CLAMP: Cross-Layer Multi-Path Transmission Mechanism for Seamless Handover over Heterogeneous Networks

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Abstract- Major research challenges in the next generation of wireless networks include the provisioning of fast vertical handoff across heterogeneous network and the improvement of end-to-end quality of service (QoS). There are two major issues which how to reduce handoff latency and packet loss rate during UMTS/WLAN handoff. In this paper, we introduce a cross-layer mobility management solution which was called a CLAMP (Cross-layer Multi-Path) scheme with the mobile Stream Control Trans-mission Protocol (mSCTP). Our fast vertical handoff approach uses the concept of relay in cooperative technique that get handoff information in anticipation to speed up the net-work layer movement detection process and the multi-homing features of SCTP so that a mobile device can have multiple IP addresses during the vertical handoff. Further, this paper compares all kinds of variants schemes and analyzes these handoff mechanisms in detail. Finally, the simulation results are presented to demonstrate the effectiveness of the proposed scheme.
Keywords – Handoff, Heterogeneous, mSCTP, Cross-layer, Relay-based

I. INTRODUCTION

With the rapid development of wireless technologies, the wireless network has become more and more popular. In the next generation wireless network, coexistence of heterogeneous wireless networks offering services at anytime and anywhere is a necessary trend. The future network architecture is expected to converge into an all-IP architecture, which includes different wireless access networks such as 4G/5G cellular networks, WLAN, Bluetooth, mobile ad hoc network (MANET), WiMAX, and ultra-wideband (UWB) systems. On the other hand, every mobile device should have multiple interfaces to connect different wireless network in the future, and the device would select an appropriate network to use. The integration of WLAN hotspots and third generation (3G) cellular network has recently received much attention [14]. Figure 1 shows the integrated architecture between 3G and WLAN. While the 3G network provides global coverage with low data rate service, the WLAN provides high data rate service within the hotspots.

When user equipment (UE) roams to foreign network from home network, the UE must execute the handoff procedure. Handoff can be classified two kinds: one is horizontal handoff which occurs in the same network type, another is vertical handoff which occurs among the different wireless network technologies. This paper addresses vertical handoff between 3G network and WLAN. IP is employed as the common network layer protocol. In order to allow the UE roaming among different heterogeneous networks and keep the connection without breaking, the Internet Engineering Task Force (IETF) Mobile IP working group proposed the solution of network layer, Mobile IP (MIP)[1][2]. But in this integrated architecture, Mobile IP based vertical handoff management increases the heterogeneous system signaling cost as well as handoff latency. One of the major challenges for seamless mobility in next-generation heterogeneous networks is vertical handoff, which is the process of maintaining a mobile user's active connections as it changes its point of attachment.

Stream Control Transmission Protocol (SCTP) [7] is the transport layer protocol, and the feature of multi-homing enables it to support the IP mobility. Because the SCTP endpoint can simultaneously bind multiple IP addresses, the session is lost on the primary path, SCTP will seamlessly exchange to the other paths. The mobile SCTP (mSCTP) [8] is the SCTP with the ADDIP extension and provides seamless handoff during the ongoing session. mSCTP allows the endpoint to add, delete and change the IP addresses dynamically. In Li Ma et al. [6], the proposed method facilitates seamlessly vertical handoff between UMTS and WLAN using SCTP. But the mSCTP only provides handoff management in transport layer, mSCTP does not provide location management. Figure 2 shows mSCTP maybe suffer some problems. A peer is communicating with UE, called a correspondent node (CN). Let CNi denote CN i, i=1, 2,..., n. The CN1 is communicating with UE. When the UE moves into the new access network, the UE can get new IP address. The UE notify the CN1 of its new IP address by sending an ASCONF message. If the new CN2 want to transmit data to the UE, the CN2 is only finding out the old IP address of the UE and resulting in transmission failure. Therefore, the mSCTP is hard to use alone and provide low handoff latency [9].

The seamless handoff across the different wireless networks is becoming increasingly important. In order to achieve seamless vertical handoff in heterogeneous network environments, it is necessary to guarantee service continuity and quality-of-service (QoS), which means low latency and low packet loss during handoff. But the Mobile IP has too long handoff latency to support real-time service. Thus conventional handover schemes have been proposed by using pre-registration or post registration method, which can reduce the handoff delay. Because these schemes separate layer 2 and layer 3 handoffs and perform the layer 3 handoff earlier or later than the layer 2 handoff. However, handoff procedure not only includes the registration procedure but also the procedures of authentication and connection setup with a new network are required. The mobile device cannot receive enough handoff information from a new access network to complete all handoff procedures before attachment with the new network. Choi et al. [20] proposed the vertical handoff scheme which uses the pre-registration mechanism to reduce packet loss during UMTS/WLAN handoff. Although the pre-registration scheme uses the larger buffer to reduce packet loss, this scheme may cause the out-of-order problem.

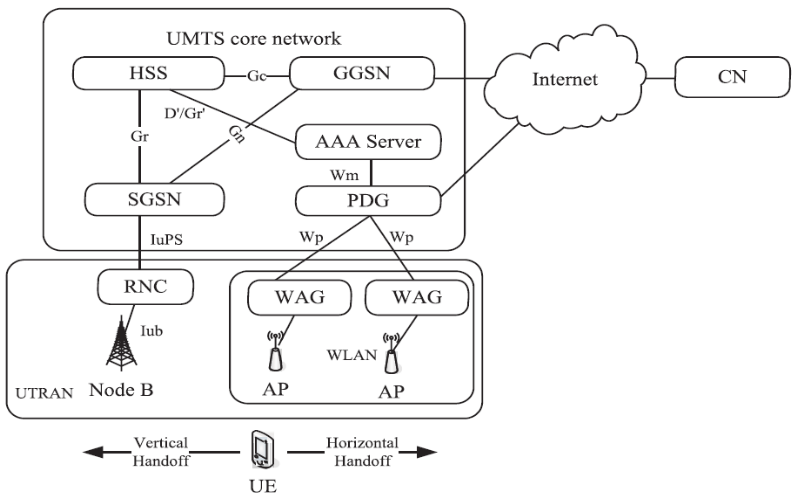


Figure 1: Network architecture: Interworking between UMTS and WLAN.

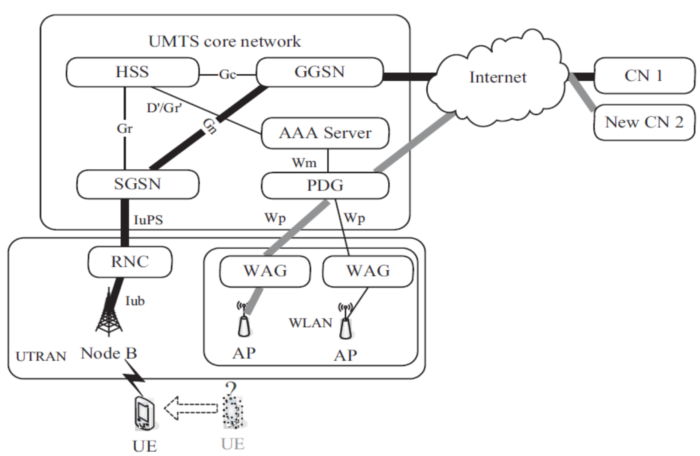


Figure 2: Disadvantage of mSCTP: Lack location management.

In cooperative network, there are many advantages in relay technique: solve the base station coverage problem, provide fast deployment, fewer infrastructures requirement, power consumption reducing, high transmission rate due to the short transmission range, higher throughput, and traffic load balance. The new architecture was proposed [3][4][5][12][16][19], and they proposed the integrated architecture of cellular and mobile ad hoc networks (MANETs). The idea of integrating MANETs with infrastructure networks is motivated not only by traffic load reduction in the BSs/APs and improving the overall throughput, but also by providing higher connectivity to the

UEs. However, these articles did not discuss the handoff problem, because they assume that all of the UEs are in the same signal coverage. Chao et al. [17] proposed the pre-binding and bi-casting scheme to reduce packet loss at a high speed handoff rate in the integrated architecture of cellular and MANET. However, their schemes focus on only the handoff procedures through multi-hop re-lay and do not consider the detailed discovery procedures of relay node needed for handoff. In the handover schemes using the multi-hop concept, the fast route discovery is more important because the long discovery time can have a bad influence on the handoff performances.

Candidate Access Router Discovery (CARD) protocol [10] and Context Transfer Protocol (CTP) [11] were designed by the IETF Seamoby working group to support connection to be seamlessly exchanged during handoff. These protocols allow user equipment to discover information about the access router (AR) candidates for the handoff. Every AR maintains a neighbor candidate AR (CAR) table where the link layer IDs of the CARs. These protocols are applied on fast Mobile IP (FMIP) [13] [15] to improve the performance of Mobile IP. The fast Mobile IP (FMIP) is proposed to reduce handoff latency and be used for real time traffic such as multimedia. Jung et al. [21] proposed the vertical handoff scheme combines the fast Mobile IPv6 to reduce the handoff latency, but the disadvantage of fast Mobile IP still exists. The fast Mobile IP depends on handoff anticipation in the AR. Therefore, there is no guarantee that the UE can be connected to the correct AR every time.

When anticipation is failed, there is a chance that the UE will lose its connectivity before the UE sent the binding update message. This results make the connection should be re-built. [18] [27] [28] proposed the virtual cell concept to improve the vertical handoff in heterogeneous networks. This scheme uses the signal strength of BS to trigger the handoff procedures. There is no common pilot to be used as an indication for the vertical handoff trigger, because the same SNR might have different throughput (data rate). A direct comparison of the SNR values will cause an error in the handoff judgment.

The concept of relay-based was provided to improve this condition for next-generation heterogeneous networks. The relay-based concept is an integrating MANET with infrastructure net-works. The mobile devices used the ad hoc mode to transmit information with each other, and these devices are called relay nodes (RNs). If relay nodes of UE are connecting with the different access networks, relay nodes perform operations for vertical handoff instead of the UE. To minimize the service quality degradations, for examples, longer handoff delay, more packet losses, decreased throughput and network disconnection, we proposed scheme are target fast connecting through the assistance of relay nodes. Therefore, this paper presents a new fast handoff scheme to further reduce the handoff delay for vertical handoff. The new method was provided and designed a new cross-layer vertical handoff scheme, layer 2 uses the extension of DeuceScan scheme [22] to reduce handoff latency and unnecessarily handoff, layer 3 uses the relay-based mechanism to get new IP in advance, and layer 4 uses the mSCTP to set up multiple connections, to reduce the handoff latency and packet loss.

The rest of the paper is organized as follows. Section II illustrates the basic idea of cross-layer relay-based mechanism. Section III presents the fast vertical handoff scheme. Performance analysis is presented in section IV. Finally, in Section V, some conclusions are made.

II. BASIC IDEA OF CLAMP

As described earlier, the vertical handoff occupies most of the handoff latency. This paper aims to develop a new approach to reduce the handoff delay time and packet loss ratio. Our proposed mechanism uses the low-layer information to assist fast handoff scheme. Generally, this mechanism is called a cross-layer method. The cross-layer design reduces the handoff gap by overlapping the handoff process and new care-of-address (CoA) establishment. The cross-layer handoff mechanism was proposed in this paper. The goal of cross-layer design is in order to achieve the accurate handoff, reduce the handoff latency and packet loss ratio. There are three parts described in this section. In the following, the existing handoff schemes were compared.

Layer-2: DeuceScan Scheme

The DeuceScan is a partial pre-scan scheme [22]. The UE collects the handoff information in the period of time before the handoff procedures. Two factors of stable signal strength and variable signal strength are both used in the DeuceScan scheme. The scheme aims to obtain the accurately stable information of the received RSSs in a short time for an UE in a spatiotemporal triangle ∇i. This stable and accurately information helps the UE make the correct decision and avoid the ping-pong effect when changing the spatiotemporal triangle from ∇i to $\nabla i+1$. We present the deuce procedure with stable signal strength, which is denoted $Ds(\alpha,\beta)$, where α is the extra number of scanning BSs/APs and β is the number of scan cycles. A scan cycle is the delay time required to scan $\alpha+2$ BSs/APs (with each AP being in a different channel). Each successive β scan cycle forms a deuce window. The use of extra α BSs/APs are to provide fault-tolerant capability and offer extra scanning chances if the next handoff BS/AP is not in spatiotemporal triangle ∇i. In addition, β is used to improve the accuracy of the candidate list of potential handoff BSs/APs. Basically, the larger α is, the higher the fault-tolerant capability is, and the larger β is, the higher accuracy of the candidate list of handoff BSs/APs is. Figure 3 shows an example. In our cross-layer handoff mechanism, the layer 2 handoff trigger is based on DeuceScan scheme but our scheme is not directly comparing the RSS to decision. Because the same SNR might have different throughput (data rate), there is no common pilot to be used as an indication for the vertical handoff trigger. A direct comparison of the SNR values will cause a low performance result or an error decision. To resolve this problem, the SNR and data rate mapping are provided as shown in Figure 4. The SNR of WLAN is represented SWLAN, and the SNR of UMTS is represented SUMTS. The data rate of WLAN is represented DRWLAN, and the data rate of UMTS is represented DRUMTS. Generally, the data rate of WLAN is higher UMTS. Basically, if the date rate of UE is below threshold, TH, the vertical handoff is triggered. In addition to this condition, the vertical handoff is also triggered when the differences between the DRWLAN and DRUMTS values exceed or drop below a threshold, ΔTH, for a continue scan cycle, β. If the condition fits equation (1) or (2), the handoff procedure is trigged.

$$DR_{WLAN} \text{ or } DR_{UMTS} < TH \text{ for } \beta \quad (1)$$

$$|DR_{WLAN} - DR_{UMTS}| > \Delta TH \text{ for } \beta \quad (2)$$

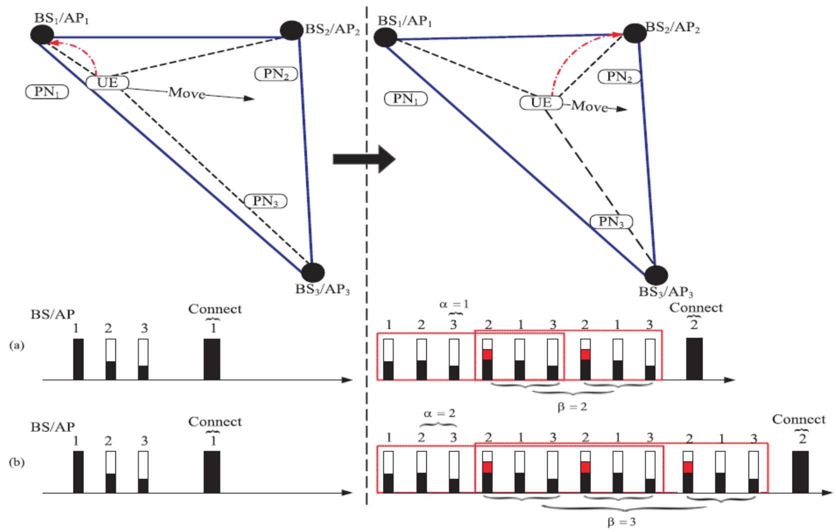


Figure 3: Layer-2: DeuceScan scheme. Examples of (a) $D_s(1,2)$ and (b) $D_s(2,3)$.

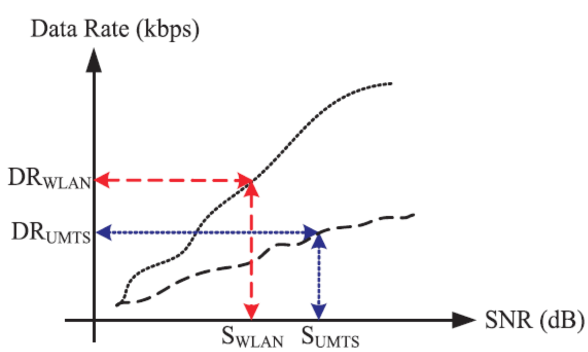


Figure 4: Data rate and SNR mapping graph.

Layer-3: Relay-Based Scheme

The next generation cellular networks are expected to provide more rich and diverse multimedia services with even much higher data rates, possibly greater than 100 Mbps. However, the current cellular network architecture may not be flexible and powerful enough to satisfy for the requirements of next generation cellular systems. A new emerging cellular network structure was proposed, Multihop Cellular Network (MCN), the network structure incorporates the ad hoc characteristic into the cellular system. In the fast vertical handoff aspect, a new concept was introduced, relay-based, which enable relay nodes to process requests of a mobile user. The relay-based scheme is an integrating MANETs with infrastructure networks extension as shown in Figure 5. MANET is a self-organizing and self-configuring multi-hop wireless network, where the network structure changes dynamically due to member mobility. Each node functions not only as a host but also as a router that maintains routes to and forwards data packets for other nodes in the network that may not be within direct wireless transmission range. In our interworking architecture, the UEs have multiple wireless interfaces to connect the heterogeneous networks, and the UEs also could use the ad hoc mode to transmit information. These mobile devices used the ad hoc mode to transmit information with each other, and these devices are called relay nodes (RNs). Let RNi denote relay node i, i=1, 2,..., n. The RNs may be located at different access network and the UE collects the neighbor access network information from RNs before moving to the access network. These relay nodes not only support higher connectivity during the handoff, but also obtain the network information in anticipation. The vertical handoff decision is more complex than horizontal handoff decision, and there are more different factors in the heterogeneous environment. So our mechanism uses the network information which is collected by RNs to assist the vertical handoff decision.

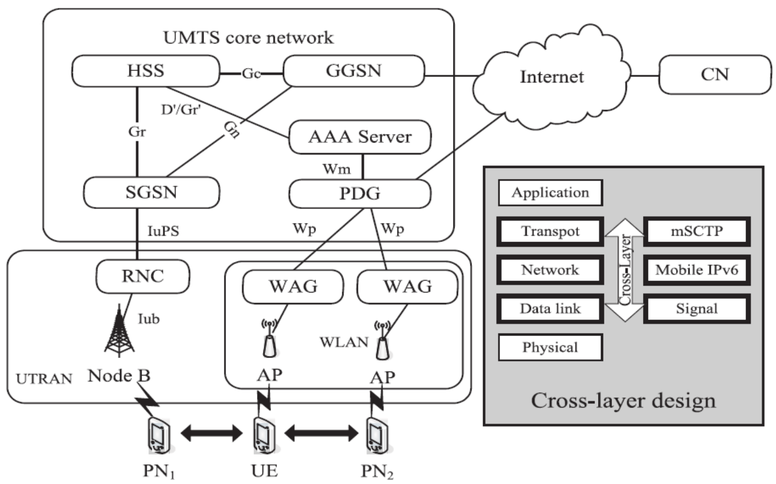


Figure 5: Layer-3: Relay-based scheme.

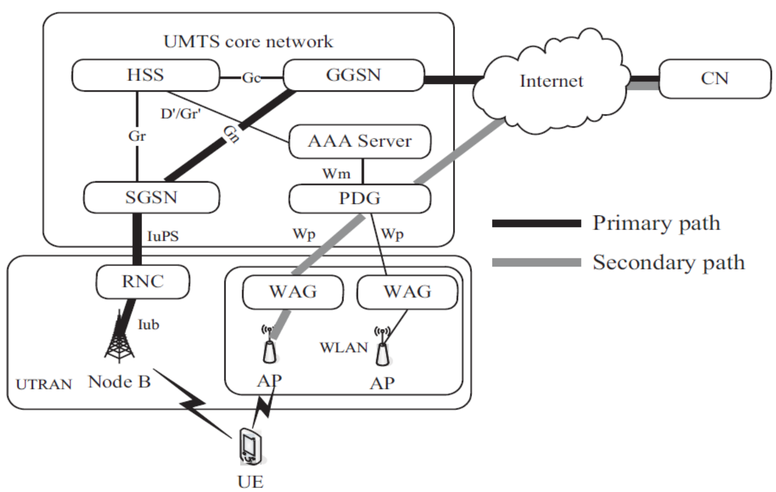


Figure 6: Layer-4: mSCTP scheme.

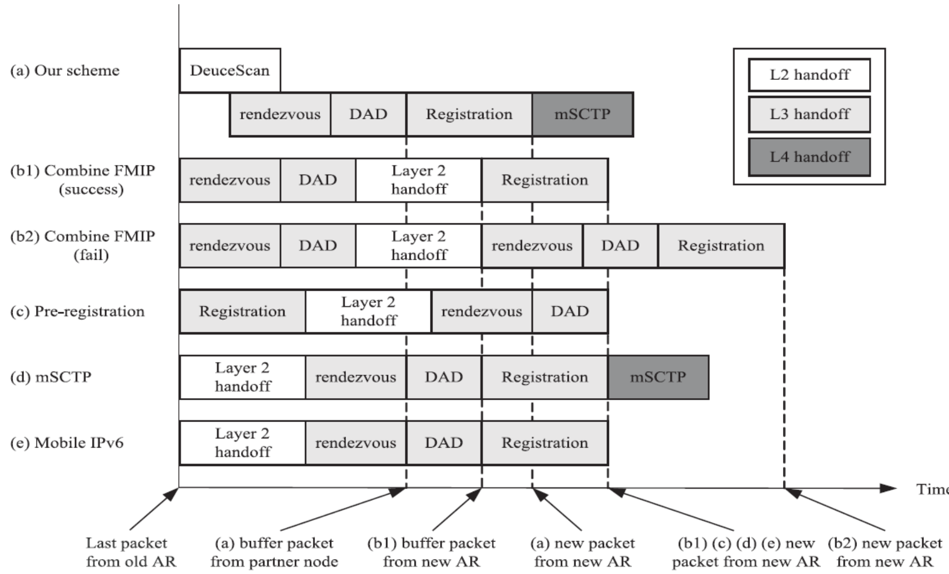


Figure 7: Handoff procedures compare with other schemes.

Layer-4: mSCTP Scheme

The feature of SCTP is multi-homing which enables an SCTP connection to be established over multiple interfaces identified by multiple IP addresses. The SCTP generally sends data to a receiver IP address through the primary address, but can transmit data to an alternative secondary IP address if the primary IP address becomes unreachable. Note that two mobile devices can have only one primary path, but more than one secondary path. Specifically, the SCTP DAR extension, referred to as mSCTP, can provide a simple but efficient framework for mobility support over IP networks. The mSCTP provides seamless handoff during the ongoing session. mSCTP allows the endpoint to add, delete and change the IP addresses dynamically. Figure 6 shows the vertical handoff scheme using mSCTP. Based on supporting the multiple IP property of mSCTP, we design a cross-layer approach which builds multiple paths between CN and UE. Even if the UE is not located in the access network, the multiple paths still can be established by multi-hop method. The detail of path building is described in the section III.C.

Advantages of CLAMP

This work aims to develop a cross-layer fast handoff mechanism over WLAN/UMTS networks. The existing fast handoff schemes were compared. Figure 7(a) shows our cross-layer mechanism obviously reduces the handoff delay time because the proposed scheme is using overlapping the handoff process to reduce the handoff latency. When the UE receives the link layer triggers, the UE starts the handoff procedure. The mobile device uses the relay-based scheme to get the IP address in anticipation and uses the mSCTP building multiple sessions to achieve the smooth handoff. Figure 7(b1) illustrates that the vertical handoff scheme combines FMIP and succeeds the handoff procedures. Figure 7(b2) shows that the vertical handoff scheme combines FMIP and failed the handoff procedures. The FMIP protocol depends on handoff anticipation in the AR. Therefore, there is no guarantee that the UE can be connected to the correct AR every time. When the anticipation is failed, this results make the connection should be re-built and cause a lot of handoff latency. Figure 7(c) uses the pre-registration scheme to reduce the handoff time but this scheme cannot reduce the duplicate address detection (DAD) time. So the reductive total handoff time of pre-registration scheme is limited. Then, there is another problem in pre-registration scheme, and this problem is the packet out-of-order problem. Figure 7(d) illustrates the mobility management of transport layer, mSCTP. Because mSCTP has no trigger of the bottom layer, the handoff latency is also much longer than our scheme. Figure 7(e) shows the traditional Mobile IPv6 handoff scheme and causes the longest handoff latency.

III. THE CLAMP PROTOCOL

This section describes the principle of operation and the detail of the mainly proposed scheme. The section is comprised of three parts: (1) the relay node selection phase, (2) the handoff decision algorithm to help the UE to switch an appropriate network, and (3) our vertical handoff process is presented. The proposed cross-layer handoff solution was called a relay-based vertical handoff scheme with the mSCTP. Then, the proposed scheme has to be described as follows:

3.1 Relay Node Selection

The discovery procedure of relay node is very important. In the handover scheme using the relay concept, the fast route discovery is more important because the long discovery time can have a bad influence on the handoff performances. The relay node in the neighboring cell must confirm to the following conditions:

(1) The relay nodes in the neighboring cell should simultaneously have good communications quality with base station or access point.

(2) The relay nodes broadcast the hello message for a period of time. The information of hello message includes the network prefix and link quality between RN and AP. The LQ denotes the link quality which is directly proportion with data rate, and the relay node selection is according to the equation (3) and (4).

$$MIN(LQ_{RN-AP}, LQ_{UE-RN}) > LQ_{UMTS} \qquad (3)$$

$$PN_i = MAX\{MIN\{LQ_{RN-AP}, LQ_{UE-RN}\}\}, i = 1, 2, \ldots, n \qquad (4)$$

(3) In relay nodes selection, the lower moving speed relay node has higher priority for selection because the link quality is more stable.

(4) When the UE discovers more than one relay nodes, the UE stores the candidate list of relay nodes.

3.2 Vertical Handoff Decision

Making the vertical handoff decision is more complex than horizontal handoff decision. In the heterogeneous environment, there are more different factors needed to discuss and metric qualities that give an indication of whether or not a handoff is needed. Generally, handoff research has been based on an evaluation of the received signal strength (RSS) at the mobile device. However, the RSS comparisons are not sufficient to make a vertical handoff decision. So we as well as consider the detail of vertical handoff decision function, which enables devices to different network factors such as quality of service, power consumption, bandwidth, and transmission cost. According to handoff decision function, we select the main access network which is maximum value of fn to connect. The notations are defined as follows:

fn: The cost function of wireless network n.

Wi: The weight of factor i, for i=1, 2,..., n. 0 ≤Wi ≤ 1 and ΣWi=1.

BWn: The bandwidth that wireless network n can offer.

N(i): The normalization function of parameter i.

Cn: The cost of wireless network n.

Qn: The QoS level that wireless network n can offer.

Vn: The velocity of UE n moving.

Pn: The power consumption of using the network device for network n.

$$f_n = W_1 * N(BW_n) + W_2 * N(\frac{1}{C_n}) + W_3 * N(Q_n) + W_4 * N(\frac{1}{V_n}) + W_5 * N(\frac{1}{P_n}) \qquad (5)$$

$$W_1 + W_2 + W_3 + W_4 + W_5 = \sum_{i=1}^{5} W_i = 1 \qquad (6)$$

3.3 Handoff Procedures

This subsection can be separated into two scenarios. One is the UE moves to WLAN from UMTS, and another is the UE moves to UMTS from WLAN. The handoff scenario assumes the connection of UMTS always on line.

3.4 Handoff Procedures: UMTS to WLAN

Figure 8 shows the detail UE handoff procedures that UE moves to WLAN from UMTS.

Step 1: Information collection. If there are relay nodes in the different access network, relay nodes use the ad hoc mode to broadcast the hello message for a period of time. The relay node selection is described in the section III.A. When the UE moves into RN’s transmission range, UE uses the multi-hop feature of ad hoc to collect the information from RNs, such as subnet prefix of WLAN, link quality between RN and AP, and network resources. When the UE receives the subnet prefix, the UE generates a new IP address. Observe that, if no RN is founded by the UE, UE performs the original mSCTP handoff procedure and skips all rest steps.

Step 2: Duplicate address detection (DAD) procedure. When the UE receives the hello message (include network resources and subnet prefix) from RNs, the UE is going to compare the network resources and decide to connect the access network. The vertical handoff decision is described in the section III.B. In this step, we can use the layer-2 information to trigger handoff procedure, and we can use the DeuceScan scheme to reduce the layer-3 handoff delay time. The UE generates the new care-of-address (COA) according to subnet prefix, and the UE uses the RN to complete the DAD procedures in anticipation.
Step 3: Build multiple paths. When the UE generates the new COA, the UE uses the dynamical multi-homing feature of mSCTP to build the secondary path (or backup path) with CN and bind update to HSS. Because our mechanism is a cross-layer design, the CLAMP scheme overcomes the disadvantage of mSCTP. Our proposed mechanism also provides a nice location management because the HSS always maintains the fresh information about the location of UE. If the new correspondent node CNi want to transmit data to the UE, the correspondent node can discovery the UE easily.
Step 4: Handoff decision. The UE collects the network information for a period of time before the handoff procedures. When the network resources are lower the threshold, the handoff procedure is going to be triggered. The vertical handoff decision is described in the section III.B.
Step 5: Change primary path. After the handoff decision, the UE sends the set primary path message to CN and HSS. In this case, the handoff latency is tASCONFSetPrimary+tASCONFACK. Figure 9 illustrates the first situation that the UE roams to WLAN from UMTS and RN in WLAN.

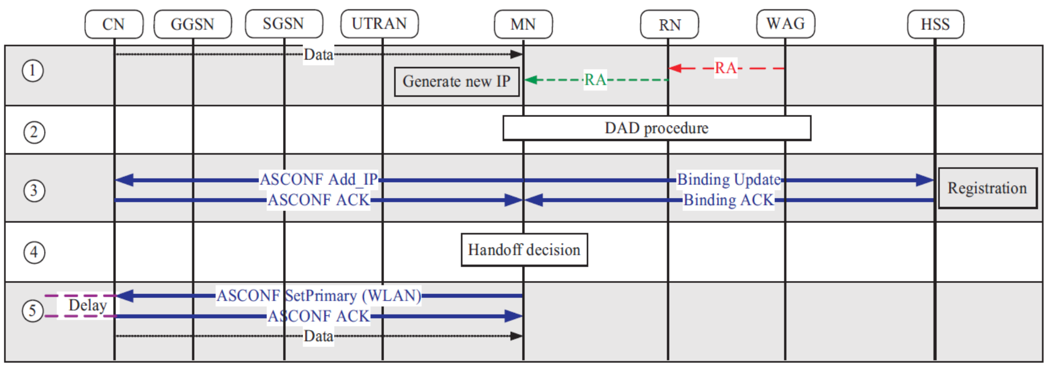


Figure 8: Handoff procedures. (UMTS to WLAN)

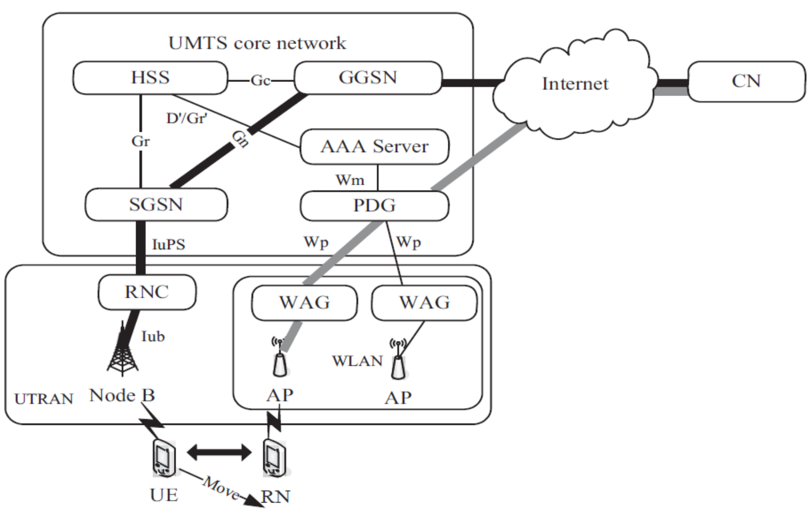


Figure 9: UE roams to WLAN from UMTS, and RN in WLAN.

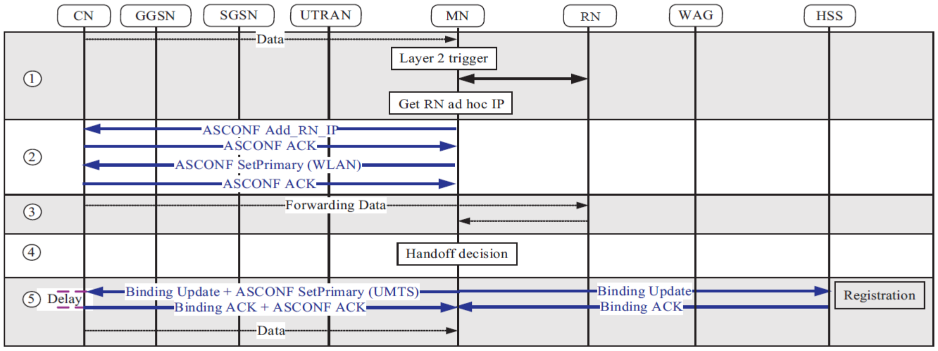


Figure 10: Handoff procedures. (WLAN to UMTS)

Handoff Procedures: WLAN to UMTS

Figure 10 shows the detail UE handoff procedures that UE moves to UMTS from WLAN.

Step 1: Handoff trigger. If the UE moves to the boundary location of serving AP, the network resources are lower the threshold, the handoff is going to be triggered. We can use the layer-2 information to trigger handoff procedure, and we can use the DeuceScan scheme to reduce the layer-3 handoff delay time. The DeuceScan scheme is described in the section II.A.

Step 2: Build multiple paths. The UE gets the ad hoc IP address of RN and builds the secondary path through the RN. The relay node selection is described in the section III.A.

Step 3: Data forwarding. When the UE moves out the transmission range of WLAN, the UE still receives the data with high data rate from the RN using relay technique. The relay-based scheme is an integrating MANETs with infrastructure networks, and the multi-hop forwarding scheme can reduce the packet loss during the handoff process.

Step 4: Handoff decision. The UE collects the network information for a period of time and uses the handoff decision function to decide which one access network is connected. The vertical handoff decision is described in the section III.B.

Step 5: Binding update and change primary path. When the link quality is lower the threshold, the UE is going to change primary path and bind update to HSS. The handoff latency is tASCONFSetPrimary+tASCONFACK.

Figure 11 illustrates the second situation that the UE roams to UMTS from WLAN and RN in WLAN. A poorly served UE can receive data from the high-speed multi-hop relay link. Figure 12 shows the third situation that the UE roams to different UMTS from WLAN and RN in UMTS. When the UE is located the boundary between two different GGSNs, the wireless link quality should be unstable. Then, our CLAMP mechanism is triggered to perform. If there are RNs in the new BS signal coverage which belongs to different GGSN, the UE can use the relay-based technique to get network information in anticipation.

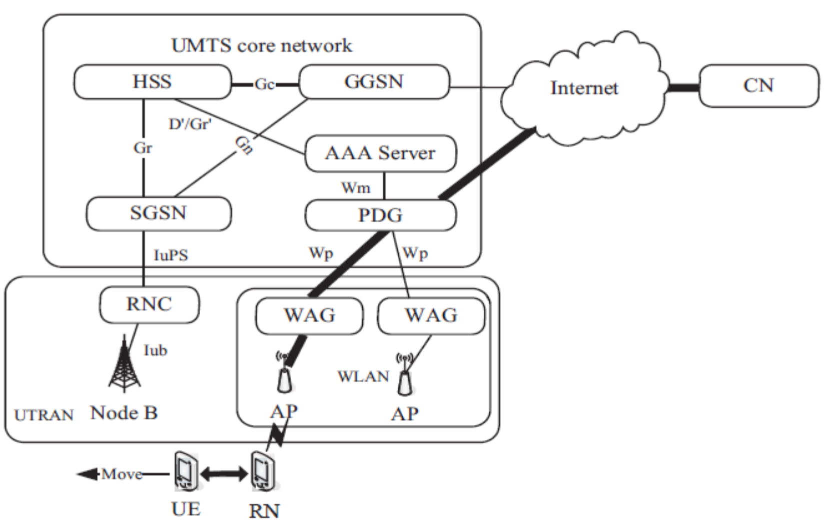


Figure 11: UE roams to UMTS from WLAN, and RN in WLAN. (UE roams to the same GGSN)

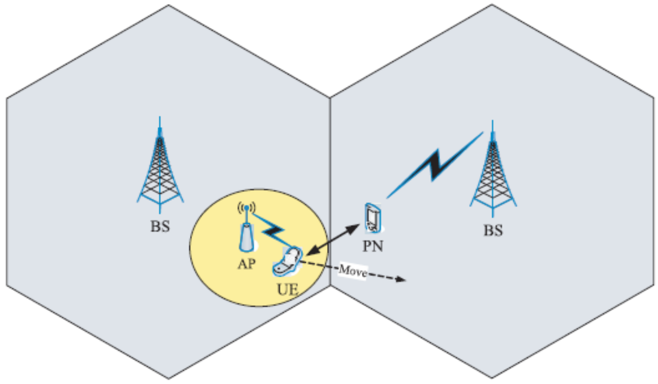


Figure 12: UE roams to UMTS from WLAN, and RN in UMTS. (UE roams to the different GGSN)

Table 1: Notations

BW_w	Bandwidth of the wired core networks
BW_{wl}	Bandwidth of the wireless link
L_w	Latency of the wired link
L_{wl}	Latency of the wireless link
S_{ctr}	Average size of the control message
$t_{Internet}$	Average delay of that a packet traveling in the Internet
t_{DAD}	Average delay of the DAD time
n	Number of hops between the UE and the router

IV. PERFORMANCE ANALYSIS

This section evaluates the performance of the proposed handoff solution by numerical analysis and simulation.

4.1 Numerical Analysis

In our mathematical analysis, the notations are given in the Table 1. The handoff latency for the proposed mechanism and other schemes were represented in the following. Let tRN be the time of RN performing the pre-action procedure, tRN = tRN discovery + trendezvous +tDAD + tbinding, where tRN discovery is the time of a UE finding the RN which is belong to new access network, trendezvous is the time of UE finding a nAR, and received the router advertisement message from nAR, tDAD is the time of a RN performing DAD operation of nAR, and tbinding is the time of RN sending binding update message to HSS and CN. Let Sctr be the average size of the control messages, BWw be the bandwidth of wired backbones, BWwl be the bandwidth of wireless link, be the value from layer-2 deuce procedure Ds(α,β), and tInternet be the average delay of that a packet traveling in the Internet. First, tRN discovery is

$$
\begin{aligned}
t_{RN\_discovery} &= \frac{n}{\beta}(t_{subnet\_\mathrm{inf}}) \\
&= \frac{n}{\beta}(\frac{S_{ctr}}{BW_{wl}}+L_{wl}) \text{ , where } n=\beta, 2\beta, \ldots. \qquad (7)
\end{aligned}
$$

Then, trendezvous = tsolicitation + tadvertisement, where tsolicitation is the time of RN sending the router solicitation message through AP, which is RN belong to, for the UE, and tadvertisement is the time of nAR sending the router advertisement message through the AP, which the RN is belong to, for the UE. Thus,

$$t_{solicitation} = (\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + (\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}, \quad (8)$$

$$t_{advertisement} = (\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + (\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}, \quad (9)$$

where tbinding ack is the time of CN sending notify-binding acknowledge message to UE, and tbinding ack is

$$t_{binding\_ack} = (\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + n(\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet} \quad (10)$$

Finally, the total binding time is $t_{binding} = 2\left[(\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + n(\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}\right]$.

Therefore, the pre-action time of CLAMP is

$$\begin{aligned} t_{RN} &= t_{RN\_discovery} + t_{rendezvous} + t_{binding} + t_{DAD} \\ &= \frac{n}{\beta}(\frac{S_{ctr}}{BW_{wl}} + L_{w}) + 2\left[(\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + n(\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}\right] \\ &\quad + 2\left[(\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + (\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}\right] + t_{DAD}. \end{aligned} \quad (11)$$

If the pre-action is succeeded, the handoff latency is

$$t_{CLAMP} = t_{ASCONFSetPrimary} + t_{ASCONFACK} = t_{binding} = 2\left[(\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + n(\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}\right]. (12)$$

From [19], we can derive $t_{pre-registration}$ as follows.

$$t_{pre-registration} = t_{layer2} + t_{rendezvous} + t_{DAD} = t_{layer2} + 2\left[(\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + (\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}\right] + t_{DAD}, (13)$$

where t_{L2} is layer-2 handoff delay time. t_{mSCTP} [6] is derived below.

$$\begin{aligned} t_{mSCTP} &= t_{L2} + t_{rendezvous} + t_{binding} + t_{DAD} = t_{L2} + 2\left[(\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + (\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}\right] \\ &\quad + 2\left[(\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + n(\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}\right] + t_{DAD}. \end{aligned} \quad (14)$$

Similarly, t_{MIPv6} [2] is derived below.

$$\begin{aligned} t_{MIPv6} &= t_{L2} + t_{rendezvous} + t_{binding} + t_{DAD} = t_{L2} + 2\left[(\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + (\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}\right] \\ &\quad + 2\left[(\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + n(\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}\right] + t_{DAD}. \end{aligned} \quad (15)$$

Finally, $t_{CombineFMIP}$ [20] is derived below.

$$t_{CombineFMIP} = t_{L2} + t_{binding} = t_{L2} + 2\left[(\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + n(\frac{S_{ctr}}{BW_{w}} + L_{w}) + t_{Internet}\right] \quad (16)$$

4.2 Simulation Results

This subsection presents the simulation results of the proposed scheme. The objective of the simulations is to evaluate two critical performance metrics, UMTS/WLAN handoff delay and packet loss rate. We use network simulator NS-2 [25] to perform the simulations and obtain the results reported in this article. In this simulation, we assumed that the network topologies are randomly generated by the NS-2 network simulator.

The IEEE 802.11 WLAN model in NS-2 is used to represent the medium access control (MAC) layer. The UMTS modules have been developed by Alfredo Todini and Francesco Vacirca at the INFOCOM department [26], University of Rome ”La Sapienza”, Rome, Italy. The simulation environment is a two kilometer square plain area under WLAN/UMTS coverage. To obviate the radio signal interference issue, the area is supposed to be free of obstacle and buildings. There are twenty relay nodes in the access network, and every relay node is located randomly with uniform distribution in whole access network coverage. The WLAN hotspots are randomly allocated and the signal range is 100 m. The mobility model in this simulation is adopted the “random waypoint” model. The mobility characteristics is determined by two parameters; speed and pause times, where the speed ranges from 0 to 20 m/s and pause time ranges from 1 to 10 seconds in our simulation. The channel propagation model used for received signal strengths (in dB) at distance d is given by:

$$RSS(d) = P_t - PL(d) \qquad (17)$$

where Pt is effective transmitted power and PL is the path loss at distance d. The bandwidths are set to be 384 kb/s for the UMTS link and 2 Mb/s for the WLAN link. There are always five traffic flows (using UDP) communicating with a pair of mobile devices at the same time. The performance metrics to be observed are:

Handoff Latency: The delay time is a mobile node changing its association from the current associated AP/BS to another one.

Packet Loss Rate: The total number of packet lost during the handoff procedure for a mobile node.

Handoff Jitter: The handoff jitter is the variable delay during the handoff time. Assumed that three consecutive received packets, Pi−2,Pi−1,and Pi, handoff jitter is defined as (Ti−Ti−1)−(Ti−1−Ti−2) = Ti−2Ti−1+Ti−2

Precise Handoff: Unnecessary handoff wastes network resources and even degrades the transmission quality, such as the ping-pong effect.

Control Overhead: The control overhead is an important factor to affect the network performance. If the heavy control overhead in the access network, the entire performance must reduce very much.

4.3 Handoff Latency

Figures 13(a) and 13(b) show the handoff latency performance for vertical handoff from UMTS to WLAN and in the reverse direction, respectively. According to the simulation results, the handoff latency is exceeded 4000 ms in MIPv6 protocol, and the handoff latency is obviously reducing in our scheme. Because our scheme is based on mSCTP which builds multiple paths, our handoff latency only includes the time of switching path. In our proposed mechanism, although the UE receives the same transmission sequence number on multiple links during the handoff, the CLAMP scheme can reduce the packet loss. Figure 13(c) shows the average handoff latency vs. moving speed of UE for our CLAMP, combine FMIP, pre-registration, mSCTP, and MIPv6. The handoff latency is measured by the time between UMTS and WLAN. Because our CLAMP is a cross-layer design, our scheme can reduce the handoff latency obviously. The average handoff latency of CLAMP mechanism was < that of the combine FMIP scheme which was < that of pre-registration scheme which was < that of mSCTP which was < that of MIPv6 under various moving speed of UE. Our CLAMP mechanism uses the concept of relay in cooperative technique that gets handoff information in anticipation to speed up the network layer movement detection process.

4.4 Packet Loss Rate

The performance effect of packet loss vs. moving speed is illustrated in Figure 14. When the UE moves in high speed, other schemes cause a lot of packet loss. Our scheme can efficiently reduce the packet loss, and the simulation result shows our scheme has lowest packet loss rate. Because the CLAMP scheme uses the concept of multi-hop and mSCTP to build multi-path, the RN can assist in getting network information and forwarding the buffer packets.

4.5 Handoff Jitter

Figure 15 illustrates the vertical handoff jitter vs. moving speed of UE for our CLAMP mechanism, combine FMIP, pre-registration, mSCTP, and MIPv6. The MIPv6 protocol has highest jitter com-pared to all existing protocols. Our

CLAMP mechanism has better handoff jitter than other protocols. This is because that the overlapping results for our cross-layer relay-based design can significantly reduce the handoff jitter.

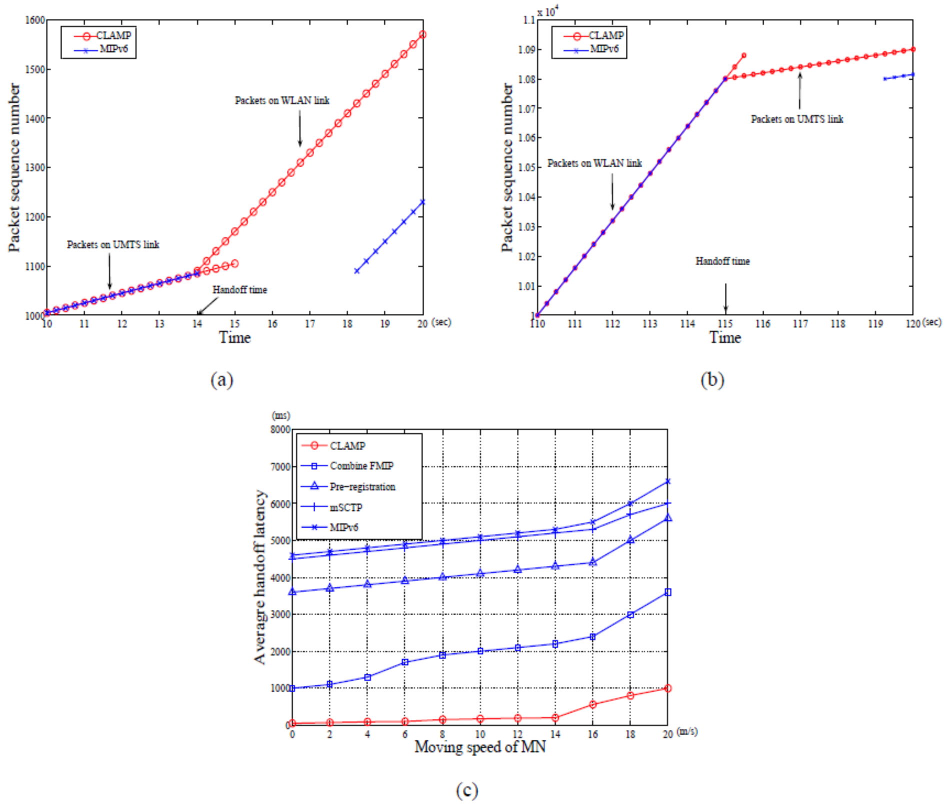


Figure 13: Performance of average handoff latency.

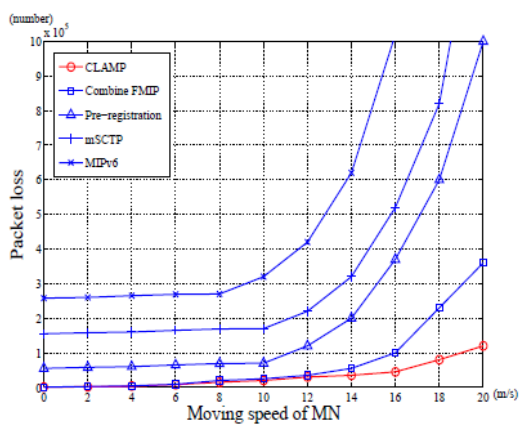


Figure 14: Performance of packet loss rate.

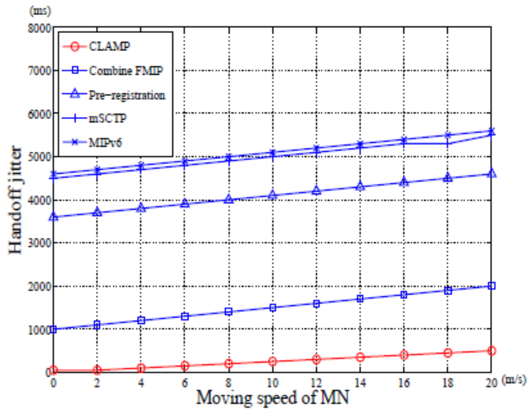


Figure 15: Performance of handoff jitter.

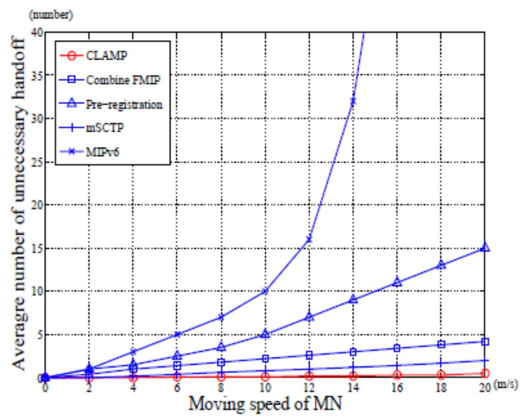
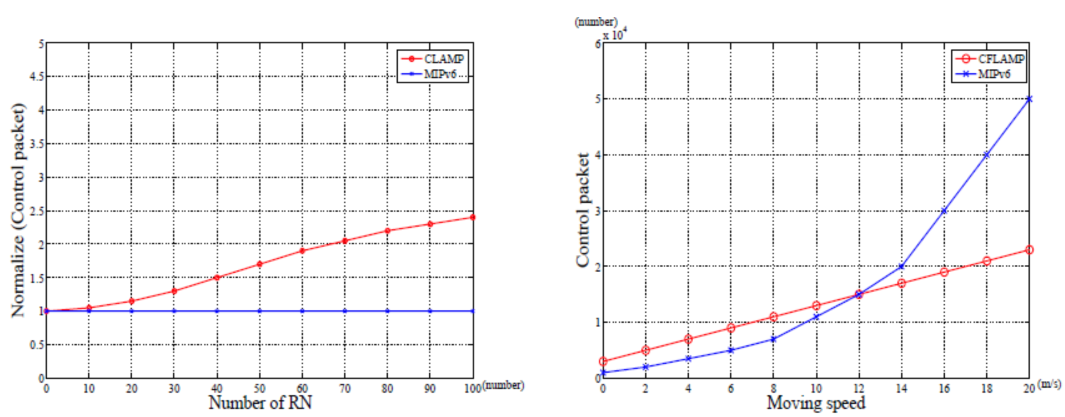


Figure 16: Performance of unnecessary vertical handoff times.



(a) (b)

Figure 17: Performance of control overhead.

4.6 Precise Handoff

The right time for vertical handoff is very important. Unnecessary handoff will waste network resources, increase handoff latency, and even degrade the transmission quality, such as the ping-pong effect. Figure 16 shows the average number of unnecessary vertical handoff in a time interval of 600 seconds. The proposed CLAMP scheme is using concept of DeuceScan which is a pre-scan approach. The DeuceScan scheme, using a pre-scan approach, efficiently reduces the layer-2 layer handoff latency. Two factors of stable signal strength and variable signal strength are both used in our developed DeuceScan scheme. So our scheme can efficiently reduce the ping-pong effect.

4.7 Control Overhead

Because our scheme is using multi-hop concept, the proposed scheme uses the "hello message" to collect the network information. We consider all kinds of different test environments to measure the control overhead. The parameters of system include the different density of RNs and different moving speed of RNs. Figure 17(a) shows the control overhead vs. various density of RNs. Al-though our CLAMP scheme offers slightly more control message, the proposed scheme can acquire low handoff latency. Figure 17(b) illustrates the control overhead vs. moving speed of RNs.

V. CONCLUSIONS AND FUTURE WORKS

The main research of this paper uses the concept of relay to assist the mobility management in heterogeneous networks. We have presented a relay-based fast vertical handoff scheme between UMTS and WLAN, and the proposed scheme can reduces the handoff latency and pocket loss rate. The key contribution of the relay-based mechanism supports precisely handoff decision by layer 2 trigger, data forwarding, obtain the handoff information in advance by relay nodes, and using the mSCTP to build the secondary path for seamless handoff. Our approach uses the multi-hop feature of ad hoc that get link layer information in anticipation to speed up the network layer movement detection process and the multi-homing features of SCTP so that a mobile device can have two IP addresses during the vertical handoff. In the future works, we are going to consider how to provide an efficient interface management for multi-interface UEs to reduce the power consumption caused by unnecessary interface activation. The power consumption of those interfaces is very critical because we are talking about UEs that use battery.

VI. ACKNOWLEDGMENTS

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