私立東海大學

資訊工程研究所

碩士論文初稿

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植基於手持裝置位置的異質性無線網絡換手機制

A Location-based Handover Scheme for Heterogeneous Wireless Networks based on IEEE 802.21

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中華民國一〇〇年七月

東海大學碩士學位論文考試審定書

東海大學資訊工程學系 研究所

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經本委員會審查，符合碩士學位論文標準。

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中華民國 100 年 7 月 14 日

致謝

首先誠摯感謝，我的指導教授呂芳懌博士，老師的教導使我得以一窺無線網路服務中的深澳。並且不時的與我討論，給予我正確的研究方向，使我在這些年中，獲得不少的重要知識，老師對學問的嚴謹更我學習的典範。

本論文的完成也得感謝其他口試委員的指導，讓我了解到哪些地方是不足的，並讓我加以補強，使得本篇論文更加完整。

三年的時光，實驗室共同的生活點滴，學術上的討論等，感謝各位學長(耀田、宏瑋、志揚、永倫、梗延)、同學(炫又、佩勳)、學弟妹(渝新、妙亨、信良)的共同培伴，讓我這三年的研究如此得多采多姿。

最後，我要感謝我的家人的支持與栽培，沒有你們就沒有今日的我。尤其是多花一年的時間拿到這個學位，是非常辛苦的

摘要

現今由於手持行動裝置(例如:手機、筆電等)的效能越來越強，手持行動裝置通常搭載多種類型無線網路介面卡，來存取異質性無線網路。而在異質性網路的無縫移動是個非常重要的功能，當使用者從原先的無線網路環境中，移動到新的異質性無線網路換境，需要平台來去跟無線站台、手持裝置和認證伺服器來互相聯絡溝通，作為一個漫遊換手的機制。網路工程協會提出 802.21 Media Independent Handover Service 通訊協定解決交流換手訊息機制，但此架構仍然不夠完全，Media Independent Information service 的訊息傳送與 MIIS 伺服器佈置方式並未敘述，而且也有 pinball problem 的問題。我們在本篇論文中，提出了 MIIS 伺服器佈置方式與手持裝置的定位方法，並提出選出最佳目標網路的演算法，以避免不必要的網路切換情形發生。本論文改善了 802.21 MIH 的缺點，以實驗的方試驗證及評估本論文所提出的方法。

Keywords：Location-based handover, 802.21 Media Independent Information service, pinball problem, target network selection algorithm

Abstract

Recently, due to quick advance in high-tech research, mobile devices which have been more powerful than they were day by day can now configure multiple wireless network interfaces to make themselves able to access resources provided by heterogeneous wireless networks. In fact, seamless handover is one of the most important issues for communication quality of wireless service, particularly when the environment is heterogeneous. To achieve a seamless handover, mobile devices need a roaming platform to proceed its communication with the correspondent node. However, the information exchange in performing handover is often a crucial work. In 2006, Internet Engineering Task Force (IETF) proposed 802.21 media independent handover function (MIHF) to help information exchange for handover in a heterogeneous wireless environment. However, this protocol does not define Media Independent Information service (MIIS for short) messages and architecture of MIIS servers. Also, MIHF has the pinball problem. To solve these problems, in this paper we proposed a location-based architecture for MIIS servers in which MIIS servers are organized as a hierarchy. The algorithms for choosing the most suitable target network are also addressed. Experimental results show that the scheme can effectively solve the abovementioned problems, and its network handover procedure has higher working efficiency than those that of 802.21 handover procedure and other tested schemes.

Keywords：Location-based handoff, 802.21 Media Independent Information service, pinball problem, target network selection algorithm, Heterogeneous wireless network

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1. Introduction

Recently, due to quick advance in high-tech research, mobile devices which have been more powerful than they were day by day can now configure multiple wireless network interfaces to make themselves able to access resources provided by heterogeneous wireless networks [1]. The WiMAX, also known as IEEE 802.16 [2], and the fourth generation (4G) wireless systems [3], such as Long Term Evolution (LTE) [4] and Ultra Mobile Broadband (UMB) [5], which provide users with wider bandwidth and huger radio coverage than WiFi [6] does, are more popularly equipped today. When a mobile device would like to move from one wireless system to another, if several APs that belong to one wireless system or different wireless environments are in front of it, it has to choose one, called target AP, to take over for its serving AP. However, the choice is a cricual work since choosing a wrong AP will result in poor communication quality or pinball problem [7]. So, target network selection as one of the key services for next-generation mobile network is an important issue that should be addressed in wireless handover.

On the other hand, the levels of QoS [8] requested by users in recent years due to the desire of high quality services are higher and more complicated than usual [9]. In fact, handover is one of the key activities that may affect communication quality of a mobile node [10]. However, current handover techniques on wireless accesses may temporarily disconnect wireless links [11], resulting in poor communication quality, particularly when users are accessing multimedia services. To avoid this, a well-designed handover platform that provides a seamless handover is required [12], regardless the wireless environment is homogeneous or heterogeneous.

In 2006, IEEE 802.21 working group proposed media independent handover function (MIHF) which can achieve seamless handover by providing cross-layer services [12], including monitoring link status, sending commands to control wireless network interfaces, providing the surrounding network information, etc. However, this protocol only defines basic components and their functions without defining required messages for communication between/among media independent information services (MIIS) and how to organize MIIS servers of concern. Further, when the signal strength that a mobile node (MN) receives from a wireless network is unstable or weak, the MN often needs to execute handover procedure several times in the overlapped area of the serving AP's and target AP's communication ranges. This phenomenon is call the pinball problem [7].

To solve the abovementioned problems, in this paper, we propose a handover scheme for heterogeneous networks, called a location-based handover scheme (LHOS for short), which is an IEEE 802.21 based service system employing MIH functions to control network interfaces and organizes all MIIS servers of a wireless system into a hierarchy so that network status and information can be efficiently collected and provided. With MIHF and MIIS–server hierarchy, the LHOS can pre-access information of target networks, and then choose the most appropriate one for the MN so as to shorten the MN's handover delay. Experimental results show that this scheme can effectively improve network performance compared to those of tested schemes.

The rest of this paper is organized as follows. Section 2 introduces the 802.21 MIHFs and related work of this study. Section 3 describes the proposed system architecture and algorithms. Simulations are presented and discussed in Section 4. Section 5 concludes this paper and outlines our future research.

2. Background and Related work

2.1 802.21 media independent handover service

MIHFs, which are 2.5-layer functions built in mobile nodes, PoAs and MIISs, as shown in Figure 1 provide three standard mechanisms, including media independent event service (MIES), media independent command service (MICS) and MIIS, to handle media independent handover services [12]. MICS on receiving requests from upper layers (e.g., an interface_enable_request from application layer) sends commands to lower layers (e.g., sending an interface_enable_command to physical layer) to control MNs or PoAs or to request lower layer services, consequently allowing an MIH user to control the behavior of the lower layers.

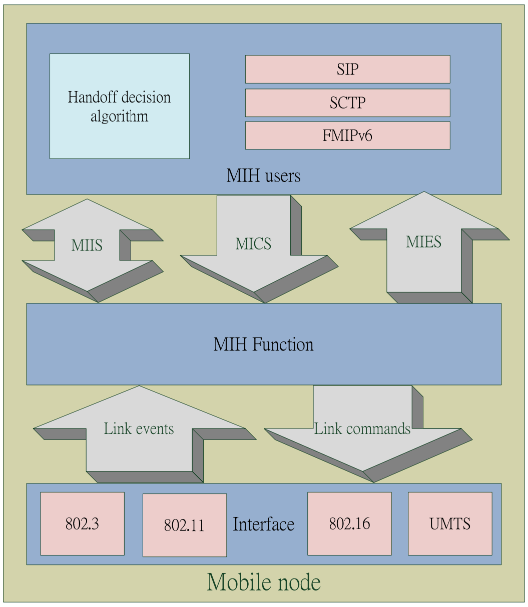


Figure 1：MIH Functions

2.2 Establishing a WiMAX connection between MN and BS

To establish a connection between MN and BS, at first MN enables its network interface to contact the target network. After that, it executes the connection procedure. For example, when the user/MN decides to connect itself to a WiMAX, the connection procedure [13] includes initial ranging, basic capabilities negotiation, authentication, security association, key exchange, registration, transport connection setup, and IP address allocation. Initial ranging is the process of acquiring the correct timing offset and power adjustments for the MN. The MN then aligns its system timing and power strength so as to meet those of the BS's transceiver. The basic capabilities negotiation is performed based on the capability supported by the MN, such as the physical layer parameters and BS's bandwidth allocation support. Meanwhile the BS authenticates the identity of MN. In the step, the BS and MN establish a shared authorization key (AK) by invoking RSA algorithm, from which a traffic encryption key (TEK) is derived and message authentication is performed [14]. This procedure is called key exchange. Then, the BS performs the authentication with the identities and properties of the primary and static security associations. Once the basic capability is successfully negotiated or MN authorization and key exchange process is completed, the MN registers itself with the network by sending a registration request to the BS. Transport connection setup has two resource allocations, including allocating connection IDs (CIDs) to the established connection, and service flow IDs (SFIDs) to service flow. After that, BS assigns an IP address to MN. Once the connection has been established, the MN registers itself with its home agent to make it globally reachable.

2.3 Establishing a UMTS connection between BS and MN

However, if MN would like to hand over from a WiMAX network to a UMTS network, it invokes the UMTS connection procedure [15] includes sending attach request, authentication, ciphering, and locating MNs position. When MN wants to attach itself to a UMTS network, it sends an attach request to its serving GPRS Support Node (SGSN) through Base-station subsystem (BSS). SGSN replies authorization information to identify the user’s access permission. If the reply confirms the UMTS attach permission, SGSN starts authenticating MN. Meanwhile, SGSN sends a ciphering request to MN, and MN replies a ciphering response to perform key exchange. After accomplishing the ciphering, SGSN sends an attach-accept message to MN, and MN replies an attach-complete message, implying the connection between BSS and MN has been successfully established. Meanwhile, the MN sends a binding update message to its correspondent node, registers itself with its home agent, disables the WiMAX network interface, and then begins its data transmission.

2.4 Related work

2.4.1 Neighbor Discovery Protocols

The neighbor discovery (ND) protocol [16], a protocol provided by the Internet Protocol Suite for IPv6 routing, takes charge of several tasks, including autoconfigurating addresses for neighbor nodes, discovering nodes for establishing LAN links, determining the Link Layer addresses for other nodes, and maintaining reachability information of routing paths for other active neighbor nodes, etc.

In a network environment that employs IEEE 802.21 standard, the ND is installed in all MNs and PoAs. With ND, an PoA broadcasts an unsolicited Router Advertisement (RA) message periodically. An MN on receiving RA messages from surrounding PoAs chooses one as the target PoA, and replies the PoA with a Router Solicitation (RS). The PoA on receiving RSs issued by MNs in a pre-defined time period chooses some of the MNs based on its service capability, and replies each of them with an accepting connection message immediately. The remaining MNs will be served in one of the following service durations. The disadvantages of the ND protocol are that the time period of the reception of an RA message is long, and the ND does not define how to choose an PoA if MN receives more than two RAs from different routers. The ND has pinball problem [7] as well.

2.4.2 Mobile IPv6 handover

Current mobile IPv6 is an extension of IPv6 by adding Care-of-address (CoA for short) and Home address (HoA for short), which are the mobility IP mechanism [17], to give MNs the capability of roaming. In other words, even through MN stays in a foreign network which is heterogeneous to MN's home network, the wireless connection can be maintained. Each MN has its own Home Agent (HA). Once the MN finishes registering with its HA, it can acquire a static IP address, i.e, HoA . When the MN visits a foreign network, an address, i.e., CoA, will be given. After that, MN sends a Binding Update (BU) to inform its HA where it is now. HA will bind the CoA to HoA to make the MN globally reachable. However, Mobile IPv6 neither supports seamless handover, nor provides MN with the network information so that the MN cannot pre-access the target network, consequently unable to effectively reduce the handover delay.

2.4.3 SCTP-based handover

SCTP [18], a standard defined by IETF signal Transport (IETF SIGTRAN) working group, has two specific features, multi-homing and multi-streaming. Multi-homing is a specific characteristic of an association. An association often consists of K connections between two nodes, and each node has K addresses, $K \geqq 1$. Before data transmission, one of the connections will be chosen as the primary path. The others are backup paths, also known as alternate paths or secondary paths. When the primary path fails or its transmission is quality poor, one of the backup paths will be requested to take over for the primary one to continue the data transmission, consequently providing high transmission-path availability and reliability. The multi-streaming capability solves the Head of Line (HOL) effect of TCP since streams operate independently. SCTP with its unique characteristics is helpful in providing seamless handover between two wireless base stations [11]. However, SCTP does not provide network-information collection scheme so users have to develop one to choose the primary path [19].

2.4.4 SIP-based handover

SIP [20] as a mobility management protocol in a heterogeneous wireless IP network is a simple, scalable, and text-based protocol that offers several benefits for network connection, such as extensibility and provision for call/session control. It is an application layer protocol, designed to be independent of the employment of the transport layer protocol. UDP, TCP, and Steam Control Transmission Protocol (SCTP) [18] are all applicable. This make itself able to exploit these protocols' characteristics to meet different requirements of different wireless network platforms. However, SIP does not provide methods to control network interfaces so that it cannot control MAC-layer handover.

2.4.5 Location assisted handover in 3GPP

Choosing one of the networks as the target network for MN's handover is a kind of location-based Service (LBS) [21] provided based on target PoA's and MN's geographical positions and RSSI to satisfy MN's current requests in a real-time maner. Mobile operators have so far developed various LBSs, like city guides and route planners [21], on GSM/GPRS and UMTS networks. The 3GPP Technical Specification adopts a network-centric location mechanism that assists MNs to discover a target AP with the Gateway Mobile Location Centre (GMLC) as the primary location source for LBSs. However, all LBSs require terminal devices being equipped with location provisioning devices or being able to access their nearby generic location sources [21] so that the LBSs can deliver accurate positioning information to the terminal devices, and these devices can then access all nearby location services. But current LBSs are only available for 3GPP systems without any capability to help MNs to hand over between/among heterogeneous networks.

3. Proposed System Architecture

The LHOS topology as shown in Figure 2 consists of a home server, access routers (ARs), an MIIS root server, a WiMAX MIIS server, a UMTS MIIS server, WiMAX PoAs, UMTS PoAs, and MNs, which cooperate with each other to support MN's seamless handover between two heterogeneous wireless environments, WiMAX and UMTS. The home server records MN's current location, i.e., CoA, and authenticates user identities. An access router has its own PoA which consists of an AP, i.e., a WiMAX base station (WiMax BS for short) or an Utran, and a Point of service (PoS), in which the PoS is responsible for periodically reporting network status and network parameters to WiMAX MIIS server or UMTS MIIS server. Here, MNs may be notebooks, cell phones, etc. A WiMAX/UMTS MIIS server collects concerned PoA's information from its surrounding networks periodically, and then provides an MN with an appropriate target network so that the MN when having to hand over can successfully switch from a WiMAX BS to an Utran or vice versa, and seamlessly continue its communication with its correspondent node (CN for short). In the following, WiMAX MIIS server and UMTS MIIS server are generally called MIIS servers. We will discriminate them when necessary.

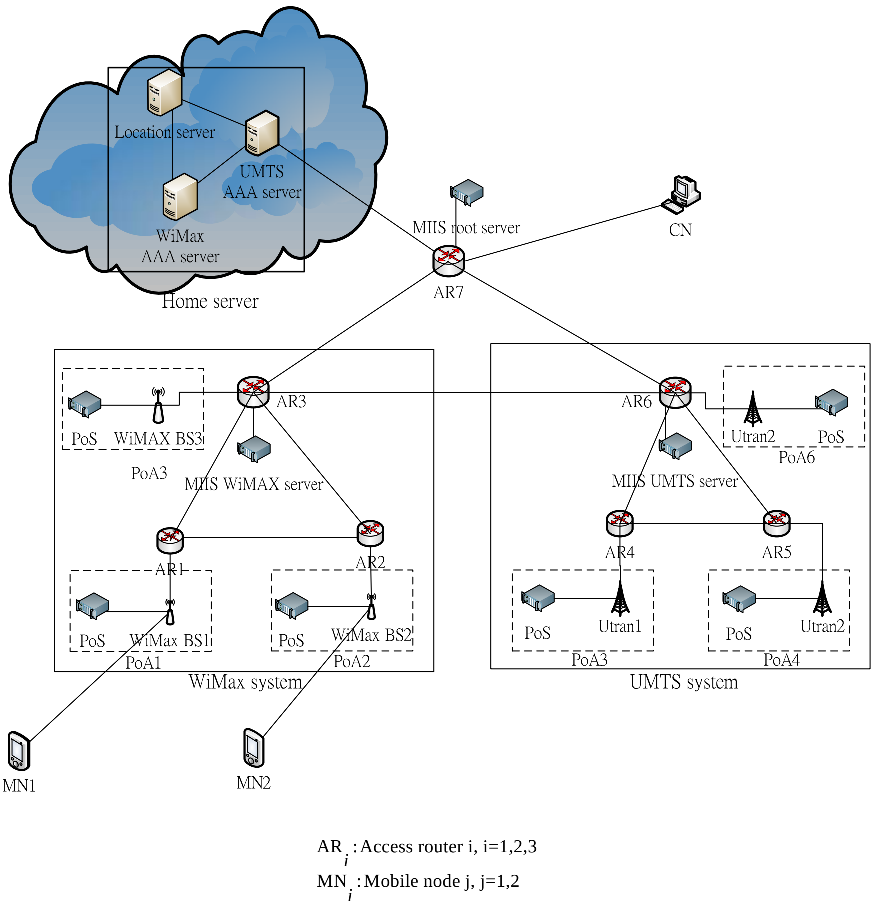


Figure 2：The LHOS system architecture

3.1 Home servers

In this study, each autonomous network has its own home server which comprises an UMTS AAA server, a WiMax AAA server and a location server. The location server records the MN's information, including an MN's current position, the MIIS server to which the MN is currently connected, and the network which is now serving the MN. When a MN moves to a foreign network and receivies a CoA, it sends a binding update message to the location server of its home server to report the CoA. When a node N would like to communicate with the MN, N should contact the MN's home server to enquiry MN's current location so that N can successfully contact the MN. WiMAX AAA server [13] and UMTS AAA server provide MN with Authentication, Authorization, and Accounting services which however are not the focus of this paper.

3.2 MIIS servers

Basically, the area which an MIIS server collects network information from has its own communication boundary. In this study, MIIS servers of a network system as stated above are organized as a hierarchy (see Figure 3) to reflect the architecture of the geographic district units and areas. For example, a building has a MIIS server, and each floor of the building has a PoA. A MIIS server, e.g., a building MIIS server, after collecting network statuses from all its PoAs and the PoAs of its child MIIS servers, sends the network information to its parent MIIS server, e.g., a village-MIIS server, which in turn delivers the PoA information collected to its parent MIIS servers, i.e., a city-MIIS server. When a MN would like to hand over, it requests its serving MIIS server to choose one of the PoAs in front of it so that the handover can be successfully and smoothly performed. When the status of the connection between an MN and a PoA changes, e.g., from a normal state to the state that the link being considered is going down, MN's MIES will inform MN the change so that MN can response immediately and properly.

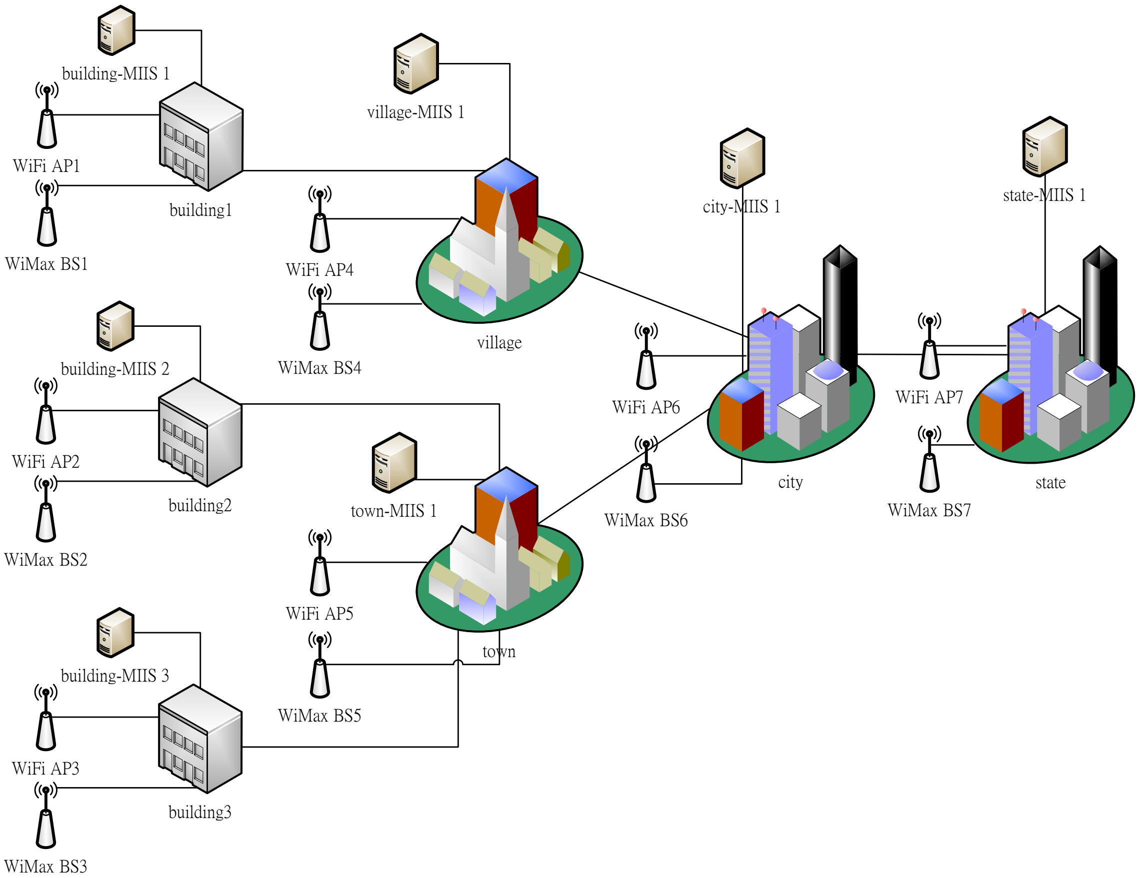


Figure 3：MIIS servers are organized as a hierarchy

An MIIS server S maintains two tables, a redirection table and a service table, for its service supports. The redirection table which records network information of its parent sever and all its successor MIIS servers as shown in Table 1 comprises three fields, including MIIS ID, MIIS position, and relationship, which, respectively, record an MIIS server ID, the server’s current position expressed by Latitude and Longitude [22], and the relationship between S and the underlying tuple’s corresponding MIIS server, i.e., parent or child. The service table which records information of S’s subordinate PoAs and the PoAs of all S’s successor MIIS server as shown in Table 2 consists of four fields, including system type, PoA ID, PoA position, and subordination. System type shows which type the wireless system being considered is, e.g., UMTS or WiMAX. The PoA ID and PoA’s position, respectively, keep the unique

ID of a PoA and the PoA's geographical position also represented by Latitude and Longitude [22]. The subordination field represents which MIIS ID the PoA belongs to.

As stated above, an MIIS server M will report the information of all its own PoAs and all its successor MIIS servers to its immediate parent MIIS server N. N will record the PoAs reported by M as M's PoAs, no matter whether these PoAs are owned by N or N's subordinated MIIS server. Tables 1 and 2 respectively list examples of a redirection table and a service table for a city MIIS server.

Table1：An example of redirection table of a town MIIS server

MIIS ID	MIIS position (GPS)	Relationship
Building-MIIS2	N: 2407.8945 W:12041.7649	Child
Building -MIIS3	N:2400.58740 W:12010.48530	Child
City-MIIS1	N:2430.3474 W:12060.55530	Parent

Table2：An example of service table of a town MIIS server

System type	PoA ID	PoA position(GPS)	Subordination
WiMax	BS5	N: 2407.8945 W:12041.7649	Own
WiFi	AP5	N:2407.58740 W:12041.48530	Own
WiMax	BS2	N:2400.1840 W:12010.375	Building-MIIS2

WiFi	AP2	N:2400.1844 W:12010.3745	Building-MIIS2
WiMax	BS3	N:2401.845 W:12011.375	Building-MIIS3
WiFi	AP3	N:2400.844 W:12010.370	Building-MIIS3

3.3 Inter-MIIS messages and MN Handover

When MN receivess a link_going_down message from its MIES, implying it needs to hand over from its serving PoA to another one in fornt of it, MN sends a handover request message, called handover-GPS request message, which as shown in Figure 4 contains MN_ID, MN IP address, MN position and MN direction, to its serving MIIS server. The MN position and MN direction respectively carry MN's current position expressed by Latitude and Longitude, and MN's current moving direction. MN_ID field conveys MN's identity. The MIIS server on receiving the request chooses a suitable PoA based on MN position, MN direction and the information recorded in its service table, and then sends a reply packet, which carries the chosen PoA ID, to the MN with the destination ID = MN IP address.

1 byte	4 byte	6 byte	2 byte
MN_ID	MN IP address	MN position	MN direction

Figure 4: Format of a handover request message

MN on receiving the PoA ID from its MIIS server starts executing the corresponding PoA connection procedure. Basically, the proposed architecture is constructed based on All-IP structure for heterogeneous handover. When MN hands over to the target PoS and sends an binding update to its location server, the MN is now globally reachable again. The reachability is held until the next handover event occurs. Then, MIH Function would inform the MN to request its current serving MIIS server to choose a target network/ PoA. The MN then tries to connect itself to the PoA. The process repeats until the MN is switched off or out of battery.

3.4 Coordinates Transformation

MN direction carried on a handover GPS request is expressed by an angle Ψ. Note that the coordinate system of a GPS is differnt from the Cartesion and Polar coordinate systems. When Ψ = 0, 90, 180 and 270, MN is moving toward the North, East, South, West, respectively, implying Ψ is the clockwise angle between the north and MN's moving direction. For example, when $\Psi = 135^{\circ}$, the MN is moving south-east, instead of north-west. In other words, a coordinate expression transformation is then required. Basically, the choice of a PoA for MN is based on two parameter, PoA type and the angle between $\overrightarrow{\mathrm{MNPoA}}$ and MN's moving direction. For PoA and network re-entry authentication consideration, we hope MN can hand over to a homogeneous PoA. From wireless communication quality view point, we choose the PoA of which the $\overrightarrow{\mathrm{MNPoA}}$ is as coincident with MN's moving direction as possible.

3.4.1. The direction of $\overrightarrow{\mathrm{MNPoA}}$

In the study, Polar coordinate system is chosen as the target, and Geographic coordinates conversion approach proposed in [23] is deployed to first transform MN's and PoA's (Longitude, Latitude)s into Cartesian coordinates. The results are, respectively, (X_{MN}, Y_{MN}) and (X_{PoA}, Y_{PoA}).

The angle of $\overrightarrow{\mathrm{MNPoA}}$ expressed in Polar coordinate system can be calculated as follows. The distance between the MN and PoA, denoted by D(MN,PoA), is

$$\mathrm{D(MN,PoA)} = \sqrt{(|X_{\mathrm{MN}} - X_{\mathrm{PoA}}|)^2 + (|Y_{\mathrm{MN}} - Y_{\mathrm{PoA}}|)^2} \qquad (1)$$

The unit vector of $\overrightarrow{\mathrm{MNPoA}}$ is

$$\vec{V}(\mathrm{MN,PoA}) = \left(X^{vector}_{(\mathrm{MN,PoA})}, Y^{vector}_{(\mathrm{MN,PoA})} \right) = \left(\frac{X_{\mathrm{PoA}} - X_{\mathrm{MN}}}{\mathrm{D(MN,PoA)}}, \frac{Y_{\mathrm{PoA}} - Y_{\mathrm{MN}}}{\mathrm{D(MN,PoA)}} \right) \qquad (2)$$

which is equal to $(\cos\theta', \sin\theta')$ where θ' is the angle between X-axis and $\overrightarrow{\text{MNPoA}}$ expressed in Polar coordinate system. Since $\cos^{-1}$ function can be 0° to 180° only, to correctly express θ', we need other transformation functions. The fourth column of Table 3 lists the conversion functions for vectors appearing in different quadrants.

Table3：Anti-trigonometric function

$\cos\theta'$	$\sin\theta'$	Quadran	conversion function	GPS's moving direction
>0	≥ 0	1	$\theta' = \theta'$	north and east
≤ 0	≥ 0	2	$\theta' = \theta'$	north and west
≤ 0	<0	3	$\theta' = 360 - \theta'$	south and west
>0	<0	4	$\theta' = 360 - \theta'$	south and east

3.4.2. MN's moving direction

The formulas that transform Ψ to θ are shown in Figure 5. In the first quadrant (see Figure 5a) $\Psi + \theta = 90^\circ$, i.e., $\theta = 90^\circ - \Psi = 450^\circ - \Psi$. In the other three quadrants (see Figures 5b~5d), $\Psi + \theta = 450^\circ$, i.e., in the four quadrants,

$$\theta = 450^\circ - \Psi \quad (4)$$

The angle between MN's moving direction and $\overrightarrow{\text{MNPoA}}$, denoted by Υ,

$$\Upsilon = |\theta - \theta'| \quad (3)$$

which as stated above is one of the key parameters used to choose a target PoA.

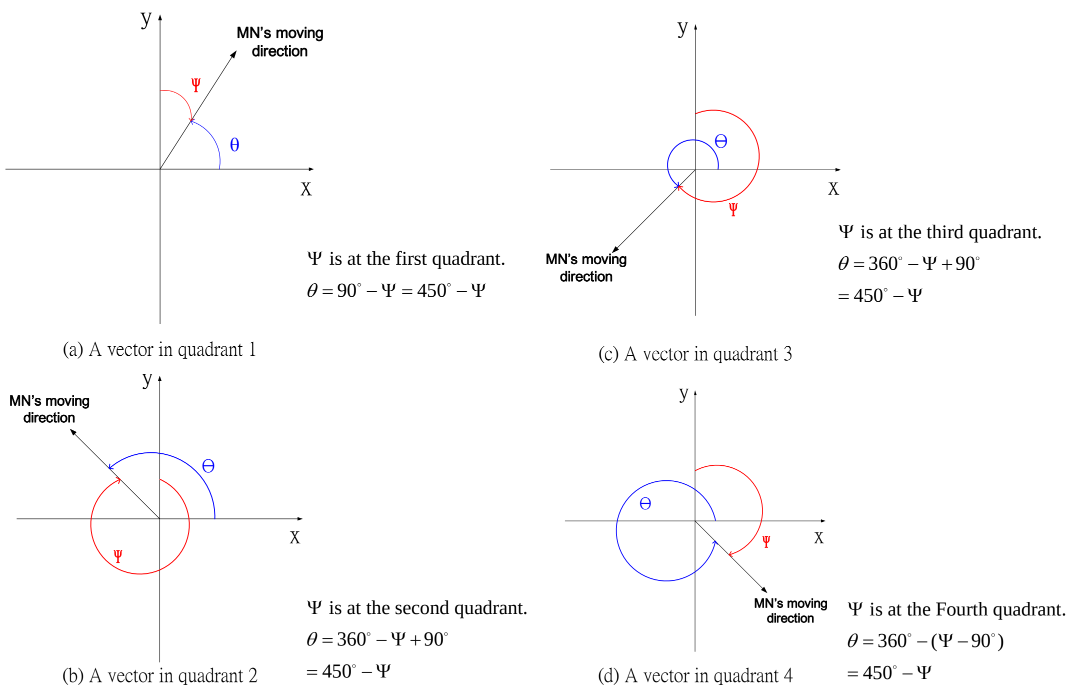


Figure 5：The formulas used to convert MN's moving direction from Ψ to a polar coordinate angle θ

3.4.3. The LHOS with SCTP

In LHOS scheme, a MN equips four network interface cards (NIC), including two WiMAX NICs and two UMTS NICs. When MN hands over to a homogeneous PoA, MN enables the second homogeneous interface by MICS to connect the target PoA. If the handoff is heterogeneous, one of the other type NICs will be enabled by MICS to connect to the target PoA. SCTP can be applied to the LHOS to improve its system performance. In other words, with the characteristic of multi-homing, MN can connect itself to two PoAs, heterogeneous or homogeneous, at the same time to shorten handover delay and avoid losing packets sent by CN. Before handover, MN can enable the second NIC to connect itself with the target PoA. This is known as make before break [11]. The SCTP's multi-streaming as stated above can also mitigate the HOL problem so as to increase the transmission throughputs and decrease transmission delays, i.e., packets can be delivered more smoothly.

3.4.4. The Network Selection algorithm

In the network selection algorithm (performed by a MIIS server, e.g, S), those PoAs, which are in front of the MN, and of which $\Upsilon \leq 30^\circ$ and network type is the same (homogeneous) as the type of S, are first considered as the candidates, among which, the one with the shortest distance between it and MN receives from will be chosen as the target PoA. If no PoA of which $\Upsilon \leq 30^\circ$, those PoAs with $\Upsilon \leq 90^\circ$ and their network type homogeneous to the type of S will be considered. Also, the one with the shorten distance form MN will be chosen as the target PoA. The third-priority PoAs are those with $\Upsilon \leq 30^\circ$ and their network type heterogeneous to type of S. The fourth-priority PoAs are those with $\Upsilon \leq 90^\circ$ and heterogeneous to the S's type. Table 4 summarizes the choosing priority. Basically, the type is the most important parameter since the target environment is the same as that of the serving PoA, i.e., the transmission bandwidth is the same and sometimes authentication for handover network re-entry can be avoided [24] . This can smoothing packet delivery, particularly when multimedia packets are transmitted since WiMax default bandwidth (72 Mbps) and UMTS default bandwidth (384 Kbps) are different [13]. Different bandwidths may cause packets congestion, or the multimedia server has to be aware the change and then adjusts its data rate. However authentication is often long, often taking a few seconds [24]. This will intermit the packet delivery so that multimedia streams cannot be smoothly delivered.

When no PoA under the underlying MIIS server, e.g. S, meets $\Upsilon \leq 90^\circ$, indicating that a vertical network search is required. S sends the handover request to its immediate parent MIIS server, e.g., Q. Q then invokes its network selection algorithm to choose a suitable target network and one of its PoAs. If Q cannot find one, it delivers a find command to its parent MIIS server. The process repeats until a PoA is chosen. The chosen PoA's ID will be sent back to S. S will deliver the PoA ID to MN. However, if at last the root of the MIIS-server hierarchy cannot find a suitable network and PoA, implying that there is no network and PoA that can take over for S's serving PoA to serve MN. MN will search the suitable network by using its own wireless interface.

Table4：the priorities of choosing a target PoA

Network environment of PoA	Choosing priority
a homogeneous PoA and $\Upsilon \le 30^{\circ}$	1
a homogeneous PoA and $\Upsilon \le 90^{\circ}$	2
a heterogeneous PoA and $\Upsilon \le 30^{\circ}$	3
a heterogeneous PoA and $\Upsilon \le 90^{\circ}$	4

Figure 6 and 7 respectively show the handover decision algorithm performed by MN and the network selection algorithm performed by MN and the network selection algorithm performed by an MIIS server.

The Handover Decision Algorithm：//performed by an MN to evaluate its link status

Input: MIH_link_going_down or MIH_link_down message

Output: doing nothing or handing over

{MIES_get_Link_status(); //Load MN status information through MIES service

If(receiving a MIH_link_going_down message)

{Initiate a timer T;

While (Until MN successfully receives target PoA ID or timer T times out)

{Send handover request message to the serving MIIS server;

//MN_GPS_message includes (X_{MN} , Y_{MN}) and MN's moving direction Ψ

wait for T times out; }

If(T times out) {Go to U;} //cannot find any suitable PoA throughout the system

Else // receiving a PoA ID from the serving MIIS server call, i.e., connection procedure (target PoA ID)

{Call connection procedure of the type of the network the target PoA belongs to;

//The type of the target network, WiMax or UMTS, can be discriminated by target PoA ID

Register with the PoA to receive a CoA;

Register with the target network AAA server; //Auditing user ID

Send a binding update message to its own home server; //updating its CoA

Send a binding update message to its CN to update the new CoA;

Add new CoA to SCTP multi-path table; // a table recording MN's IPs

Inform old PoA to set the new CoA as the primary IP ; // to redirect packets that have been sent by CN before CN receives the binding update message to MN}}

Else //receiving a MIH_link_down message

U: MN searches a suitable network and PoA with its own network interface; }

```
Void connection procedure (target PoA_ID)
    { if (the network type of the serving PoA is WiMAX)
       {if (the network type of the target PoA is WiMAX)
          Turn on the second WiMax NIC through MICS server to connect to the target PoA;
        Else //target PoA is UMTS
          Turn on the first UMTS NIC through the MICS server to connect to the target PoA;}
    else // the serving PoA is UMTS
       {if (the target PoA is WiMAX)
          Turn on the first WiMAX interface via MICS and connect to the target PoA;
       else //network type of target PoA is UMTS
          Turn on the second UMTS NIC through the MICS to connect to the target PoA;}
```

Figure 6：The handover decision algorithm performed by MN

Network Selection Algorithm： //performed by MIIS server

Input : MIH_MN_ho_candidate.request, MN_GPS_message

Output : Target PoA ID

{If(Receive an error message “no PoA is available” from parent MIIS server)

{Transfer error message to MN or child MIIS depending on the undelaying MIIS server is MN’s serving MIIS server or net;} // cannot find a suitable PoA

Else if (Receive a return message “PoA ID” from its immedinate parent MIIS server)

{If (the underlying MIIS server is MN’s serving MIIS server)

Return (PoA ID) to MN;

Else return (PoA ID) to the child MIIS server that issues the corresponding handover request; }

Else{

If(Receive handover_GPS_request from MN or child MIIS server)

{For (each PoA in its service table)

Calculate the angle Υ between MN moving direction and $\overrightarrow{MNPoA}$;

// invoking eqs.(1), (2), (3) and (4)

Records each distance between each of request's MNs and PoAs;

$S_{30} = S_{90} = \varnothing$; //Find a suitable target PoA

For (each PoA, e.g., x)

{if ($\Upsilon_x \le 30^\circ$) $S_{30} = S_{30} \cup \{\text{PoA\_ID of x}\}$; // $\Upsilon_x : x's\ \Upsilon$

else if ($\Upsilon \le 90^\circ$) $S_{90} = S_{90} \cup \{\text{PoA\_ID}\}$;}

If ($S_{30-ho} = S_{30} \cup \{$PoA ID: the type of the PoA is the same as the type of MN's serving PoA in the serving MIIS server's service table$\} \neq \varnothing$)

{choose the PoA with the shortest distance between the PoA and MN from $S_{30\text{-ho}}$ as the target PoA; Return (PoA ID) to MN or the corresponding child MIIS server;}

Else if($S_{90-ho} = S_{90} \cup \{$PoA ID: the type of the PoA is the same as the type of MN's serving PoA in MN's serving MIIS server's service table$\} \neq \varnothing$)

{choose the PoA with the shortest distance between the PoA and MN from $S_{90\text{-ho}}$ as the target PoA; Return (PoA ID);}

Else If ($S_{30-he} = S_{30} \cup \{$PoA ID: the type of the PoA is differnet from the type of MN's serving PoA in MN's serving MIIS server's service table$\} \neq \varnothing$)

{choose the PoA with the shortest distance between the PoA and MN from $S_{30\text{-he}}$ as the target PoA; Return (PoA ID) to MN or the corresponding MIIS server;}

Else if($S_{90-he} = S_{90} \cup \{$PoA ID: the type of the PoA is differnet from the type of MN's serving PoA in MN's serving MIIS server's service table$\} \neq \varnothing$)

{ choose the PoA with the shortest distance between the PoA and MN from $S_{90\text{-he}}$ as the target PoA; Return (PoA ID) to MN or the corresponding MIIS server;}

Else // $S_{30} = S_{90} = \varnothing$

If(the underlying MIIS is not the root MIIS server)

Transfer the handover request to the immediate parent MIIS server recorded in the serving MIIS server's redirection table;

Else if (the undelaying MIIS server is MN's serving MIIS server)

Send "No PoA is available" message to MN; }

Else send "No PoA is available" message to the corresponding child MIIS server;

Figure 7：The network selection algorithm performed by an MIIS server

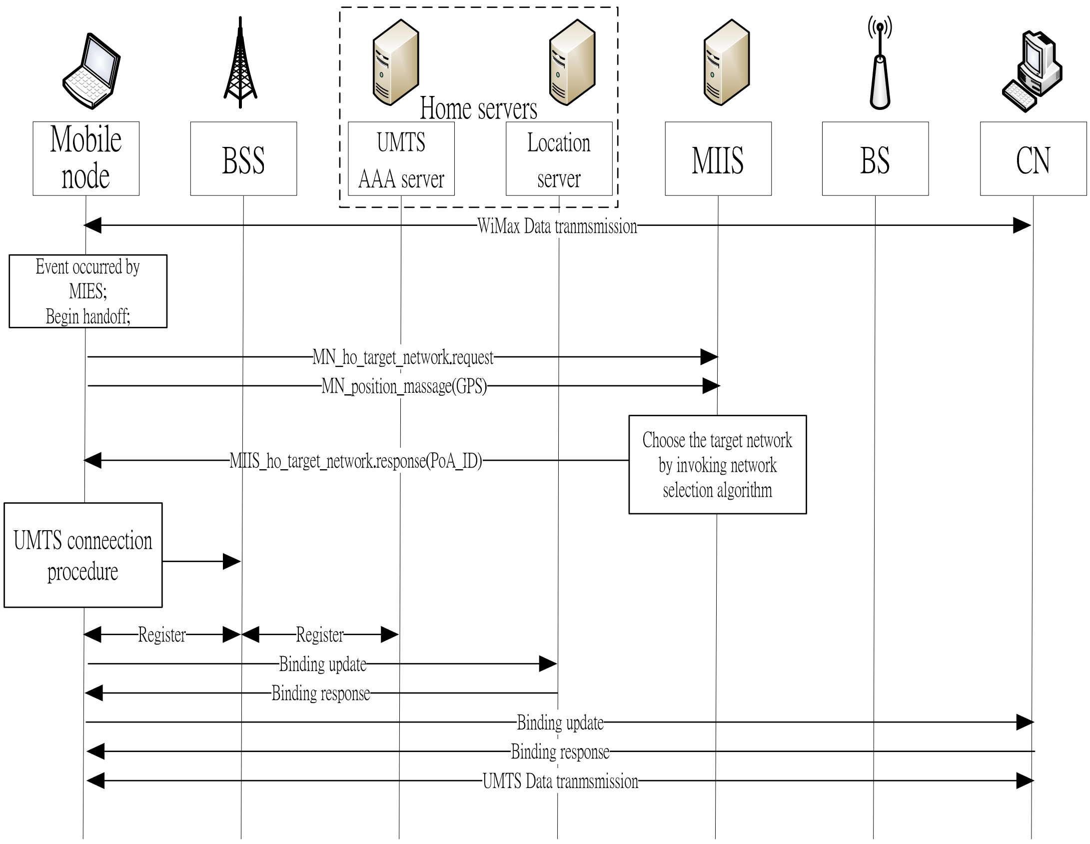


Figure 8：Procedure of a handover from WiMAX to UMTS

(MN_ho_target network_request is a kind of handover request, which carries MN's IP address to MIIS server and asks MIIS server to shoose a suitable target PoA for it)

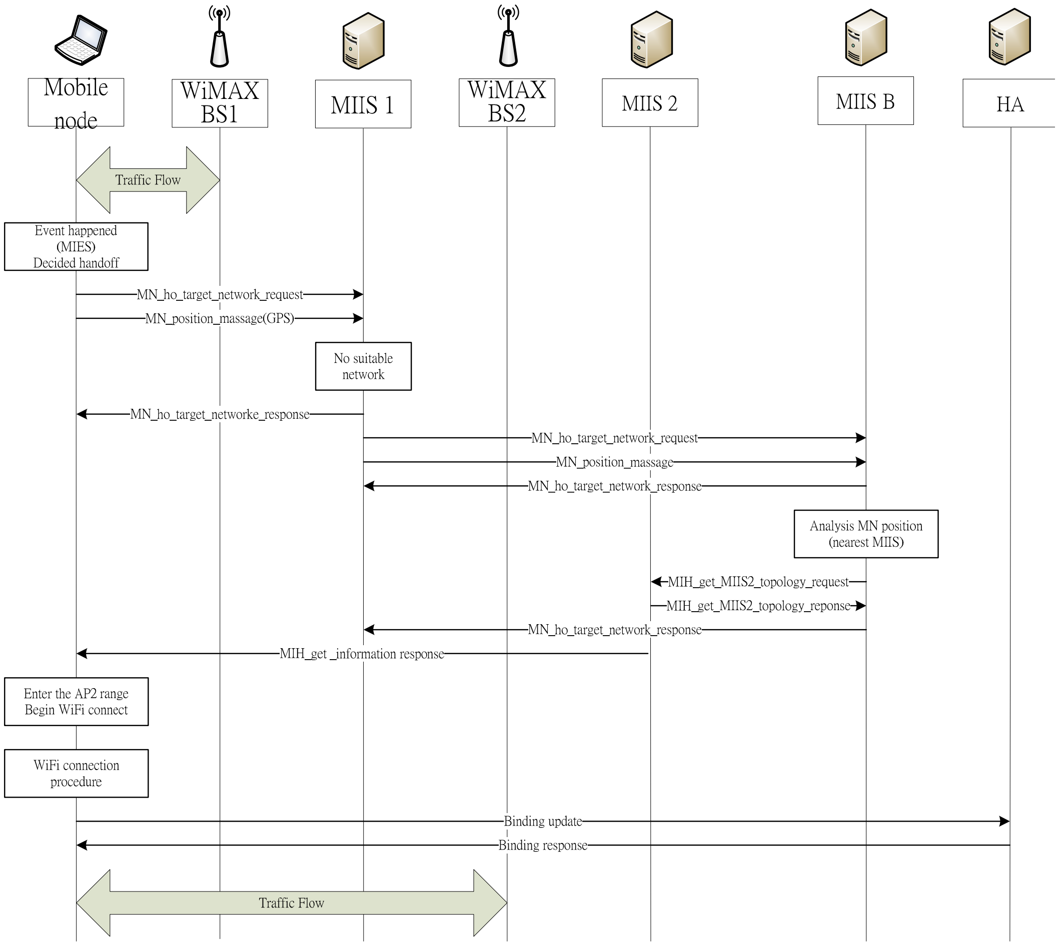


Figure 9：MIIS server roaming procedure

4. Experiments and Discussion

To evaluate the performance of the proposed handover scheme, we extend the mobility framework of NS-2 by integrating it with the simulation models of IEEE 802.16 and its mobility extension developed by National Institute of Standards and Technology (NIST) [25]. The simulation topology as shown in Figure 10 consists of two WiMAX PoAs and a UMTS PoA. The communication areas of the two WiMAX PoAs, individually overlap with the communication area of the UMTS PoA. The default parameters used in the following experiments are listed in Table 5. The tested schemes include LHOS, ND algorithm [16], LHOS-SCTP, and the one without handover algorithm (WHA for short), in which LHOS-SCTP employed SCTP transport layer protocol, while LHOS and ND used TCP. In the following experiments, the parameter values may be changed when necessary.

Eight experiments were performed in this study. The first evaluated the performance of the tested schemes when MN handed over from the WiMAX to the UMTS and then handed over to the WiMAX again in a heterogeneous wireless environment providing link-going-down detection and messages. The second redid the first experiment but in a homogeneous environment in which the WiMAX was employed. The third redid the second experiment in a homogeneous environment given different data rates. The fourth redid the second experiment in a heterogeneous environment on different data rates. The fifth redid the second experiment in a homogeneous environment and a heterogeneous environment on different MN moving speeds. The sixth redid the second experiment in a heterogeneous environment and in a homogeneous environment given different packet sizes. The seventh studied the multi-hop transmission delays among MIIS servers given different number of relay stations and different numbers of packets sebt by MN. The eighth redid the third experiment given different numbers of requesting mobile nodes.

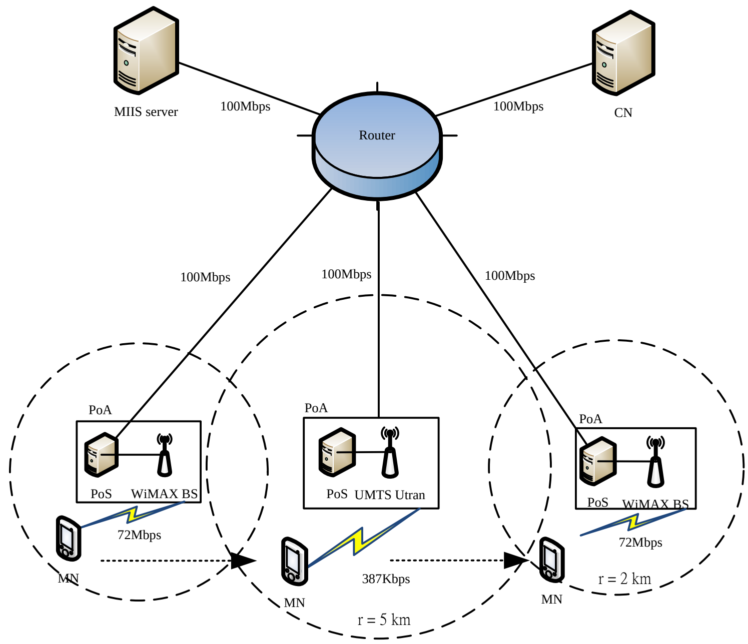


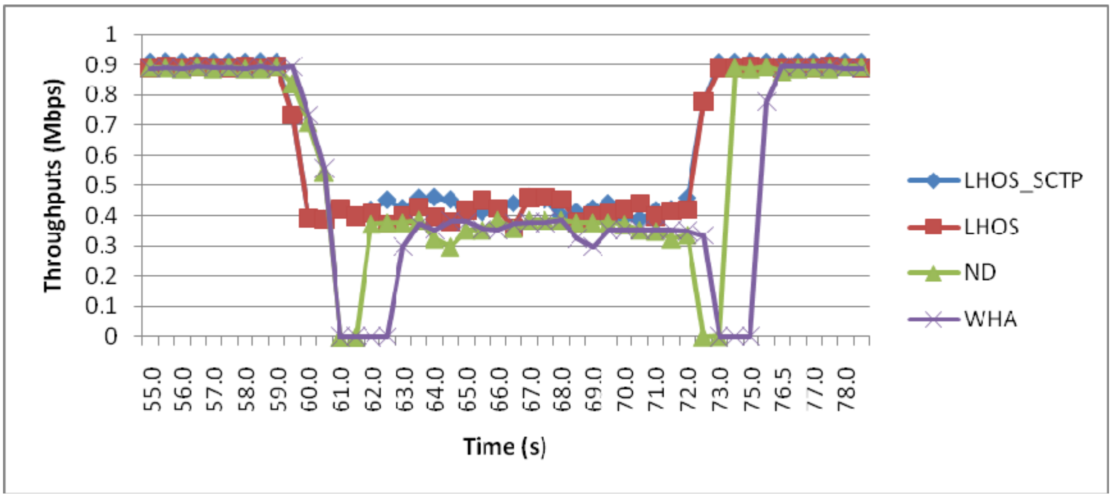
Figure 10 : The environment of a link-going-down simulation

Table5：Default parameters of the following experiments

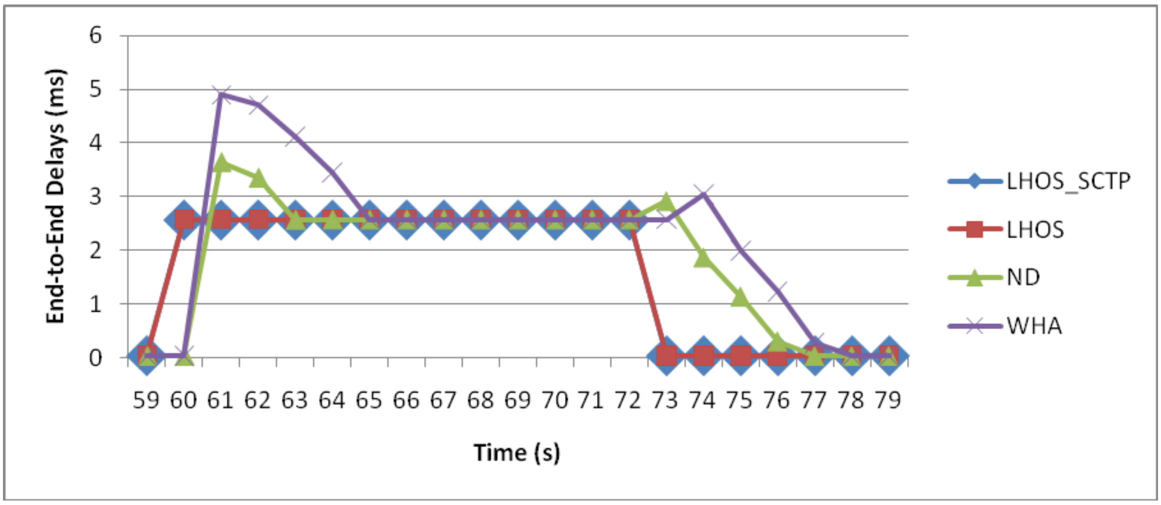
Network parameter	Description
WiMAX bandwidth	72Mbps
UMTS bandwidth	384Kbps
Default Transmission Time Interval of UMTS	2 ms
Bandwidth of a wired link	100Mbps
Packet size	1Kbit
Date rate	1Mbps
MN’s moving speed	1 m/s (=3.6km/hr)
Simulation time	100 sec

4.1 The performance in a heterogeneous environment

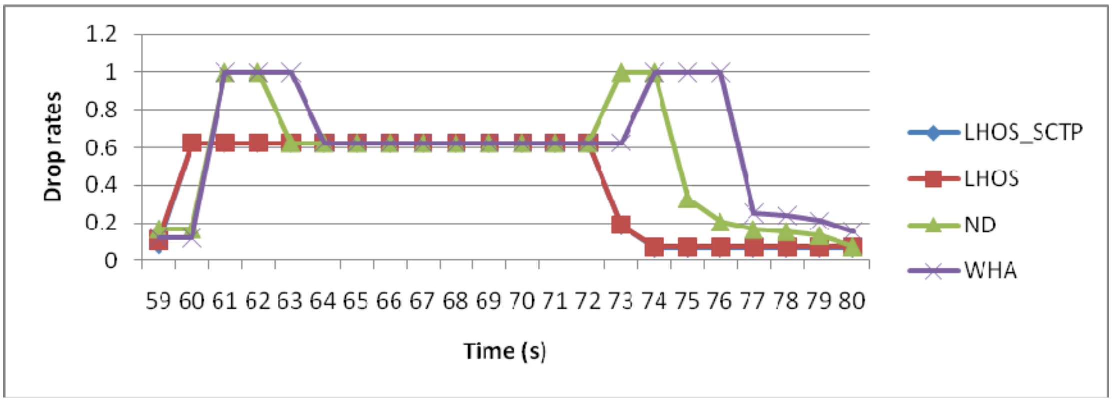
In the first experiment, MN sends a connection request to request connecting itself to a WiMAX PoA at the 15th sec. MIES service sends a link_going_down message at the 59th sec. After handing over to the UMTS PoA, MN's MIES service issues another link-going-down message at the 72th sec. MN prepares to hand over to WiMAX again. The ND, LHOS and LHOS_SCTP used MIES service to tell when the wireless link is going down. The latter two then asked MIIS server to provide the most appropriate target network in advance. So, due to a shorter link disconnection and/or shorter communication disruption time, the two schemes throughputs during handover are relatively higher than those of the other two, i.e., the ND and WHA. Further, the target network is chosen by the MIIS severs, so the load of MN during handover is light, consequently prolonging its battery lift time. But during handover, the LHOS did not completely utilize the bandwidth. The reason is that the LHOS spent, about 1 sec to deliver binding update messages to the home server and CN through the original routing path. Further, for achieving a make-before-break, an MN is given two network interface cards, one for WiMAX and the other for UMTS, which are assigned two different IP addresses and two different channels.



(a). The throughputs



(b). The network delays between the 59th and the 79th



(c). The drop rates ranging between the 59th and the 80th sec

Figure 11：The network throughputs of the first experiment in which MN currently under a WiMAX PoA receives a link-going-down message at the 59th sec and starts handing over to the UMTS. MN receives another link-going-down message again at the 72th sec and starts handing over to the WiMAX.

Figures 11a, 11b, and 11c respectively show the throughputs, end-to-end delays, and drop rates for the tested algorithms. Obviously, the ND's and WHA's throughputs are not better than those of the LHOS and LHOS_SCTP. The reason is that the ND spends a few seconds to detect RA messages, and replies a PoA with an RS message once the PoA is selected. Often the detection/reply procedure lasts several seconds. Thus, the link may break. Also, the ND has not provided buffers to collect packets sent by CN, resulting in packet loss during handoff. The link when employing the WHA breaks at the 61th sec. Hence, it must detect the target PoA for a network re-entry. The reason why its performance is not better than that of the ND is that the ND has its handover procedure, and the WHA starts detecting RA messages only when current connection breaks. On the other hand, owing to asking the MIIS server to provide the most appropriate target PoA much earlier, the LHOS and LHOS_SCTP can effectively perform pre-handover, so as to establish a UMTS (WiMAX) link before the WiMAX (UMTS) link breaks. It is also the reason why the LHOS and LHOS_SCTP can connect themselves to UMTS PoA at about the 60^{th} sec, one second after receiving the link_going_down message, while the ND (WHA) connects to the UMTS PoA at about the 62^{th} (the 63^{th}) sec. Furthermore, due to having multi-homing characteristic the LHOS_SCTP can establish a new connection to connect itself to the target PoA before the connection between itself and the serving PoA breaks. In fact, as the overlapped area of the WiMAX and UMTS is huge enough, the LHOS-SCTP without MIH function can also achieve make-before-break by itself. But the LHOS needs MIH function before it can achieve this. Although the ND starts detecting surrounding PoAs when receiving a link_going_down_message. On receiving an RA message issued by the UMTS's PoA, it considers the bandwidth of the UMTS PoA is very lower than that of its serving WiMAX PoA, implying that this is not a good choice. Its MN connects itself to the UMTS PoA until the WiMAX connection breaks [16]. Also, multi-streaming can avoid head of line effect [18] and is helpful for MN to more highly utilize link bandwidth.

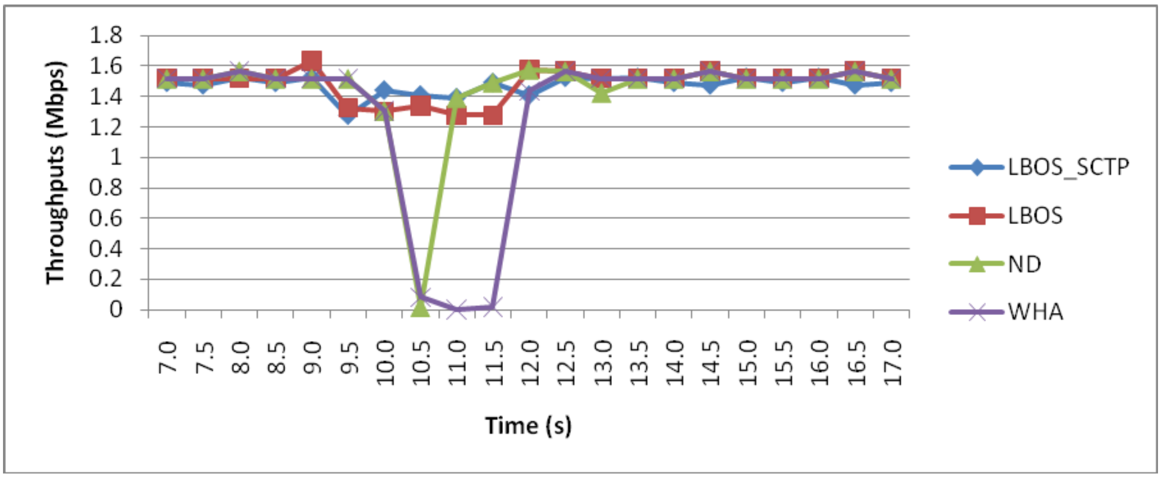
The average end-to-end delays of the LHOS_SCTP is about 0.01 msec. Those of the other three algorithms range between 2.7 and 2.8 msec due to using the TCP protocol. Further, the UMTS bandwidth (384kbps) is much smaller than that of the WiMAX (72Mbps). After handing over from the WiMAX to the UMTS, MN does not change its data rate. Thus, while MN is connected to the UMTS network, the drop rates of the four algorithms are all high about 61%.

The drop rates of the WHA are the worst among the four algorithms since it has link down problem during handover. In fact, the WHA spent about 2 sec from the 61th sec to the 63th sec and from the 73th sec to 75th sec to recover its wireless link when handing over from WiMAX to UMTS and from UMTS to WiMAX, respectively. The ND receives the second link_go_down message at the 72th sec and starts detecting its surrounding PoA RA messages. Since the WiMAX's bandwidth is higher than of the UMTS, on receiving the WiMAX PoA's RA message, MN chooses that the WiMAX PoA immediately, and starts establishing a WiMax connection between itself and the PoA. Owing to having fast recovery mechanisms, the ND has less drop rates than the WHA has. With the LHOS and LHOS_SCTP, the MIIS server chooses the best target network for MN so as to ensure low packet drop rates, and their pre-handover mechanisms effectively shorten handover delays. With the LHOS, MN under the assistance of MIES service can create a new link before the old link is disconnected, even tcp does not support multi-homing.

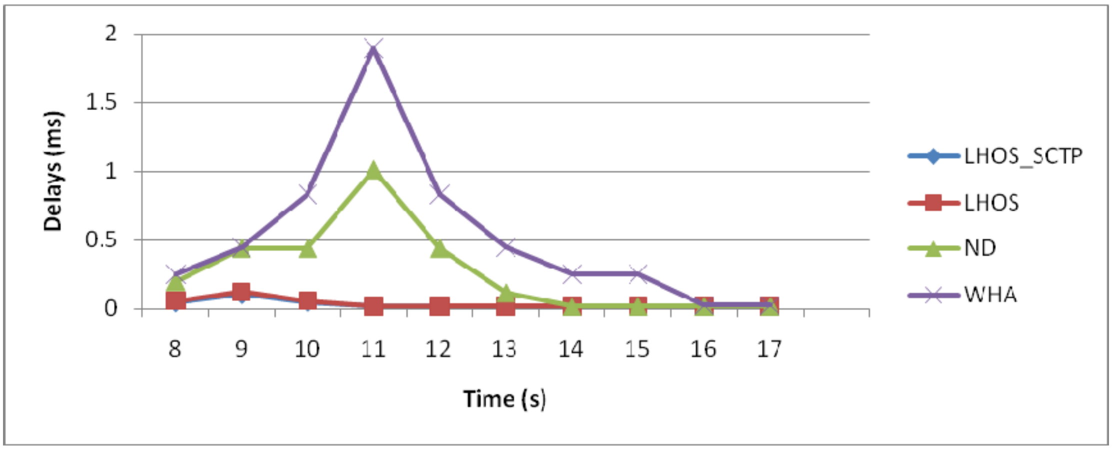
4.2 The simulation in a homogeneous wireless network

In the second experiment, the IEEE 802.16e standard with 50Mbps bandwidth was employed, implying the handover is performed on a homogeneous environment. The bandwidth of a wired link is 100Mbps. The MN receives of a link-going-down message at the 10th sec after the start of a tested algorithm. Real data rate is 2Mbps ($\doteq$1 Kbits/(1 Kbits / 50 Mbps + 0.5)) instead of 1Mbps listed in table 5 where 0.5 sec is the inter-message interval of a CBR. The MN is equiped with two network interface cards which are assigned two different IP addresses and the same channel, thus causing channel contention which results in about 20% of packet drop rate.

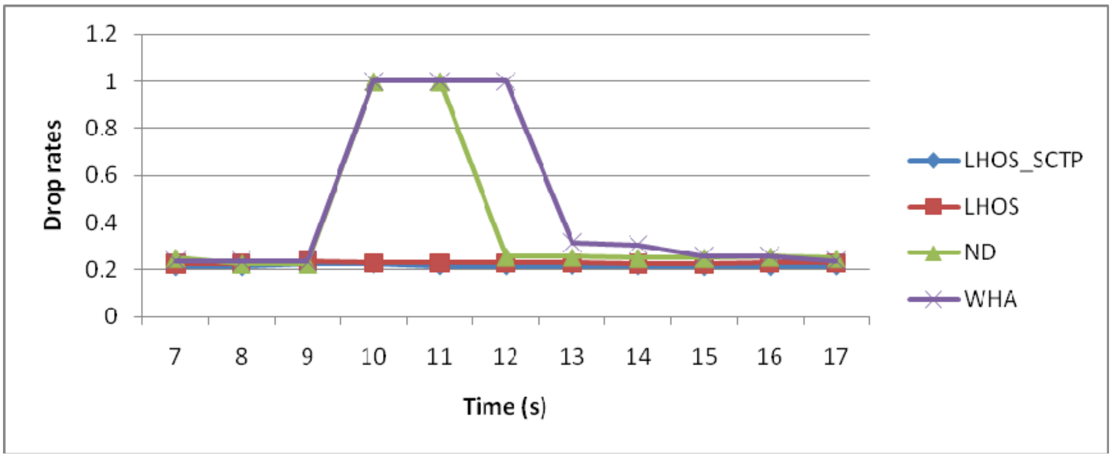
4.2.1 The performance in a homogeneous environment



(a). The throuhgputs



(b). The end-to-end delays



(c). The drop rates

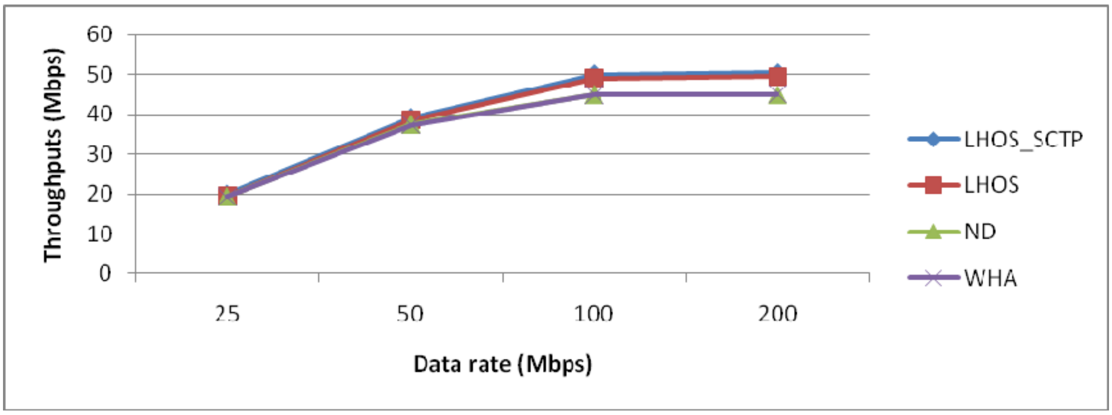
Figure 12：The performance of the tested algorithms given a homogeneous environment which is 802.16e WiMAX with bandwidth 50Mbps

Figures 12a, 12b and 12c respectivly illustrate the throughputs, end-to-end delays, and drop rates for the tested schemes. As shown in Figure 12a, during handover the throughputs of the LHOS and LHOS_SCTP in the homogeneous environment are higher than those of the WHA and ND since MN connects itself to the target PoA much earlier without waiting for RA messages issued by the surrounding target networks. In other words, MN has longer time to prepare handover and then connect itself to the target PoA before the link between itself and the serving PoA is disconnected. The ND algorithm needs longer time than the LHOS does to detect RA message after receiving a link-going down message from MIES service. Hence with the ND, a wireless link may be disconnected during handover (see Figuire9a). Although the ND can quickly recover its network throughputs, but the throughputs are approximately zero during the time period around the 10.5^{th} sec. Due to having no pre-access scheme, the WHA has to scan its surrounding environment, i.e., detecting RAs, for a target PoA. After that, MN has to perform a network-entry precedure, thus taking a few second to conncet itself to the target PoA. In other words, the ND and WHA are not very suitable for real-time streaming multimedia serives. Like that in the the heterogeneous enviornment, the LHOS_SCTP has better performance than the LHOS has. The reason is stated above.

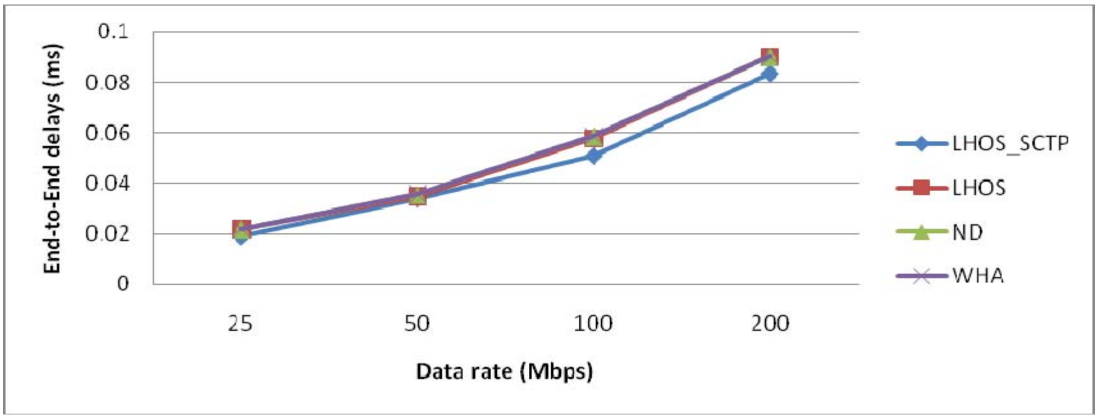
Besides, the ND's (WHA's) end-to-end delay is long about 1 sec (2 sec) which is almost equal to the time period that its wireless link is disconnected. Owing to having a handover algorithm, the ND recovers more quickly than the WHA does. Its delays are only one half of the WHA's. The LHOS's delays are a little longer than those of the LHOS_SCTP. The reason is the head-of-line problem.

Figure 12c shows that the drop rates of the four tested algorithms are individually lower than those of themselves in the heterogeneous environment. The key reason are the channel contention on MN's network interface cards. The handover procedure ranges between 2 and 3 sec. If the WHA is employed, in this time period, the packets that MN and CN sent are almost lost. That is why its drop rates are the highest. Due to pre-accessing the target network much earlier, the LHOS's drop rates are lower than those of the ND algorithm. Owing to having multi-streaming characteristics and alternate routing path(s), the LHOS_SCTP in turn has lower drop rates than the LHOS has.

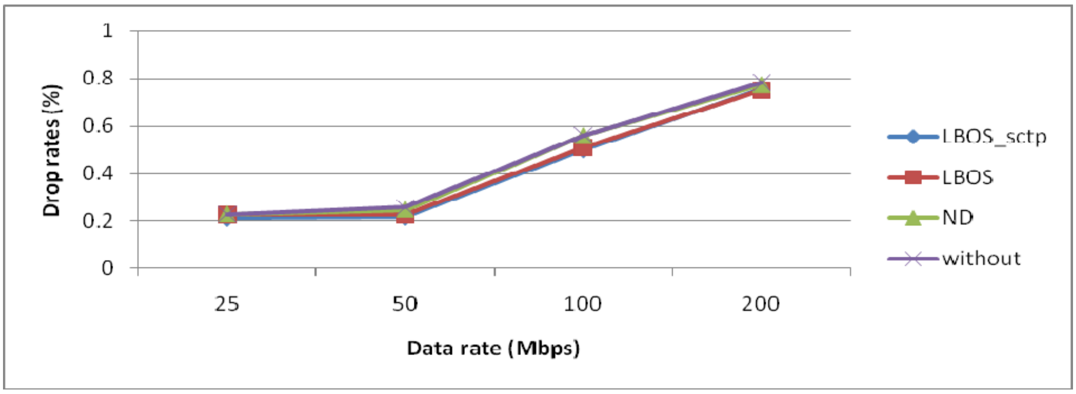
4.2.2 The performance in a homogeneous environment given different data rates



(a). Throughputs



(b). The network delays

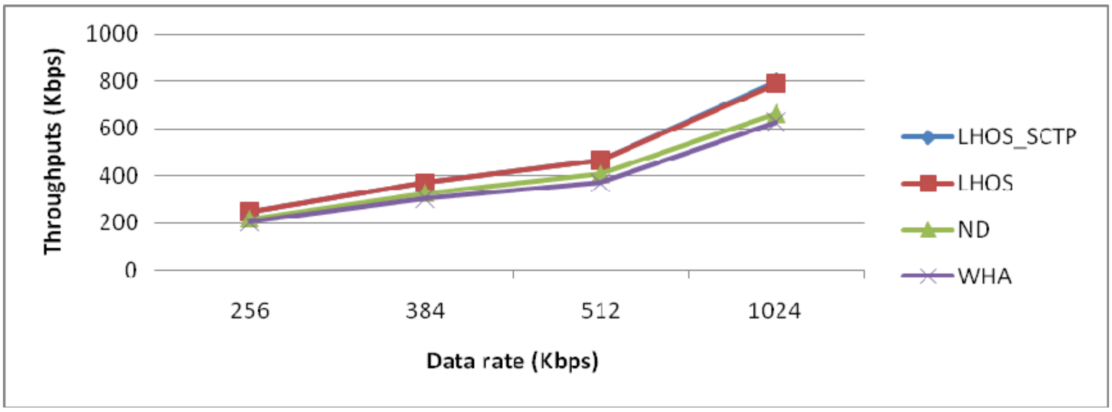


(c). Drop rates

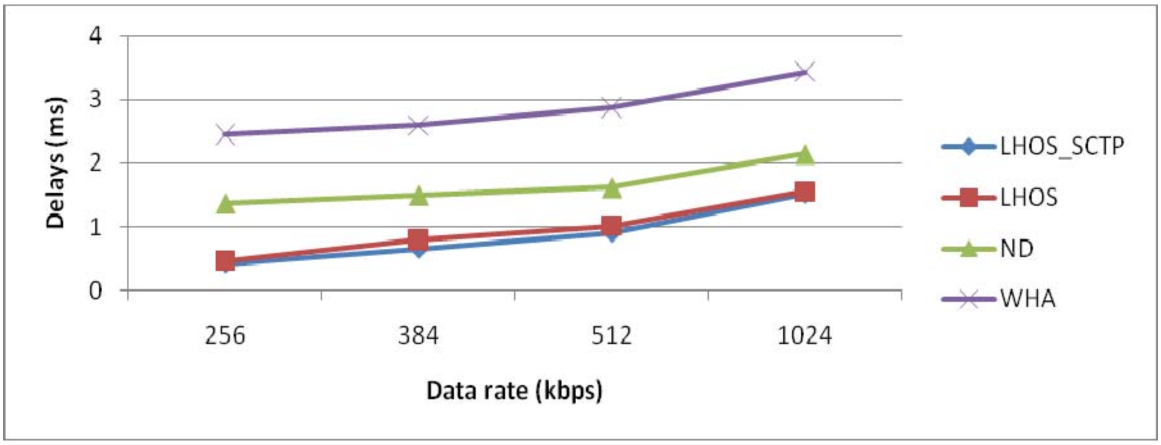
Figure 13：The performance of the tested algorithms in a homogeneous environment given different data rates

The third experiment redid the second experiment given different data rates, including 25, 50, 100, and 200Mbps rather than 1Mbps listed in table 5. MN and CN mutually send packets to each other. Figure 13a, 13b and 13c respectively illustrate the throughputs, end-to-end delays and drop rates. As shown in Figure 13a, when data rates are higher than 50Mbps, which is the default bandwidth of the wireless system, the throughputs increase slowly since the bandwidth is gradually saturated. The drop rates are about 20% when data rates are less than or equal to 50Mbps. The reason is channel contention and packet collision between MN's two network interface cards. The end-to-end delay includes the retransmission time of a dropped packet. The LHOS_SCTP has shorter delays since the multi-streaming of the SCTP solves the Head-of-Line problem and SCTP resends dropped packets throughput an alternate path [18] rather than via the primary one. This is particularly helpful when the quality of the primary path is poor. Due to using the same network environment and applying the TCP protocol, delays of the three algorithms other than the LHOS-SCTP as shwon in Figure 13b are almost the same. Figure 13c shows that the drop rates are between 20% and 80%. The drop rates of the LHOS and LHOS_SCTP are lower than those of the ND and WHA because the latter two methods during handover lost all most of their delivered packets. The LHOS has lower drop rates and end-to-end delays than the ND has. The reasons are the same as those described above. The LHOS_SCTP's drop rates and end-to-end delays are lower than those of the LHOS. From Figures 13b and 10c, we can conclude that data rate really affects the drop rates and end-to-end delays. When data rate is higher than the bandwidth of a wireless PoA, the packets delivered by CN (MN) will be congested and dropped at CN's (MN's) wireless end, i.e.,MN's (CN's) PoAs. Therefore, it would be better if data rate is not higher than that of a wireless link.

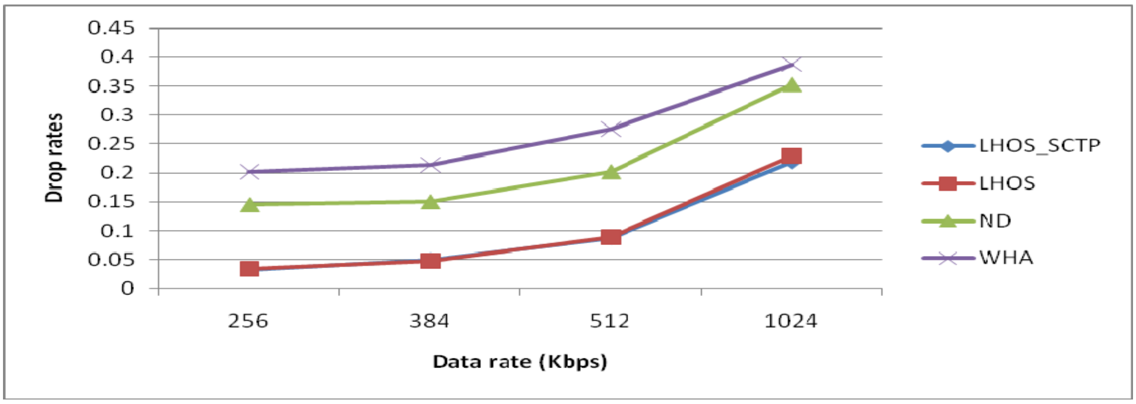
4.3 The performance in a heterogeneous environment given different data rates



(a). **Throughputs**



(b). Delays

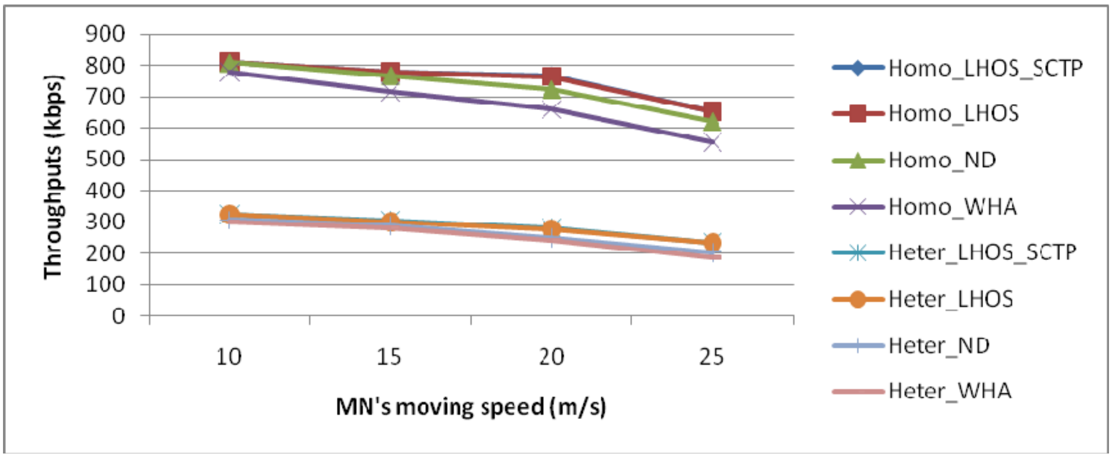


(c). Drop rates

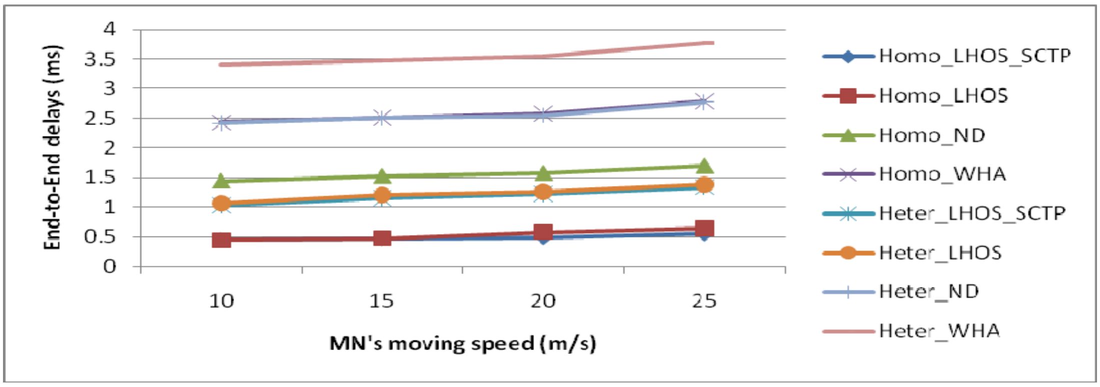
Figure 14：The performance of the tested algorithms in a heterogeneous environment given different data rates

The fourth experiment redid the third experiment in a heterogeneous environment shown in Figure 14, rather than a homogeneous environmnet given different data rates, including 256, 384, 512, and 1024 kbps. The throughputs are higher than that of the UMTS bandwidth (384kbps) since are generated by the connection when connecting to the WiMAX and UMTS before and handover respectivly. Because the bandwidth of the UMTS is 384Kbps, MN has high drop rates when data rates are higher than the bandwidth. Figure 14a, 14b and 14c respectively illustrate throughputs, end-to-end delays and drop rates of this experiment.The throughputs are higher when data rates increase. The end-to-end delay including retransmission delay. When data rate is ranging between 512Kbps and 1024Kbps, drop rates are high. CN resends those dropped packets again, resulting in long end-to-end delays.

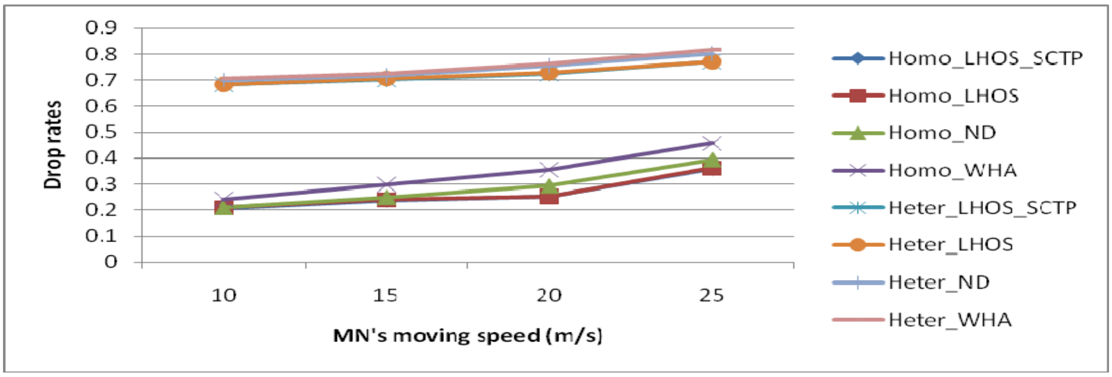
4.4 The performance given different MN's moving speeds



(a). Throughputs



(b). The network delays

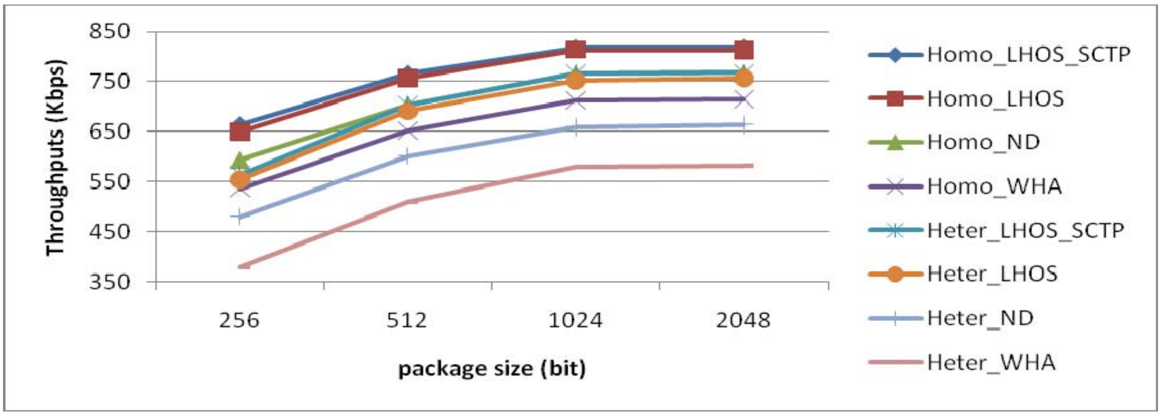


(c). Drop rates

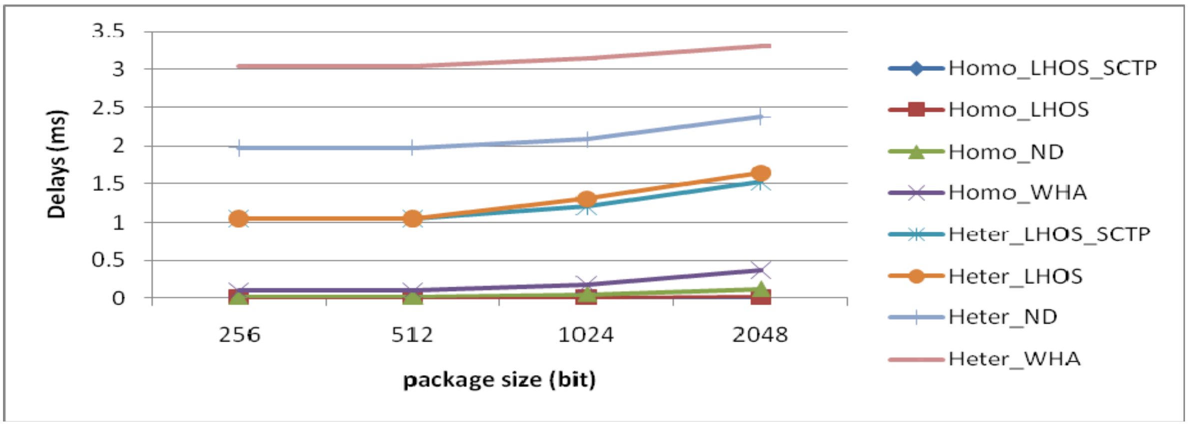
Figure 15：The performance of the tested algorithms in a homogeneous environment and in a heterogeneous environment given different moving speeds

The fifth experiment redid the second one on different MN moving speeds of MN, ranging between 10m/sec (36 km/hr) to 25m/sec (90 km/hr), rather than 0.1m/sec listed in Table 5, given a homogeneous and a heterogeneous envrionment. The data rate is 1Mbps. Figure 15 a shows that throughputs are worse when MN moves faster in both environments since when moving faster, probability that a new wireless connection cannot successfully/established before the original link is disconnected during handover will be higher. The LHOS and LHOS_SCTP can use the second network interface to pre-connect to the target network, resulting in a higher probaility of successfully establishing a connection. This is the reason why they have higher throughputs and lower drop rates than those of the other two schemes. Figure 15b shows that the LHOS_SCTP has shorter delays than the LHOS has due to exploiting multi-homing characteristic. Figure 15c illustrates that with the SCTP, a scheme can decrease packet drop rates, even MN is moving in a high speed. In the hetergeneous environment, the bandwidths of the WiMAX and UMTS are not the same.

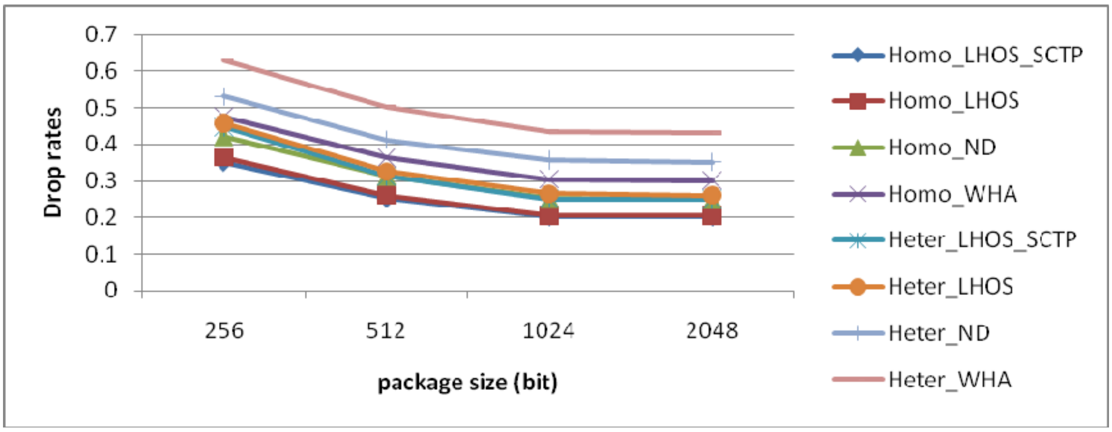
4.5 The performance in a homogeneous and a heterogeneously environment given different package sizes



(a). Throughputs on 1 Mbps data rate



(b). Delays on 1 Mbps data rate



(c). Drop rates on 1 Mbps data rate

Figure 16：The performance of the tested algorithms in a homogeneous environment given different package sizes

The sixth experiment redid the second one on different package sizes ranging between 256 bit to 2048 bit per packet rather than 1kbit per packet listed in table 5. The data rate is 1Mbps, which means (packet rate $\times$ packet size) is a constant. The throughputs are higher than that of the UMTS bandwidth (384kbps) since are generated by the connection when connecting to the WiMAX and UMTS before and handover respectivly. When packet size is larger, the number of packets sent is smaller, e.g., when packet size = 256 bit, packet rate = 4K pkts/sec. When many more packets are sent, the probability of packet collision and channel congestion will be highers implying when packet size = 1024 bits (packet rate = 1K pkts/sec), the probability will be lower. But smaller packet size has a little longer end-to-end delays since times of contention are higher many more packets are dropped and retransmitted. The LHOS_SCTP and LHOS have the best performance on matter in the heterogeneous or in the homogeneous environment.

4.6 The performance of multi-MIIS-server information delivery

In the seventh experiment, MN continuously sent i packets to CN, i = 1,2,…,22, and we analyzed the transmission performance for MIIS servers connected either by a wired network, in which the bandwidth of a link between two adjacent MIIS servers, maybe parent-child or two-siblings relationship, is 100Mb, or by a wireless mesh network in which the protocol used is the WiMAX ad-hoc mode with 50Mbps wireless bandwidth. Network information is transmitted hop by hop among the MIIS severs.

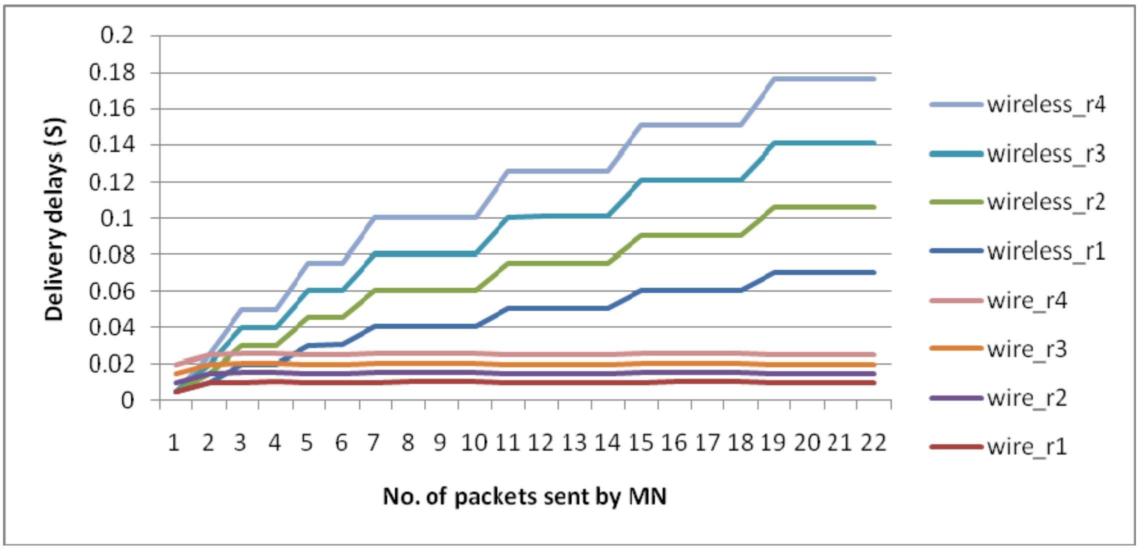
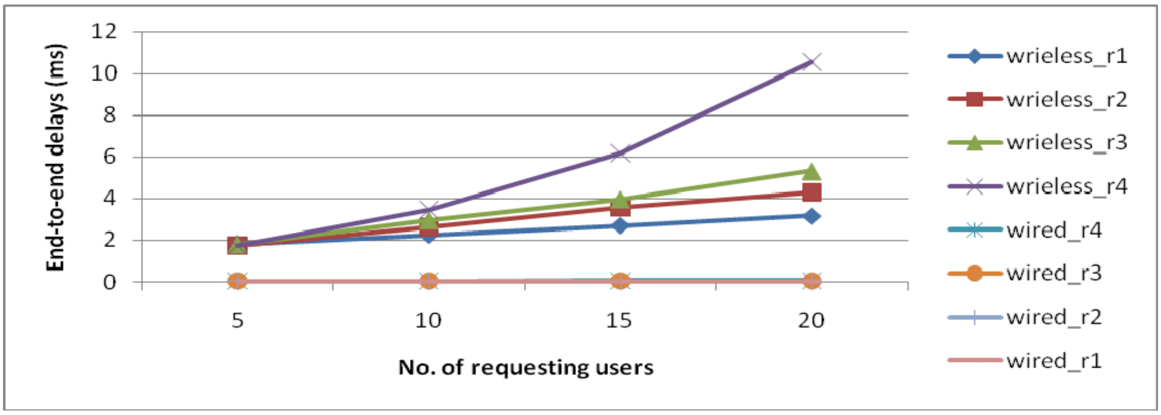


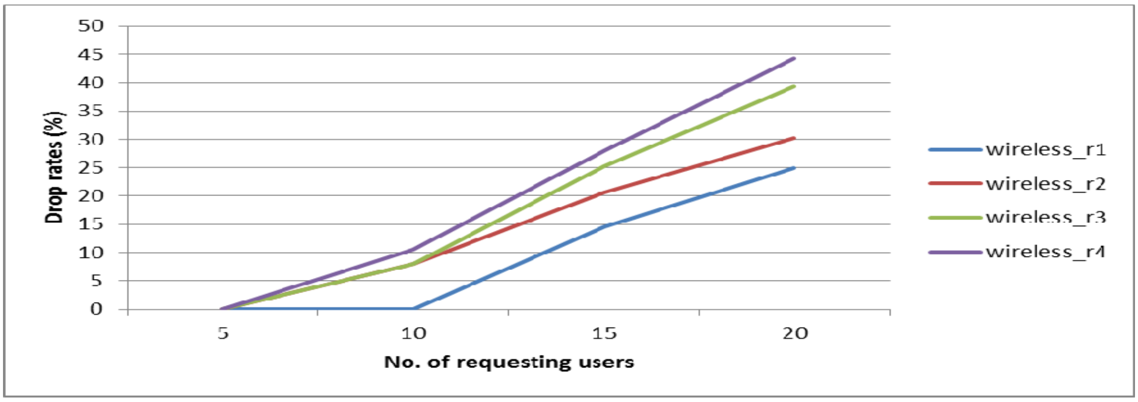
Figure 17: Packet delivery delays in a wired MIIS-server network and in a wireless MIIS-server network

Figure 17 illustrates the packet delivery delays where a packet is 1Mb in length and ri represents that a message is relayed i hops before arriving at its destination, i=1,2,3, 4. When 22 packets were delivered through the wired links, the delay of a packet on 4 relays, denoted by wired-r4, was 25 msec. It is clear that the delays in the wired network are almost constant with less influence by the number of relays. The reasons resulting in worse performance on the wireless mesh network were packet collision [26], signal attenuation [26], data congestion [26], and the fact when MN is moving fast, the wireless connection may break. If the number of relays increases, the delay time is longer. But the size the packets transmitted between two MIIS servers for delivering network information is small, about 13 bytes. Hence, the delays when number of relays is small are not serious. We can now conclude that from packet delivery viewpoint it would be better if MIIS servers can be connected by wired links,

4.7 The delays of an MIIS server given different numbers of user requests



(a) The delays of an MIIS server loading in a wireless network environment and in a wired network environment



(b) Drop rates

Figure 18：The drop rate of MIIS user loading in wireless network environment

In the eighth experiment, we analyze the processing delays of a MIIS server when it receives different numbers of user requests at the same time. Figure 18 illustrate the experimental results in a wireless and a wired environment. Figure 18a shows that the delays of the wireless network are very longer than those of the wired MIIS network. The situation is worse when many more requests are submitted simultaneously.

The delays of a wired network are not affected by the number of issued requests. Hence, in a heavy user loading area, a wired MIIS server network environment is preferred.

5. Conclusions and Future Research

In this paper, we have described the propose architecture of MIIS servers, and their algorithms, including the network decision algorithm and the network selection algorithm. Eight experiments were performed to evaluate the performance of the proposed architecture and the tested algorithms. The experimental results show that the LHOS and LHOS-SCTP can pre-access network information before the original network connection is disconnected so as to improve throughputs and packet drop rates and shorten end-to-end delays during handover. The network information exchange in a wired MIIS-server LAN as expected has better performance than that in a mesh network. Further, the handover performed in a heterogeneous environment, containing the WiMAX and UMTS wireless system, is more complicated than that performed in a homogeneous environment. Also, in current state of wireless research, MIIS servers are better connected by wired links.

In future work, we will further employ a navigation system to predict the probable target network so as to reduce the computation and efforts for target network/PoA selection, and define a new Link_going_down message so that we can hand over much earlier than the one used in this study so as to perform pre-hand over further in advance to make the communication between MN and CN be suspended as short as possible, consequently shortening the overlapped communication area of two consecutive PoA. Then, we can lengthen the distance of the two PoAs to reduce the number of required PoAs when a service area is given. These constitute our future research.

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