適用於無線網路快速交遞協定中的改良式暫存區管理

An Enhanced Buffer Management Scheme for Fast Handover Protocol

研 究 生：姚維民　　Student：Wei-Min Yao

指導教授：陳耀宗　博士　　Advisor：Dr. Yaw-Chung Chen

國 立 交 通 大 學

資 訊 工程 系

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研究生：姚維民　　　　　　　　　　　　　　　　指導教授：陳耀宗　博士

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中文摘要

近年來隨著無線網路技術的發達，人們對於通訊品質的要求也日益提升。在目前的網際網路中，結合 IEEE 802.11 無線區域網路和 Mobile IP 的技術，可以提供使用者在網域間漫遊的服務。藉由快速交遞協定(Fast handover)與階層式 Mobile IP(Hierarchical Mobile IP)的幫助，大幅縮短了 Mobile IP 在交遞基地台的過程。由於在交遞的過程中，使用者會有短暫的時間無法接收資料，Fast handover 協定中採用了暫存區來保存這部分的封包。不過在 Fast handover 協定中，卻缺少了一個有效的暫存區管理機制。當使用者數目增加的時候，通訊品質會無法保障。

在本篇論文中，我們提出了一個適用於 Fast handover 協定的暫存區管理機制。藉由同時使用交遞過程中的兩個路由器，我們可以提高網路中路由器內的暫存器的使用量。而針對不同資料流採取相對應的暫存機制，則提供了在交遞過程中保護重要資料的能力。另外，此方法也提供使用者在任意交遞過程中，要求路由器暫存資料的機制。同時由於大部分的控制訊息都是附加於原本 Fast handover 協定上，因此並沒有增加過多的訊息負擔。透過 ns-2 程式的模擬，我們驗證了此機制的效能，證明其確實可提升交遞時的速度與品質。

關鍵字：快速交遞協定；無接縫交遞；暫存區管理；交遞；服務品質

An Enhanced Buffer Management Scheme for Fast Handover Protocol

Student: Wei-Min Yao **Advisor: Dr Yaw-Chung Chen**

Institute of Computer Science and Information Engineering
National Chiao-Tung University

ABSTRACT

With the quickly development of wireless technology, the requirement on communication quality also arises. Today, users have the ability to roaming between subnets with the cooperation of IEEE 802.11 wireless LAN and Mobile IP technologies. The combination of Hierarchical Mobile IP and Fast handover protocol greatly reduces the handoff delay in Mobile IP. Since a mobile host suffers a temporary disconnection from network during the handoff process, a buffer is used in the Fast handover protocol. However, there is no efficient buffer management mechanism in the protocol, thus service quality cannot be guaranteed when there are too many users.

We propose an enhanced buffer management mechanism for Fast handover protocol in the thesis. With the cooperation of both access routers during the handoff process, the buffer utilization in the network can be improved. The proposed method also supports QoS service. High priority packets are protected from dropping and the real-time packets are protected by minimizing the delay time during a handoff process. Moreover, buffering operations during a link layer handoff is supported. Since most of the control messages are piggybacked on the original fast handover protocol, the proposed method does not involve additional signaling overhead. We evaluate the performance of the proposed method using the ns-2 simulator, and it is proven that our method really improves the quality of communications during a handoff process.

Keywords: Fast Handover; smooth handoff; buffer management; handoff; QoS

Table of Contents

List of Figures

List of Tables

Chapter 1.

Introduction

1.1 Overview

With a growing number of mobile computing devices and wireless networking products like laptops and Personal Digital Assistants (PDA), wireless technologies have experienced immense development in the last few years. Among all wireless technologies, IEEE 802.11 based wireless local area networks (wireless LAN) plays an important role. Wireless LAN offers convenient network connectivity and high-speed link at a low price. It is a promising wireless technology to integrate voice and web data in a beyond third generation all-IP based mobile communications system.

A series of IEE802.11 technologies have been standardized at a rapid pace and are expected to offer part of the capabilities for system beyond third generation technologies. Wireless LAN technologies provide link layer roaming, a mobile host can attach to different access points within the same network domain without extra configuration. However, when there are a large number of users as current cellular phone system, it is inefficient to serve all users in such a large domain. The large service domain must be separated into several small wireless LAN domains with different network prefix. When a mobile host enters another wireless LAN domain, it must reconfigure its Internet Protocol (IP) address. With this change of IP address, the mobile host needs to reestablish all existing connections.

Mobile IP [1] provides IP level mobility to overcome the problem. It allows a mobile host roaming around different wireless LAN domains without disrupting its current connections. Mobile IP allows a mobile host to communicate with its home address as IP address. When a mobile host enters another domain other than its home domain, it obtains a care-of-address. The home agent in the mobile host's home domain intercepts all packets for the mobile host and forwards them to the mobile host's care-of-address. Mobile IP provides a suitable solution for mobile hosts roaming around different domains. However, each time when a mobile host enters another domain, a registration process between the mobile host and its home agent is required. The process may take several seconds and results in great packet loss or delay.

The handoff delay in mobile IP is unacceptable for real-time service, and also degrades TCP data transfer rate. Several mechanisms have been proposed and standardized to reduce the delay. Hierarchical architecture [2] aims to reduce the registration time between mobile host and home agent. Fast handover [3] mechanism focus on reducing the lengthy address resolution time when entering a foreign domain. With the combination of these two mechanisms, we can minimize the handoff delay caused by network layer handoff.

The combination of Hierarchical architecture and Fast handover greatly reduces the handoff latency, but there are several potential problems. The Fast handover mechanism does not support quality of service (QoS) and lacks of a buffer management mechanism. In the Fast handover protocol, all packets are treated the same the buffer and results in inefficient usage of the buffer space. For example, the buffer spaces are full of low priority packets and high priority packets are dropped instead. In order for mobile hosts to achieve seamless connectivity during their movement, an efficient buffer management mechanism should be included into the Fast handover protocol.

1.2 Goals

In this thesis, we proposed a buffer management mechanism in Fast handover protocol to achieve the following goals.

- Support QoS during handoff process
- Support real-time traffic during handoff
- Maximize buffer utilization in access router
- Integrate with Fast handover protocol

1.3 Organization of the Thesis

The rest of this thesis is organized as follows. Chapter 2 presents the background material and related works of our method. This includes the basic features of Mobile IP and two enhancement mechanisms on solving the handoff latency problem. A buffer management mechanism integrated into our method is also described in this chapter. In Chapter 3, we propose an enhanced buffer management mechanism for Fast handover, the detail operations of the mechanism is described here. In Chapter 4, we present the performance evaluations of our method. The conclusion of this thesis is presented in Chapter 5.

Chapter 2

Background And Related Works

In this chapter, we describe the background and related works of the thesis. We first describe the problem called "host mobility", and its solution, Mobile IP. Then we describe handoff latency problem in Mobile IP [1]. Hierarchical Mobile IP [2] and Fast handovers [3] mechanism are two major enhancements to the handoff delay problem. In the end of the chapter, we mention a mechanism called "Buffer management for smooth handovers in IPv6" which is integrated into our method discussed in Chapter 3.

2.1 Mobile IP

Mobile terminal such as Laptops, PDAs, are more and more popular nowadays. These devices have greatly changed our working style and made our live more convenient. We can now work outside, or play computer games on a train with our laptop. Using IEEE 802.11 wireless network card, we can even surf the Internet outdoors. However, this is only called host portability. The computer can be operated at any point of attachment, but not during the time it changes its attached points. If we want to achieve host mobility, that is, the laptop can maintain continuous connectivity when moving across domains, more efforts are needed.

The infrastructure of current Internet is based on top of Transmission Control Protocol (TCP) and Internet Protocol (IP) protocol suite. All packets in the network are delivered according to their IP address. If a mobile host moves to another subnet with different network prefix, it needs to reconfigure its IP address. This terminates all current connection sessions with the mobile host. IEEE 802.11 wireless LAN provides us only Link Layer connectivity to network, which allows a mobile host roaming only inside a subnet with same network prefix. Since higher-level protocols require IP address of a host to be fixed for identifying connections, an extension of IP protocol is required.

2.1.1 Mobile IP Overview

To solve the problem for host mobility, Internet Engineering Task Force (IETF) proposed an extension to the Internet Protocol, which is the Mobile Internet Protocol (Mobile IP). In Mobile IP, a mobile host is allowed to have two IP addresses. One is a permanent *home address,* and another is called *care-of-address*. Home address is used to represent a mobile host when receiving or transmitting data. The care-of-address changes whenever a mobile host enters a new network subnet. It can be considered as the mobile node's topologically significant address, which indicates where to find the mobile host now. Each mobile host belongs to a network where its home address resides in. This network is the *home network* of the mobile host, while others are called *foreign network*. All traffic for a mobile host is first sent to the mobile host's home address. If the mobile host is currently outside its home network, an agent in the home network called *home agent* will forward all traffic to the mobile host. This makes it appears that the mobile node is continuously able to receive data on its *home network*.

Mobile IP supports mobility by transparently binding the home address of the mobile node with its care-of-address. In mobile IP, there are some specialized routers known as mobility agents. Mobility agents are of two types: *home agents* and *foreign agents*. The home agent is a designated router in the home network of the mobile host. It maintains the mobility binding in a *mobility binding table*. Each entry in the mobility binding table has three columns, which are "home address", "temporary care-of-address", and "association lifetime". The purpose of this table is to map a mobile host's home address to its care-of-address and forward packets accordingly. The foreign agent resides in each foreign network. Comparing with a home agent, a foreign agent maintains a *visitor list*. Each entry in the list is identified by four columns: “home address”, “home agent address”, “MAC address of the mobile node”, and” association lifetime”. With these two tables, home agents and foreign agents can maintain communications between a mobile host and its correspondent communication node. The message flows of Mobile IP are illustrated in Figure 2.1.

The basic Mobile IP protocol has four distinct stages, these are:

1. Agent discovery

   When a mobile host enters a network, it needs to associate with an agent. This helps to determine whether it is on the home network or a foreign network. There are two ways for a mobile host to discovery the agent.

   (a) Mobility agents advertise their presence by periodically broadcasting *Agent Advertisement* messages. Mobile host finds out the agent once it receives the message.

   (b) The mobile host can also send out *Agent Solicitation* messages if it does not wish to wait for the periodically advertisement. Mobility agent will respond once it receives the message.

2. Registration

   When mobile host enters another network, it needs to notify its home agent. Thus a process called registration is required. This process operates as follow:

   (a) If a mobile node discovers that it is on the home network, it operates without any mobility services.

   (b) If the mobile node enters a new network, it sends a *Registration Request* message to the foreign agent. This message includes the home address of the mobile host and the IP address of its home agent.

   (c) Upon receiving the *Registration Request*, the foreign agent in turn performs the registration process by sending a *Registration Request* to the home agent. This message contains the home address of the mobile node and the IP address of the foreign agent.

(d) When the home agent receives the *Registration Request*, it updates the mobility binding by associating the care-of-address of the mobile host with its home address. Then it sends an acknowledgement back to the foreign agent.

(e) The foreign agent in turn updates its visitor list by inserting the entry for the mobile host and relays the reply to the mobile host.

3. In service

When a correspondent node wants to communicate with the mobile node, the following steps are performed.

(a) The correspondent node sends an IP packet addressed to the home address of the mobile host.

(b) If the mobile host is currently visiting a foreign network, the home agent intercepts this packet, and forwards it to the mobile host's care-of-address by *IP-within-IP* encapsulation.

(c) When the encapsulated packet reaches the mobile node's current network, the foreign agent decapsulates the packet and forwards to the mobile host.

When the mobile host wants to send a message to a correspondent node, it forwards the packet to the foreign agent. The foreign agent relays the packet to the correspondent node using normal IP routing.

4. Deregistration

If a mobile host wants to cancel its care-of-address, it sends a Registration Request with lifetime field set to zero. There is no need to deregistration with foreign agent. The registration automatically expires when lifetime becomes zero.

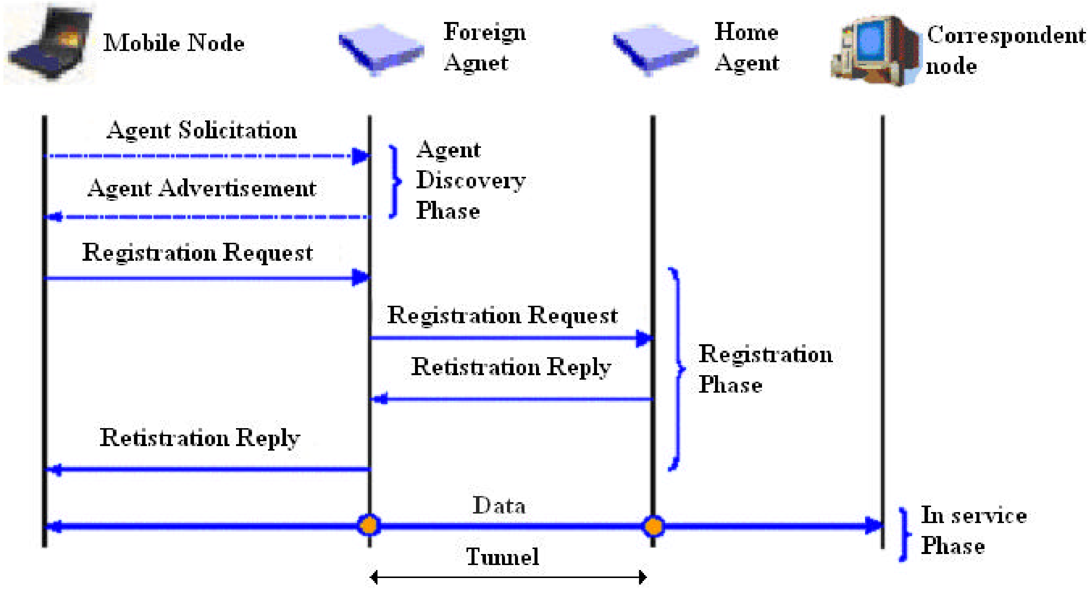

Figure 2.1: Mobile IPv4 messages.

2.1.2 Mobile IPv6

The Mobile IP protocol described above is based on IPv4. Although IPv6 supports mobility to a greater degree than IPv4, it still needs Mobile IP to achieve host mobility. However, IPv6 includes many features designed for mobility support, such as Stateless Address Autoconfiguration [4], and Neighbor Discovery [5]. With these features, Mobile IPv6 [6] has many improvements over Mobile IPv4. The operation of Mobile IPv6 is illustrated in Figure 2.2. Some advantages of Mobile IPv6 over Mobile IPv4 are:

- Route Optimization is built in as a fundamental part of Mobile IPv6.
- Foreign Agents are not needed in Mobile IPv6.
- Coexistence with Internet ingress filtering.

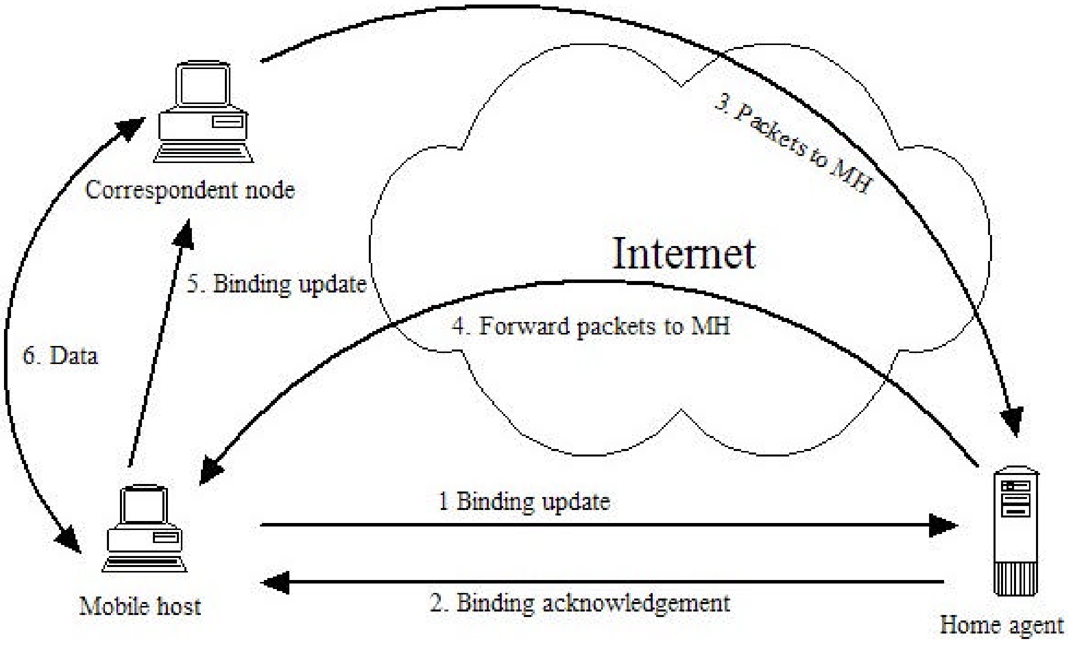

Figure 2.2: Mobile IPv6 operations.

2.1.3 Handoff delay problem in Mobile IP

One major problem in Mobile IP is the handoff delay. When a mobile host moves from one foreign domain to another, a registration process is required in order to update its location to home agent. Before completing the process, a mobile host is unable to receive packets from its home agent. The registration process results in long handoff latencies, which leads to packet loss and severe TCP performance degradation [7].

Mobile IP handoff delay can be divided into two elements - *signaling delay for registration* and *movement detection*. Signaling delay for registration is caused by the latency between a mobile host and its home agent, especially when the mobile host is far from its home network. When a mobile host moves to another network, it will not notify the change unless it receives an *agent advertisement* message. According to Section 2.3 of RFC2002, which specifies Mobile IP, the recommended rate of sending *agent advertisement* is once per second. The time before a mobile host finds out the change of foreign agent is the movement detection delay.

Several mechanisms have been proposed to solve the problem. One approach to reduce the registration signaling delay is called micro-mobility [8]. By dividing the network into a hierarchical structure, location management can be handled locally while the mobile host moves within a smaller area. This greatly reduces the round trip time for registrations when there is a large distance between the visited network and the home network of the mobile node. Many micro-mobility protocols have been proposed, such as Cellular IP [9], HAWAII [10], and Hierarchical Mobile IP [2]. Fast handovers [3] mechanism minimizes the movement detection delay by pre-configuring a new care-of-address before mobile host moves to a new network.

The mechanism proposed in this thesis is based on the Hierarchical Mobile IP and Fast handovers mechanism. They are described in the following section.

2.2 Hierarchical MIPv6

The Hierarchical Mobile IPv6 is an enhancement of Mobile IPv6 proposed by the IETF. It designs to reduce the amount of signaling required and to improve handover speed for mobile connections. The protocol is described in this section.

2.2.1 Protocol overview

Under hierarchical schemes, mobility management is separated into two parts; i.e., *macro-mobility* (global mobility) and *micro-mobility* (local mobility). Mobile IP is suitable for managing global mobility, but results in high signaling latency in the case of local mobility. Hierarchical Mobile IPv6 reduces the registration delay of mobility by handling local movements locally and hiding them from home agents. Hierarchical Mobile IPv6 adds another level, built on Mobile IPv6, which separates local from global mobility. Just as many other micro-mobility protocols, in Hierarchical Mobile IPv6, macro-mobility is managed by the Mobile IPv6 protocols, while local handoffs are managed locally.

In order to accommodate local movement management within the current network, a new Mobile IPv6 node called *Mobility Anchor Point* (MAP) is introduced. The MAP is a specialized router that maintains a binding between itself and the mobile host. It replaces Mobile IPv4's foreign agent, and can be thought of as a local home agent for mobile hosts. Unlike foreign agent in Mobile IPv4, there is no requirement for a MAP to reside on each subnet; it can be located at any level in a hierarchical network of routers. The MAP helps to decrease registration delay because a local MAP can be updated more quickly than a remote home agent far away from the mobile host.

In Hierarchical Mobile IPv6, a mobile node is assigned with two care-of-addresses. The addresses are called *Regional Care-of-Address* (RCoA) and *On-Link Care-of-Address* (LCoA). RCoA is an address on the MAP's subnet, or usually the MAP's IP address. The mobile host use RCoA as its care-of-address when registration with home agent. LCoA is the same as the care-of-address in the Mobile IPv6. While moving between subnets inside the MAP's domain, mobile host only changes its LCoA. This hides the movements from its home agent. The following steps show how hierarchical Mobile IPv6 operates.

1. When a mobile host enters a new MAP domain, it gets *Agent Advertisement* containing one or mare local MAPs. The mobile host then selects one of the MAPs and obtains an RCoA on the MAPs domain. The mobile host also gets an LCoA from the access router on the subnet. The mobile host sends a *Binding Update* to the MAP. The MAP records the binding between the RCoA and LCoA of mobile host by inserting an entry into its Binding Cache.
2. The MAP sends *Binding Update* messages to the mobile host's home agent and to the correspondent node the mobile host is communication with.

3. The MAP then functions as a local home agent to mobile host. It intercepts packets sending to the mobile host's RCoA, and tunnels them to the mobile host's LCoA using IPv6 encapsulation. However, the mobile host is always able to send data directly to all correspondent nodes.
4. When mobile host movies between subnets inside the MAP's domain, it gets a new LCoA from the subnet. Its RCoA remains unchanged when it is still inside the MAP's domain. No registration process to its home agent is required. A mobile host sends binding update only to the MAP and all correspondent nodes.

2.3 Fast Handovers Protocol

Fast handovers protocol is proposed by IETF as a way to minimize the movement detection delay during a handoff process. The operation is described in this section.

2.3.1 Protocol overview

The key operation of Fast handover is to pre-configure a temporary address before breaking the mobile host's connection with its *previous Access Router* (**PAR**). Then, when the mobile host is attached to the *new Access Router* (**NAR**), it can resume its communications with its new already-known care-of-address. If the anticipated registration fails (unable to pre-configure new care-of-address), the mobile host continues the handoff process when it is attached to the NAR. Moreover the Fast handover sets up a bi-directional tunnel between the PAR and the NAR. This makes mobile host able to send packets before it finishes the Mobile IP registration process. Finally, the mobile host continues on normal Mobile IP registration process.

2.3.2 Detailed descriptions

There are three phases in the Fast handover protocol operation: *handover initiation*, *tunnel establishment*, and *packet forwarding*. The overall handoff protocol is illustrated in Figure 2.3.

a. Handover Initiation:

Fast handover is triggered by a specific L2 event or from policy rules that might determine the need for handoff. Handover initiation may occur while the mobile host is still attached to the PAR, or it may take place after it attaches to the NAR.

- Anticipation

When a mobile host receives external events such as a determination at link layer to undergo handoff, the mobile host requests its access router (PAR) to assist in handoff. The mobile host sends a *Router Solicitation for a Proxy* (RtSolPr) to PAR, which includes a link-layer identifier of NAR. In response to RtSolPr message, the PAR sends a *Proxy Router Advertisement* (PrRtAdv) message, which provides the link-layer address, and network prefix information about the NAR. Mobile host then can obtain necessary information to formulate a *new care-of-address* (NCoA) on NAR domain.

- No Anticipation

If a mobile host failed to anticipate a handoff event, the mobile host may change its link without engaging in protocol messages with the PAR on its previous link. Mobile host just skips the operation and sends a FBU to the NAR.

b. Tunnel Establishment:

Fast handover protocol establishes a bi-directional tunnel between NAR and PAR. There are two purposes for building a bi-directional tunnel. Since a mobile host cannot use NCoA until it completes Binding Update with its home agent (or MAP), NAR needs to tunnel packets that still use the *previous care-of-addresses* (PCoA) as their source addresses back to PAR. Second, before a mobile host finishes Binding Update process, the home agent (or MAP) still forwards packets for the mobile host to its PAR. The PAR then tunnels these packets to NAR by the tunnel.

The tunnel establishment is achieved through *Handover Initiate* (HI) and *Handover Acknowledge* (HAck) messages. The HI message contains the PCoA, link-layer address and the NCoA (when known) of the mobile host. The PAR sends the HI message to the NAR when the PAR does any of the following events:

- Receives RtSolPr and determines that the mobile host needs to attach to NAR.
- Decides to send a PrRtAdv message without receiving the mobile host's RtSolPr message first.
- Finds out the mobile host is attaching to NAR without sending PrRtAdv.
- Receives an FBU message from a mobile host to which it has never previously sent a HI message

After receiving the HI message, the NAR responses by:

- Creating a host route for PCoA that allows NAR to forward packets to the mobile host.
- Setting up a tunnel for packets using PCoA as the source IP address back to PAR.
- Verifying if NCoA supplied in the HI message is a valid address in the subnet.
- Returning the status of handoff by sending a HAck message back to PAR.

When PAR receives a HAck message, the tunnel establishment is completed. There could be delay results from link layer handoff. Packets forwarded to NAR during this delay will be lost unless the routers buffer packets.

c. Packet Forwarding:

After receiving PrRtAdv message from PAR, the mobile host sends a *Fast Binding Update* (FBU) to PAR with PCoA as its source IP before disconnecting the link. If it is unable to do that, it should send FBU as soon as it connects to the NAR. This allows the PAR to start tunneling packets with PCoA as destination address to NAR. PAR then sends Fast Binding Acknowledgement (FBAck) message to both mobile host (on the old link) and NAR after verifying that the NAR has accepted the handoff request. A mobile host receives FBAck message from either old link on PAR or new link on NAR. The fast handover protocol operation is completed once the mobile host receives the FBAck message.

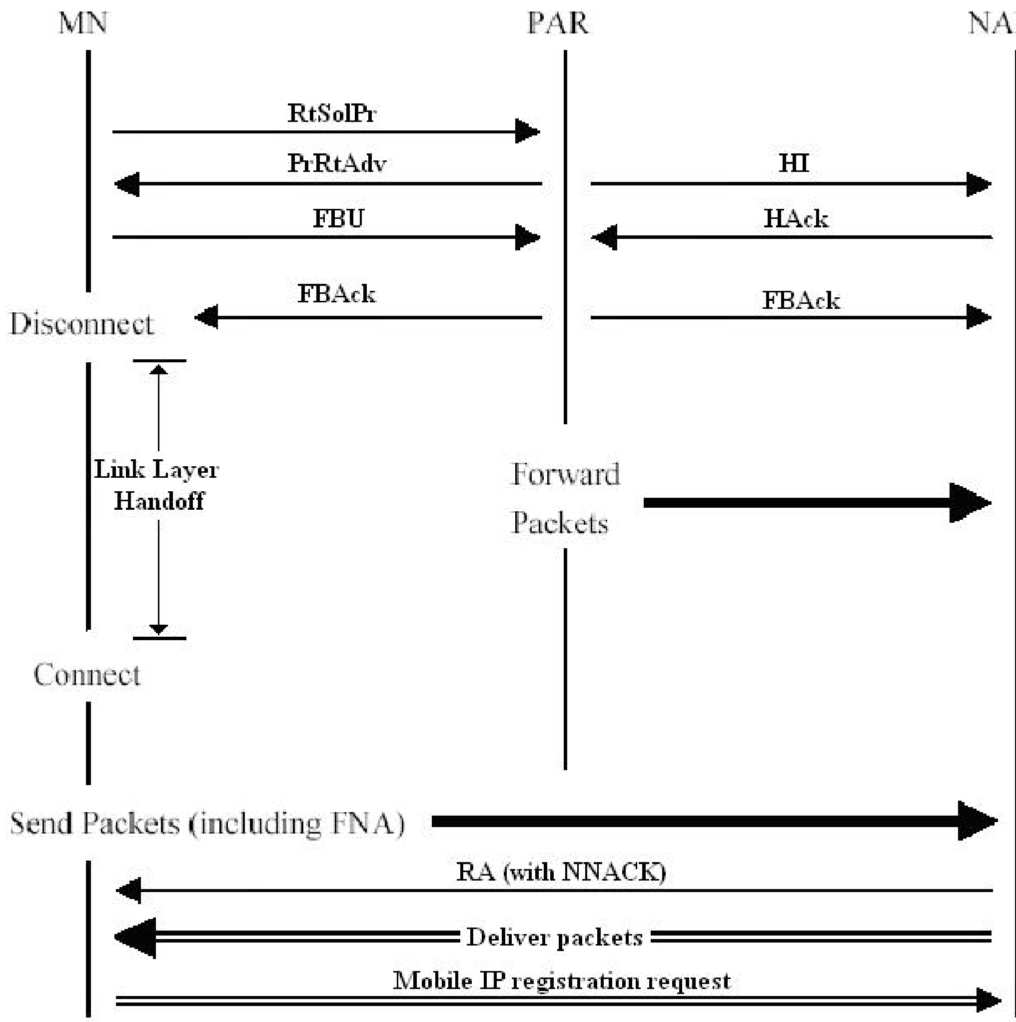

Figure 2.3: Fast Handover protocol messages.

2.4 Buffer Management for Smooth Handovers in IPv6

Mobile IP handoff delay results in packet loss or delay. Currently available IEEE 802.11 wireless LAN card can only access one access point at a time. This limitation results in an inevitable link down time during handoff process. The only solution to avoid packet loss during the link down time is to buffer those packets. A buffer management protocol is integrated into the proposed scheme described in Chapter 3. The original buffer management protocol is describing in the following section.

2.4.1 Protocol overview

The buffer management mechanism named "Buffer management for smooth handovers in IPv6 [11]" defines a buffering mechanism for a mobile host requesting its current access router to buffer packets. When the mobile host moves from one subnet into another, the mechanism works as following:

I. A router that enables buffering mechanism advertises its capability by setting up a "B" flag in its router advertisements.

II. Before doing handoff, the mobile host sends a *buffer initialization* (BI) message to requests its access router for buffering the packets. The mobile host may request a size for the requested buffer in the message.

III. In response to the message, the PAR sends a *buffer acknowledgement* (BA) message back to the mobile host. Incoming packets to the mobile host are then buffered in the PAR (previous router)

IV. When the mobile host completes registration process to NAR and obtains a new care-of-address, it sends a *buffer forward* (BF) message to PAR. PAR forwards the buffered packets to the mobile host when receiving the message and finishes the process.

The overall buffering management protocol is illustrated in Figure 2.4.

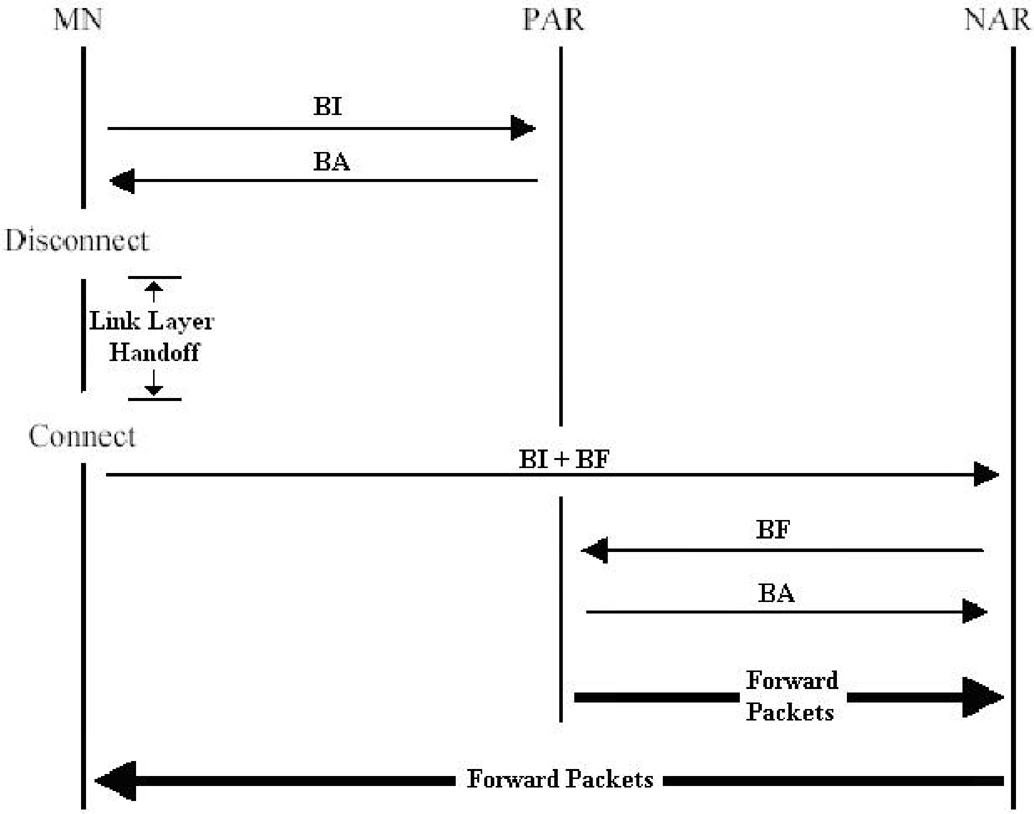

Figure 2.4: Buffer management for smooth handovers in IPv6 messages.

Chapter 3

Proposed Approaches

In this chapter, we propose an enhanced buffer management mechanism for Fast Handover. In the first section, we describe the motivation and design goals or the proposed approach. The following section describes the detail of our mechanism. The contribution of our mechanism is illustrated in the last section.

3.1 Motivation and Design Goals

3.1.1 Motivation

In chapter 2, we described the handoff latency problem in Mobile IP. With the combination of Hierarchical Mobile IPv6 and Fast Handover mechanism, the handoff latency caused by layer 3 and up can be greatly minimized [12]. However, the handoff latency results from link layer handover procedure are still unavoidable. With the different combination of IEEE 802.11 WLAN card and base station, the handover procedure may take from 60ms to 400ms [13]. During this period of time, the mobile host can neither receive nor send data. Several mechanisms have been proposed to avoid packet loss during handoff period. We can categorize them into two groups. Simultaneous binding [14] is the representation of the first group. It maintains multiple care-of address binding with access router on different subnets and can receive packet from any of them. Since the mobile host maintains at least one connection with the access router during the handoff process, packet loss can be avoided. But the currently available IEEE 802.11 wireless LAN card can only access one access point at a time; the Simultaneous binding mechanism will not work under this condition. Another approach, and it is the only feasible one, to prevent packet loss during handoff process is to buffer packets.

The Fast Handover protocol described in Chapter 2.3 also includes buffering mechanism. A mobile host can request its new access router for buffering packets forwarded from its previous access router. However, the simple buffering mechanism suffers from scalability problem. Consider the following condition: The buffer size in a router is 50 packets. Handoff latency for every handoff is 200ms. Each mobile host transmits 160 bytes UDP packet with an interval 20ms. During the handoff process, the router needs to buffer 10 packets for each mobile host. Thus the router can only serve at most 5 simultaneously handoff users. If the number of users in a subnet is as many as current cellular phone system, the condition of buffer full will occur and many users will suffer packet loss during handoff. The simplest way to solve the problem is to increase the buffer size in a router. However, large buffer size leads to longer queuing delay for packets in the buffer. This delay may degrade the performance of many real-time applications. Comparison with circuit switching based telecom network, traffics on packet switching based data network are not all of a kind. Not all of them need real-time transport, examples are WWW and FTP packets. Many mechanisms have been proposed to implement quality of service (QoS) on Internet, such as integrated services [15] (Intserv) and differentiated services [16] (Diffserv). Based on the similar concept, not all packets during handoff process need to be buffered, and packets with different priority should be treated differently. In order to optimize the usage of buffers in an access router, we proposed an enhancement on buffering mechanism in Fast Handover protocol.

3.1.2 Design Goals

We have four design goals in the buffer management mechanism.

- Support QoS during handoff process

  We define three types of services in our mechanism. The buffering operation should adapt to accommodate the characteristics of each type.

- Support real-time traffic during handoff

  For real-time packets, the access router should transfer them to the mobile host as soon as possible after link layer handoff process. We should minimize its waiting time in buffer and forwarding time from previous access router to new access router.

- Maximize buffer utilization in access routers

  The buffering space in an access router is limited and we should make good use of them. These include only buffer important packets when running out of buffer, and use both buffers in the previous access router and new access router during handoff process.

- Integrate with Fast Handover protocol

  The proposed buffering mechanism should be able to integrate with Fast Handover protocol; the modifications to the original protocol message flow should be minimized.

3.2 Enhanced Buffer Management Mechanism for Fast Handover Protocol

3.2.1 Protocol overview

The reference scenario for handover is illustrated in Figure 3.1. A mobile host moves from the PAR to NAR. We modified the original Fast Handover protocol and combined it with the buffering mechanism described in Section 2.4. The enhanced buffering management mechanism mentioned above can be separated into three phases: *handover initiation, packet redirection,* and *buffer release*.

In the *handover initiation* phases, the handover process is triggered by specific link layer events or policy rules just as the original Fast Handover protocol. On receiving the trigger event, the mobile host sends a request to the PAR for requesting the buffer spaces. During the time when PAR and NAR establish a bi-directional tunnel between them (original step in Fast Handover protocol), they also negotiate the allocation of buffer spaces requested by the mobile host. The PAR then returns the result of negotiation to the mobile host in the *Handover Acknowledge* (HAck) message.

In the *packet redirection* phases, the mobile host sends a *Fast Binding Update* (FBU) to PAR after receiving the HAck message. When PAR receives the FBU message, it starts buffering packets or forwarding them to NAR. The NAR may either buffer packets from PAR or drop them. Packets are treated differently based on their type of service. We defined three types of packets in our method. Detailed buffering operation and packet classification is described in Section 3.2.2.1.

Finally, in the *buffer release* phases, the mobile host reestablishes connection on NAR. When connecting to NAR, the mobile host sends a *Buffer Forward* (BF) message to both NAR and PAR. Upon receiving the BF message, the NAR and PAR forwards packets in their buffer to the mobile host, and ends the handover process. The overall handover protocol is illustrated in Figure 3.2. We will describe them separately in the following section.

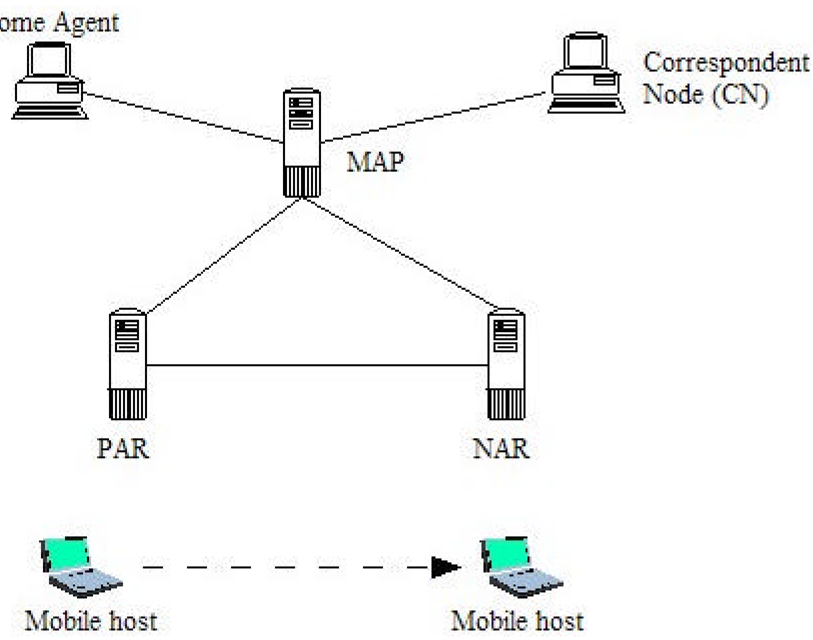

Figure 3.1: Reference scenario for handover.

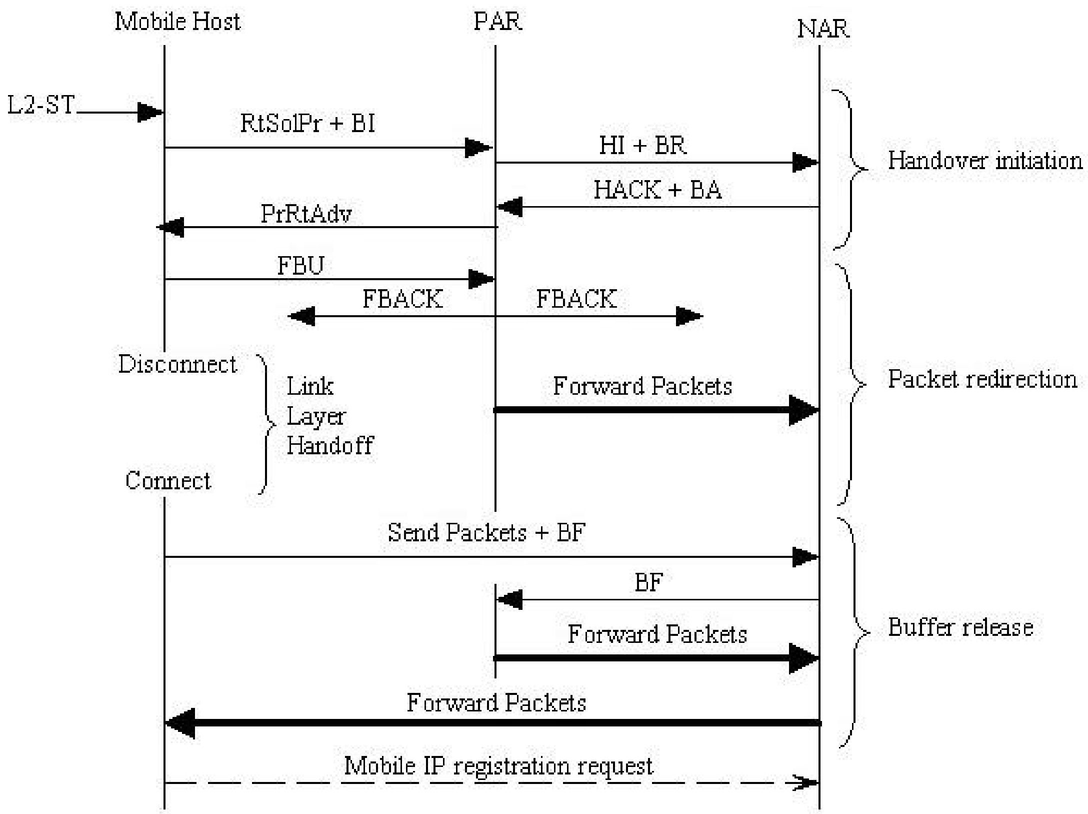

Figure 3.2: Enhanced buffer management mechanism for Fast Handover protocol messages.

3.2.2 Protocol details

In this section, we describe the detailed operations in the Enhanced buffer management mechanism for Fast Handover. The reference scenario for handover is shown in Figure 3.1. The mechanism proposed in this thesis is a modification version of Fast Handovers for Mobile IPv6 [3]. We use IPv6 as the network architecture when describing our mechanism. However, with a slightly modification, we can easily apply it on IPv4 network.

3.2.2.1 Terminology

The following terminology and abbreviations are used in this thesis:

Mobile host (MH)

A Mobile IPv6 host

Access Router (AR)

The default router of the MH

Previous Access router (PAR)

The MH's default router before handover

New Access Router (NAR)

The MH's anticipated default router after its handover

The proposed buffering mechanism processes packets according to their type of service. We define three types of packets in our mechanism.

- Real-time packets

  These packets need real-time transmission. Packets are useless when the delay is too long. No retransmission mechanism is needed for them.

- High priority packets

  These packets are most important. We should minimize their drop rate.

- Best effort packets

These packets are low priority packets. They can suffer long delay time or even be dropped. We can sacrifice them when out of buffer space.

3.2.2.1 Handover initiation

In the *handover initiation* phases, the mobile host sends handoff request to its access router (the PAR). The PAR and NAR negotiates the allocation of buffer spaces and establishes a bi-directional tunnel. The message flows are shown in Figure 3.3.

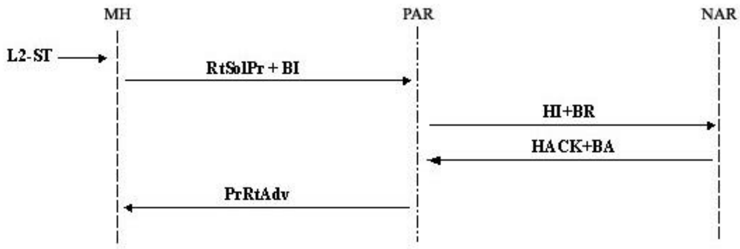

Figure 3.3 Message flows in Handover initiation.

In the original Fast Handover protocol, two types of handoff are considered; the *network initiated handover* and the *mobile initiated handover*. In the first case, the network initiates a handoff process; the network monitors all mobile hosts and decides if a handoff process is needed. In the second case, the mobile host decides itself whether to handoff or not. Since it is not practical to monitor all mobile hosts in a network with large amount of users, the first case is not considered in our method.

The handover process starts when it is triggered by specific link layer events or policy rules, which is same as the original Fast Handover protocol. The link layer triggers are described in [17]. When a mobile host receives a link layer trigger, *link layer source trigger* (L2-ST), it sends a *Router Solicitation for Proxy + Buffer initialization* (RtSolPr+BI) message to PAR. The BI message piggybacks on original RtSolPr message in Fast Handover protocol. The BI message contains three additional fields, *buffer size*, *start time*, and *lifetime*. The *buffer size* field specifies the requested buffer size by the mobile host. The *start time* field specifies the time when the PAR starts buffering packets for mobile host. This is used to prevent the case when a mobile host moves too fast, and it would be disconnected from the PAR before sending a FBU message. The PAR automatically starts buffering packets after the specific time. The *lifetime* field specifies the lifetime for the buffering space. The mobile host can cancel the handoff process by sending an RtSolPr+BI message with *start time* and *lifetime* field set to 0.

When the PAR receives an RtSolPr+BI message, it sends a *Handover Initiate + Buffer Request* (HI+BR) message to the NAR. The BR message contains *buffer size* and *lifetime* requested by the mobile host. The NAR replies with a *Handover Acknowledge + Buffer Request Acknowledge* (HAck+BA). With these two messages, a bi-directional tunnel is established between the PAR and NAR (original step in Fast Handover protocol). The PAR and NAR also negotiates for the allocation of buffer spaces. The NAR returns whether or not it can provide the requested buffer space in BA message. The PAR then sends a *Proxy Router Advertisement* (PrRtAdv) message to mobile host. This notifies the mobile host that the preparation of handoff process is completed.

3.2.2.2 Packet redirection

In the *packet redirection* phase, the mobile host lost its connection with the network while doing link layer handoff process. The PAR and NAR redirect packets for the mobile host during this period of time. Packets will be buffered or dropped depending on their class of traffic and current available buffer spaces in the NAR and the PAR.

The mobile host sends a *Fast Binding Update* (FBU) message before it disconnects from the network (starts the link layer handoff). The PAR sends a *Fast Binding Acknowledgment* (FBACK) in response. When the PAR receives the FBU message, it starts the packet redirection operation. The redirection operation on each packet depends on the packet's class of service. The mobile host and its correspondent node can specify the priority of a packet on the *class of traffic* field in IPv6 header. Since the value of the field is not defined in the specification of IPv6, we define it in Table 3.1.

Class of service field	Type of service
0	Not specified, treated as Best effort packets
1	Real-time packets
2	High priority packets
3	Best effort packets

Table 3.1 Values in class of service field

In the *handover initiation* phases, the PAR and the NAR negotiates with the allocation of buffer spaces. Table 3.2 shows four possible results. The "Yes" and "No" field means if there are available buffer spaces in the NAR or PAR. For example, Case 1 is the case when both the NAR and the PAR can offer sufficient buffer spaces for the handoff process.

NAR \ PAR	Yes	No
Yes	Case 1	Case 2
No	Case 3	Case 4

Table 3.2 Allocation of buffer spaces

We defined three types of packets in Section 3.2.2.1. In order to satisfy the characteristic of each class, we assign different buffering operation on each case. The buffering operation in each case is illustrated in Table 3.3.

Traffic type	Buffering operation
Case 1：NAR (Yes) PAR (Yes)	
Real-time (a)	Buffer at NAR only. If buffer full, drop the first real-time packet.
High Priority (b)	Buffer at both NAR and PAR
Best effort (c)	Buffer at PAR when PAR > a
Case 2：NAR (Yes) PAR (No)	
Real-time (a)	Buffer at NAR only. If buffer full, drop the first real-time packet.
High Priority (b)	Buffer at NAR only.
Best effort (c)	Forward to NAR only. (Do not buffer)
Case 3：NAR (No) PAR (Yes)	
Real-time (a)	Forward to NAR only. (Do not buffer)
High Priority (b)	Buffer at PAR only.
Best effort (c)	Buffer at PAR when PAR > a
Case 4：NAR (No) PAR (No)	
Real-time (a)	Forward to NAR only. (Do not buffer)
High Priority (b)	Forward to NAR only. (Do not buffer)
Best effort (c)	Drop at PAR. (Do not forward to NAR)

Table 3.3 Buffering operations

In Case 1.a, all packets arrive at PAR will be forwarded to the NAR first, and then NAR buffers the packets. If the NAR runs out of buffer space, the first packet in the buffer will be dropped to buffer the new packet.

In Case 1.b, packets to PAR will be forwarded to NAR first and buffered there. When NAR runs out of buffer, a *Buffer Full* message will be sent to the PAR. When PAR receives the message, it will buffer the rest of the packets.

In Case 1.c, packets are only buffered at the PAR when the available buffering space is greater than a. The value of a is a constant value configured by the network administrator. Packets will be dropped when the buffer space is less then a.

In Case 2, the PAR cannot provide buffer space. Only real-time and high priority packets are buffered in the NAR (Case 2.a, Case 2.b). The best effort packets are forwarded to NAR without buffering.

In Case 3, the NAR cannot provide buffer space. Real-time packets are forwarded to NAR without buffering. High priority packets and best effort packets are buffered at PAR.

In Case 4, no buffer spaces are available. The traffic load on the PAR and NAR should be heavy. We drop best effort packets at PAR directly to ease the loading of the network. Real-time and high priority packets are forwarded to the NAR without buffering.

3.2.2.3 Buffer release

When the mobile host connects to the NAR after link layer handoff, it sends a *Fast Neighbor Advertisement + Buffer Forward* (FNA+BF) to the NAR. The NAR sends a BF message to PAR when receives the FNA+BF. The NAR and PAR forward all buffered packets to the mobile host when they receive a BF message. The handoff process is terminated when the mobile host receives the buffered packets. The mobile host then starts the registration process in Mobile IP. The message flows are shown in Figure 3.4.

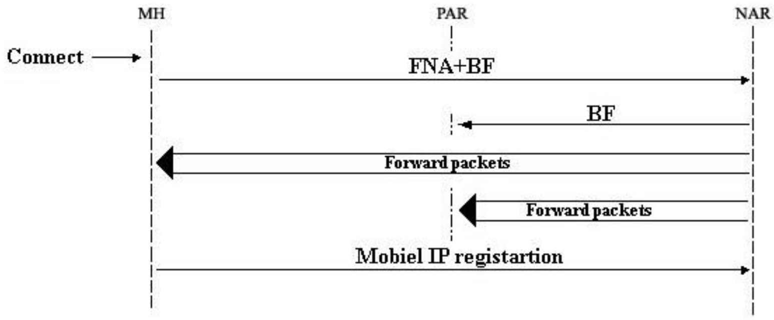

Figure 3.4 Message flows in buffer release.

3.2.2.4 Buffer support on link layer handoff

The Fast Handover protocol focuses on inter domain handoffs, a mobile host moves from one subnet to another. Since there might be multiple WLAN access points in a subnet, link layer handoff also happens when the mobile host is remaining inside a subnet. The enhanced buffer mechanism proposed in the thesis can apply on this condition. When a mobile host detects a handoff event, it sends an RtSolPr+BI to the current access router (PAR). If the PAR finds out that it is only a link layer handoff, it allocates the buffering space and replies a PrRtAdv directly to the mobile host. The PAR starts to buffer packets when receives a FBU message from the mobile host. After the mobile host completes the link layer handoff, it sends a BF message to PAR. The PAR then forwards the buffered packets back to the mobile host. The message flows are illustrated in Figure 3.5.

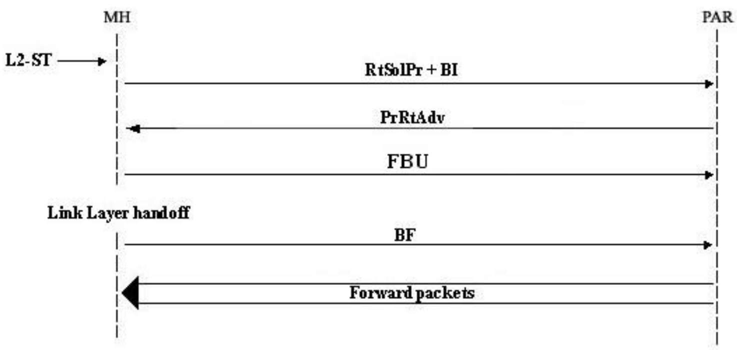

Figure 3.5 Buffer support for link layer handoff.

3.3 Performance Consideration

Following the design goals listed in section 3.1.2, we proposed a buffering mechanism, *Enhanced buffer management mechanism for Fast Handovers*, described in Section 3.2. The proposed method has the following improvements on original Fast Handover protocol.

- Full utilization of buffering space in both PAR and NAR.

  In the original Fast Handover protocol, all packets are buffered at the NAR. With the proposed mechanism, both buffer spaces in the NAR and PAR are used during the handoff process. This helps to minimize packet lost due to buffer full.

- QoS support during handoff

  Three classes of service are defined in the buffering mechanism. The buffering mechanism reduces the delay for real-time packets in buffer and drop rate of high priority packets. By mapping the classes of service with the per hub behavior (PHB) in Diffserv, the proposed method can operate in a Diffserv network.

- Low signaling overhead

  Most of the control messages in the buffer management mechanism are piggyback on original Fast Handover control messages. Only BF message in the *buffer release* phase is added.

- Supports buffering mechanism during normal link layer handoff

  The original Fast handoff protocol does not buffer packets for handoffs between access points in the same subnet. With the buffering mechanism integrated into Fast handoff protocol, a mobile host is now able to request its access router buffering packets before any handoff operations. A mobile host can also buffer packets at its access router when poor connection quality on a wireless link is detected.

- A integration of Fast Handovers and Buffer management mechanism

  The proposed mechanism integrates a buffering mechanism into Fast handoff protocol and provides a solution to the scalability problem. Most of the additional control messages can be integrated into the option field in original Fast handoff control message. This makes the proposed method compatible with original Fast handoff protocol.

Chapter 4

The Simulation Model and Results

In this chapter, we make use of the *ns-2* [18] simulator to evaluate the performance of the proposed approaches as mentioned in Chapter 3. In the first part of Chapter 4, we describe the simulation configuration and network topology in our simulation. Four simulation cases are used to verify the performance of our proposed method, we present each of the simulation results in the second part of this chapter.

4.1 Simulation Configuration and Testing Scenarios

We verify the performance of the enhanced buffer management mechanism proposed in Chapter 3 by means of a simulation performed using the Network Simulator (*ns-2*). The standard *ns-2* distribution version *ns-allinone2.1b6* was patched with the freely available *Columbia IP Micro-Mobility Suit* (CIMS) [19] module. Based on the patched *ns-2* program, we add some additional features including the fast handover protocol and the proposed mechanism described in Chapter 3.

The network topology for most of the simulations in this chapter is illustrated in Figure 4.1. The topology depicts a generic Hierarchical Mobile IPv6 network. The bandwidth (Megabits/sec) and the delay (milliseconds) are shown beside the link. The distance between the two access routers is 212 meters and the interval of router advertisement is one per second. On each access router (PAR and NAR), there is a wireless LAN access point located. The wireless coverage area of the access point is approximately 112 meters, which also means the overlapping area between the PAR and the NAR is 12 meters. During a handoff process in the real world, there is a link layer handoff delay from 60ms to 400ms [20]. We set the link layer handoff delay to 200ms in our simulation. Finally, all mobile nodes in our simulations move linearly from one access router to another at a constant speed of 10m/s (36KM/Hr), which is fast enough for a car driving in the urban areas. Since the overlapping area between the PAR and the NAR is 12 meters, the mobile host can receive at least one router advertisement from the new access router before leaving the old one. This also assures that the mobile host has enough time to trigger Fast Handover protocols before leaving the old network.

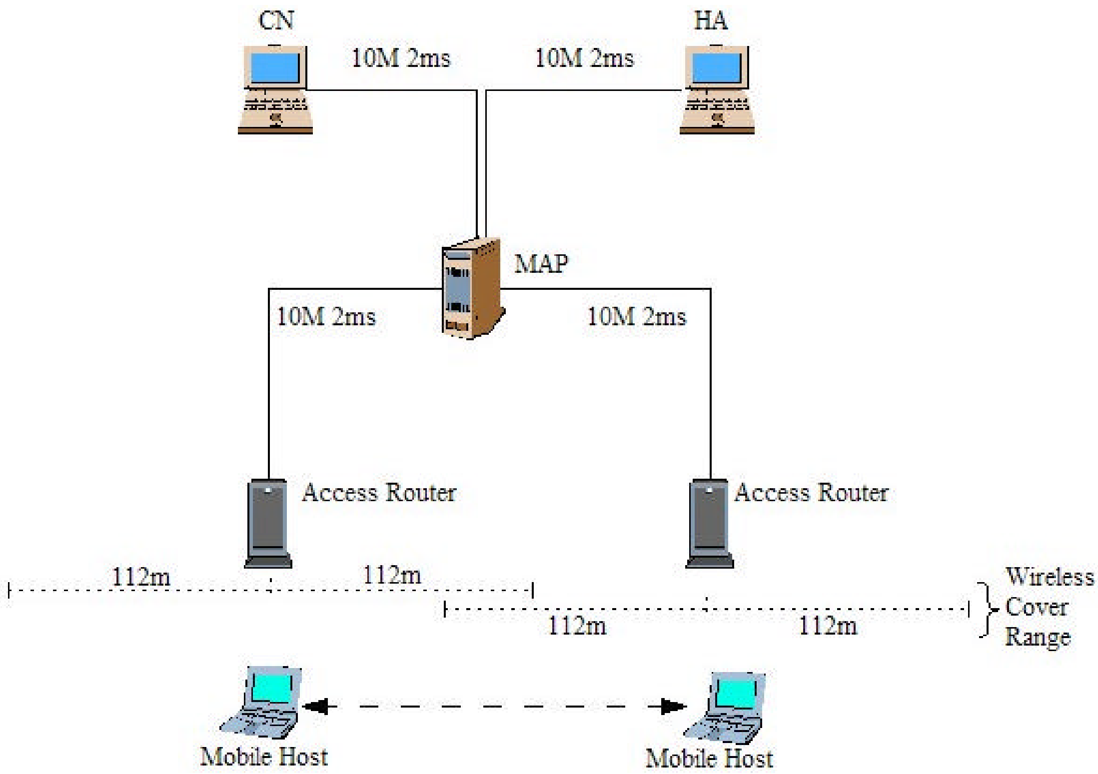

Fig 4.1: The network topology for simulations.

4.2 The Numerical Results and Analysis

Several advantages of our proposed buffering management mechanism are described in Section 3.3. However, they are not convincing enough since no conclusive proofs have been done. In this section, we verify them by simulations. In Section 4.2.1, we test the maximum number of handoffs the network can handle simultaneously. Then the QoS support for both high priority and real-time packets is presented in Section 4.2.2 and 4.2.3. In the last part of this section, we illustrated the improvement of TCP performance on link layer handoff when the proposed method is applied.

4.2.1 Buffer utilization

In the fast handoff protocol, the mobile host always buffer packets in the NAR. Since the handoff process involves two access routers (the PAR and the NAR), buffer spaces in both access routers should be utilized. We use both of the buffer spaces in the proposed buffer management mechanism in this thesis. In the best case, where both buffer spaces are available, the proposed method should be able to serve twice as many users as the original fast handover protocol. The proposed method should have the same performance as the original fast handover protocol when there is only one buffer space available.

We use the following simulation to evaluate the buffer utilization of different handoff mechanisms. The network topology is shown in Figure 4.1. All mobile hosts in the simulation move along the same path simultaneously (from the PAR to the NAR), and one handoff event occurs during the movement. The CN transmits 160-byte UDP packets every 20ms (64-kb/s audio) to each mobile host. We increase the number of mobile hosts to evaluate how many handoffs the network can service at the same time.

We compare four types of handoffs in Figure 4.2. The NAR line represents the case that all packets are buffered at the NAR, which is also the case of original fast handover protocol. The PAR line shows the condition that all packets are buffered at the PAR. The DUAL line shows the condition where packets are buffered at both the PAR and NAR. The FH line shows the condition for fast handover protocol without buffering spaces. The DUAL line is the best case of the proposed method. The network can service 7 simultaneously handoffs without drop any packets; this is twice as much as the original fast handoff protocol (the NAR line). If there are only one buffer spaces available (the NAR and PAR lines), the proposed method has the same performance comparing with the original fast handoff protocol. The FH line is the worst case for our method when there are no buffer spaces available.

We can conclude from the simulation that the proposed method has better buffer utilization than original fast handover protocol. In the latter, no packets can be buffered when the NAR runs out of buffer spaces. However, with the proposed mechanism, the network runs out of buffer spaces only when both the NAR and PAR are out of buffer spaces.

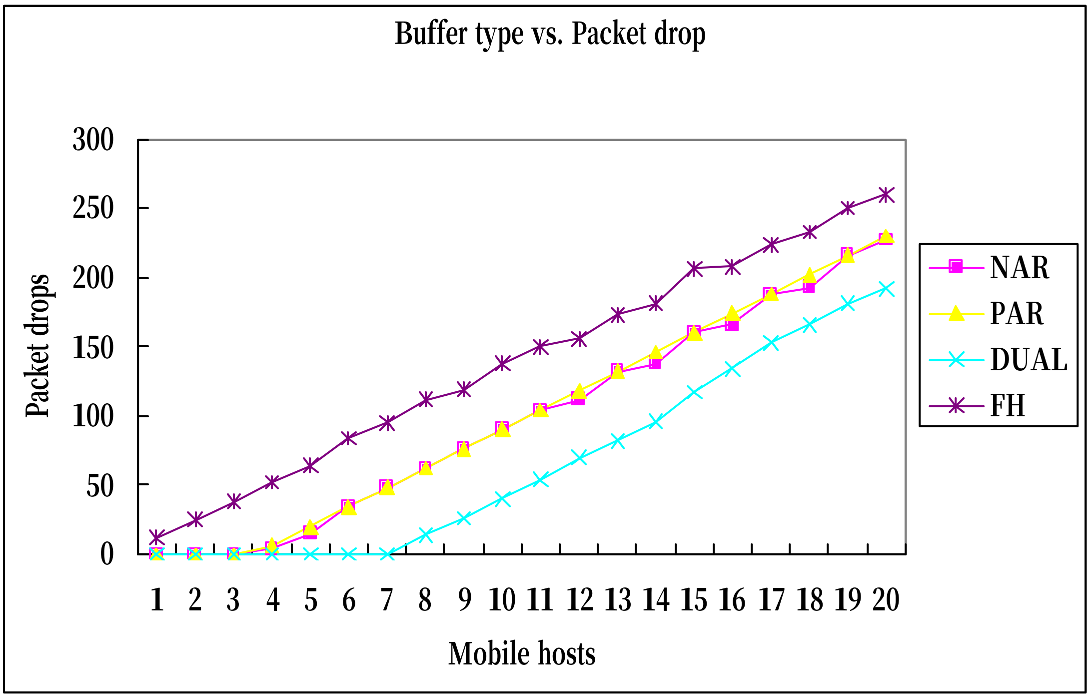

Figure 4.2: Buffer utilization of different handoff mechanisms.

4.2.2 QoS support during handoff

We define three types of packets in the proposed method. Different types of packets are served differently during the handoff process as described in Section 3.2.2.2. With the buffering mechanism, packet dropping due to buffer full should be minimized.

The network topology is shown in Figure 4.1. There is only one mobile host moving back and forth between the two access routers. The CN transmits three 64-kb/s audio flows (160-byte UDP packets every 20ms) with different priorities to the mobile node. We use F1, F2, and F3 to represent each of the flows in the following description. We define F1 as the real-time traffic, F2 as the high priority traffic, and F3 as the best effort traffic. In Figure 4.3 ~ 4.5, we compare the packet drop rate (the slope of F1~F3) versus the number of handoff occurred.

Figure 4.3 shows the packet drop rate of F1 to F3 with original fast handover method. The buffer size in access router is set to 40, which is double the size to our proposed method, in order to get similar total packet drop rate (summary drop rate for F1, F2, and F3) with the proposed method. Figure 4.4 shows the packet drop rate for the proposed method, but we disable the packet classification function, which means that all packets are treated the same. We can see from Figure 4.3 and Figure 4.4 that all the flows have the same packet drop rate when no QoS support is used. However, when we enable the classification function in the proposed method (Figure 4.5), the drop rate of high priority packets is greatly reduced.

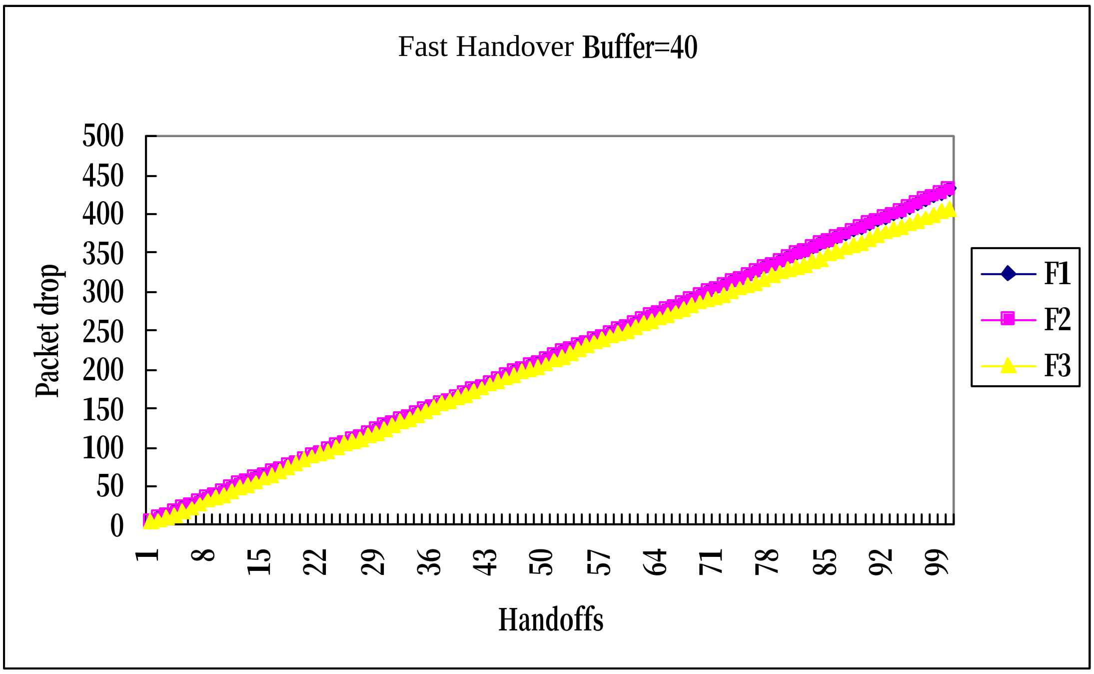

Figure 4.3: Packet drop rate on original fast handover method.

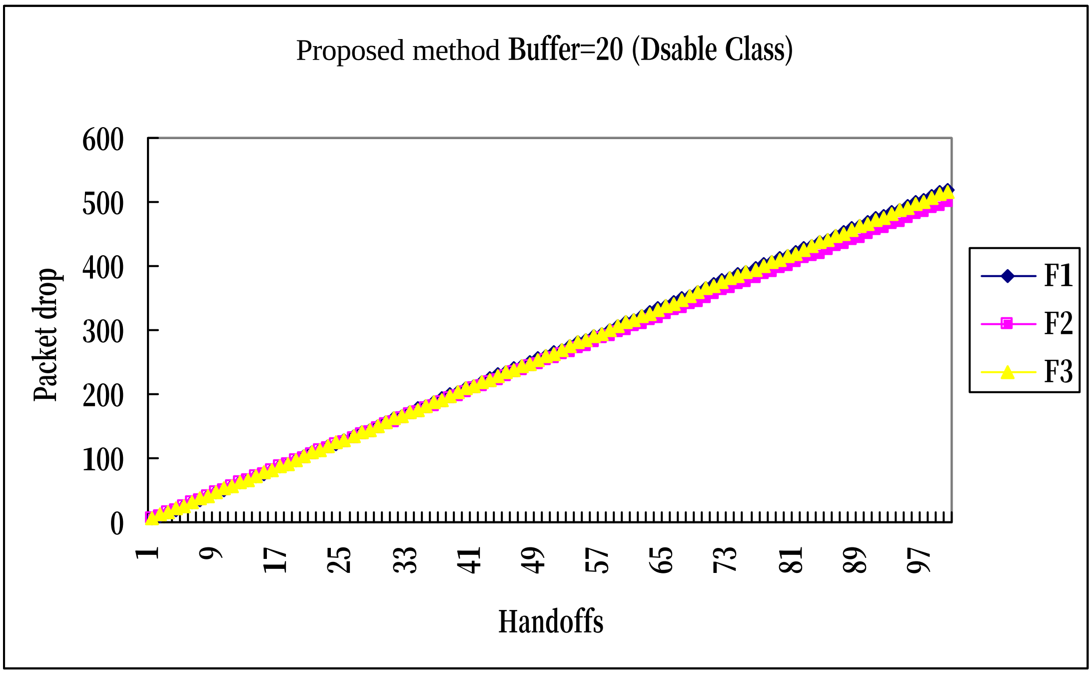

Figure 4.4: Packet drop rate on the proposed method (class disabled).

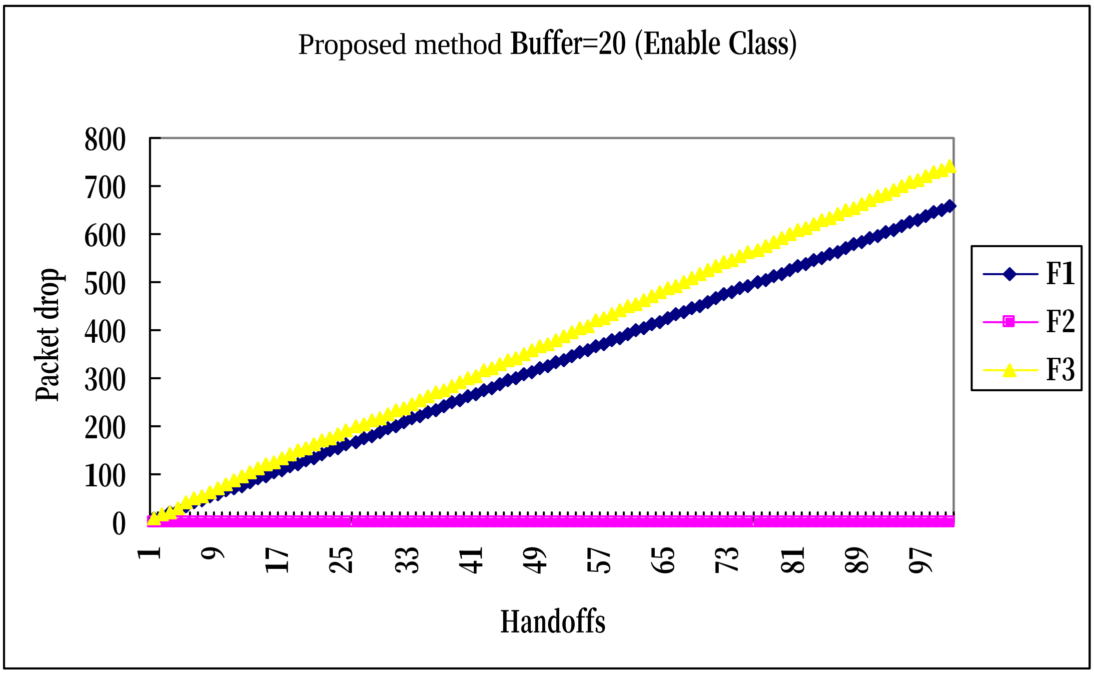

Figure 4.5: Packet drop rate on the proposed method (class enabled).

In Figure 4.6, we increase the data rate of F1~F3 and compare the packet dropping in one handoff process. As we can see from the figure, packet dropping from the high priority flow (F2) is always the lowest. When running out of buffering spaces, we successfully saved most of the high priority packets at the cost of dropping best effort and real-time packets. We can also see from Figure 4.3 ~ 4.5 that the total packet drops in each case are similar, which means the QoS function does not results in additional packet drops.

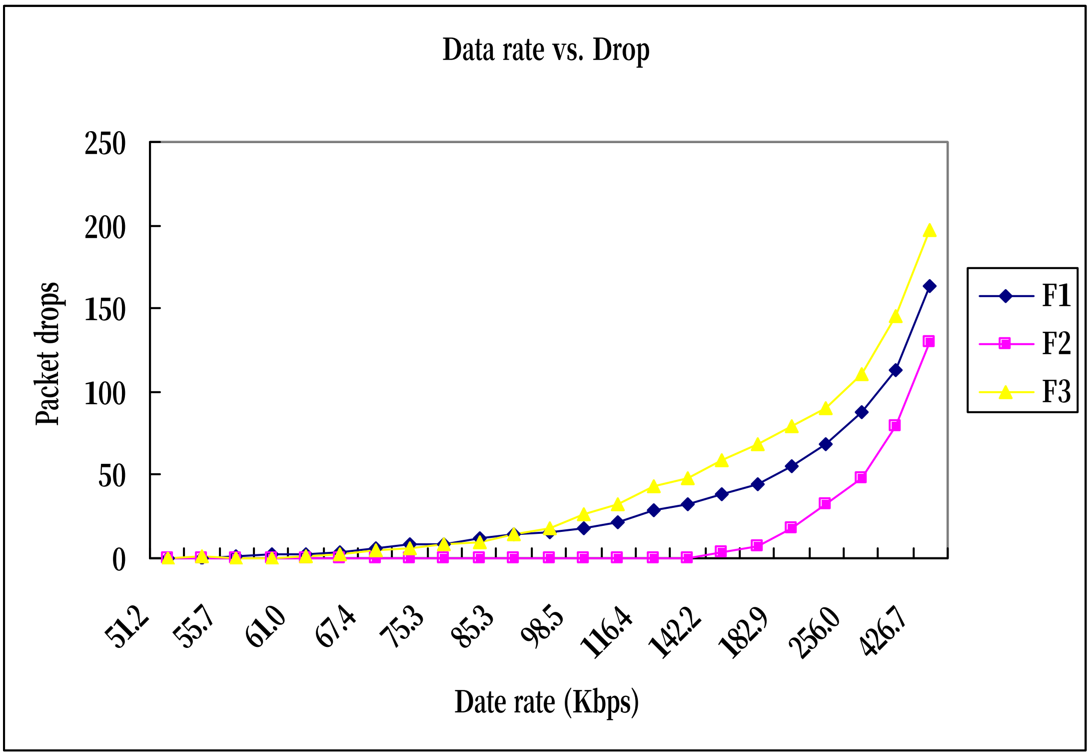

Figure 4.6: Packet loss for different data rates in the proposed method.

4.2.3 Support for real-time traffic

Real-time traffic requires bounded end-to-end delays beyond which information loses its value. These packets should be transferred to the mobile host as soon as possible after the handoff process. In the proposed method, real-time packets are forwarded to the NAR and buffered there during the period of link layer handoff. This saves the transfer delay from the PAR to the NAR when forwarding these buffered packets to the mobile host.

The simulation in this section shows the end-to-end delay on packets of different priorities during one handoff process. The network topology is shown in Figure 4.1. There is only one mobile host moving from one access router to another. The CN transmits three 128-kb/s audio flows (160-byte UDP packets every 10ms) with different priorities to the mobile node. We use F1, F2, and F3 to represent each of the flows in the following description. We define F1 as the real-time traffic, F2 as the high priority traffic, and F3 as the best effort traffic.

In Figures 4.7 and 4.8, we disabled the classification function, all flows are treated the same. Figure 4.7 shows the end-to-end delay in the original fast handover protocol. There is no transfer delay from the PAR to the NAR because all packets are buffered at the NAR. However, we need twice the buffer spaces than the proposed method (in figure 4.8) to store all the packets during the handoff process. Since the NAR should not interrupt its job of forwarding incoming packets and we cannot dump all the buffered packets at the same time, there will be some additional processing delay when forwarding the buffered packets to the mobile host.

In Figure 4.8, packets are buffered at both the NAR and the PAR. Because the link delay between the NAR and the PAR is quite small (only 2ms), both the ARs dump the buffered packets at almost the same time. Packets with sequence number from 213 to 219 are buffered at the NAR and from 220 to 225 are buffered at the PAR. Comparison with Figure 4.7, there is a gap between packet 219 and packet 220. Because the first packets in both buffering spaces (packet 213 and 219) are sent to the mobile host almost at the same time, the gap is resulted from the buffer queuing delay. The proposed method has a smaller summary delay for the buffered packets than the original fast handover protocol.

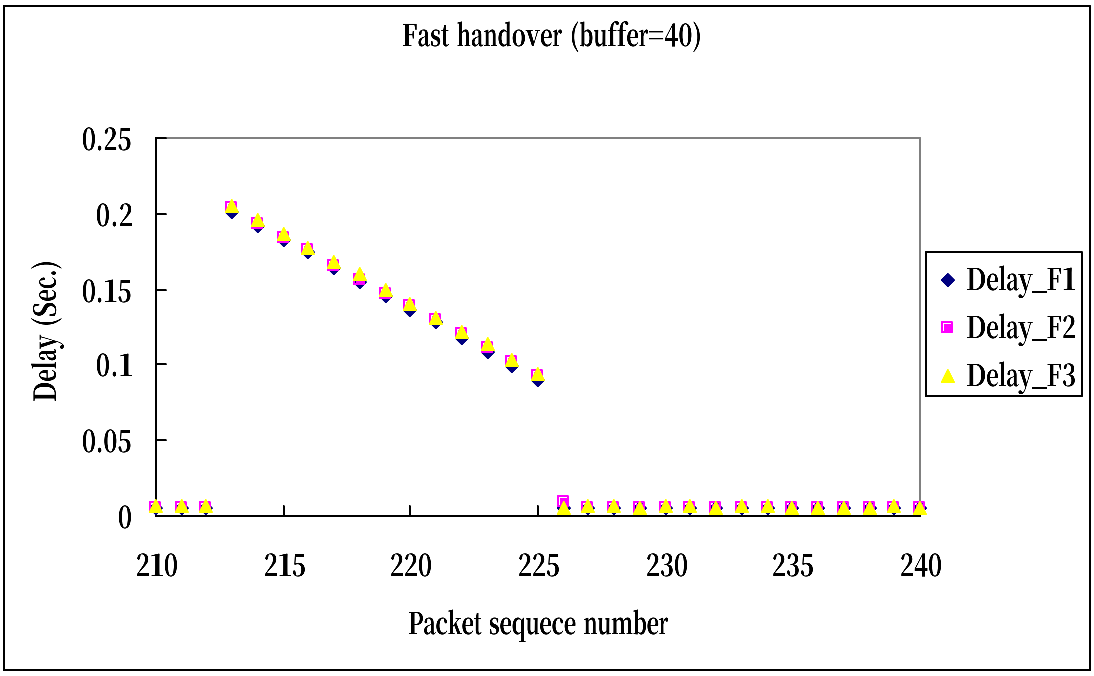

Figure 4.7: End-to-end delay in fast handover protocol.

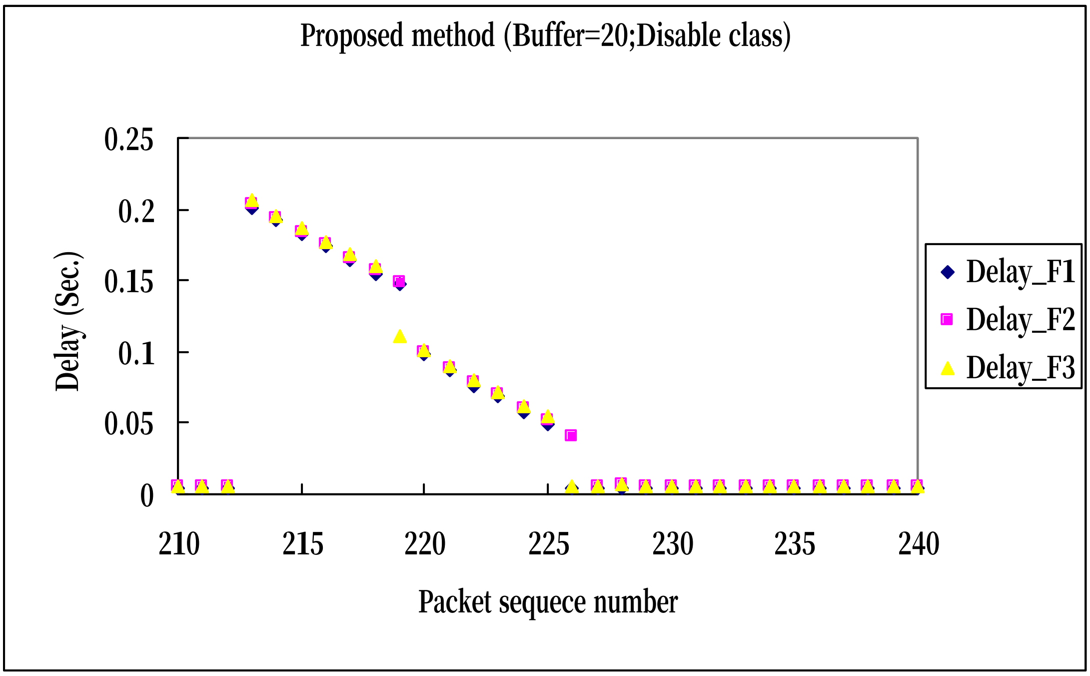

Figure 4.8: End-to-end delay in the proposed method.

In Figures 4.9 and 4.10, we enable the classification function in the proposed method. The link delay between the NAR and the PAR in Figure 4.9 is set to 2ms and in Figure 4.10 is set to 50ms. Since the classification function is enabled, real-time packets (F1) are buffered only at the PAR. When the link delay is small (Figure 4.9), the end-to-end delay is similar for all flows. However, as we increase the link delay in Figure 4.10, the end-to-end delay for best effort packets (F3) increase significantly.

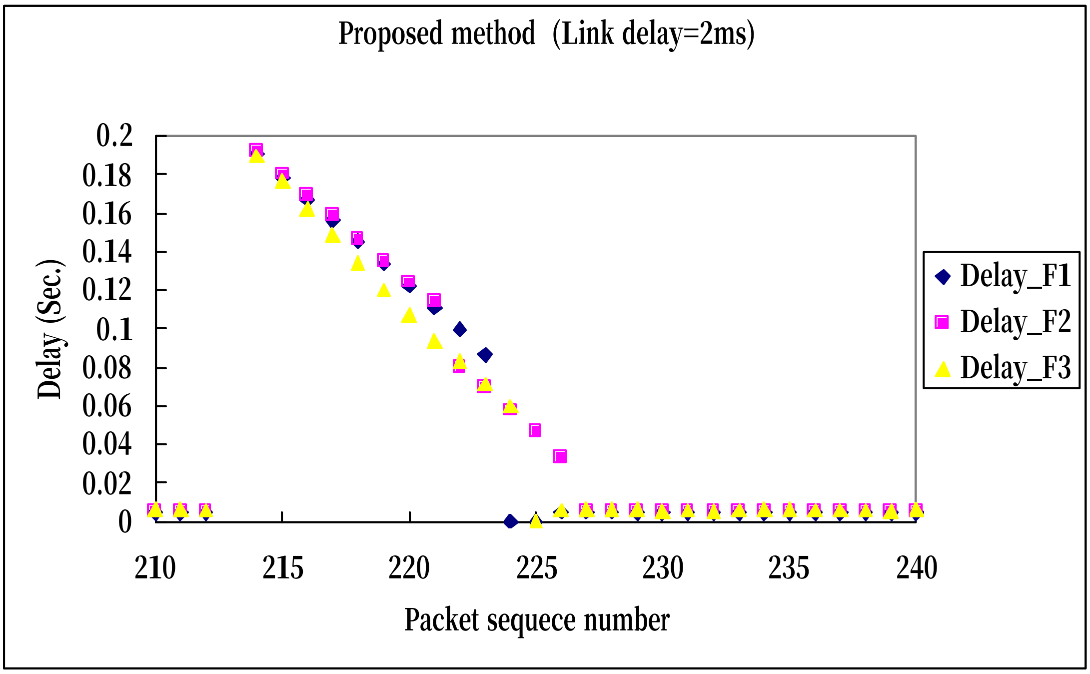

Figure 4.9: End-to-end delay for low link delay between two ARs.

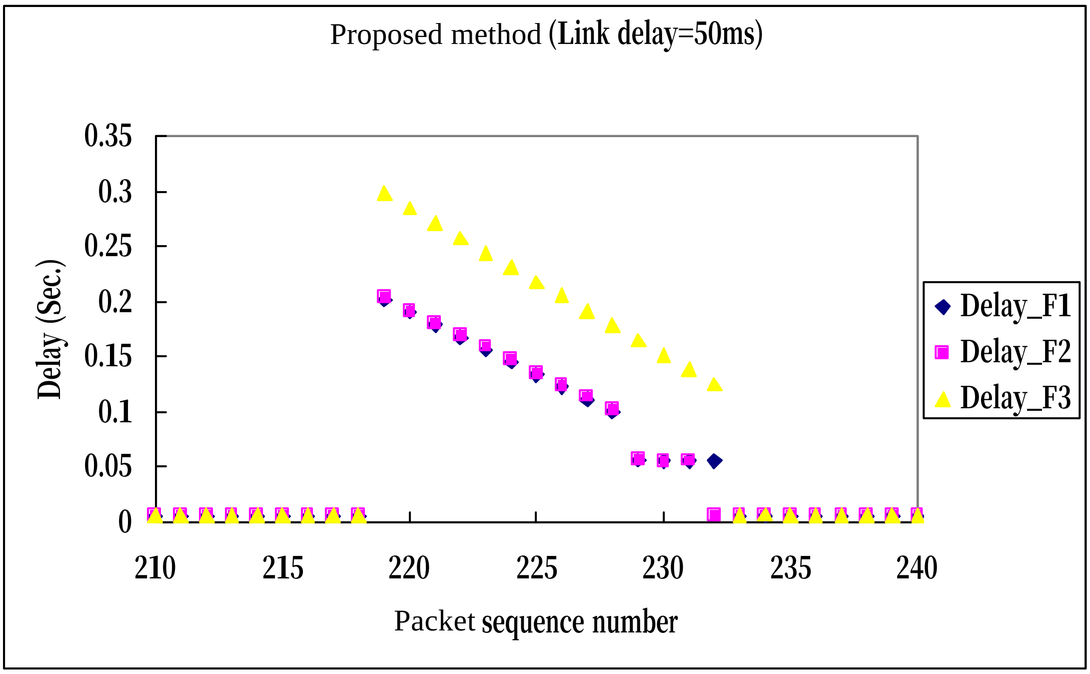

Figure 4.10: End-to-end delay for large link delay between two ARs.

From the simulation, we can conclude that it is reasonable to buffer real-time packets at the NAR during a handoff process. This reduces both the transmission delay from the PAR to the NAR and the queuing delay for buffered packets. The proposed method assures that real-time packets can be transferred to the mobile host without any unnecessary delay caused by the handoff process.

4.2.4 Supports buffering mechanism during link layer handoff

The original fast handover protocol does not support buffering mechanism during a pure link layer handoff. Which means a mobile host is unable to buffer packets at the access router while switching between WLAN access points under the same access router. This temporary disconnection results in packet loss and degrades the throughput of TCP connections. However, the proposed buffering mechanism supports buffering packets on any handoff conductions, and we verify the improvements by the following simulation.

The simulation topology is shown in Figure 4.11. This is a simple WLAN network topology. Between the CN and the mobile host, there is a TCP connection (FTP traffic). The link layer handoff delay is set to 200ms. The version of TCP connection used here is TCP Reno, and the TCP tick interval is set to 500 ms, the same as most BSD implementation.

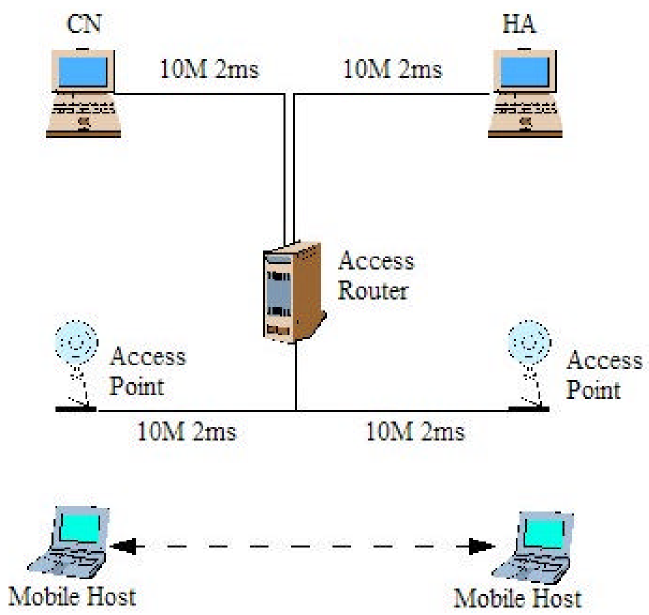

Figure 4.11: Simple WLAN network topology.

In Figure 4.12, we can observe that the link layer handoff results in long TCP connection timeout, and degrades the throughput. The link layer handoff process starts at 11.47 second and finishes at 200ms after. All packets sent to the mobile host during this period are lost. The TCP retransmission starts at 11.7 second. However, not all the lost packets can be recovered since the congestion window is full. The TCP connection now must wait until the timeout occurs. In most TCP implementations, the minimum TCP retransmission timeout is 1 second. Considering the TCP tick interval (500ms), the connection takes 1 to 1.5 second to resume the transmission.

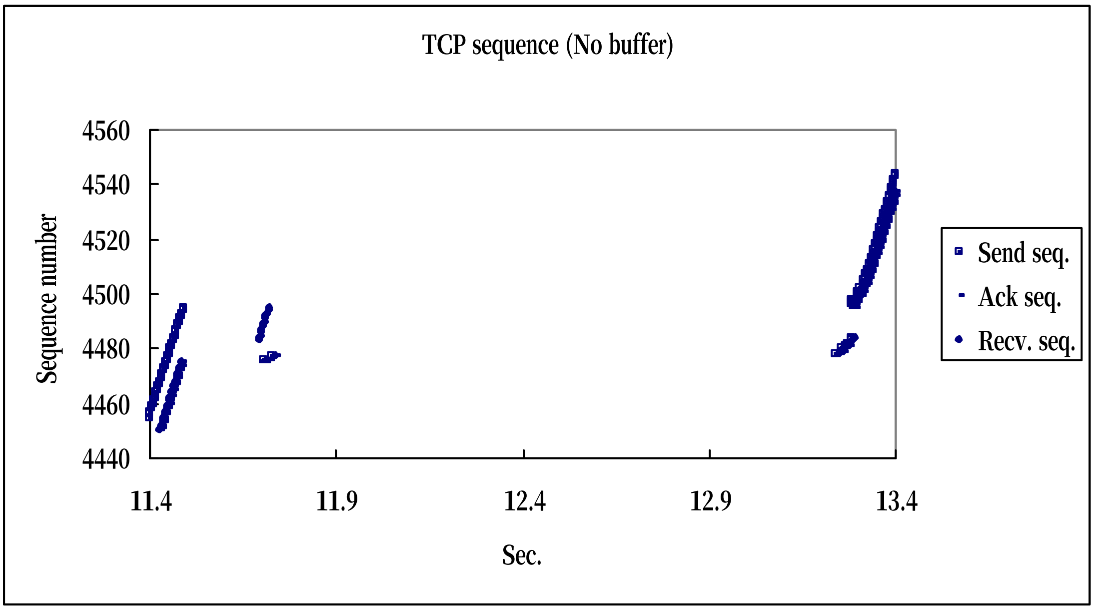

Figure 4.12: TCP sequence during handoff process (without buffering).

With the proposed method, a mobile host can buffer packets at the access router during the handoff process. We can see in Figure 4.13, packets coming during the handoff period are buffered at the access router, and forwarded to the mobile host after link layer handoff completes. Since no packets are lost, there is no transmission timeout and the CN starts transfer right after the handoff process. Figure 4.14 illustrates the TCP connection throughput during the handoff period. We can clearly observe the performance improvements of the TCP connection while the proposed method is adopted.

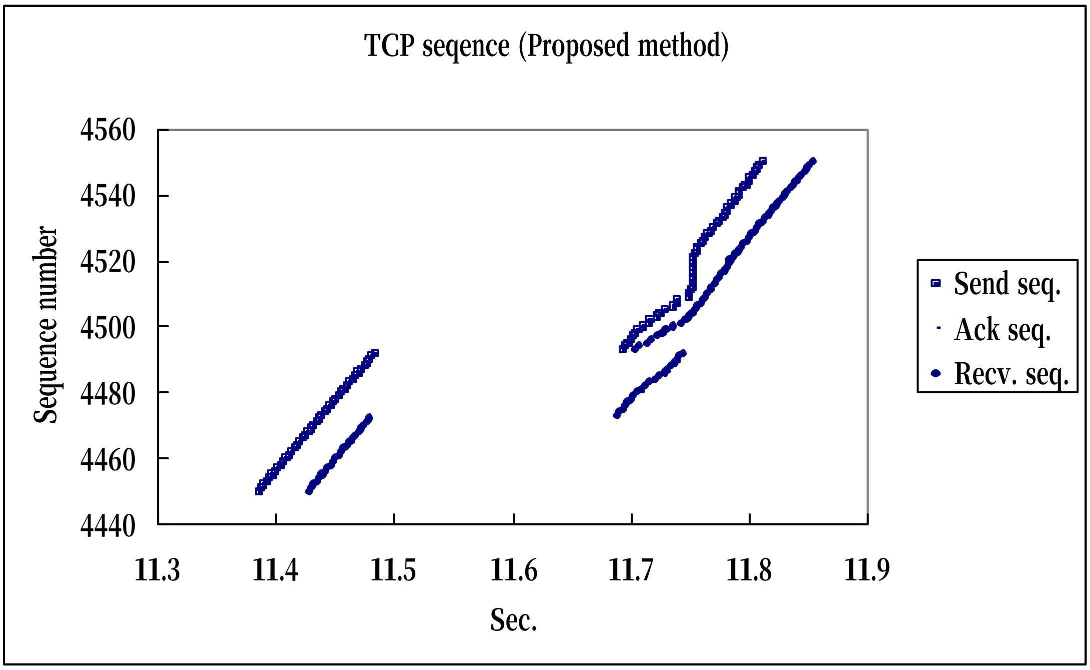

Figure 4.13: TCP sequence during handoff process (Proposed method).

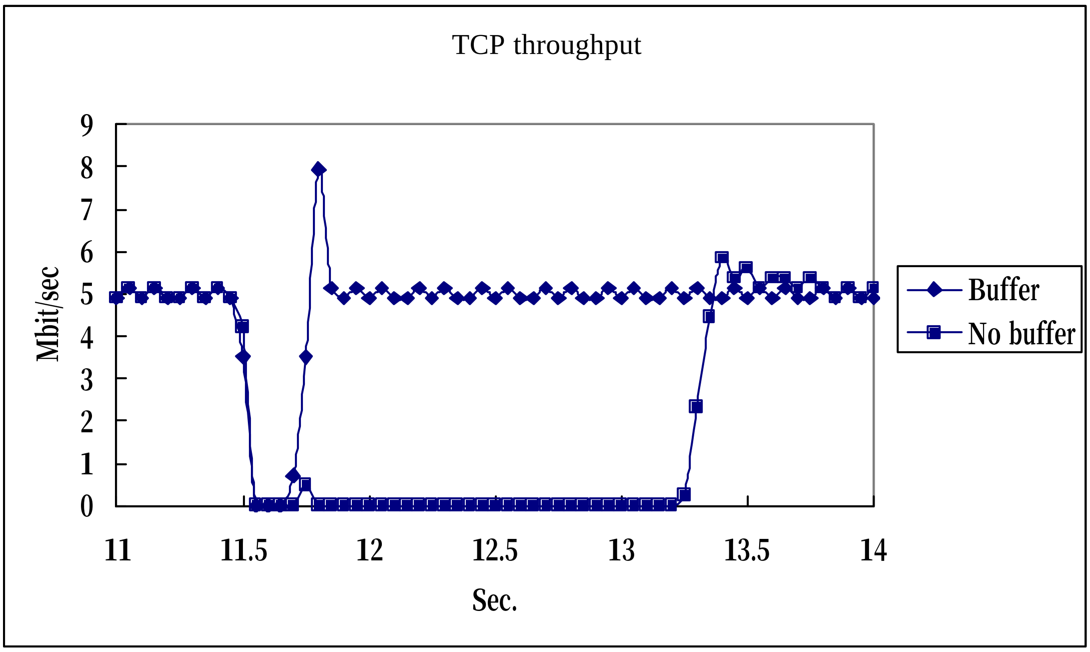

Figure 4.14: TCP throughput during link layer handoff.

Chapter 5

Conclusions

In this thesis, we proposed an enhanced buffer management mechanism for Fast handover. The motivation of this thesis is the lack of a buffer management mechanism in the fast handover protocol. In order to utilize the limited buffer spaces in the access router, we use both buffer spaces in access routers during a handoff process (the PAR and the NAR) and define different buffering operations corresponding to the characteristics of traffics.

There are several advantages of the proposed buffer management mechanism. First of all, the cooperation of both buffering spaces in the PAR and the NAR assures the full utilization of buffering spaces. The network will be able to serve more handoffs simultaneously. Second, the proposed method supports QoS mechanism. The high priority packets are protected from being dropped and the real-time packets are protected by minimizing the delay during a handoff process. Third, with the buffering mechanism integrated into the fast handover protocol, the proposed method also supports buffering operations during a link layer handoff. This helps to improve the performance of TCP connections when the mobile host handoffs. Finally, the proposed method piggybacks most of the control messages on the original fast handover protocol thus do not cause additional signaling overhead.

There are several possible research directions for this work. First, we can improve the negotiation mechanism between the PAR and the NAR to support a more precise buffer allocation when a mobile host handoffs. Second, the proposed method should be able to cooperate with DiffServ network. The mapping between DiffServ traffic and the buffering mechanism should be defined. Third, security issue should also be considered during the handoff process. Authentication mechanism is required before the NAR accepts handoffs from mobile hosts.

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