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Enhancement of packet reordering in a mobile stream control transmission protocol for a heterogeneous wireless network vertical handover

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Abstract. Future wireless access networks will be heterogeneous wireless network (HWN) environment which consists of various wireless technologies including universal mobile telecommunications system (UMTS) networks and wireless local area networks (WLAN). They are used together through vertical handover (VHO) to ensure global mobility and service continuity. The mobile stream control transmission protocol (mSCTP) layer supports dynamic association reconfiguration. This protocol allows mSCTP endpoints to dynamically add, change and delete IP addresses when the mobile node (MN) is switched between HWNs. During a mSCTP handover, the endpoints of the mSCTP are required to change the primary link from an old link to a UMTS into a new link to a WLAN. However, due to the disparity between UMTS/WLAN bandwidth, a packet reordering problem will occur when the MN of the mSCTP leaves to a new network. This packet reordering problem can then causes additional drawbacks such as impossibility of growing an mSCTP congestion window, unnecessary fast retransmissions, actual packet losses, and reduced efficiency of the receiving mSCTP. In this paper, we propose a packet reordering model (PRM) that is inserted inside the MN, and works as a special buffer of a large capacity with one input and one output port to receive all transmission sequence numbers (TSNs). It then forwards all incoming data chunks to the MN/WLAN networks after the VHO. The performance of the system is simulated and analyzed using NS-2 simulation tool. The simulation results show that the suggested model enhances the performance throughput and the congestion window of the conventional mSCTP through VHO by handling the packet reordering problem. In other words, the average performance throughout of the proposed PRM scheme is 181.48 Kbps or 16% increment compared to conventional mSCTP at 165.54 Kbps.

Keywords: Vertical handover, 3G, WLAN and UMTS, mSCTP, PRM

1. Introduction

Integration of third-generation (3G) cellular networks such as the universal mobile telecommunications system (UMTS) and wireless local area networks (WLAN) has been intensively investigated in recent years because of their complementary characteristics. IEEE 802.11 WLAN has been widely deployed in offices, homes, campus, airports and hotels given its low communication cost, high data rate (11 Mbits/s), and ease of deployment. However, a serious disadvantage of 802.11 is the small coverage area (up to 300 m) and low mobility [6,17]. The most known standards belong to the IEEE 802.11 WLAN family, which includes the popular 802.11b, the 802.11a and the 802.11g as shown in Table 1.

International Telecommunication Union (ITU) defines 3G as devices that can transfer data up to 384 Kbps. As comparison, the global system for mobile communications (GSM) bandwidth is up to 14.4 Kbps and general packet

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Table 1
IEEE 802.11 WLAN family

802.11	Date	Freq. Band and Mod.	Throughput (typical) (Mbit/s)	Net bit rate (Mbit/s)	Range (indoor) (m)
802.11b	October 99	2.4 GHz/DSSS	∼5	11	∼38
802.11a	October 99	5 GHz/OFDM	27	54	∼35
802.11g	June 03	2.4 GHz/DSSS or OFDM	∼22	54	∼up to 100

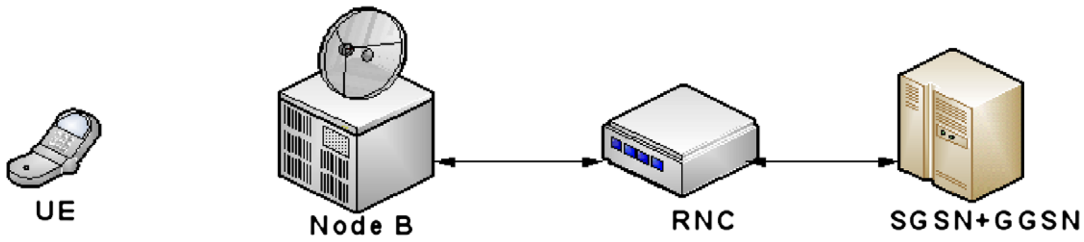

Fig. 1. UMTS architecture. (The colors are visible in the online version of the article.)

radio service (GPRS) bandwidth is around 53.6 Kbps. Both are used in 2G and 2.5G, respectively [6]. UMTS is a 3G wireless protocol that is part of the ITU. UMTS is expected to deliver low-cost, high-capacity mobile communications, offering data rates of about 1 Mbps. The wireless radio access network for UMTS contains user equipment (UE) and UMTS terrestrial radio access network (UTRAN), which includes the node-B and radio network controller (RNC) [6,17,21]. The packet domain core network includes the serving GPRS support node (SGSN) and the gateway GPRS support node (GGSN) as shown in Fig. 1.

The complementary characteristics of UMTS and WLAN suggest the possibility of combining these two wireless technologies. WLANs offer low mobility with much higher data rates compared to mobile nodes and a low communication cost over a geographically small area, while UMTS networks provide relatively low data rates with high connectivity and high mobility to mobile nodes but the communication cost is relatively high [6,17,21]. To achieve an ongoing continuous connection for a mobile node (MN) that leaves across the heterogeneous wireless network (HWN) regions a vertical handover (VHO) is required. This is contrary to horizontal handover (HHO) that is occurred between homogeneous networks of a wireless access system.

The type of handover between UMTS and WLAN networks is known as a VHO [15]. This VHO provides seamless internet access for the MN that switches from one wireless network to another as shown in Fig. 2. Towards this end, some new mechanism for smooth mobility management is needed to reduce the long VHO latency between UMTS/WLAN networks. The radio resources must be professionally treated to guarantee the delivery of data between two MNs between UMTS/WLAN networks. Thus, VHOs are executed across various wireless networks, which differ in several aspects such as communication cost, bandwidth, frequency of operation and data rate. To support the ongoing VHO research into UMTS/WLAN networks, the stream control transmission protocol (SCTP) was previously proposed to minimize transition time during VHO over HWNs [2,5]. In particular, SCTP has a highly reliable transport layer protocol which is placed at the side of the user datagram protocol (UDP) and transmission control protocol (TCP) [11,12,16,18]. It provides ordered delivery and stability of data between two endpoints similar to UDP and TCP. Unlike UDP and TCP, the SCTP offers such advantages as multihoming and multistreaming capabilities.

A multihoming host can use more than one network layer address to communicate. For a MN, it can use multiple network interfaces simultaneously. If the primary path fails, the protocol will send traffic over the alternate path. Multistreaming can be used to deliver multiple objects (webpage, audio, video and text) that belong to the same association independently. Each stream is given a stream number that is encoded inside SCTP packets flowing through the association. Hence, SCTP enables its endpoints to be installed across multiple wireless interfaces that are recognized by many IP addresses [4]. SCTP usually transmits data chunks to a destination IP address appointed by the main address. It can redirect the data chunks to an alternative IP address if the main IP address becomes

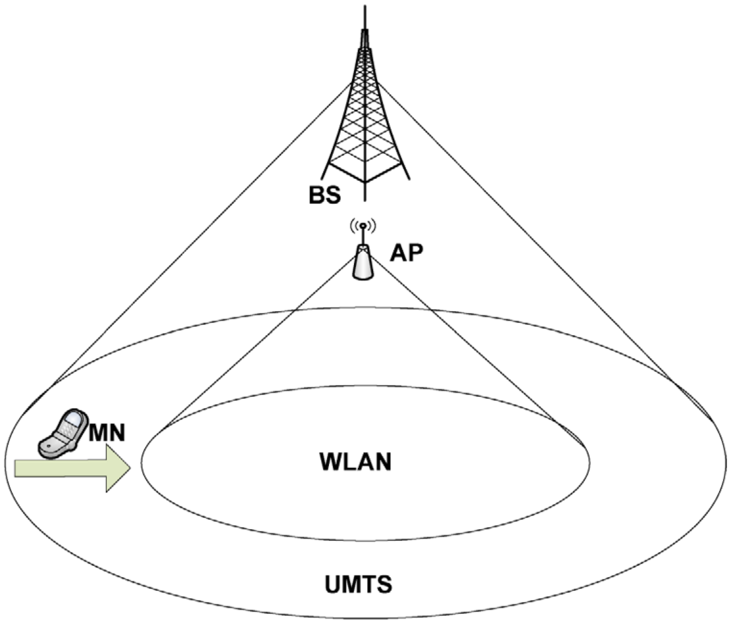

Fig. 2. Vertical handover heterogeneous network. (The colors are visible in the online version of the article.)

unreachable. The link between two MNs that employ the main IP address is known as the main link and the link between two MNs using an alternative IP address is known as the secondary link. Note that two MNs in SCTP can have only one main link, but more than one secondary link. This kind of data session is explained in SCTP [4,11,12,18,19].

In order to support ongoing VHO research into UMTS/WLAN networks, a mobile SCTP (mSCTP) has recently been proposed by internet engineering task force (IETF) [11,12]. The mSCTP VHO supports dynamic address reconfiguration (ASCONF), which allows the MN to dynamically add, change and delete IP addresses when MN travels between HWNs. However, in such different wireless network technologies, the radio interface may have asymmetric features that lead to the degradation of reception of the data chunks between the MNs. This results in packet reordering problem. In mSCTP VHO, the packet reordering problem can arise from the disparity between the propagation delay and the bandwidth between UMTS/WLAN networks when MN moves across them. Moreover, this packet reordering problem leads to additional negative side effects such as the impossibility of growing an mSCTP congestion window, actual packet losses, unnecessary fast retransmissions and reduced efficiency of the receiving mSCTP [9,14].

There are some recent approaches aimed to overcome the mSCTP handover drawbacks in HWNs. Ma et al. in [14] presented a new method to make possible the VHO between wide region cellular data networks such as UMTS and WLANs employing SCTP. The dynamic address configuration extension and multihoming capability of SCTP has been used in the overlay architecture of UMTS/WLAN to reduce the VHO delay and to improve throughput performance. Experimental results show that the suggested scheme can avoid the problem of a long latency during VHO, particularly when using the dual-homing SCTP configuration.

Keun et al. in [9] present an SCTP Efficient Flow Control (SCTP-EFC) mechanism through a VHO by enabling a mobile client to freely switch between IP addresses acquired in different networks. The SCTP-EFC reduces the change of traffic data rates and improves the throughput performance significantly during a VHO. The result shows that SCTP-EFC adjusts to a network wireless environment after VHO and gives a throughput enhancement for a few seconds after a VHO.

Seok et al. in [3] dealt with the packet reordering problem which occurs during the mSCTP handover. However, the researchers only focused on the unnecessary retransmission at the endpoints of the mSCTP. They solved this problem by using a new model in the corresponding nodes (CN) to resend the outstanding data chunks before sending the newly generated data chunks across the new link. Huang et al. in [8] proposed a solution to avoid the packet reordering problem using a mobile multipath SCTP (m^2-SCTP) that allows a MN that desires to send data to use UMTS/WLAN multiple paths. The result shows that m^2-SCTP achieves a throughput enhancement during a VHO.

In this paper, we propose a packet reordering model (PRM) to solve the packet reordering problem that is inherent in the mSCTP VHO between MNs by increasing the congestion window (CWND) of the conventional mSCTP in a HWN. This new PRM scheme is used to hold all the outstanding data chunks. They are then forwarded to the MN if it becomes free during the round-trip time (RTT) interval. After that the CWND will be increased when mSCTP MN moves across UMTS/WLAN networks. The simulation results show that the proposed PRM scheme has a higher performance throughout in the mSCTP VHO and has a larger CWND than the conventional mSCTP. In other words, the proposed PRM model has an advantage in some aspects; increasing the throughput by about 16% compared to the conventional scheme, reducting the VHO delay and achievement of seamless VHO.

The rest of this paper is organized as follows: Section 2 discusses the mSCTP handover while Section 3 introduces the packet reordering problem during a vertical handover. Section 4 covers the packet reordering model work to enhance the vertical handover between UMTS/WLAN networks. Simulation of the proposed approach is presented in Section 5. Finally, we conclude the paper in Section 6.

2. Mobile stream control transmission protocol (mSCTP) handover

The mSCTP is an order of data packet delivery between two endpoints. It has a highly reliable transport layer protocol that provides stability (similar to TCP) and also preserves the boundaries of the data message (similar to UDP). However, unlike TCP and UDP, mSCTP offers advantages such as the capabilities of multihoming and multistreaming, which both enhance reliability and availability. The mSCTP with dynamic association reconfiguration (DAR) allows IP addresses to be added and removed from an SCTP association, meaning that data packets can then be transmitted to the new destination. Through the VHO, the endpoints of the mSCTP are needed to change the main link from the old link of cellular UMTS network to a new link of the UMTS network as shown in Fig. 3.

Figure 3 shows the mSCTP VHO between UMTS/WLAN networks, where the MN first travels into the WLAN and then leaves away again from it. We consider the MN that initiates an mSCTP data session with any CN. The following steps are executed when the MN travels into a WLAN network [19]:

Step 1: Obtain an IP address for a new location from the new access router of the WLAN by transmitting an mSCTP address configuration change ASCONF data chunk. The MN may receive a replying ASCONF-ACK data chunk from the CN.

Step 2: Change the main IP address by transmitting an ASCONF data chunk with a set main IP address. In response, the CN replies with an ASCONF-ACK data chunk.

Step 3: Delete the old IP address after the MN moves away from the coverage of the WLAN network by transmitting an ASCONF data chunk with a delete IP address. The MN receives the ASCONF-ACK data chunk reply from the CN [4,11,12,14,19].

3. Packet reordering problem during a VHO

When an mSCTP MN moves across UMTS/WLAN networks, the MN should change its main link to a new link with the WLAN with a higher data packet rate and/or lesser transmission delay. Unexpected packet reordering may occur due to the disparity of propagation delay and bandwidth between UMTS/WLAN networks [3,8]. Packet reordering in a UMTS/WLAN network VHO is caused by the data chunks that are transmitted using the cellular UMTS link may arrive at the WLAN before VHO. It is also possible that these data chunks may arrive later than the data chunks that are transmitted using the link of the WLAN after VHO. This scenario is shown in Fig. 4.

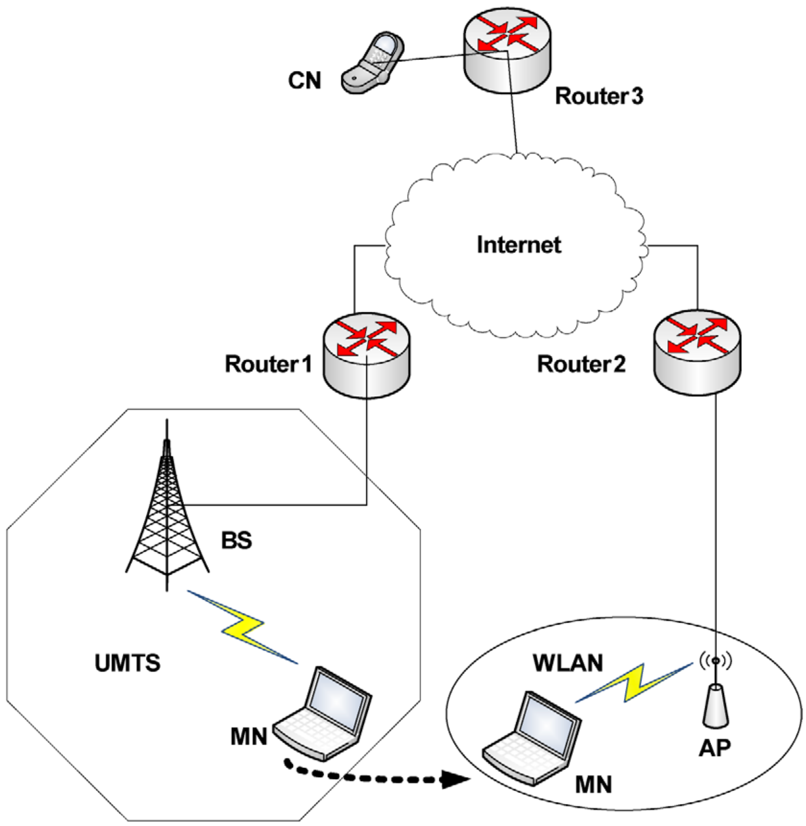

Fig. 3. Vertical handover between UMTS/WLAN networks. (The colors are visible in the online version of the article.)

The packet reordering problem then causes additional negative side effects such as the impossibility of growing an mSCTP CWND, unnecessary fast retransmissions, packet losses and reduced efficiency of the receiving mSCTP. Note that the packet reordering problem is occurred only when an mSCTP MN moves from UMTS network to WLAN network. This is because the data rate of UMTS network is smaller than WLAN data rate.

For example, the four data chunks of transmission sequence number (TSN) such as TSN1, TSN2, TSN3 and TSN4 are sent from the CN to a MN/UMTS during which the link become congested before the VHO as shown in Fig. 4. We assume that the MN moves from a cellular UMTS to a WLAN network where an IP1 address was used in the cellular network of the UMTS and an IP2 address is used in the WLAN network. Hence, these four data chunks (TSN1, TSN2, TSN3 and TSN4) are transmitted before the main link is changed from the UMTS-IP1 to the WLAN-IP2 address [10,13]. After the main link is changed, the CN transmits two new data chunks (TSN5 and TSN6) to the new destination of the MN/WLAN, which has much better conditions than the old link of the cellular UMTS. Since the traffic data rate of the WLAN is much better than that of the cellular UMTS, therefore, the two data chunks (TSN5 and TSN6) may reach at the WLAN sooner than the four data chunks (TSN1, TSN2, TSN3 and TSN4), which will cause a packet reordering problem. Moreover, the problem of packet reordering may reduce the CWND for the WLAN-IP2 address and degrade the utilization of the mSCTP VHO [20].

4. Proposed packet reordering model (PRM)

To solve the packet reordering problem, we propose a PRM in which the MN can enhance the VHO performance and the CWND of a conventional mSCTP in HWNs. This new scheme of PRM is used to hold all the outstanding

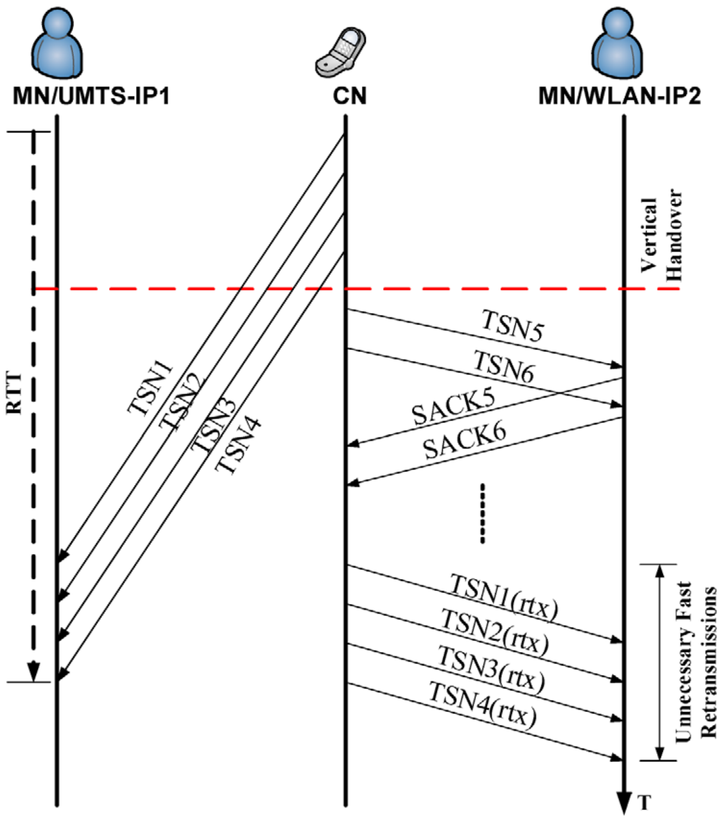

Fig. 4. The packet reordering problem caused by changing the main link to the alternate link. (The colors are visible in the online version of the article.)

data chunks. They are then forwarded to the MN if it becomes free during an RTT interval. After that the CWND will be increased when the mSCTP MN moves across UMTS/WLAN networks. The PRM works as a special buffer that has a large capacity with one input and one output port to receive and hold all TSNs during the VHO. It will then forward all incoming data chunks to the MN/WLAN-IP2 after the VHO.

Figure 5 shows the algorithm used in a PRM to solve the packet reordering problem and avoid reduction of CWND when VHO occurs. After VHO occurs the PRM has information about all the outstanding data chunks. If these outstanding data chunks arrive when the retransmission timer expires, the PRM holds the outstanding data chunks and forwards them to the MN if it becomes free during an RTT in order to avoid a reduction of the CWND. Otherwise, the outstanding data chunks will prompt the PRM to initialize two jobs. First, it sends an acknowledgment to the CN to retransmit the outstanding data chunks, and it also increases the CWND by an amount greater than the slow start/avoidance congestion mode by the number of the outstanding data chunks. The second job is to avoid the reduction of the CWND where the PRM repeats the previous hold/forward procedure.

Slow start and avoidance congestion are modes that mSCTP uses to control congestion inside the network. When a MN begins to send data it is required to use the slow start algorithm at the beginning of the transfer. The congestion is controlled by increasing the mSCTP congestion window for each acknowledgment that is received. The value of CWND is increased by one TSN. It continues until either the CWND reaches the maximum window size or packet loss is detected. In contrary, the avoidance congestion mode deals with packet loss which occurs due to congestion of a network. When the maximum window size is reached, the avoidance congestion mode will increase the CWND by one TSN for each RTT.

In part A of Fig. 5, the CN labels all the outstanding TSN_n by employing the added variable "out_ TSN_n" added by the proposed scheme when it receives the data chunks of the ASCONF. Part B shows an "out_counter"

(A) Corresponding Node (CN) Side Behaviour
To determine the outstanding TSN_n When vertical handover occurs
On receipt of vertical handover *ASCONF_ACK* data chunk
for each outstanding TSN_n do
out_TSN_n = **TRUE**
end
(B) Packet Reordering (PRM) Model Side Behaviour
To calculate the amount of outstanding TSN_n that are sent before vertical handover occurs
reset $out\_counter = 0$
for each outstanding TSN_n
increment *out_counter* by 1
end
To handling the outstanding TSN_n that arrived before expiration of retransmission timer occurs
for each outstanding TSN_n
if outstanding TSN_n receipt before expiration of retransmission timer occurs
add *ack* of outstanding TSN_n into next SACK
decrease *out_counter* by 1
hold outstanding TSN_n then forward it to MN if it becomes free
end
end
(C) CN Side Behaviour
On receipt the currant *SACK*
Increment congestion window *(CWND)* by slow start/congestion avoidance mode + *out_counter*
Sent the newly data chunks and retransmission the outstanding data chunks
(D) PRM Side Behaviour
for each TSN_n
if out_TSN_n = **TRUE**
hold TSN_n then forward it to MN if it becomes free
end
eals forward TSN_n to MN
end

Fig. 5. Algorithm of the proposed PRM scheme.

variable is employed to compute the amount of outstanding TSN_n that are sent before VHO occurs. This part is used to handle the outstanding TSN_n that arrived before the expiration of the retransmission time occurs. Part C explains the growth of the CWND by the slow start/avoidance congestion mode plus the "out_counter" variable when the CN receives the current selective acknowledgment (SACK). SACKs have three functions; acknowledge data received, track the RTT of a path which is used calculate the retransmission timeout (RTO), and monitor the status of each path. In this part, the CN will transmit the new created data chunks and retransmit all the outstanding TSNs to the MN/WLAN-IP2 address when expiration of retransmission time occurs. In part D, the PRM checks whether the TSN_n are new or outstanding data chunks in order to forward or hold/forward respectively when the MN becomes free. In this way, unnecessary CWND reductions and possibly unnecessary fast retransmissions can thus be avoided. To help illustrate the proposed PRM scheme, the procedure can be summarized as shown in Fig. 6.

5. Performance of PRM over mSCTP VHO

This section presents performance analyses of the proposed PRM scheme which are simulated using the NS-2 network simulator version 2.29 [7]. The SCTP module for our simulation is taken from the University of

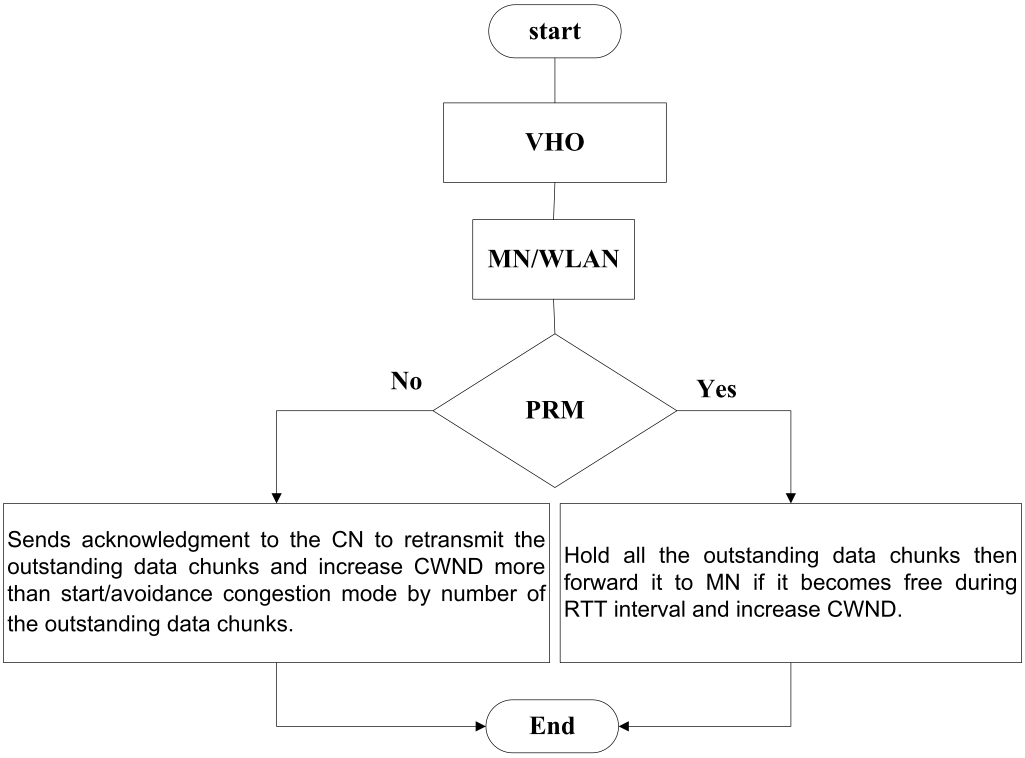

Fig. 6. Flowchart of the procedure of PRM when VHO occurs in UMTS/WLAN networks.

Table 2
Network parameters

Network parameters	UMTS	WLAN
Bandwidth	384 Kbps	10 Mbps
Transmission delay	25 m/s	15 m/s
MN's speed	25 m/s	25 m/s
Wireless network coverage	radius 2000 m	radius 100 m
Fixed links between CN	10 Mbps	10 Mbps
RSS	−50 dBm	−70 dBm

Delaware [1]. In addition, the following parameters listed in Table 2 are configured in our proposed scheme for the VHO in HWNs. Figure 7 shows the throughput performance for a VHO when a MN moves into a WLAN area and then adds the new IP address from the WLAN where the CN changes the WLAN link to a primary transmission link. This figure compares the throughput of a conventional mSCTP and the proposed PRM scheme with the same operational conditions, and with a packet delivery time interval of between 20 and 40 s. It can be observed that in all scenarios after VHO in the UMTS/WLAN networks, the PRM provides a clear throughput improvement from 21 to 30 s compared to the conventional mSCTP. It indicates that in a WLAN area the PRM scheme has a higher performance throughout in the mSCTP VHO and a larger CWND than the conventional mSCTP. The average performance throughout the proposed PRM scheme is 181.48 Kbps compared to the conventional mSCTP which is 165.54 Kbps. In other words, our proposed model outperforms the conventional mSCTP by about 16%. The proposed PRM scheme achieves the same performance as the conventional mSCTP scheme with a time of 30 s as the PRM is handling all outstanding data chunks at that time.

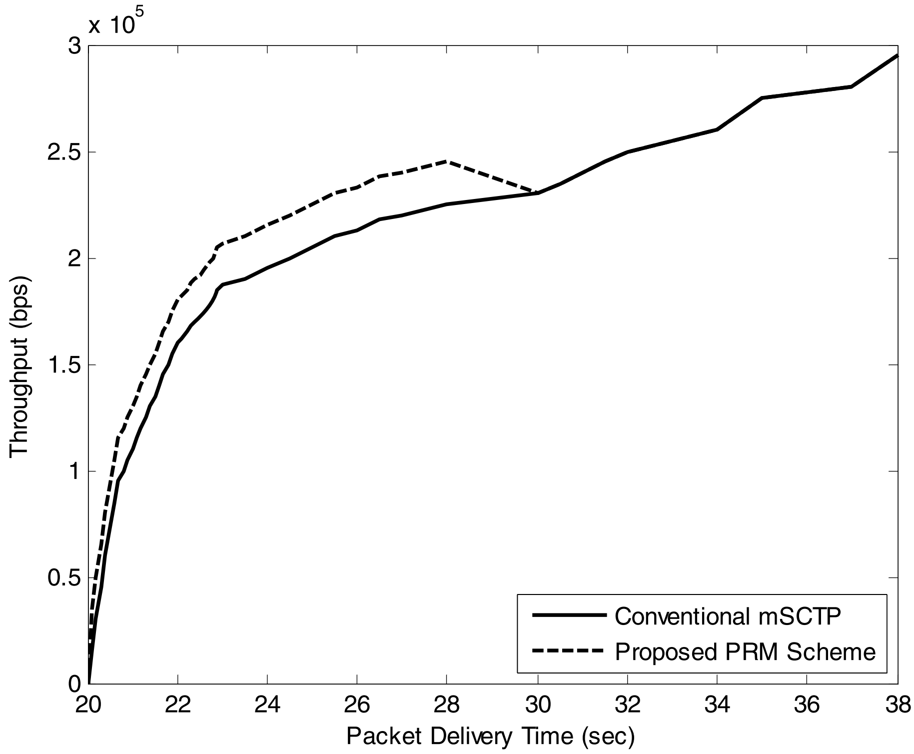

Fig. 7. Throughput of conventional mSCTP and proposed PRM scheme.

We also compare the performance of our proposed PRM scheme with the conventional mSCTP in terms of the CWND which is shown in Fig. 8. The abscissa (x-axis) denotes the packet delivery time and the ordinate (y-axis) denotes the CWND. When the MN sends data chunks using the UMTS link at the beginning, the CWND of the UMTS link is increased by nearly 65,000 bytes before VHO occurs. At time of 21 s, the MN performs a handover to the WLAN link where the mSCTP or the proposed PRM scheme association switches its main link to the WLAN link. In this condition, the ongoing conventional mSCTP association is changed to a slow-start phase because the congestion window and slow-start threshold will be set to half in the WLAN link. Thus, this transmission rate degradation is caused by the VHO as a result, while the proposed PRM scheme shows an enhancement in CWND even after VHO because it does not suffer the initial slow-start phase. On the other hand, the proposed PRM scheme skips the slow-start phase by using the hold/forward procedure. As shown in Fig. 8, it can be observed that our proposed model provides a clear enhancement in CWND compared to the conventional mSCTP during VHO between 21 and 30 s.

In general, the proposed PRM scheme can solve the packet reordering problem during VHO. Through the simulation results, we found that our proposed PRM scheme has the following features:

- It introduces about 16 percent enhancement in performance throughput over the conventional mSCTP scheme.
- It handles all outstanding data chunks at time 30 s.
- It skips the slow-start phase at time 21 to 30 s.

6. Conclusions

During an mSCTP VHO in HWNs, the endpoints of the mSCTP will change from the old link of using UMTS to a new link using a WLAN. Due to the disparity between UMTS/WLAN bandwidth, the packet reordering problem

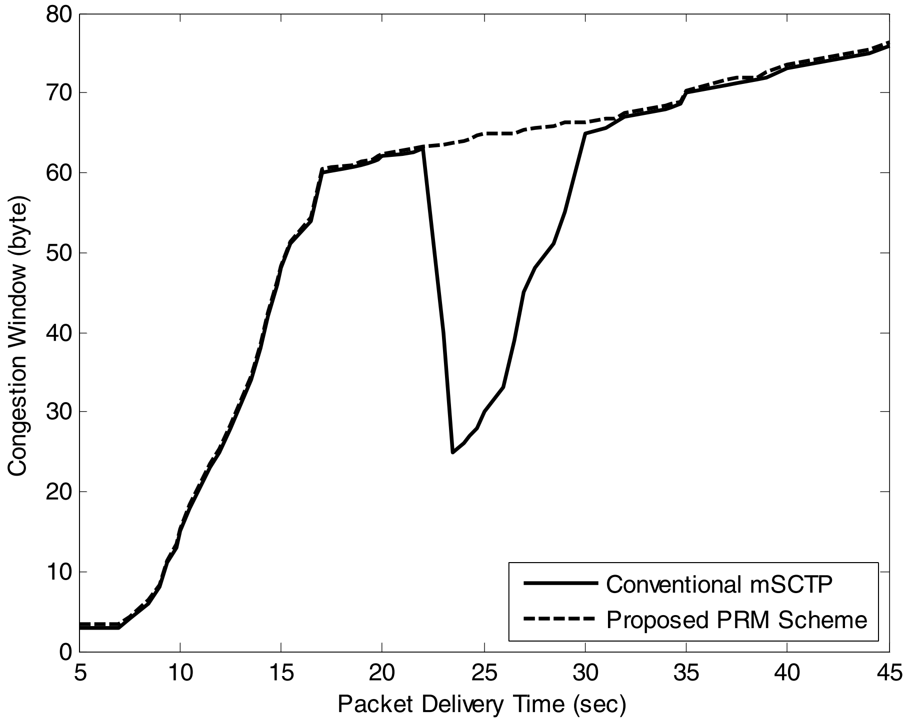

Fig. 8. The Congestion windows of conventional mSCTP compared with the proposed PRM scheme.

will occur when the MN of an mSCTP moves to new network. To overcome this packet reordering problem a new model of PRM in the MN is proposed in this paper. The proposed PRM scheme will hold all the outstanding data chunks and then forward it to the MN if it becomes free during an RTT interval. The CWND is increased to more than slow start/avoidance congestion mode by the number of the outstanding data chunks. Simulations results show that the proposed PRM scheme gives the following advantages: increases the throughput by about 16% to outperform the conventional mSCTP scheme, reduces the VHO delay and achieves a seamless VHO. It also shows that the CWND is enhanced by several seconds because it skips the slow-start phase after VHO.

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