Improved TCP Performance during the Upward Vertical Handover Using an IEEE 802.21 MIHF Framework

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Abstract. In Upward Vertical Handover(UVHO) from a fast WLAN link to a slow 3G cellular link, the TCP sender may encounter precocious timeout since the RTT of the 3G link is too large for the RTO(Retransmission Time Out) which is tuned to the small RTT of the WLAN. Although IEEE 802.21 MIHF framework provides the vertical handover procedure, it does not deliver RTT of the new link since this does not belong to static information to be delivered by IEEE 802.21 MIHF. Conventional TCP such as TCP Reno, even with IEEE 802.21 MIHF, may encounter timeout after UVHO, degrading TCP throughput considerably during UVHO. In this article, we propose a modified TCP scheme in which we estimate the RTT of the new link using timeout instant, the ACK traveling through the new link just after UVHO and the old RTT. We also estimate appropriate CWND size for the new link. Simulation results show that our proposed scheme improves TCP performance during the UVHO compared with previous schemes as well as TCP Reno.

Keywords: Upward Vertical Handover, TCP, Congestion Control, Congestion Window, IEEE 802.21 MIHF.

1 Introduction

As smart phones equipped with a WLAN interface as well as a 3G cellular interface dominate the cellular service market, the TCP performance degradation during the vertical handover between these two different links stands out as a major problem.

The IEEE 802.21 working group establishes standard for performing the vertical handover called Media Independent Handover Function(MIHF)[3]. However this standard does not address the TCP performance degradation during vertical handover. For example, in upward vertical handover(UVHO) from a fast WLAN link to a slow 3G cellular link, small retransmission timeout(RTO) is applied right after the UVHO. As seen in figure 1 (a), this may cause precocious timeout because the 3G cellular link has larger RTT than WLAN link. Since the RTO is set according to small RTT in WLAN, packet traveling through the new link(3G) with large RTT may not arrive at the TCP sender before RTO, causing a precocious timeout. This timeout initializes congestion window(CWND) to 1 right after UVHO as shown in Figure 1 (b).

Lim and Jang[1] use two probe packets to verify the UVHO situation of the TCP receiver. If the TCP sender realizes the UVHO situation, the TCP sender sets the

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CWND size as the same CWND before timeout event occurs. Ko and An[2] use the TCP Westwood algorithm to estimate available bandwidth and if the TCP sender realize the sudden change of available bandwidth, the TCP sender adapt CWND size to the available bandwidth gradually.

Lim and Jang[1], however focus only on the removal of the abnormal behavior after UVHO. They did not consider low link capacity of the new link while our scheme takes one step further to adjust CWND size to the new link capacity. Ko and An[2] did not suggest actual UVHO mechanism. As a result they did not consider the unnecessary congestion control caused by RTT difference between the old link and the new link after the UVHO. On the other hand we propose an effective UVHO mechanism to prevent unnecessary congestion control. We adopt a new signaling called HO Information Inform Message. This message includes available bandwidth and buffer size of the new link. The TCP sender uses this information to estimate appropriate CWND size for the new link. In addition we devise a scheme to estimate the RTT for the new link. The RTT cannot be delivered by IEEE 802.21 MIHF since it is allowed to convey only static information about the link such as maximum data rate, QoS support and AP's buffer size to the MN. The RTT belongs to dynamic information which cannot be delivered by IEEE 802.21 MIHF[3]. In Section 3.2 we show a new scheme to estimate RTT of the new link using the timeout during UVHO and the arrival time of the ACK which travels through the new link.

The remainder of this paper is organized as follows. We review the IEEE 802.21 MIHF message flow in section 2. In section 3, we propose a new TCP algorithm to improve the performance and we present the performance evaluation in section 4. Finally we conclude this paper in section 5.

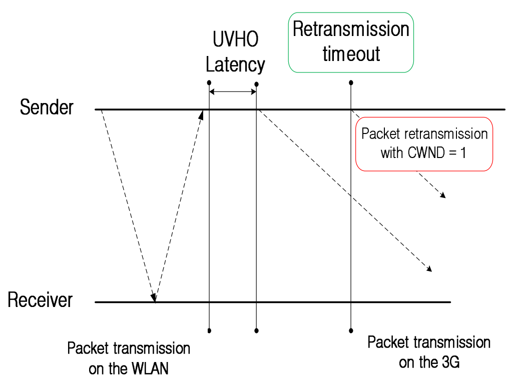

Fig. 1(a). The TCP sender suffers from the unnecessary congestion control after the UVHO.

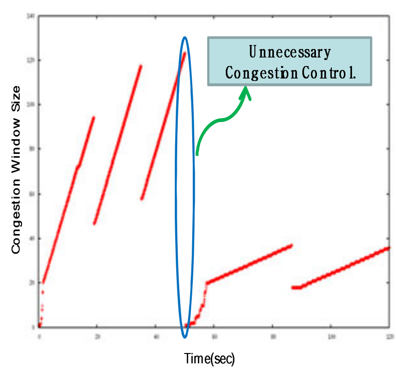

Fig. 1(b). Reduction of the CWND caused by unnecessary congestion control.

2 IEEE 802.21 MIHF

IEEE 802.21 MIHF(Media Independent Handover Function) provides MNs a framework for efficient handover between the different access networks[3]. Figure 2 shows an IEEE 802.21 MIHF message flow in mobile-initiated handover from a

WLAN to the 3G cellular network. First, the MIHF on the MN sends Information Request message to IS(Information Server) to gather static information about surrounding networks, e.g. maximum data rate, QoS support and AP's buffer size.

After receiving the Information Response from the IS, the MN queries about the availability of resources in the network which is recommended by serving PoA(Point of Access). This Query Request message is sent through the serving PoA and the Query Response message is also sent through the serving PoA.

If MIHF on the MN decides to perform handover to the target network after receiving the Query Response message, it sends a HO Commit Request message. After receiving the final HO Commit Response message from the target network, the MN establishes a Layer 2 connection with PoA of the target network. The 3G cellular network is the target network in Figure 2. HO Complete Request/Response message is exchanged following the successful handover. Resources which are used in the previous link are released in this step.

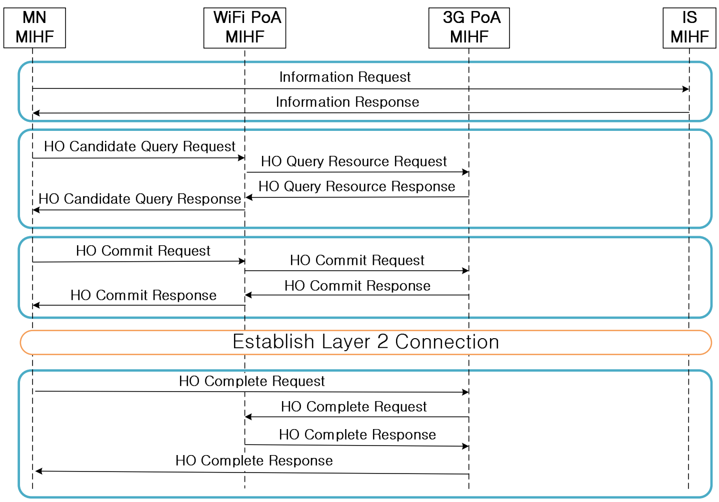

Fig. 2. IEEE 802.21 assisted Handover message flow

3 Proposed Scheme

IEEE 802.21 MIHF[3] provides a handover mechanism between different wireless access networks which may have different handover policies. Using IEEE 802.21 MIHF each MN can perform handover without service interruption. However there is no consideration about the high layer performance, e.g. TCP performance.

Although the TCP receiver performs UVHO successfully without service interruption, the TCP sender faces the problem as we mentioned in section 1. The TCP sender performs the unnecessary congestion control due to precocious timeout caused by the difference in RTT after UVHO. Thus, TCP throughput is degraded.

To solve this problem, we propose a new IEEE 802.21 MIHF message flow as well as a modified TCP scheme.

3.1 Proposed IEEE 802.21 MIHF Message Flow

Figure 4 presents the proposed IEEE 802.21 MIHF message flow in mobile-initiated handover procedure from a WLAN to the 3G cellular network(UVHO). Mobile Node(MN) is assumed to be the TCP receiver here. When the layer 2 connection to new link(3G) is established MN send ACK packets through the new link with 'HO option field = 1'. We make MN acquire information about available bandwidth and AP's buffer size of the new link using HO Query Request/Response procedure and Information Request/Response procedure. We also adopt a new signaling called HO Information Inform Message. This message includes available bandwidth and buffer size of the new link. The TCP sender uses this information to estimate appropriate CWND size for the new link. The detailed algorithm is explained in the next section. However, RTT for the new link cannot be delivered by IEEE 802.21 MIHF since it is allowed to convey static information about the link such as maximum data rate, QoS support, and AP's buffer size. The RTT belongs to dynamic information which cannot be delivered by IEEE 802.21 MIHF[3]. In Section 3.2 we show a new scheme to estimate RTT of the new link using the timeout during UVHO and the arrival time of the ACK which travels through the new link.

3.2 Proposed TCP Scheme

As we mentioned above, when MN performs the UVHO, the TCP sender may suffer from precocious timeout because the current RTO was set according to the small RTT of the WLAN while RTT of the new link(3G cellular) is larger. After UVHO, the ACK packet travels through the new link and arrives at the TCP sender much later than expected by the current RTO, resulting in retransmission timeout as indicated in Figure 3. As a result, although there is no congestion, the TCP sender initializes CWND to 1. To solve this problem we propose a new TCP scheme in which we estimate the RTT for the new link using the interval from the instant the last packet before UVHO is sent to the instant the precocious timeout happened(Time 1 in Figure 3), the interval from the instant the precocious timeout happened to the instant that the ACK with HO option field = 1 arrived(Time 2 in Figure 3). Then we use Equation (3) to estimate RTT of the new link from Time 1, Time 2, and RTT of the old link(estimated RTT in Equation (3)). Following a brief description of our scheme as illustrated in Figure 3.

1. If MN(TCP receiver) performs the UVHO, it send an ACK packets with 'HO option field = 1' through the new link(3G cellular).
2. When the TCP sender encounters the retransmission timeout, set Time 1 as described above and also shown in Figure 3. The CWND size is initialized to 1.
3. When the TCP sender receives ACK packet with 'HO option field = 1', set Time 2 as described above and also shown in Figure 3. CWND for the new link is obtained using the static information delivered by proposed IEEE 802.21 MIHF message procedure. The details will follow. RTO for the link is obtained using the RTT for the new link which is obtained using Equation (3).
4. The TCP sender now uses new CWND size and RTO in congestion avoidance mode.

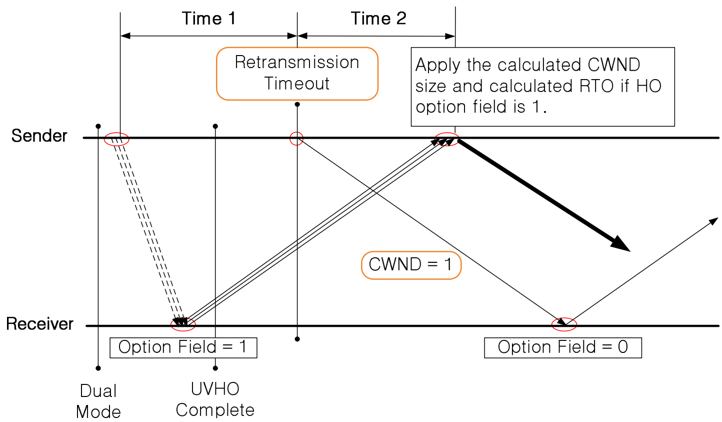

Fig. 3. Proposed TCP scheme

The new CWND size is obtained as follows.

$$C_{new} = BDP_{new}(\lambda_{new} + 1) \tag{1}$$

$$CWND_{new} = \frac{C_{new}}{Segment\ size} \times \frac{1}{2} \tag{2}$$

C_{new} and BDP_{new} denote the channel capacity and bandwidth delay product of the new link, respectively. λ_{new} represents a proportion of the size of AP buffer to the BDP of new link. For example, if BDP_{new} is 100 packets and the buffer size of new link AP is 50 packets, λ_{new} is 0.5. Only BDP is used to estimate channel capacity in [4]. However we include the size of the AP buffer based on the observation that the buffer size also affects the link capacity[5]. The TCP sender can obtain an available bandwidth and buffer size information using our proposed signaling in IEEE 802.21 MIHF as explained in section 3.1.

However, IEEE 802.21 MIHF cannot provide RTT of the new link since it belongs to dynamic information. Therefore we estimate RTT for the new link(RTT_{new}) using Equation (3).

$$RTT_{new} = \{(Time\ 1 + Time\ 2) - \frac{estimated\ RTT}{2}\} \times 2 \tag{3}$$

Estimated RTT in Equation (3) denotes the RTT for the old link. When the ACK with HO option field is 1 arrives, the TCP sender stops updating *Estimated RTT*. $CWND_{new}$ is set to half of the estimated CWND (as in Equation (2)) for conservative reasoning that the link capacity may change during UVHO and congestion may occur if we use the full size of the estimated CWND.

RTO for the new link is obtained as in conventional TCP implementations[6] using Equation (4) from the RTT_{new} in Equation (3).

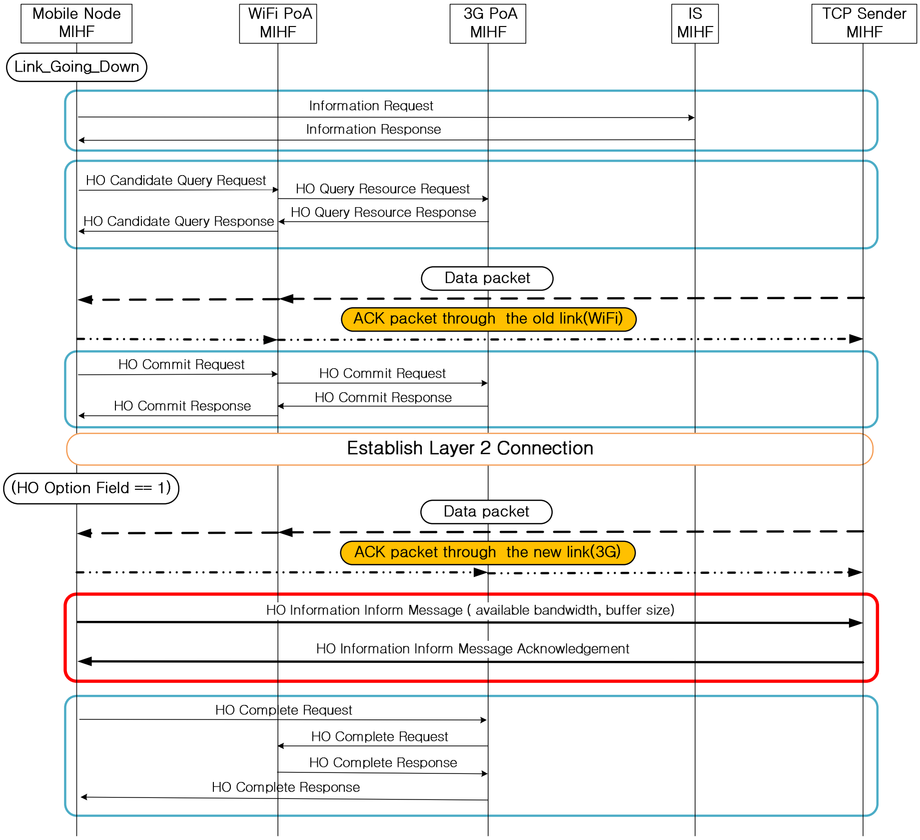

Fig. 4. Proposed IEEE 802.21 MIHF message flow

$$RTT_{dev} = (1-\beta)\times RTT_{new}$$
$$RTO_{new} = RTT_{new} + (4\times RTT_{dev}) = \{1+4\times(1-\beta)\}\times RTT_{new} \quad (4)$$

In our proposed scheme the TCP sender applies RTO_{new} as soon as it receives ACK packet with 'HO option field = 1'. Therefore our scheme prevents additional unnecessary congestion control which is caused by RTT difference between the old link and the new link.

4 Performance Evaluation

We performed a simulation of our proposed scheme as well as the TCP Reno and the Lim and Jang[1] using NS-2(Network Simulator-2)[7]. Bandwidth and end-to-end RTT of the old link(WLAN) are set to 10Mbps and 100msec, respectively while bandwidth and end-to-end RTT of the new link(3G cellular) are set to 1Mbps and 500ms, respectively. We summarized the simulation parameters in Table 1.

Table 1. Parameters used in our simulation

Parameter	3G cellular	WLAN
Packet loss model	Uniform random loss model with rate 0.1%	Exponential random loss model with rate 0.5%
Bandwidth	1Mbps	10Mbps
RTT	500ms	100ms
Router's buffer	20	50
Wired part		
bandwidth	100Mbps	
RTT	10ms	

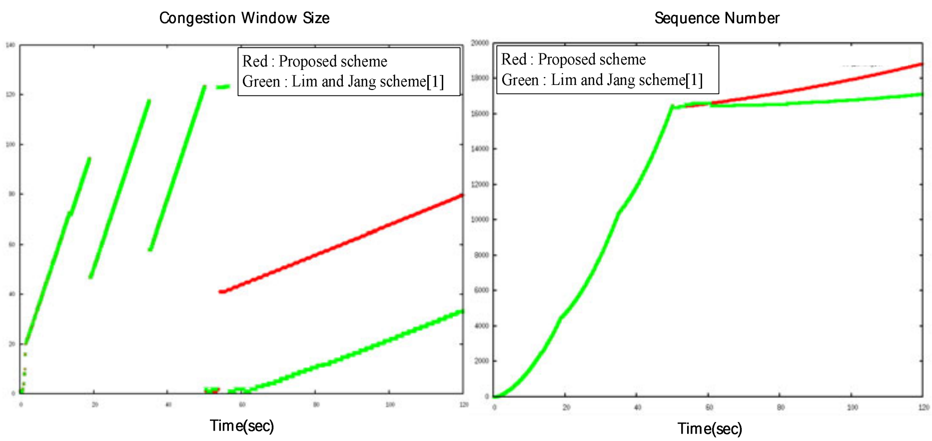

Fig. 5. The change of the CWND size and the sequence number

The performance of the TCP Reno is already explained in section 1. Therefore we analyze Lim and Jang[1] and the proposed scheme in this section. The performance of the Lim and Jang[1] and our proposed scheme are shown in figure 5. The UVHO is complete at 50s. After UVHO, our proposed scheme and [1] perform the congestion control because the TCP sender encounters the retransmission timeout event. So the CWND size is initialized to 1. In [1], after UVHO, the TCP sender sets up the CWND size as to the old CWND. This may result in second congestion control because the old CWND is too large for the new 3G cellular link. However our proposed scheme sets CWND size according the link capacity of the new link with safety margin as in Equation (2). As a result, our proposed scheme prevents the second congestion control. Thus our proposed scheme has better TCP performance than the Lim and Jang[1] as shown in Figure 5. The CWND is shown in the left of the Figure 5. Note that CWND after UVHO is initialized to 1 due to second congestion control in Lim and Jang[1] while it remains high since it is adapted to the new link in our scheme. As a result, the sequence number in our scheme grow faster than that of Lim and Jang[1].

5 Conclusion

We modified the TCP and IEEE 802.21 MIHF message procedure to improve the TCP performance over the UVHO from the WLAN to the 3G cellular network. As seen in our simulation results, our proposed scheme has better performance as compared with other schemes after UVHO. First, we proposed the new signaling based on the IEEE 802.21 MIHF. The TCP sender knows about the new link by receiving this information and we estimate CWND for the new link. So the TCP sender can adapt CWND size as soon as after the UVHO. Second, we estimate RTO for the new link using precocious timeout due to RTT difference during UVHO. This prevents additional unnecessary congestion control.

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