types of CN. Handovers have been performed in all of the 3 types of the movement described in Section 4. Regarding direction of the traffic, the CN keeps sending packet to the MN. Each bar represents the average delay out of 20 times handovers in each type of movement. With respect to the DAD handling, the MN does not perform DAD in all cases.

Figure 3 shows the measurement result of handover delay. The result indicates that in all types of movement, non-mip6-aware CN produces the shortest delay and mip6-aware CN without RR and mip6-aware CN with RR produce longer delay respectively. Especially in Foreign-to-Home and Foreign-to-Foreign movements, the mip6-aware CN with RR hit considerably large value. It is interesting to know that in Home-to-Foreign movement, the mip6-aware CN with RR does not hit large value. This is due to routing path between the MN and the CN. In each type of the CN, it keeps sending packets to the MN's home address and the HA is responsible for forwarding the packets to the MN. When the MN performs movement and BU is reached to the HA, the HA will start tunneling the packets to the MN's CoA. Even if the CN were mip6-aware, packets will be tunneled to the MN before RR procedure is done.

In Foreign-to-Home movement, difference between the non-mip6-aware CN and the mip6-aware CN without RR is about 100 milliseconds. This means that there is about 100 milliseconds disruption while BU travels to the CN and it starts delivering packets directly to the MN. The difference between the mip6-aware CN without RR and the mip6-aware CN with RR is about 700 milliseconds, which is relatively large. This is assumed to be overhead of RR procedure taken place when the MN returns home. According to the specification, the MN and the CN just perform Home Test when the MN returns home.

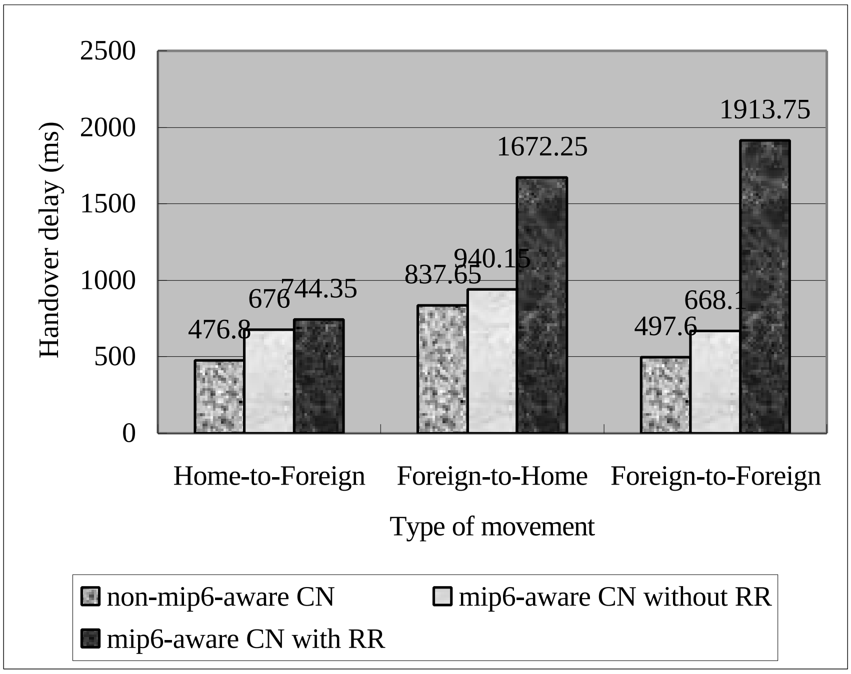

Figure 3: Handover delay in comparison of CN type

In Foreign-to-Foreign movement, difference between the non-mip6-aware CN and the mip6-aware CN without RR is about 160 milliseconds. Comparing the mip6-aware CN without RR and the mip6-aware CN with RR, there is about 1,200 milliseconds difference, which is larger than that of Foreign-to-Home movement. This is assumed that there was an additional overhead due to CoTI/CoT exchange. When the MN performs Foreign-to-Foreign movement, it needs to exchange CoTI/CoT along with HoTI/HoT.

Difference between Foreign-to-Foreign movement and Home-to-Foreign movement is due to routing path of inbound traffic: how the route optimized packets are delivered to the MN. In case of Home-to-Foreign movement, the CN keeps sending packets to the previous CoA which is identical to the home address. In contrast, packets will be misrouted to the previous CoA in case of Foreign-to-Foreign movement. Result above seems to be inline with the analysis.

In all, results give an interesting lesson of handover delay in end-to-end traffic. Route optimization is one of key feature in Mobile IPv6, which aims to prevent inefficient routing so called triangular routing. It is effective especially when the delay is huge between MN-HA or between HA-CN. However when looking into handover delay, the Route Optimization enabled CN is hurt by the cost of sending BU. RR procedure is the primary solution in Mobile IPv6 for authorizing BU sent to the CN. Therefore impact of RR procedure on handover delay should be well examined and considered. Result above gives a lesson that Route Optimization is not always beneficial when it comes to effect to the end-to-end handover delay.

4.3. Comparison based on traffic direction

In the second experiment, we tried to figure out how much there is in inbound and outbound traffic. In this experiment, the CN is non-mip6-aware IPv6 node. Thus the packets sent from the MN to the CN is reverse tunneled by the HA, and packets sent from the CN to the MN will be tunneled by the HA. When the MN moves to the foreign networks, it does not perform DAD for its newly obtained CoA.

Figure 4 shows the measurement result of handover delay in comparison based on traffic direction. Result shows that handover delay in inbound case hits higher value in Foreign-to-Home and Foreign-to-Foreign movement than those in outbound case. In both cases, the HA has binding cache of the MN before the movement. This means that packets sent by the CN will be misrouted to the MN's previous CoA until BU reached to the HA. Only in Home-to-Foreign movement, outbound traffic hit higher value than inbound traffic did. It is rather difficult to give a reason for the result. In theory, there should be equal or more handover delay in case of inbound traffic.

We can see that in Foreign-to-Home movement, difference in handover delay of inbound and outbound is more than 150 milliseconds. The big difference is due to link layer address resolution factors. The MN implementation tries to resolve link layer address of HA's address upon returning home[5]. This is to prevent MN from sending Neighbor Solicitation packet using its own address. Measurement result taught us a need to make improvements in returning home process at the MN.

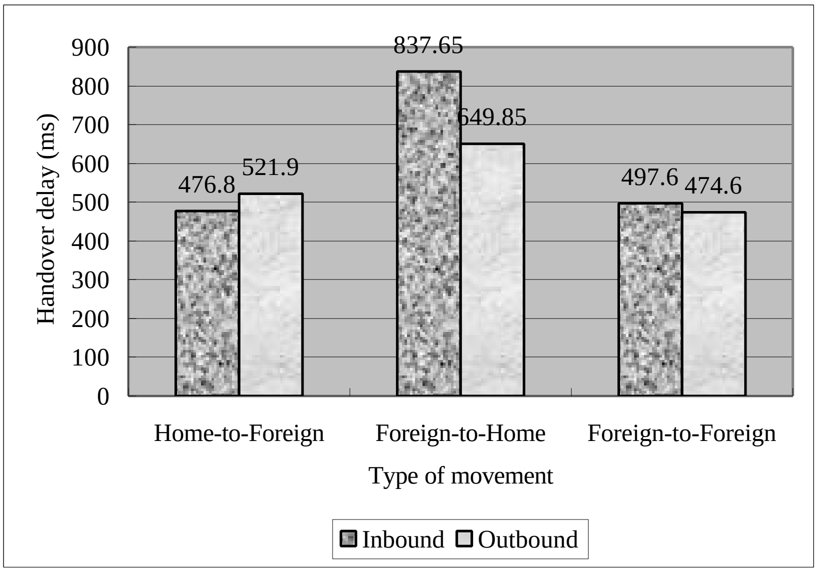

Figure 4: Handover delay in comparison of traffic direction

4.4. Comparison based on DAD handling

In the last experiment, we focused on influence of DAD handling on handover delay. Handover delay was measured in scenarios in which DAD is handled in two different ways. In the first case, the MN performs DAD procedure upon its movement (with-DAD). In the second case, the MN skips DAD procedure upon its movement (without-DAD). There is no Foreign-to-Home movement because it is not allowed for the MN to perform DAD procedure for its home address in returning home. The MN must not perform DAD until it receives valid BA from the HA. In the with-DAD cases, MN performs DAD in advance of CoA assignment and will wait for 1 second DAD procedure to be completed[6]. Until DAD procedure completes the MN cannot send any packet whose source address is CoA nor receive packets destined to the CoA.

Figure 5 shows measurement result of handover delay. From the result, we can see that both in Home-to-Foreign and Foreign-to-Foreign movements DAD procedure incurs additional delays to inbound and outbound traffic. In Home-to-Foreign movement, difference between "with-DAD" and "without-DAD" is about 1,000 milliseconds, which is nearly equal to the estimated duration required for the DAD procedure. As the result shows, DAD directly influences handover performance of the MN regardless of traffic direction. It is obvious

[5] In the current (version 20) specification, there is no need for the MN to resolve HA's link layer address it maybe already given by Source Link-Layer Address option in a Router Advertisement from the HA.

[6] In NetBSD-1.5.2 Release, DAD procedure takes 1 seconds to complete in accordance with suggestion of the NDP specification

that proportion of DAD procedure to the handover delay is considerably large. This indicates that DAD handling must be primary concern in series of effort to reduce handover delay of Mobile IPv6. There is a suggestion which makes DAD optimistic in order to avoid overhead by the huge delay of DAD procedure [9]. The mechanism simply works when there is no collision of the address, however it will hurt other node in collision case. If the optimistic DAD is performed, handover delay will become same as that of "without-DAD" cases in the experiment.

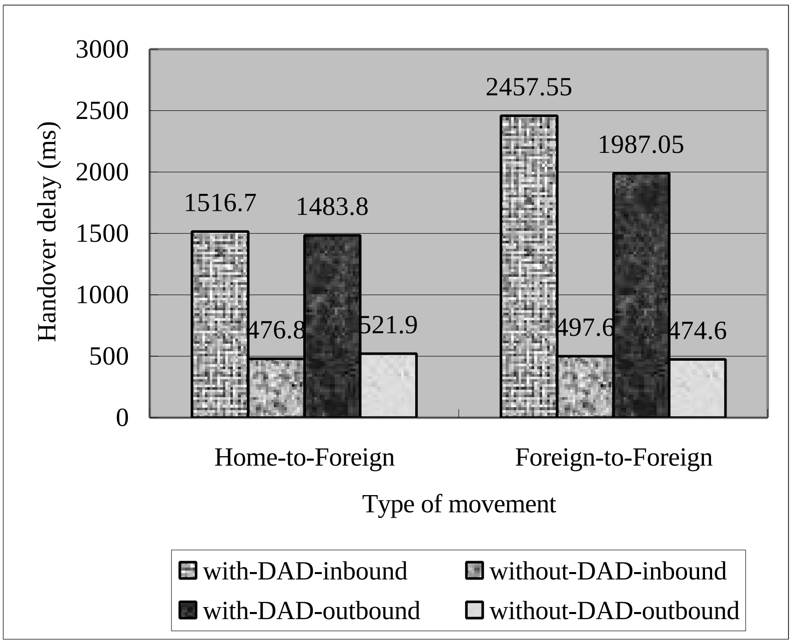

Figure 5: Handover delay in comparison of DAD handling

5. Conclusions

We examined Mobile IPv6 handover in variant scenarios. In comparison based on CN type, the experimental result showed that non-mip6-aware CN had better performance than the mip6-aware CN with/without RR capability. It was also found that overhead of RR procedure is considerably large when the CN has binding cache of the MN before its movement. In comparison based on traffic direction, it was observed that inbound traffic experienced longer delay in Foreign-to-Home and Foreign-to-Foreign movements. Comparison based on the DAD handling showed considerably large overhead incurred by DAD process.

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