Improving handover performance in Mobile IPv6

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***Abstract* — A seamless handover scheme with low latency and low packet loss is important to maintain TCP performance of mobile users. Several solutions have been proposed such as Hierarchical Mobile IPv6 (HMIPv6), Fast Handover protocol for Mobile IPv6 (FMIPv6), Seamless Handoff architecture for Mobile IP (S-MIP), ..., however, the overall handover latency is still too high for time-sensitive services.**

This paper proposes a novel improvement to existing frameworks by optimizing the address configuration stage so that the handover latency is further reduced. The proposed framework is based on Fast Handover for Hierarchical Mobile IPv6 and Optimistic Duplicate Address Detection.

***Keywords* — Mobile IPv6, Fast Handover, Hierarchical Mobile IPv6, Optimistic Duplicate Address Detection, optimistic Fast Handover for Hierarchical Mobile IPv6.**

1. Introduction

The Mobile IPv6 specification enables mobile nodes to change their point of attachment to the Internet whilst not breaking existing application sessions. When a MN changes its point of attachment to the network, it moves from one network to another new network and this process is known as handover. During the handover process, the MN usually has disconnected from the old network before connecting to the new network and thus there is a time when the MN has lost connectivity to the Internet. During this period, it cannot send or receive IP packets to maintain existing application sessions. While many TCP applications are designed to cope with intermittent loss of connectivity by retransmitting unacknowledged packets, UDP applications will not be able to recover such losses. Furthermore, both TCP and UDP applications that rely on timely packet delivery within certain acceptable thresholds (e.g. VoIP and audio/video streaming applications) will be sensitive to the length of time a MN loses connectivity while performing handover.

A seamless handover is the handover that has both smooth (with no or very little packet loss) and fast (low latency) features. There are several standard and non-standard solutions for making the handover seamless such as HMIPv6, FMIPv6, S-MIP, … These solutions obviously improve the handover performance, especially the latency, but in practice the handover delay is still very high for time-sensitive services. It is the purpose of this paper to analyze existing handover implementations and propose suitable improvements to the Mobile IPv6 protocol architecture so that latency of the handover is minimized. The remainder of this paper is organized as follows: Section 2 provides some background of fast handover in Mobile IPv6 as well as the F-HMIPv6 framework and the Optimistic Duplicate Address Detection procedure, Section 3 presents the proposed improvement: the Optimistic F-HMIPv6 framework with its control flow and message format, Section 4 presents simulation results, finally the conclusion and future works are presented in Section 5.

2. Background

To reduce the handover delay and packet loss, many authors have suggested their ideas for optimizing the protocol. Some concentrate on the link-layer [9] to detect the movement of Mobile Nodes (MN) as early as possible, others focus at network-layer [10] to accelerate the binding update process by buffering and simulcasting packets.

IETF introduces 2 extensions of Mobile IPv6 which are widely accepted: HMIPv6 and FMIPv6.

Hierarchical Mobile IPv6 (HMIPv6) [3] divides the Internet into administrative domains which are managed by Mobility Anchor Points (MAP). HMIPv6 aims to reduce the amount of signaling between the MN and its correspondent nodes (CN) during a handover, and to improve the performance in terms of handover speed. In HMIPv6, the MN sends Binding Updates (BU) to the local MAP rather than the home agent (HA) and CNs, which are typically further away. Moreover, only one BU message needs to be transmitted by the MN before traffic from the HA and all CNs is re-routed to its new location, regardless of the number of CNs that MN is communicating with.

The Fast Handover Protocol (FMIPv6) [2] is an extension of Mobile IPv6 that allows an access router (AR) to offer services to an MN in order to anticipate the layer-3 handover. The movement anticipation is based on the layer-2 triggers. MN has the possibility to prepare its registration with new access router (NAR) and obtain its new care-of-address (NCoA) while still connected to its previous access point (PAR). Moreover, MN can instruct the PAR to forward packets addressed to its PcoA to its NCoA.

S-MIP [8] provides a novel architecture that builds on top of the hierarchical approach and the fast handover mechanism, in conjunction with a newly developed handoff algorithm based on pure software-based movement tracking techniques. S-MIP introduces a new entity in the network, the Decision Engine (DE), that is similar to a MAP in its scope, and makes handover decision for its network domain. S-MIP provides improvement in both delay and packet loss, however, the operation of DE entity is difficult to simulate in test-bed and therefore the evaluation for this framework is not clear so far.

A. F-HMIPv6

Evaluations show that FMIPv6 and HMIPv6 can improve the handover delay significantly when they are implemented separately. Some authors suggest that by integrating FMIPv6 into HMIPv6 architecture, the performance can be even better. Jung et al. [7] proposed a combination of the Fast Handovers and Hierarchical Mobile IP extensions to Mobile IPv6. The scheme is called Fast Handover for Hierarchical Mobile IPv6 (F-HMIPv6). When a MN enters a new MAP domain, it first performs the HMIPv6 registration procedures with HA and MAP. Later, when MN moves from a PAR to a NAR within the MAP domain, it will follow the local Binding Update Procedure of F-HMIPv6. During the handover, data packets sent by CNs will be tunneled by MAP toward NAR via a bi-directional tunnel, similarly to the FMIPv6 procedure. It should be noted that no bi-directional tunnel is established between PAR and NAR. The authors proved that F-HMIPv6 provide better performance than a simple FMIPv6 and HMIPv6 combination. The F-HMIPv6 operation is depicted in figure 1. Our improvement is based on this framework.

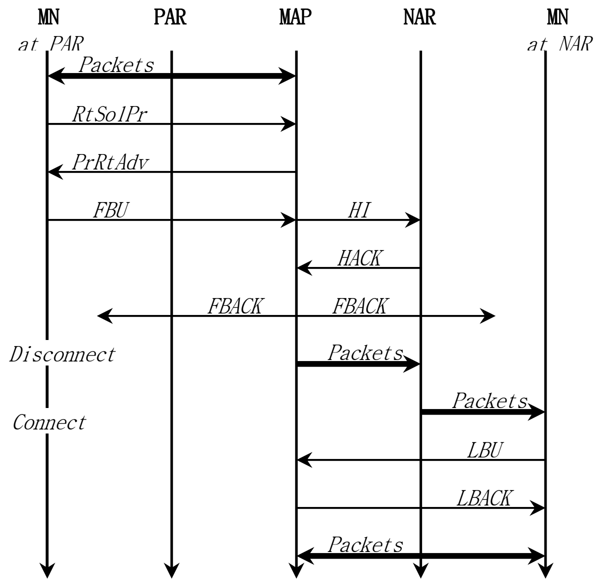

Figure 1: F-HMIPv6 handover

B. Optimistic Duplication Address Detection

IPv6 provides a very flexible mechanism for hosts to configure their IP addresses automatically via the Neighbor Discovery procedure [5] and Stateless Address Autoconfiguration mechanism [6]. The host performing Duplication Address Detection (DAD) sends a Neighbor Solicitation (also referred to as DAD probe) message to the solicited-node multicast address including the tentative address in the Target Address field. The node may retransmit the probe multiple times, but each probe is separated by a specified timer. After sending the DAD probe(s), the node waits for *RetransTimer***,** whose value is one second, before it declares DAD process over. This time badly effects the handover's overall delay.

RFC 4429 [4] proposes a modified method to perform DAD, refered to as Optimistic DAD, in which the RetransTimer is removed. This is achieved by defining a new state of IP address, the Optimistic state. When in Optimistic state, a MN can send and receive packets using the tentative address in a special manner so that: 1- Neighbor Caches of other hosts in the subnet will not be updated until the tentative address becomes preferred address, and 2- MN does not have to wait for the RetransTimer to expire to proceed its activity.

Optimistic DAD uses the 'O flag' in its Neighbor Advertisement (NA) message to advertise its link address while not changing other nodes' Neighbor Cache. With this procedure, DAD delay can be reduced dramatically in the successful cases. The fact that the probability of address duplication in practice is very low makes Optimistic DAD applicable.

3. Optimistic F-HMIPv6

Although the probability of address duplication is very low, the DAD check should not be ignored as recommended by RFC 4068 [2]. In a fast handover, DAD check is carried out twice by two entities: NAR and MN. Before sending Handover Acknowledgement (HACK) to MAP, NAR has to check the NCoA for duplication and indicates the result in HACK message.

NAR can perform address duplication check by one of two methods: First, NAR carries out a full DAD check as specified in [5]. With this method, NAR can only uses standard DAD because Optimistic DAD provides no benefit here, the RetransTimer cannot be removed, the delay caused by this procedure must be more than one second.

Second, instead of implementing standard DAD procedure, NAR may already have the knowledge required to assess whether the MN's address is a duplicate or not. For example, the NAR can have a list of all nodes on its subnet, perhaps for access control,… and by searching this list, it can confirm if the MN's address is duplicated. Because there is no requirement for all the hosts on a subnet to register itself with the access router, or, in case that another host (may be a fixed host or mobile node) is configuring the same tentative address as the MN in question at the same time, the access router can not detect the duplication and therefore, this fact can lead to potential address conflicts.

In Optimistic F-HMIPv6 framework (referred to as oF-HMIPv6), we remove the DAD function from NAR and get it done by MN. This will benefit as follows:

- NAR does not have to check NCoA for duplication, instead, it will immediately send HACK message to MAP to accelerate the bi-direction tunnel setup between MAP and NAR.
- MN performs Optimistic DAD check mandatorily instead of standard DAD. This procedure eliminates the RetransTimer from handover delay.

When MN connect to NAR, it will implement Optimistic DAD together with sending Fast Neighbor Advertisement

(FNA) message to NAR. This message will be sent with the ‘O flag’ reset to the unicast address of NAR. Because MN already has link layer address of NAR (included in PrRtAdv message), it does not have to send any Neighbor Solicitation (NS) message or Router Solicitation (RS) messages when it is in Optimistic state [4].

The operation of oF-HMIPv6 (figure 2) is as follows:

1. Based on L2 handover anticipation, MN sends RtSolPr message to MAP. The RtSolPr message includes information about the link layer address or identifier of the concerned access point. ‘O flag’ in this message must be set to indicate the MAP that MN is oF-HMIPv6-aware. With this indication, MAP will put link layer address of NAR as SLLAO (Source Link Layer Address Option) in PrRtAdv message [5].
2. In response to the RtSolPr message, MAP sends the PrRtAdv message to the MN, which contains information about NLCoA (new on link CoA) for MN to use in the NAR region. In F-HMIPv6, MAP already knows the network prefix and link layer address of the associated NARs.
3. MN sends Optimistic Fast Binding Update (oFBU) message to MAP. The oFBU message contains PLCoA (previous on link CoA) and IP address of the NAR. ‘O flag’ in this message is set to indicate that MN wants to initiate an oF-HMIPv6 handover.
4. After receiving the oFBU message from MN, MAP will send an Optimistic Handover Initiate (oHI) message to the NAR so as to establish a bi-directional tunnel. ‘O flag’ in this message is set to indicate that MN will perform the Optimistic DAD it self. NAR will respond immediately with a Handover Acknowledge (HACK) message without doing DAD check. As a result, a bi-directional tunnel between MAP and NAR is established. NAR may buffer those data packets forwarded from MAP, until it receives the FNA message from the newly incoming MN.
5. MAP sends Fast Binding ACK (FBACK) messages toward the MN over PLCoA and NLCoA. Then, MAP begins to forward the data packets destined to MN to NAR using the established tunnel.
6. MN set its address state to Optimistic and sends NS messages to initiate Optimistic DAD. At the same time, it sends oFNA messages to NAR (note that the MN already has link-layer address of NAR from PrRtAdv message). NAR delivers the buffered data packets to the MN.
7. MN then follows the normal HMIPv6 operations by sending a Local Binding Update (LBU) to MAP. When MAP receives the new Local Binding Update with NLCoA from MN, it stops the packet forwarding to NAR and then clear the tunnel established for fast handover.
8. In response to LBU, MAP sends Local Binding ACK (LBACK) to MN, and the remaining procedures will follow the HMIPv6.

The oF-HMIPv6 framework requires some minor modifications to the signaling messages in F-HMIPv6 as follows:

- *Router Solicitation for Proxy (RtSolPr) message*: an O (Optimistic) flag is added to indicate that the MN wants to initiate an Optimistic handover. This indication requires the MAP to include link-layer address of NAR in the Proxy Router Advertisement (PrRtAdv) message.
- *Fast Binding Update (FBU) message*: an O (Optimistic) flag is added to request for an Optimistic Handover. This is necessary only in the “network-initiated” case where MN des not send RtSolPr message to MAP.
- *Handover Initiate (HI) message*: an O (Optimistic) flag is added to inform the NAR that it should not perform a duplication check on NCoA. This may results in the HACK message being sent immediately without delay.

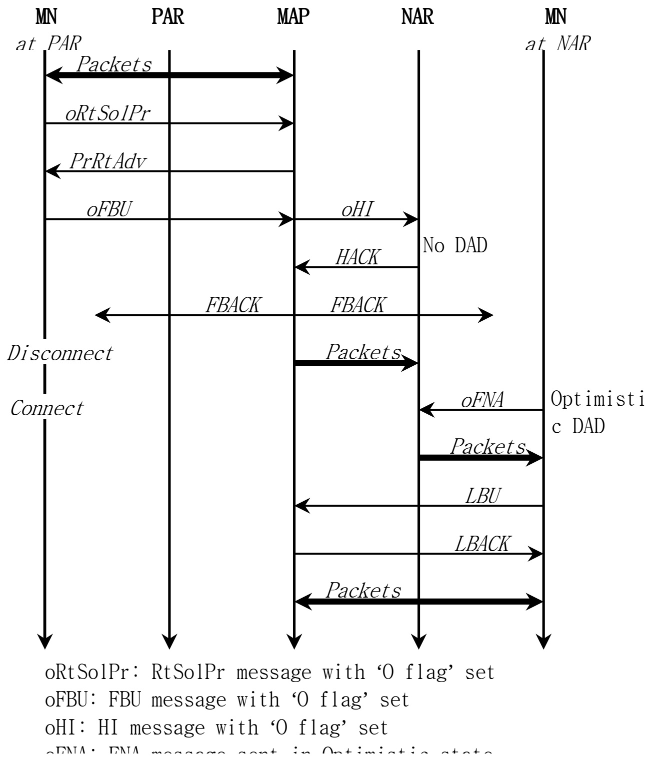

Figure 2: oF-HMIPv6 handover

4. Evaluation

The DAD procedure takes a long time (more than one second) to finish, and because the probability of address duplication is very low, in many handover simulations as well as implementations, this step is often omitted. This is not recommended by mobile IP specifications [1], [2]. With the application of Optimistic DAD and modification of fast handover protocol, the DAD delay is minimized as much as in no-DAD implementation because the MN performs DAD concurrently with Neighbor Advertisement step. Moreover, by removing DAD check function from NAR, there is no delay exists at this stage, the forwarding tunnel can be established earlier, the overall delay and packet loss are reduced.

We simulate oF-HMIPv6 with NS-2 in comparison with F-HMIPv6 and observe that the performance of oF-HMIPv6 is improved significantly. In the simulation scenario, a MN is implementing an FTP session while moving from PAR to

NAR at the speed of 1m/s. The simulation result is presented in table 1, figure 3 and figure 4.

Table 1: Comparison of simulation results between F-HMIPv6 and oF-HMIPv6

Framework	F-HMIPv6	oF-MIPv6
TCP disruption time (s)	0.8541	0.842399
Packet drop (packets)	17	15
Handover delay (s)	1.150294	0.67484

The graphs in figure 3 and figure 4 illustrate the effect of handover schemes in the TCP sender's and receiver's viewpoint. Each graph consists of 4 curve: *source_send* curve indicating the CN's TCP sending buffer and *source_recv* curve showing the CN's TCP receiving buffer, *sink_recv* and *sink_send*, corresponds to MN's TCP receiving and sending buffer. The handover delay in this paper is measured from the time MN sends request to PAR to initiate handover process until the time the first packet from CN, routed through NAR, reaches MN.

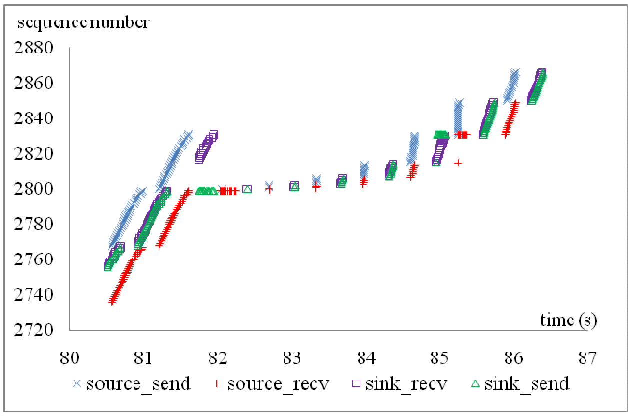

Figure 3: F-HMIPv6 simulation result

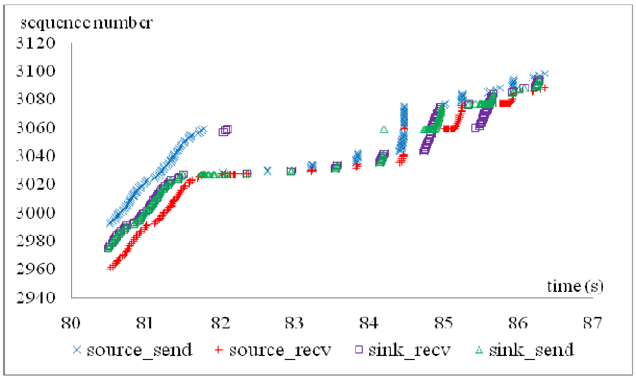

Figure 4: oF-HMIPv6 simulation result

5. Conclusion

Analyses of existing mechanisms showed that it is possible to further optimize the handover performance of Mobile IP. FMIPv6 and HMIPv6 so far are feasible approaches in the Internet community and they are widely used as the basic platform to develop new mechanisms of handover improvement. Optimistic DAD is a useful optimization which can remove the delay of standard DAD check. Our framework, oF-HMIPv6, by combining these together with some necessary modifications to the handover protocol, provides a significant enhancement to Mobile IP performance. In future works, we plan to implement oF-HMIPv6 in different topologies and scenarios in order to analyze its operation, identify its weak points and suggest some further improvements.

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