Network-layer Soft Vertical Handoff Schemes without Packet Reordering

Tong Shu[1,2], Min Liu[1], Zhongcheng Li[1], Kun Zheng[1,2]
[1]Institute of Computing Technology, Chinese Academy of Sciences
[2]Graduate School of the Chinese Academy of Sciences
Beijing 100190, P.R.China
{shutong, liumin, zcli, zhengkun}@ict.ac.cn

***Abstract*—Existing soft handoff techniques lead to plenty of out-of-sequence packets during downward vertical handoffs (DVHOs). In this paper, we present two new network-layer soft vertical handoff schemes, called SHORDER and E-SHORDER. The former can prevent mobile nodes from receiving reordered packets during DVHOs with a low overhead. The latter further hinders their correspondent nodes from receiving out-of-order packets caused by mobile nodes' DVHOs. Then, we analyze the performance of our proposed approaches. By experiments, we show that they have a good effect in practice.**

Keywords-soft downward vertical handoffs; packet reordering; heterogeneous wireless networks

I. INTRODUCTION

Recently various wireless access technologies with different characteristics have been developed. Because of their complementarity, the fourth generation (4G) networks for the integration of these wireless networks can satisfy various needs of mobile users. Vertical handoffs (VHOs) are a major challenge for 4G-system implementation. VHOs refer to handoffs between BSs and APs using different wireless network technologies, and are divided into downward vertical handoffs (DVHOs) and upward vertical handoffs. The former are handoffs to a wireless overlay with a smaller cell size and higher bandwidth per unit area, such as handoffs from wireless wide area networks (WWANs) to wireless local area networks (WLANs). The latter are reverse. [1]

Conventional handovers are often hard handoffs. In hard handovers, mobile nodes (MNs) stop receiving from the previous network and then start receiving from the new network. As a result, in-flight packets destined to the previous network are discarded. Contrary to hard handoffs, in a soft handoff, a MN does not release the old link until it has established the new link [2]. Note that it is the prerequisite of soft handoffs that MNs are located in the overlapping region of more than one wireless network.

Although the Mobile IPv6 (MIPv6) protocol [3] has been presented for handovers, there is packet loss due to hard handoffs. Since MNs moving to WLANs often are in the coverage area of WWANs, the soft handoff methods can be used for DVHOs to avoid packet loss. Chakravorty et al. improve the standard MIPv6 mechanism and present client-based soft handovers (CSH) in the network layer to ensure no loss of packets destined to MNs during VHOs. In the CSH method, a client-based handover module is hooked to the MN's IPv6 stack to support soft handovers, such that after every handover, it allows all in-flight packets destined to the MN's previous interface to be read and be given to the application. Thus, this method keeps receiving packets from the previous network interface. At the same time, it allows for complete migration of IP points of attachment, before starting to send packets from the new interface [4]. Most existing studies consider the packets from MNs to correspondent nodes (CNs) not to be lost during soft VHOs. The loss of incoming and outgoing packets can be eliminated simply by an extension of the CSH method. A similar handover module can also be hooked to the IPv6 stack of the home agent (HA), so that after every handover, it allows all in-flight packets from the MN's previous care-of address (CoA) to be forwarded to its CNs. In this paper, this technique is referred as to extended client-based soft handovers (ECSH). The ECSH method does not need to bicast duplicate packets on both new and previous paths.

However, soft handover approaches result in out-of-order delivery of packets. It is well-known that out-of-sequence packets can degrade the performance of applications. In [5], Tandjaoui et al. discuss the impact of receiving out-of-sequence packets on TCP and UDP applications. On the one hand, out-of-sequence packets cause duplicate acknowledgements according to the TCP congestion algorithm in the transport layer and invoke unnecessary fast retransmissions. On the other hand, real time services require more buffers and more complex mechanisms to compensate packet streams correctly.

At present, a common solution to packet reordering is adding sequence numbers in IP headers of packets and leaving the task of sorting to receivers. The method has the time complexity of $O(n\log n)$, where n is the number of out-of-order packets. In order to better avoid reordered packets during DVHOs, we propose two network-layer soft handoff approaches: SHORDER (Soft Handoff in ORDER) and E-SHORDER (Extended SHORDER).

The rest of this paper is organized as follows. In Section II, we present our network-layer soft handoff approaches and illuminate their efficiency. Section III gives our experimental

This work has been supported by the National Natural Science Foundation of China (No. 60803140).

results in a heterogeneous wireless environment, with some conclusions being provided in Section IV.

II. NETWORK-LAYER SOFT HANDOFF APPROACHES

In this section, we propose two network-layer soft handoff approaches to avoid out-of-order packets during DVHOs and analyze their performance.

Ahead of all, for the CSH / ECSH method, we analyze the reasons why out-of-order packets happen in a DVHO process. Since the path delay from the HA/CN through the WLAN to the MN is often less than the path delay through the WWAN, the packets destined for the MN's WLAN interface during the DVHO may anticipate the arrival of the packets previously forwarded to the MN's WWAN interface. As a result, the MN receives reordered packets. Similarly, as the path delay from the MN through the WLAN to the HA/CN is usually also lower than the path delay through the WWAN, the packets transmitted through the WLAN by the MN after the DVHO may reach the HA/CN earlier than the packets formerly sent through the WWAN. Consequently, the packets received by the CN are out-of-sequence.

A. The SHORDER Approach

In order to prevent MNs from receiving reordered packets during DVHOs, we propose the SHORDER approach based on the prerequisite of no out-of-order packets in the WWAN in MNs' DVHO period.

The basic idea is sketched as follows. On the one hand, the MN and the HA maintain the tunnel between the MN's previous CoA and the HA for some time after the VHO is triggered, for the sake of correctly decapsulating in-flight packets with double IPv6 headers in the previous network. On the other hand, the MN's network layer buffers packets from the new interface after initiating a DVHO, and orderly delivers these packets to the transport layer on receipt of all in-flight packets in the previous network, so that the MN's transport layer cannot perceive the occurrence of out-of-order packets caused by the DVHO.

In detail, we describe the signaling procedures of the SHORDER technique as shown in Fig. 1 and focus on MNs' VHO between two foreign networks.

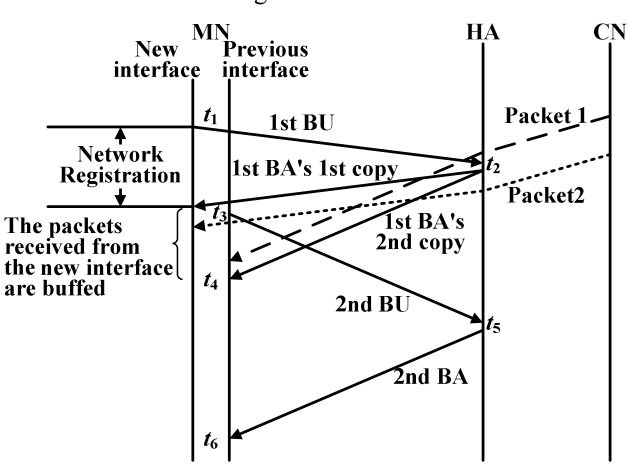

Figure 1. The SHORDER method

t_1: Having initiated a DVHO, the MN creates an IPv6-in-IPv6 tunnel between its new CoA and the HA, but does not delete the IPv6-in-IPv6 tunnel between its previous CoA and the HA. Then, it sends the first binding update (BU) message through the new network to the HA with an additional "S" flag set to 1. After that, the MN continues sending packets through the previous network and starts to buffer the packets received from the new network interface in a first-in-first-out (FIFO) queue in sequence.

t_2: On the arrival of the first BU message with the "S" flag set to 1, the HA updates the binding cache entry for the MN and creates an IPv6-in-IPv6 tunnel between itself and the MN's new CoA. However, it does not delete the IPv6-in-IPv6 tunnel to the MN's previous CoA. Furthermore, the HA stop forwarding packets from the CN via the old tunnel and start to forward them via the new tunnel. Then, it generates two copies of the first binding acknowledgement (BA) message with the "S" flag set to 1, and sends one to the MN's new CoA and the other to the MN's previous CoA simultaneously.

t_3: On the receipt of one copy of the first BA message, the MN starts transmitting packets through the new network and sends the second BU message through the previous network to the HA with the "S" flag set to 0.

t_4: When the other copy of the first BA message reaches the MN, the MN deletes the IPv6-in-IPv6 tunnel between its previous CoA and the HA. Moreover, the MN orderly passes all the packets buffered in the queue to the transport layer, and does not buffer packets any longer.

t_5: After receiving the second BU message with the "S" flag set to 0, the HA deletes the IPv6-in-IPv6 tunnel to the MN's previous CoA, and sends the second BA message to the MN with the "S" flag set to 0.

t_6: The VHO finishes when the MN receives the second BA message.

Generally, for a DVHO, the first BA message through the new network anticipates the arrival of the first simulcasted BA message through the previous network to the MN.

B. The E-SHORDER Approach

With the SHORDER approach, no out-of-order packets are received by the MN's transport layer during DVHOs. However, the packets from the MN to the CN are out-of-sequence. The CN can also receive no reordered packets, by simply extending the SHORDER approach, if necessary. In the extended SHORDER (E-SHORDER) approach, the HA also start buffering packets from the MN's new CoA at t_2, and then stop buffering packets and forward buffered packets to the CN in turn at t_5.

C. Analysis of the Validity and Efficiency

In this sub-section, we specify the validity of the SHORDER and E-SHORDER approaches about avoiding packet reordering during DVHOs, and then analyze their performance in terms of the time complexity and the unnecessary delay.

Sporadically, networks can invert the order of packets in a connection. However, much recent research indicates that packet reordering is an extremely rare and insignificant event on a fixed path in actual networks in most cases. Hence, we assume that there are no out-of-order packets when the path between the MN and the CN does not change. Based on the assumption, the following propositions hold. The proof of these propositions is ignored due to space limitations.

Proposition 1: With the SHORDER approach, the MN's transport layer does not receive reordered packets during a VHO, if no packet reordering occurs on the previous and new paths from the CN to the MN through the HA.

Proposition 2: With the E-SHORDER approach, no reordered packets arrive at the CN when the MN performs a VHO, if no packet reordering occurs on the previous and new paths from the MN to the CN through the HA.

The SHORDER and E-SHORDER methods regard the arrivals of the first BA's second copy and the second BU as the signs of having received all the packets through the previous network, respectively. They can make use of a FIFO queue to recover the original packet sequence from out-of-order packets caused by DVHOs. Here, the time complexity of sorting is as low as $O(n)$. Accordingly, these two methods can rapidly process a large number of out-of-order packets.

By the SHORDER method, the last packet through the previous network reaches the MN at the time t', and the MN's transport layer can receive the packets buffered in the network layer at the time t''. The unnecessary delay introduced by the SHORDER method is $t''-t'$ and it has a uniform distribution from 0 to the interval of packets destined for the MN. The average unnecessary delay of the SHORDER method equals a half of the mean packet interval. That of the E-SHORDER method is similar. Thus, these two approaches do not interrupt data streams between the MN and the CN.

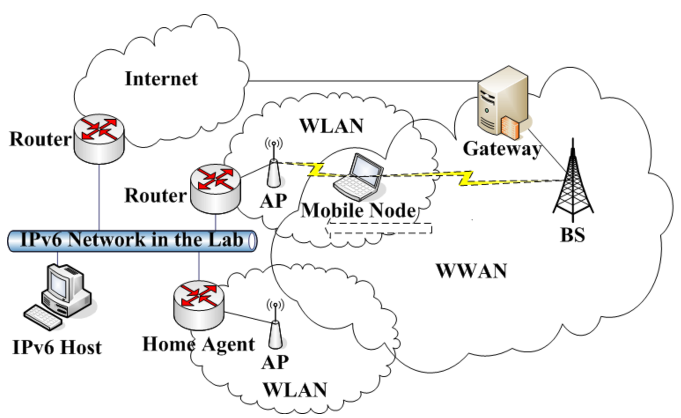

Figure 2. The loosely-coupled, Mobile IPv6-based WWAN-WLAN experimental test bed.

TABLE I. THE DEGREE OF REORDERING IN WWANS

WWANs		CDMA	GPRS
From the IPv6 host to the MN	The number of received packets	98,892	98,784
	The number of out-of-order packets	0	0
From the MN to the IPv6 host	The number of received packets	99,989	99,748
	The number of out-of-order packets	0	16

In sum, the SHORDER and E-SHORDER methods do not only impede the disorder of packets in the DVHO period, but also have a low time complexity and a short unnecessary delay.

III. EXPERIMENTAL RESULTS

In order to demonstrate the feasibility and effectiveness of our proposed methods, we have implemented a prototype system based on modifying some modules of the Mobile IPv6 for Linux [6]. Our experimental setup consists of a loosely-coupled, MIPv6-based WWAN-WLAN test bed as shown in Fig. 2. Here, the WWAN is a GPRS or CDMA network. Two WLANs are deployed in the test bed and the AP in each WLAN is connected to an IPv6 local network via the respective IPv6 access router. One WLAN is referred to as the home network, and the other is the foreign network.

A. Condition Tests

The SHORDER and E-SHORDER approaches for avoiding out-of-order packets caused by DVHOs rely on the assumption that packet reordering is nonexistent in the WWAN during DVHOs. Hence, we need to verify whether this condition holds. We test the degree of reordering in CDMA and GPRS networks. The MN in the WWAN and the IPv6 host in the IPv6 local network send a packet per 100 milliseconds to each other. Then, we check the sequence numbers of all the packets received by them. The results are shown in Table I.

In our tests, no out-of-sequence packets appear during data transfer in the CDMA network and the downlink of the GPRS network. Only 16 out-of-order packets exist on the uplink of the GPRS network. Displacement is the number of positions in the sequence the expected packet got delayed [7]. In the 16 out-of-order packets, there are one packet whose displacement value is -3, two packets whose displacement value is -2, three packets whose displacement value is -1, and ten packets whose displacement value is 1. Clearly, out-of-order packets in WWANs are infrequent and thus the probability of packet reordering in the WWAN during transitory DVHOs is tiny. Consequently, the requirement of our approaches is usually satisfied.

B. The SHORDER Approach

We test the performance of the SHORDER approach in comparison to the CSH method. In the following, we choose the GPRS network as the WWAN for more evident experimental phenomena. We inspect the packets received by the MN during a DVHO with the CSH (See Fig. 3) and SHORDER (See Fig. 4) methods separately, when the IPv6 host transmits a UDP packet every 50ms. From Fig. 3, we can see that from 1s to 1.3s, the packets from the WLAN with sequence numbers from 23 to 29 are interleaved with the packets from the GPRS network with sequence numbers from 17 to 22. The UDP stack of the MN receives out-of-sequence packets. Figure 4 shows that the MN's network layer does not only receive all UDP packets during DVHO, but also delivers them to the transport layer in sequence. Just 10ms after the last packet from the GPRS network arrives at the MN at 1.2s, the UDP packets with sequence numbers from 24 to 27 in the buffer queue are handed on to the transport layer. Thus, the

SHORDER approach can effectively prevent the MN's transport layer from receiving out-of-order packets during DVHOs.

C. *The E-SHORDER Approach*

In this sub-section, we pay attention to the effect of the E-SHORDER approach in comparison with the ECSH method. We examine the packets received by the IPv6 host in the MN's DVHO process by the ECSH (See Fig. 5) and SHORDER (See Fig. 6) methods separately, in the case that the MN sends a UDP packet per 50ms. Figure 5 reveals that the IPv6 host receives the packets of sequence numbers from 22 to 44 mixed with the packets of sequence numbers from 45 to 75 in the interval between 1s and 2.7s. From Fig. 6, it can be observed that no out-of-order packets arrive at the IPv6 host when the MN performs a DVHO. The IPv6 host suddenly receives a string of UDP packets at 2.45s. The reason is that the packets with sequence numbers from 51 to 88 through the WLAN are buffered by the HA and forwarded to the IPv6 host in turn just after the second BU reaches the HA. Hence, the E-SHORDER approach can also avoid the out-of-order arrivals of packets to the CN in the MN's DVHO process.

We repeat these experiments (in Section III.B and Section III.C) 10 times and obtain the similar results. It is proved that our methods can effectively ensure no lost and out-of-order packets during DVHOs.

IV. CONCLUSIONS

With the help of the MIPv6 and soft handoffs, ongoing sessions can remain active and avoid packet loss during handoffs. However, applications still suffer from the performance degradation due to serious packet reordering during DVHOs. This paper proposes two network-layer soft vertical handoff approaches, called SHORDER and E-SHORDER, and illuminates their efficiency. Our proposals can keep MNs and CNs from receiving reordered packets caused by DVHOs, respectively. By experiments, we empirically demonstrate the good performance of our approaches.

REFERENCES

[1] Mark Stemm and Randy H. Katz, "Vertical handoffs in wireless overlay networks", ACM Mobile Networks and Applications, vol. 3, no. 4, pp. 335 - 350, Dec. 1998.

[2] Nidal Nasser, Ahmed Hasswa and Hossam Hassanein, "Handoffs in fourth generation heterogeneous networks", IEEE Communications Magazine, vol. 44, no. 10, pp. 96 - 103, Oct. 2006.

[3] D. Johnson, C. Perkins, J. Arkko, "Mobility Support in IPv6", RFC 3775, June 2004.

[4] Rajiv Chakravorty, Pablo Vidales, Kavitha Subramanian, Ian Pratt and Jon Crowcroft "Performance Issues with Vertical Handovers -- Experiences from GPRS Cellular and WLAN Hot-spots Integration", 2nd IEEE PerCom, pp. 155 - 164, 2004.

[5] D. Tandjaoui, N. Badache, H. Bettahar, A. Bouabdallah and H. Seba, "Performance Enhancement of Smooth Handoff in Mobile IP by Reducing Packets Disorder", 8th IEEE ISCC, vol.1, pp. 149 - 154, Jun. - Jul. 2003.

[6] http://www.mobile-ipv6.org/

[7] Tarun Banka, Abhijit A. Bare, Anura P. Jayasumana, "Metrics for Degree of Reordering in Packet Sequences", 27th IEEE LCN, pp. 333 - 342, Nov. 2002

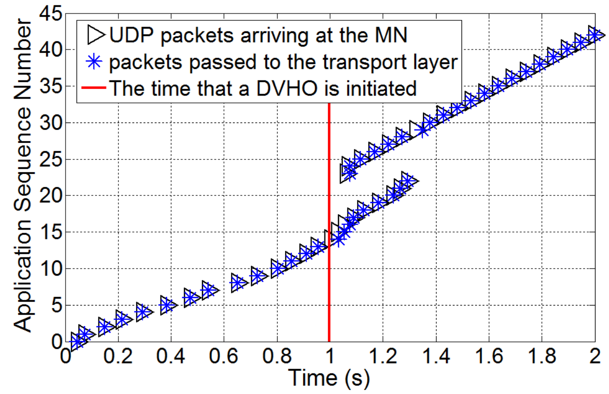

Figure 3. The packets received by the MN with the CSH method

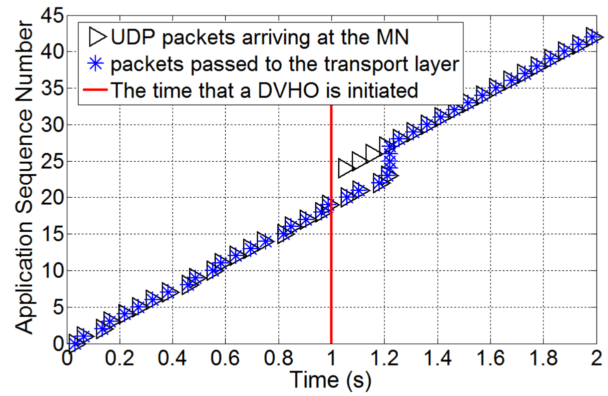

Figure 4. The packets received by the MN with the SHORDER approach

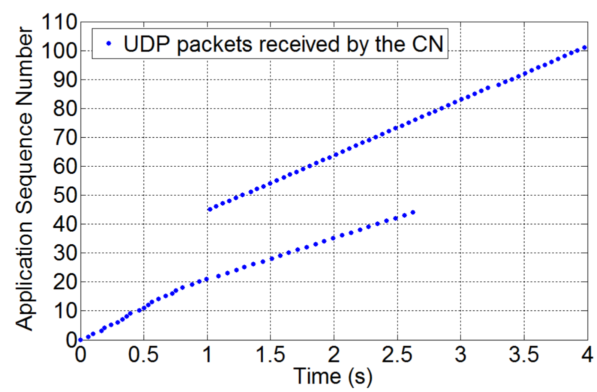

Figure 5. The packets received by the CN with the ECSH method

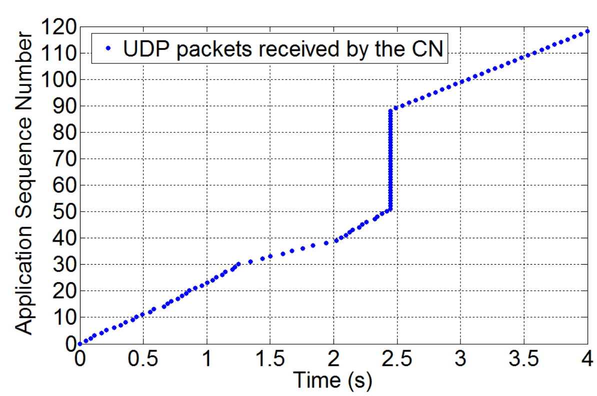

Figure 6. The packets received by the CN with the E-SHORDER approach