SIMULATION BASED INVESTIGATION OF MOBILE IP IMPROVEMENTS

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ABSTRACT

SIMULATION BASED EVALUATION OF

MOBILE IP HANDOFF SCHEMES

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In this thesis, performances of some Mobile IP handoff schemes have been compared. The comparison has been based on simulation results. Simulation study has been carried out with a MIP model developed using OMNeT++ and available model frameworks.

The literature on Mobile IP and several improvements including handoff management schemes have been surveyed. A MIP model has been constructed and then validated with the help of some scenarios in the literature, especially the one found in [7]. The model has been then used to investigate performances of FMIP. The study also included performance of FMIP under local traffic where mobile hosts communicate with each other in the same domain.

Simulations are carried out under several scenarios involving UDP and TCP transfers. Mobile host speed and base station buffer size variables have been changed throughout the simulations.

The result show that use of L2 triggers reduces handoff latency as both FMIP Post-Reg and Pre-Reg have better performance than HMIP without L2 triggers. The results also show that FMIP Post-Reg is a good candidate for future MIP infrastructures with its low latency handoff characteristics due to bidirectional tunneling between old and new points of attachment. Moreover, the results suggest that FMIP Post-Reg is also the best handoff scheme under local traffic where mobile hosts communicate among each other in the same foreign network.

Keywords: Mobile IP, handoff, Fast Handoffs, Pre-Reg, Post-Reg

ÖZ

MOBILE IP AKTARMA YÖNTEMLERİNİN SİMÜLASYON YOLU İLE KARŞILAŞTIRILMASI

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Bu tezde bazı Mobile IP aktarım yöntemlerinin performansı karşılaştırılmıştır.

Mobile IP ve aktarım yöntemlerini de içeren bazı geliştirmeler hakkındaki yayınlar incelenmiştir. Bir MIP modeli geliştirilmiş, ardından da literatürdeki bazı senaryolarla, özellikle [7]'de bulunan senaryo ile doğrulanmıştır. Model daha sonra FMIP performansının incelenmesinde kullanılmıştır. Çalışma ayrıca FMIP'in mobil kullanıcıların aynı ağda birbirleriyle haberleştikleri yerel trafik altındaki performansını da içermektedir.

Benzetimler UDP ve TCP transferleri içeren senaryolar altında gerçekleştirilmiştir. Benzetimlerde mobil kullanıcı hızı ve baz istasyonu tampon boyutu kontrollü olarak değiştirilmiştir

FMIP Post-Reg ve Pre-Reg yöntemlerinin her ikisinin de L2 tetiklerini kullanmayan HMIP yönteminden daha iyi performansa sahip olduğunu gösteren sonuçlar, L2 tetiklerinin aktarım gecikmesini düşürdüğümü göstermiştir. Sonuçlar eski ve yeni ilişme noktası arasında iki yönlü tünel kurarak en düşük aktarım gecikmesi karakterine sahip olan FMIP Post-Reg yönteminin gelecekteki MIP altyapıları için iyi bir aday olduğunu göstermektedir. Ayrıca sonuçlar FMIP Post-Reg yönteminin, mobil kullanıcıların yabancı bir ağda kendi aralarında haberleştikleri yerel trafik altında da en iyi performansa sahip olduğunu göstermektedir.

Anahtar Kelimeler: Mobile IP, aktarım, Hızlı Aktarımlar, Pre-Reg, Post-Reg

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LIST OF ABBREVIATIONS

2G	Second generation mobile networks
3G	Third generation mobile networks
4G	Fourth generation mobile networks
ARP	Address Resolution Protocol
CH	Correspondent Host
FA	Foreign Agent
FMIP	Mobile IP Fast Handoffs
GFA	Gateway Foreign Agent
HA	Home Agent
HMIP	Mobile IP with Hieararchical Foreign Agents
IGMP	Internet Group Management Protocol
IP	Internet Protocol
L2	Layer 2, Data Link Layer
L3	Layer 3, Network Layer
MH	Mobile Host
MIP	Mobile IP
MIP-RO	Mobile IP Route Optimization
MITH	Mobile Initiated Tunneling Handoff
NS	Network Simulator
OMNeT++	Objective Modular Network Testbed in C++
OPNET	Optimized Network Engineering Tool
SCTP	Stream Control Transmission Protocol
TCP	Transmission Control Protocol
TCP-SACK	TCP-Selected Acknowledgements
UDP	User Datagram Protocol

VoIP	Voice over IP
WIPPOA	Wireless IP Point of Attachment

CHAPTER I

INTRODUCTION

Increasing popularity of mobile computing has attracted attention of researchers for years. As a 2G-to-3G switch is taking place and 4G appearing on the horizon, researchers pay a great deal of attention to mobile networking protocols.

New protocols are designed to provide Internet access to mobile users. Apart from data link layer (L2) protocols (wireless access technologies), transport layer or cross-layer solutions, there are two main approaches in providing a mobility solution: Network layer mobility support and application layer mobility support. Although application layer mobility support has quickly gained significant acceptance as it can "compensate for the lack of deployment of network layer mobility support" [20], network layer mobility support is still a very important area of research.

As a solution to the mobility support in the network layer, Mobile IP (MIP) [8] has been suggested. In Mobile IP, a host has a home address which does not change regardless of its point of attachment to the Internet. It also uses a care-of address whenever it is attached to the Internet on a foreign network, i.e., a visited network. When the mobile host (MH) is in its home network MIP is the same as IP. When the MH is visiting a foreign network, it makes use of IP tunneling such that inner datagram is the original packet sent by a correspondent host anywhere on the Internet destined to the home address of the MH, whereas the outer datagram is destined to the care-of address of MH.

Mobile IP suffers the triangular routing problem [9]. This problem results from the fact that packets routed to MH experience a long delay as they are routed to MH's home network first. However, packets generated by MH are delivered not necessarily on that route. Mobile IP Route Optimization (MIP-RO) [11] solves this problem by adding mobility caches at correspondent hosts so that correspondent hosts directly send datagrams to the care-of address pf MH eliminating the need for packets to visit home network of mobile host first. Although this is a solution to the triangular routing problem, its scalability problems are clear, since adding mobility binding to each host (or router) in the Internet is not practical.

Apart from triangular routing, handoff management is another issue in MIP. A MH initiates a handoff whenever it enters into the coverage area of a mobility agent different from its current foreign agent. During a handoff, MH is unreachable and packets may be lost if no buffering scheme is used, which may severely degrade TCP performance. Another handoff related problem is the high delay during handoff, which is not acceptable for real time applications such as VoIP; hence handoff is a major problem to be solved in MIP.

Several improvements have been suggested to overcome the frequent local handoff problem [9]. Among these improvements, Hierarchical Mobile IP (HMIP) [7] is important since it significantly reduces handoff delays by using information that mobile hosts experience localized frequent handoffs with base stations covering smaller areas, which is the expected situation for most cases. HMIP offers a hierarchy of foreign agents (FA), and localizes handoff by forwarding registration request up to the required level in the hierarchy. A home registration, in which the registration is relayed to home agent, only occurs whenever the mobile host moves into a different network. Inside the network, registrations are handled locally. Eliminating frequent home registrations provides significant improvement over base MIP, since a home registration can take a relatively long time.

HMIP also makes use of previous foreign agent notification, allowing previous FA to deliver buffered packets to new FA. Another buffering solution has been suggested by C´aceres and Padmanabhan [18], in which base station foreign agents forwards all buffered packets to MH, which sometimes result in duplicated packets. Duplicated packets degrade TCP performance if not eliminated, since modern TCP implementations react to duplicates as congestion indication. Perkins and Wang offer buffering with duplicate elimination, which is achieved by caching source address – identification field pairs at MH and deliver this cache to new FA during handoff.

Although mentioned suggestions significantly improve MIP performance, it is still a problem to start network layer handoff delay after the link layer handoff is complete, especially when the link layer handoff is relatively high. To overcome this problem, Fast Handoffs scheme (FMIP) has been offered [12]. In FMIP, L2 triggers are used to initiate the network layer (L3) handoff, if the access technology supports. FMIP reduces handoff delay by proactively handling handoffs.

One case where handoff management schemes can be compared is the case of local traffic, where two mobile hosts communicate in the same foreign network. It can be the case in any military or commercial application; hence, has been investigated in our study.

With the improvements mentioned, MIP may deliver better performance. In order to evaluate MIP performance with the above improvements, a simulation study has been carried out. Simulation models are implemented using the open source simulator OMNeT++.

In the simulation study, a MIPv4 model has been developed based on existing models. The model has been used in relatively simple simulations first to reproduce the same results as in some of the studies in the literature. Having obtained the reproduced results, the model has been validated. It has been then used throughout the rest of the study, producing original results for evaluating the performance gains introduced by Fast Handoff mechanism proposed in [12]. These results include the effects of pre- and post-registrations. One other novelty examined in this study is the behavior under intra-domain traffic.

The thesis is organized as follows:

In Chapter 2, a brief literature survey on network layer mobility support is presented. Moreover, Mobile IP and improvements offered are explained. Also brief information on OMNeT++ and related modeling projects, namely INET Framework, Mobility Framework and IPv6Suite, is given this chapter.

In Chapter 3, MIPv4 model developed for the simulation study is explained. In order to validate the correctness of the MIP model developed, both reproduced and contributed simulation results are presented in this chapter. Simulation study covers MIP – MIP-RO comparison, HMIP performance with UDP packet loss, duplicated packets and packet gap, TCP throughput and buffer handover rate, effect of Fast Handoffs on UDP packet gap and jitter, and TCP throughput in local traffic.

In Chapter 4, results are discussed with a conclusion. Also a discussion on possible related future work is presented.

CHAPTER II

LITERATURE SURVEY

2.1 INTRODUCTION

In this chapter, related work in the all-IP mobile network literature is surveyed with a particular focus on Mobile IP and its handoff management problem. In addition, a very brief overview of simulation tools for communication networks is presented in Section 2.5.

Today's wireless cellular networks, also known as second generation (2G) offer digital voice transmission together with data at low speeds. However, Internet applications have been moving towards multimedia rich content such as IP telephony and video conferencing. Fourth generation (4G) wireless networks will operate on broadband connections and will be based on packet switching. These networks require new protocols, without which applications designed for stationary hosts may not work [9].

Mobility protocols have been offered in different layers. Session Initiation Protocol [10], for example, is an application layer protocol which enables creating sessions for audio visual applications where one or more participants may communicate. This protocol requires applications to use its services, in other words, legacy applications based on TCP, UDP or IP will not work. Hence, in order to make legacy applications work on 4G networks, a network layer mobility protocol is needed.

2.2 MOBILE IP

Mobile IP was proposed by IETF as a mobility solution in the network layer [8]. It is transparent to the upper layers so that applications need not know whether they run on a stationary or a mobile host.

When a mobile host moves while connected to the Internet, it may need to change its point of attachment to the Internet, in other words, it must move from one network to another. This change requires changing the IP address of the network interface in it, since local networks have different IP address ranges assigned to them. Mobile IP, in simplest terms, hides these changes from upper layers.

In order to handle changing IP addresses, Mobile IP defines “home address” and “care-of address”. Home address is the permanent address of the mobile host. It must be assigned by the administration of its home network (service provider). Care-of address is a temporary address advertised by the foreign (visited) networks. Home address makes applications work as if they run across stationary hosts and makes mobile host reachable from anywhere, where care-of address is required for routing packets destined to mobile host when it is away from its home network [8].

When the mobile host is in its home network, i.e., attached to a Wireless IP Point of Attachment [9] (WIPPOA) of its own network, Mobile IP works exactly the same as IP. When a correspondent host sends packets destined to the mobile host, Internet routers forward them to the home network of the mobile host. When home agent receives the packets, it forwards them to Mobile Host, which is the same routing for stationary hosts as shown in Figure-1.

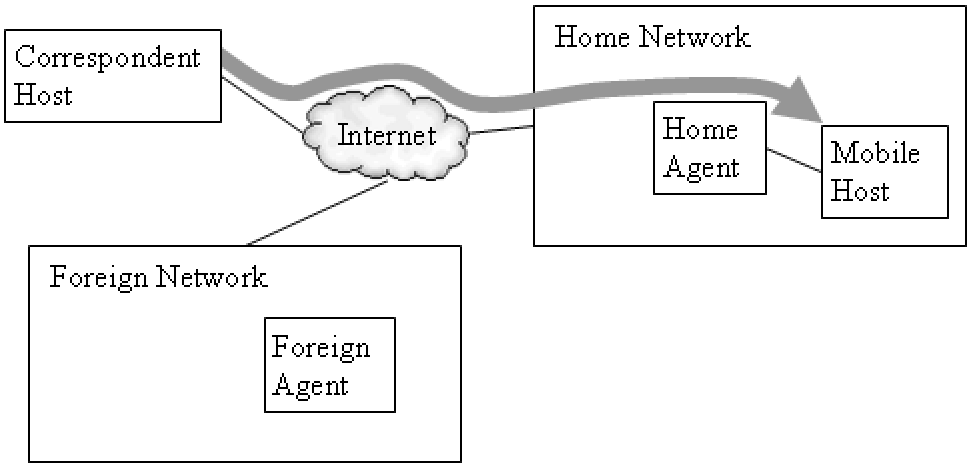

Figure-1 Mobile Host in its Home Network [8]

If Mobile Host leaves its home network, it is unreachable until it returns to its home network or makes a successful registration with its Home Agent. When Mobile Host receives agent advertisements from a foreign agent, it detects the foreign network and attempts registration with its Home Agent. Registration is a critical process in Mobile IP, since Home Agent is made aware of the care-of address of Mobile Host. When Home Agent receives a registration request, it creates a mobility binding consisting of three fields: Home Address, Care-of Address and lifetime of that binding. After creating the binding, Home Agent responds to the request with a registration reply. If the registration is successful, Mobile Host is reachable again from anywhere on the Internet. When a correspondent host sends packets to the Mobile Host, the packet is first routed to Mobile Host's home network. Home Agent encapsulates the packet into another datagram destined to care-of address of Mobile Host. The encapsulated packet is routed to the foreign network since its destination address is the care-of address, which has the network prefix of that network. When the Foreign Agent receives the encapsulated packet, it decapsulates the packet and forwards the inner datagram to the mobile host (Figure-2).

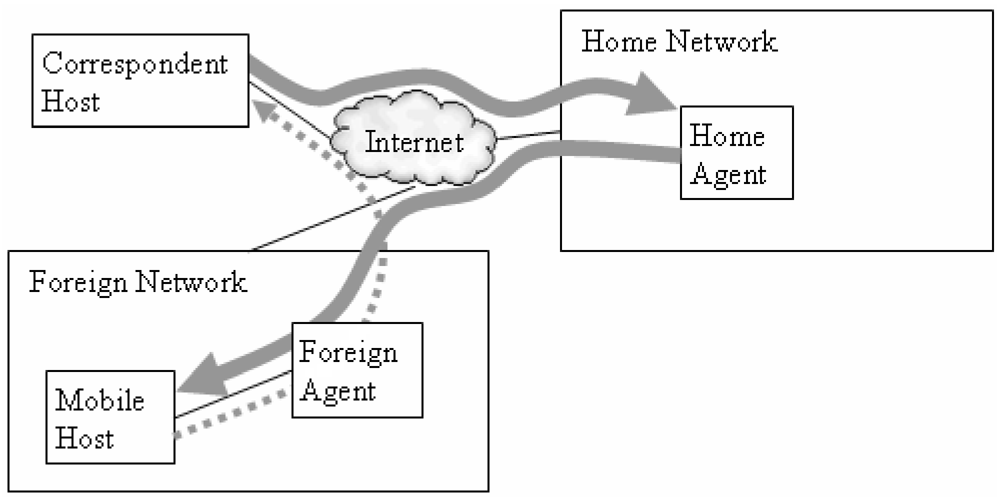

Figure-2 Mobile Host visiting a foreign network [8]

Some problems of Mobile IP have required optimizations for better performance. These problems include triangular routing, inefficient handling of frequent local handoffs and packet loss during handoffs [7]. The optimizations attempt to solve some or all of these problems. Among these attempts, one [7] is of particular interest. That work proposes the Hierarchical Foreign Agent architecture abbreviated as HMIP, which will be discussed in the next section. The authors also suggest buffering packets sent to Mobile Host in order to reduce packet loss during handoff. Throughout the rest of this document, the phrase Base Mobile IP will refer to Mobile IP without optimizations.

Triangular routing is the problem of Mobile Host sending and receiving datagrams in different paths [7]. In Figure 2, the Mobile Host receives packets through its Home Network; however, when it sends packets to the Correspondent Host, the packets are routed normally according to the dashed line in Figure 2. The routing is inefficient since every packet sent to Mobile Host must be forwarded to Home Agent first and hence experiences a much longer delay. The inefficiency is more significant when Mobile and Correspondent hosts are close to each other.

Mobile IP Route Optimization (MIP-RO) [12] attempts to solve this problem by making Correspondent Host aware of mobility. If Correspondent Host also supports mobility, when it sends a packet to Mobile Host, Home Agent sends the care-of address of Mobile Host so that succeeding packets can be routed directly to the foreign network instead of the home network. When Mobile Host changes its WIPPOA, Home Agent sends the care-of address again in order to maintain a working binding at Correspondent Host. Since route optimization requires adding mobility support to all the routers in the Internet, it is poor in terms of scalability.

2.3 HANDOFF MANAGEMENT IN MOBILE IP

Reinbold et. al. [9] list major mobility issues as handoff management, types of connectivity (support for paging), and handling intra-domain traffic. Among these issues, handoff management is of particular interest since handoffs are the major source of delay and packet loss [9]. When base stations cover smaller areas, mobile hosts experience frequent local handoffs. These handoffs require frequent registrations with home agents during which mobile hosts are unreachable, hence handoff management optimizations focus on handling local handoffs locally. Perkins and Wang [7] suggest a hierarchical structure in foreign networks. With its hierarchical structure, Hierarchical Mobile IP (HMIP) handles localized frequent handoff problem efficiently. Whenever the Mobile Host moves from one base station to another, the registration request is handled by the nearest Foreign Agent in the hierarchy as shown in Figure-3.

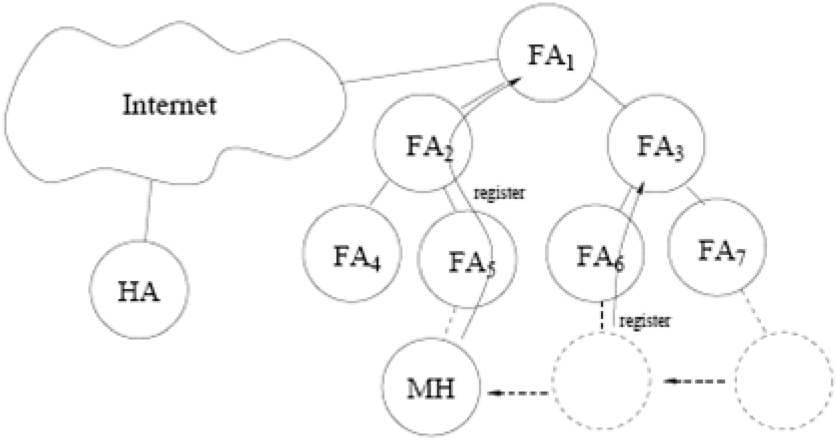

Figure-3 Registration in HMIP [7]

Perkins and Wang [7] also suggest buffering packets during handoffs, to eliminate or at least minimize packet loss.

Although Perkins and Wang's [7] proposal addresses several issues, some problems still require solution. These problems are the lack of support for real time applications and inefficient handling of intra-domain traffic [9]. These problems are effectively addressed at by the Fast Handoff scheme [12]. Since network layer handoff cannot begin before the link layer handoff is complete, handoff takes too much time for real time applications, even with HMIP. In some cases, network layer can be informed that a handoff is about to begin, allowing it to start its handoff earlier. Fast Handoff suggests using link layer (L2) triggers where available, to reduce handoff latency. L2 triggers significantly lower the handoff latency since the MH does not wait until the L2 handoff completes. The scheme has methods called Pre-Reg and Post-Reg. In Pre-Reg handoff, MH starts registration even before the L2 handoff completes, while it can still communicate with its old FA. Old FA then delivers registration request to the new FA. On the contrary, in Post-Reg registration is delayed until L2 handoff completes. Post-Reg makes use of tunneling between old FA and new FA, reducing the handoff delay to theoretical limits [19]. FMIP is also the only solution to the triangular routing problem inside a domain [9]. When a foreign agent receives a packet from a MH located somewhere below itself in the hierarchy, it checks whether destination is also below itself in the hierarchy with the help of its visitor list. The solution is illustrated in Figure-4.

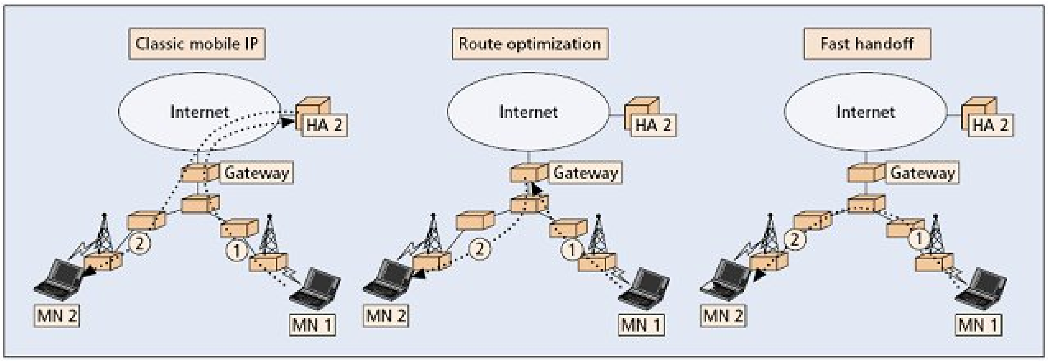

Figure-4 Intra-domain triangular routing and proposed solutions [9]

Performances of HMIP and Fast Handoffs are studied in [7] and [19], respectively. In [7], Perkins and Wang suggest HMIP and evaluate its performance with a comparison of Base MIP and ARP-Based Smooth Handoff [18]. Their results show that HMIP eliminates packet loss and duplicates, and reduces the delay. In another performance study [19], Gwon, Fu, and Jain suggest the Mobile Initiated Tunneling Handoff Protocol (MITH). MITH is similar to Fast Handoff Post-Reg [12] in the sense that in both schemes a bidirectional tunnel is established between old and new foreign agents. However, in FMIP handoffs can be mobile-initiated or network initiated, while in MITH handoffs are always mobile initiated [19]. Results presented in [19] show that performance of MITH is close to FMIP Post-Reg, both in terms of packet loss and handoff delay.

Although FMIP Pre-Reg and Post-Reg have their advantages, these advantages come with some costs. Post-Reg has higher complexity due to the fact that old FA must maintain its mobility binding and a bidirectional tunnel must be maintained at both old and new FA's, even after the L2 handoff is complete, until MH decides to attempt a new registration [19]. However, this high complexity pays back since MH is reachable at all times other than during L2 handoff. Although Pre-Reg has lower complexity, it cannot provide the same connectivity as during the registration MH is unreachable even if L2 handoff is complete.

Some other studies investigate TCP performance with MIP. Hsieh and Seneviratne compare end-to-end TCP performance under HMIPv6, Fast HMIPv6, Fast MIPv6, MIPv6 with simultaneous bindings, and seamless handoff (S-MIP) [21]. Simultaneous bindings scheme requires FA's to keep a MH's mobility during the handoff. Both old and new FA's forward packets to MH, resulting in duplicated packets. The S-MIP scheme [22]; however, network keeps track of MH's location and movement patterns and takes the handoff decision. MH then initiates the handoff. MH is assisted on when and how the handoff will take place. This way, packet losses during handoffs can be completely avoided. Thus, the authors conclude that S-MIP provides the best end-to-end TCP performance due to lossless handoffs.

Another TCP related study is conducted by Fu and Atiquzzaman [23]. They compare TCP-Reno, TCP-Selected Acknowledgements (TCP-SACK) [25] and Stream Control Transmission Protocol (SCTP) [26]. TCP-SACK is able to handle packet losses efficiently, especially in the case where multiple packets are lost in the same window, which is the typical scenario during a Mobile IP handoff [23]. SCTP is a transport layer protocol having some features to efficiently work over wireless links. Simulation results of the authors show that SCTP has the best performance since a large number of SACK blocks are allowed in SCTP. This study also shows the importance of multi-layer optimization approach.

Pack and Choi analytically investigate signaling and packet delivery costs of Fast Handoffs with a comparison to Base MIP (v6) [24]. The authors' results show the importance of finding an optimum value for the L2 trigger time is critical in handoff performance. This study is another example of multi-layer optimization approach.

2.4 SIMULATION OF COMMUNICATION NETWORKS

Simulation is a common method in analysis and design of communication network protocols, systems, topologies, and algorithms. Since it is quite difficult to make a mathematical model for a communication system, these systems are often modeled by discrete event simulation also known as discrete time simulation. In discrete event simulation, events occur at discrete time instants and handled by appropriate entities [1]. These entities model the behavior of a real world communication system.

There are many tools for simulation of communication networks. OPNET [15] is one of them. OPNET is considered to be the state-of-art in communication network simulation [1]. It has a wide range of available protocol models. It has built-in graphical editors. However, its price is quite high.

Another tool is the Network Simulator (NS) [14]. It is a free, open source simulator. It has a wide range of TCP/IP related protocol models. However, changing something in an NS model requires a thorough knowledge of the suite since classes make heavy use of each other's member functions [13].

OMNeT++ [1] [16] is another simulation tool. It is the one used in this study. It is a well document set of libraries and tools for discrete event simulation. It is released under Public Academic License [2], a software license similar to GNU General Public License [3] in the sense that it provides users access to source code. In contrast to NS, the preferred way of inter-module communication is sending messages in OMNeT++, which provides ease of change in models [13].

There are active projects in OMNeT++ domain including OMNeT++ itself. Simulation models are being developed in several separate projects. Among these project INET Framework, IPv6Suite, and Mobility Framework has significance since most of the networking protocols are modeled in these projects.

These frameworks are not designed for interoperability; hence, to be able to use these frameworks together, modifications in the code are inevitable, as in the case of our study. In this study, several modules from INET and Mobility Frameworks have been used, with modifications and additions to the original code. Current work in these projects includes merging all available models in a single model library.

CHAPTER III

SIMULATION STUDY

3.1 INTRODUCTION

In this chapter, details of the simulation study are presented. Mobile IP model developed is given in detail. Topologies and scenarios used in simulation are presented. Finally, results of the simulation study for simulated scenarios are given.

3.2 RESEARCH MOTIVATION

Mobile IP improvements and optimizations discussed in Chapter II require validation. Researchers choose one of the two ways. In some studies it is preferred to implement the improvements running on actual hardware, creating a testbed for the system under discussion, simulating scenarios like handoffs and link layer blackouts, in order to get the results of the effects of the suggested improvements often comparing with Base MIP and other MIP improvements. In some cases; however, creating a physical testbed can be impossible, due to costs of time and money. In this case, modeling and simulation are the preferred way.

This study is based on performance evaluation of MIP, MIP-RO, HMIP, and FMIP (also known as Fast Handoffs) with the help of discrete time simulation. Performance metrics measured are delays, UDP packet gap, buffer handover rate, registration delay and TCP throughput. Performance under intra-domain traffic is of particular interest since with increasing popularity of Vo-IP, it is not surprising that users in the same domain may often want to communicate with each other.

The tool used for the simulation is OMNeT++. The only disadvantage of using this simulator was the lack of out-of-box models to simulate scenarios under discussion. However, this was also a source of motivation, since a Mobile IPv4 model was to be written from scratch, which was itself a challenging project. Parts of the existing simulation frameworks for OMNeT++ were patched in order to make them work together.

In the comparisons with the results from the literature, exactly the same number of runs and samples as the referred works have been used but the achieved confidence levels have also been computed. All reported average simulation results fall with ± 9.53% interval with 90% confidence.

3.3 MOBILE IP PERFORMANCE STUDY

In this section, performances of Mobile IP and some improvements are studied. First, details of modeling and simulation are presented. Scenarios used in validation of developed models are given next. Detailed results of the simulation results are given last.

3.3.1 MOBILE IPV4 MODEL

The MIPv4 model developed for this study is simplified and not intended to be a general MIPv4 model. Although it can be used for any purpose if it fits, it may" need to be detailed to be used in scenarios different than ours. Our aim in developing this model is to have MIPv4 model enough to study effects of

MIPv4 and improvements suggested. Hence, a just-enough-modeling approach is followed throughout this study.

Mobile IPv4 model developed for this study consists of three main classes, and supporting modules around them. There are 4 core nodes: MobileHost, ForeignAgent, HomeAgent, and CorrespondetHostWithMobility-Cache. There are also standard IPv4 nodes without mobility support: Router and CorrespondentHost.

Overall structure of the MobileHost compound module is given in Figure-5, which is followed by explanations of modules contained.

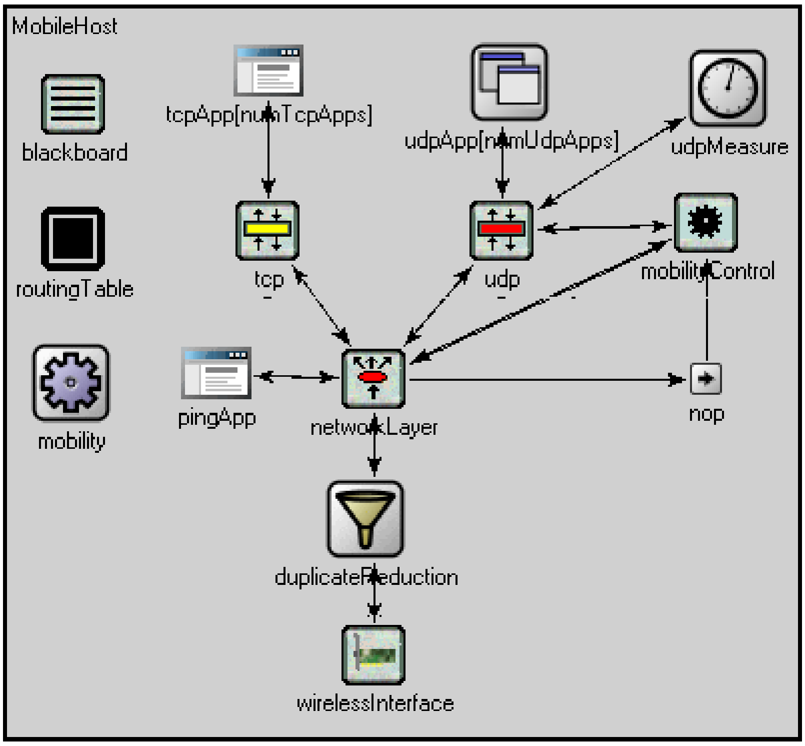

Figure-5 MobileHost compound module, its submodules and connections

In Figure-5, "blackboard" module is used for inter-module communication in a subscribe-publish manner. It is used both in INET and

Mobility Frameworks. “routingTable” module reads the routing table information together with network interface list from a text file and creates necessary lists for routing entries and network interfaces. “mobility” module manages position, speed and similar physical variables of mobile hosts and updates them according to the moving algorithm. “tcpApp”, “udpApp”, “tcp”, “udp”, “pingApp” are self explanatory. “udpMeasure” module measures and records UDP inter-packet gap and number of duplicate packets. “duplicateReduction” module records source address – identification pairs of incoming packets, also delivers these records to foreign agents on registration, as required by the method proposed in [7]. It could be embedded into the “mobilityControl” module, but specifically put here for simplicity of that module. “mobilityControl” module is specifically designed for and at the heart of this study, since most of the work is done in that module. It manages all Mobile IPv4 related issues including registration, agent solicitation; home network detection… etc. “wirelessInterface” module is a very simple L2 module, capable of wireless data transfer at specified bit rate. It has no noise or interference details, since our scenarios do not need such details, though it is capable of producing L2 triggers, detailed enough for our purposes of MIPv4 evaluation.

Nodes in this model share the same topology in the network layer. The structure of the shared network layer pattern together with “mobilityControl” module is given in Figure-6. “networkLayer” module in Figure-6 is the network layer found in INET Framework, with the exception that IGMP does not exist, since it is not needed. In the network layer there is IP and ICMP, where all the network layer functionality is provided. However, all the MIPv4 related functionality is separated from network layer. The reason for this design decision was that INET Framework is still under development. From time to time, it is updated. Modifying INET code would make it impossible to adopt changes in INET updates; hence, mobility related code is isolated into “mobilityControl” module.

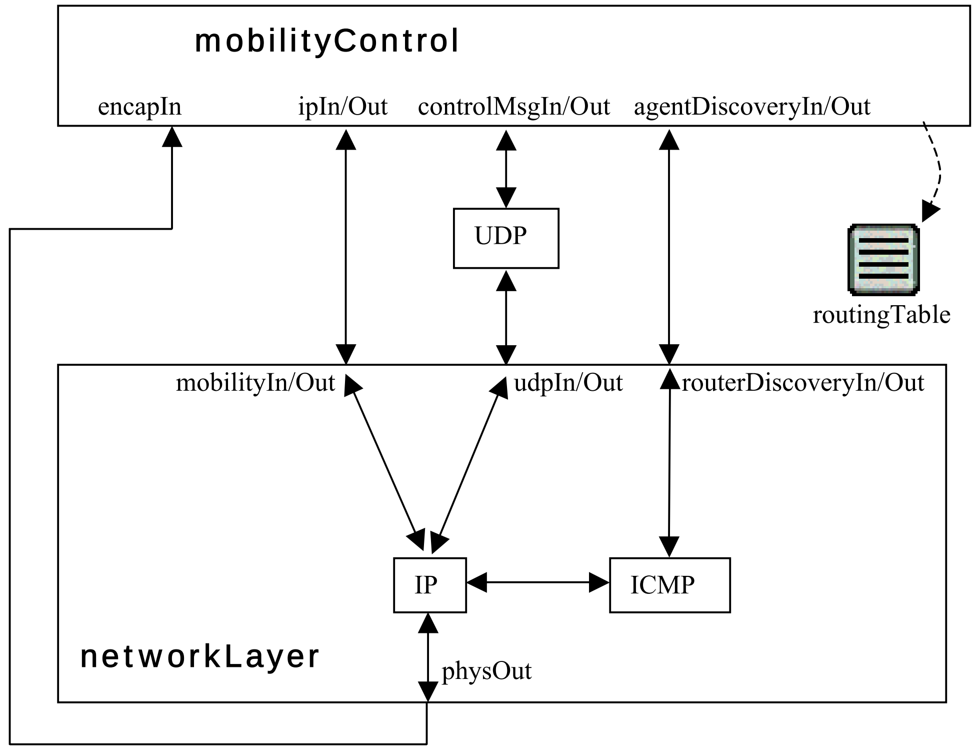

Figure-6 MobilityControl module in connection with NetworkLayer module of INET Framework (modified and simplified)

In this MIPv4 model, there is a "mobilityControl" in each node, where the type of that module is specific to the type of the node. MobileHost module has a mobilityControl of type MobilityMH, where HomeAgent module has MobilityHA, ForeignAgent module has MobilityFA, and CorrespondentHost has MobilityCH. Each of these types are C++ classes derived from cSimpleModule of OMNeT++. The class hierarchy is given in Figure-7. In Figure-7, it can be noted that all agents are derived from the same base class. Although a concurrent host is usually is not a mobility agent, MobilityCH class is also derived from MobilityAgent class since a binding cache is required in correspondent hosts supporting MIP-RO. This inheritance structure maximizes code re-use.

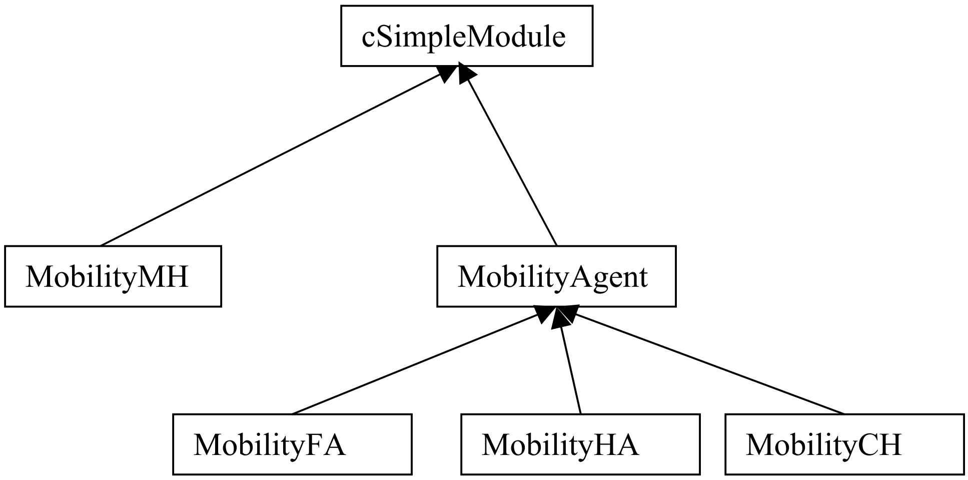

Figure-7 Class inheritance diagram for the developed MIPv4 model

Among these classes, MobilityMH has been implemented as a FSM. This is due to the fact that mobile nodes have distinct states of operation. State transition diagram of MobilityMH class is given in Figure-8. In INIT state, MH waits for agent advertisements to detect whether the network serving it is its home network or a foreign network. If it receives a home agent advertisement, it checks whether it is its own HA, if it is, it registers with its HA, allowing HA to delete all mobility bindings of the MH if it has. If MH receives a FA advertisement, it starts registration by sending a registration request. In this simplified model, registrations have infinite lifetime and they are always accepted. If MH does not receive an agent advertisement in 3 seconds, it starts sending periodic agent solicitations hoping that a mobility agent receives it. It leaves SOLICIT state as soon as it receives an advertisement.

Only MobilityMH class has been implemented with a FSM. Other mobilityControl classes are ordinary simple modules.

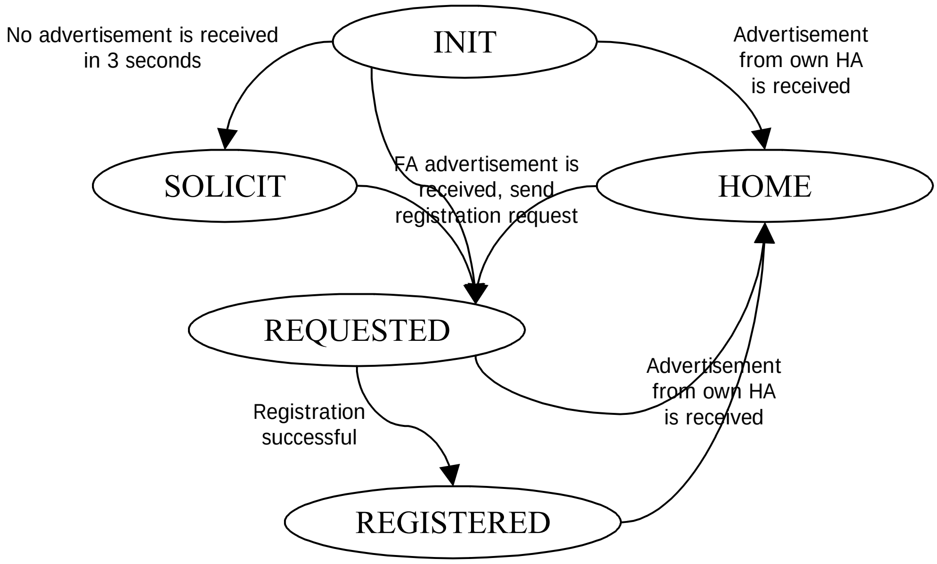

Figure-8 State transition diagram of FSM used in MobilityMH class.

Inter-module connections of other nodes in the simulation are similar to MobileHost module. ForeignAgent module, as seen in Figure-9, has “blackboard”, “routingTable”, “mobility”, and “networkLayer”, and “mobility-Control” modules. The type of the “mobilityControl” module is MobilityFA. Since ForeignAgent is a router, it does not need TCP, TCP applications, or UDP applications. However, it has PPP and Ethernet network interfaces as well as a wireless interface. The number of these interface are determined as needed, i.e., OMNeT++ creates enough of these interfaces while creating the network at the beginning of the simulation. ForeignAgent also has UDP, since, MIPv4 administrative messages are sent over UDP (port 434, by default).

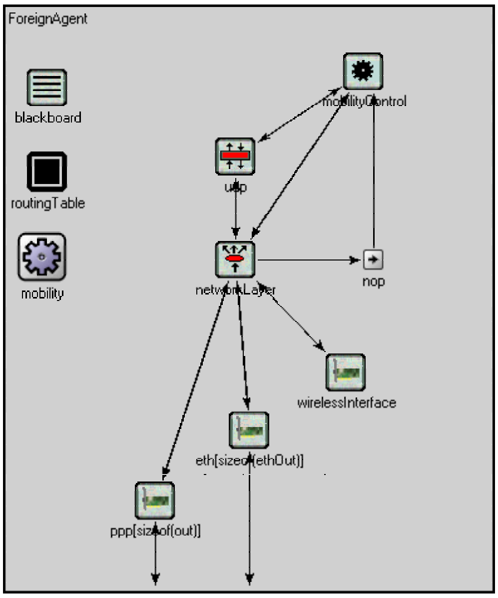

Figure-9 ForeignAgent compound module, its submodules and connections

HomeAgent module is almost the same as ForeignAgent with one difference, it has a "mobilityControl" of type MobilityHA. Seperating HA functionality from FA simplifies the code; however, a node cannot be both FA and HA in this model, which is allowed by Mobile IP specification. Although this is a limitation of this model, it conforms to our just-enough-modeling approach.

Every host in this model is based on the StandardHost node of INET framework, with modules added or removed. Among them, CorrespondentHost is actually a StandardHost.

3.3.2 BASE MOBILE IP – MOBILE IP ROUTE OPTIMIZATION COMPARISON

It is important to prove accuracy of the model developed before using it in original scenarios. For that purpose, a simple MIP vs MIP-RO comparison is used first. Chen and Trajkoviç [6] compare these two mobility schemes with time graphs, which we have used to test our model. The topology simulated in this test is given in Figure-10 and Figure-11. The scenario of this simulation is that the

CH sends packets to the MH. Details of some parameters are not provided by the authors, like delay characteristics of links and PN module, as well as the initial position and speed of the MH. The period of generation of these packets is not given, either, in [6]. These parameters are assigned proper values by guessing and iterative comparison of results reproduced with original results.

For this simulation, a linear mobility model has been developed. It has been used in mobileHost so that it maintained a linear motion throughout the simulation. This linear mobility model is derived from the base mobility class found in Mobility Framework.

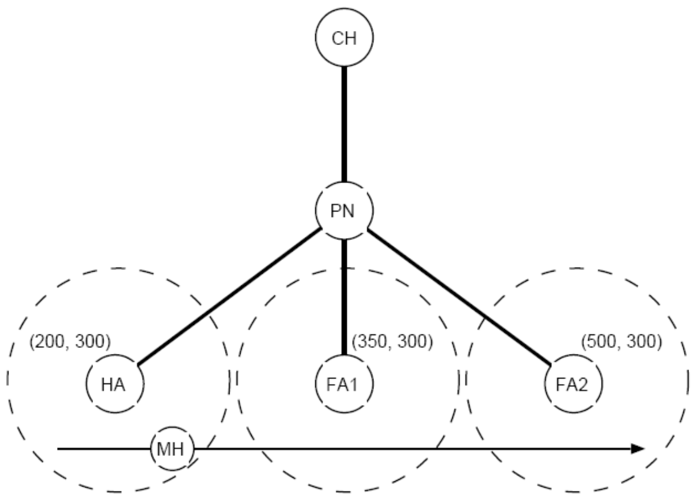

Figure-10 Topology simulated in [6]

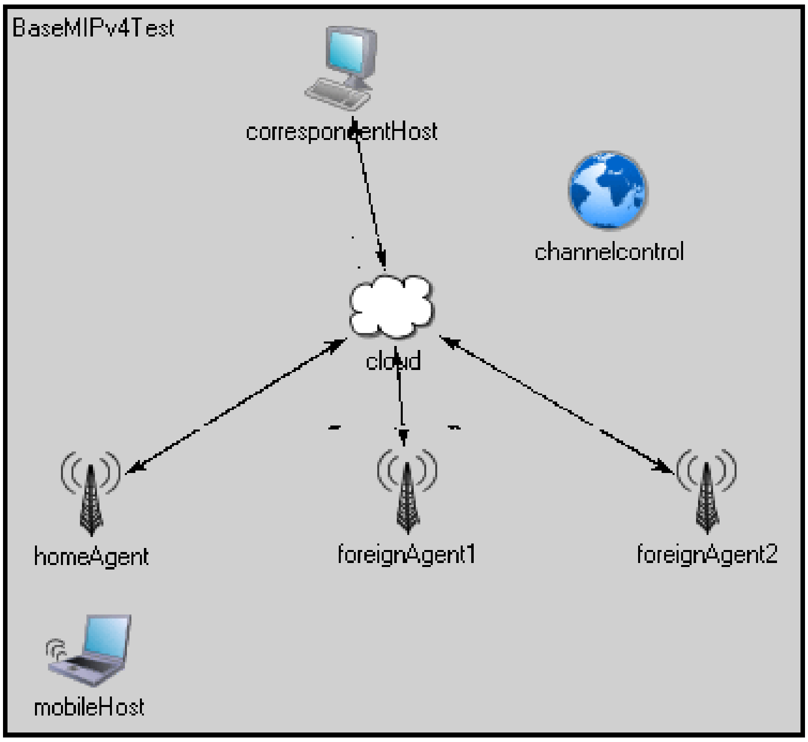

Figure-11 Topology simulated in [6] implemented with the MIPv4 model developed

Average delay values observed in this scenario are presented in Figure-12 and compared with the result of Chen & Trajkoviç. The results reproduced with the MIPv4 model developed start to overlap as soon as the average converges to 67ms. During the first 25 seconds of the simulated time, the original and reproduced statistics differ to unsettled statistics, i.e., insufficient number of samples.

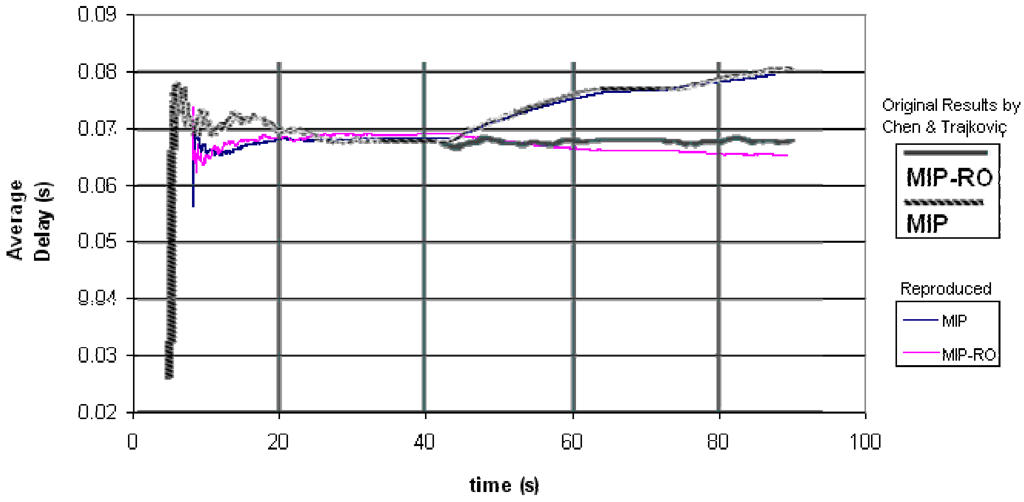

Figure-12 Average delays of Base MIP and MIP-RO, plotted on Figure-3 of [6]

In the end, this simulation has been a good warm-up exercise for our study, the real test of our model has been the reproduction of results in [7], as discussed in the next subsection.

3.3.3 PERFORMANCE OF MOBILE IP - HIERARCHICAL FOREIGN AGENTS

As for the previous one, this simulation also aims to prove the accuracy of the model. For this purpose, a more detailed simulation is taken as reference study [7] and the results are reproduced with the MIPv4 model developed.

The topology simulated in [7] and also in this simulation is given in Figure-13. It is a network with hierarchical foreign agents, with 2 levels of hierarchy below the gateway foreign agent. The foreign agents on the lowest level are base stations with wireless network interfaces, where MH can directly communicate. Each FA in the middle level has 4 child FA's. Similarly, the GFA has also 4 child FA's. Each base station FA is capable of receiving signals from an area of square shape. Movement of the MH is random inside a playground of 4x4 squares, as shown in Figure-14.

The authors used NS for the simulation.

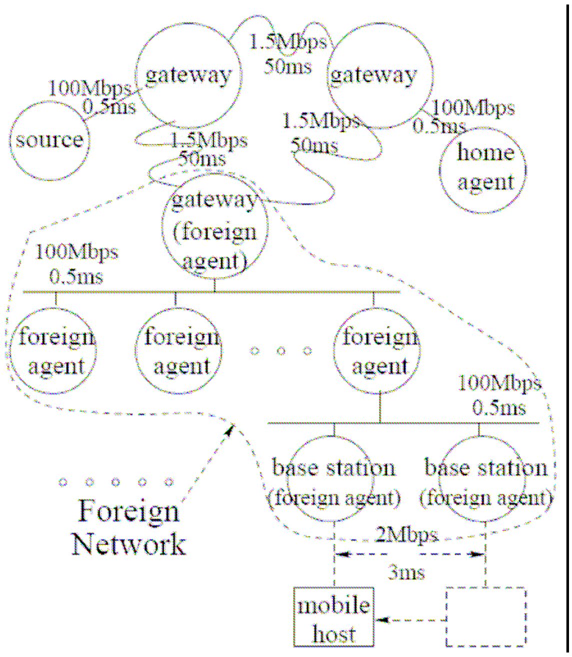

Figure-13 The topology simulated in [7]

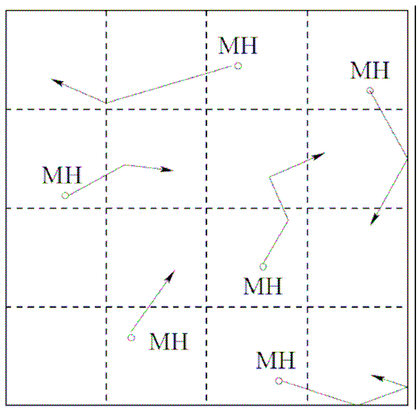

Figure-14 4x4-square playground where MH moves randomly. Each square is served by a base station FA. Each quadrant is served by a mid-level FA. The whole playground is served by the GFA. [7]

In this simulation, physical mobility model of the MH tries to mimic the motion of a mobile user with a mass; hence, it cannot abruptly change its direction of motion, stop or start [7]. According to this physical mobility model, mobile host chooses a speed and a direction at discrete time instants. The period of these instants are a normally distributed random number with an average of 5 seconds and a standard deviation of 0.1 seconds. The speed value chosen at these instants have a controlled average ranging from 0.1 to 0.45 units per second and a standard deviation of 0.01 units per second. The angle of motion is picked in such a way that its average equals to the previous angle and its standard deviation is 30 degrees. This moving scheme ensures that the MH does not turn with angle larger than 90 degrees, which is expected for a user with a non-zero mass. The MH bounces from the walls when it hits one as shown in Figure-14 [7].

The implementation of this topology is shown in Figure-15. Every square in the play ground is sized at 100x100 units, for better visibility. Consequently, MH speed is also scaled by 100.

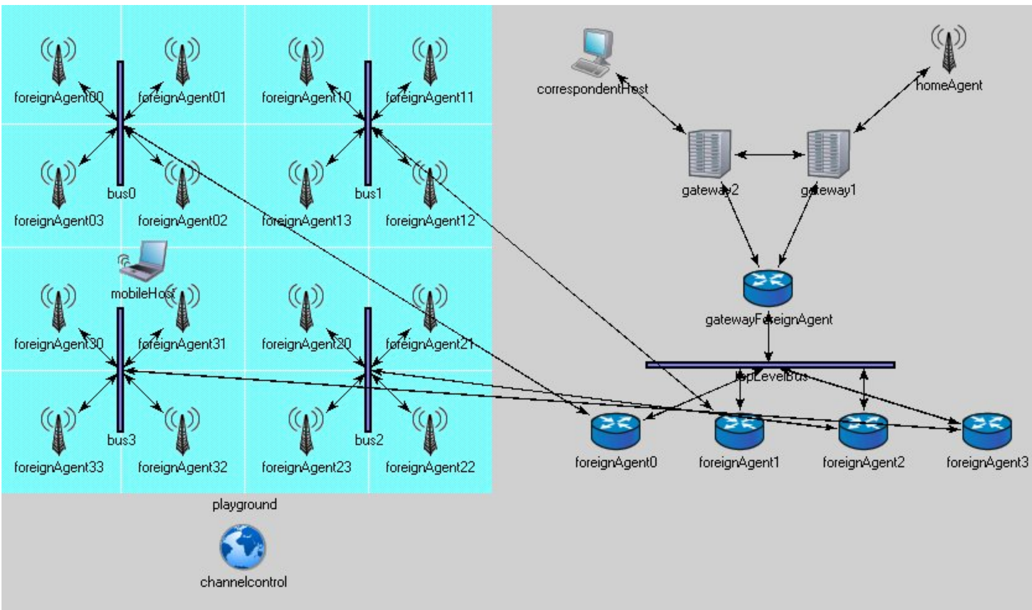

Figure-15 Topology simulated in this simulation

There are two scenarios in this simulation. In the first scenario, CH sends 200 files of length 1 MB over TCP, while in the second scenario it sends packets of length 200 bytes every 20 ms over UDP. In the UDP case, the simulation lasts until 200th handoff [7]. Results are given in the following subsections.

3.3.3.1 UDP PACKET LOSS

UDP packet loss during handoff is a critical performance criterion for real time applications such as VoIP; hence it should be minimized if cannot be avoided. Packet loss during handoff can be completely avoided only if packets are buffered at base stations and MH does not experience too long link layer blackouts. In our scenarios, MH does not experience link layer blackouts since the playground consists of square cells and MH does not make home registrations with the help of regional registrations; hence, base station buffering suffices to eliminate packet losses. However, when base stations do not buffer, packets can be lost during handoffs. In Figure-7 of [7] the average number of lost packets during handoffs is shown around 3.5. The developed MIPv4 model produces the same result when base station buffer size is zero. This is expected since beacon period for base stations is set to 100 ms and CH sends packets every 20 ms. If the MH misses the latest beacon during handoff, it has to wait about 100ms, which costs 5 packets. It has to wait a little more for registration to be able to receive packets. So, in the worst case, MH misses 5 or 6 packets, which make ~3.5 packets in the average. This average is calculated after the average of each simulation (run for different MH speeds) was taken when simulation ends, and then those averages were averaged.

As for the buffered case, the results show that average number of lost packets is actually very close to zero. However, in some rare cases packet losses occur despite the buffering mechanism. This is due to the fact that HMIP scheme proposed in [7] starts buffering as soon as the registration completes. However, MH sometimes moves from one FA to another even before the registration completes. This rare case occurs more often as the MH speed increases. The effect of this situation is more visible in Subsection 3.3.3.6 where effect of MH speed on TCP performance is presented.

3.3.3.2 UDP DUPLICATED PACKETS

Modern implementations of TCP treat duplicated packets as indications of packet loss and start congestion avoidance mechanisms. Consequently, duplicated packets result in unnecessary TCP back-offs, reducing the throughput [7]. The characteristics of a networking regarding duplicated packets can be easily verified under a UDP scenario. Each packet can be assigned a unique id and can be counted on the receiving end. If a network can generate duplicate packets in a UDP scenario, it definitely can do the same in a TCP scenario, since this behavior is independent of the transport layer protocol used. Handoff scheme offered in [7] successfully eliminates duplicates, as can be seen in Figure-7 of [7]. Our developed MIPv4 model produces the same result.

3.3.3.3 UDP PACKET GAP

The largest gap between two consecutive UDP packets is important for real-time applications since wider gap means larger player buffers, and larger player buffer results in longer delays in audio/video. Results reproduced with the developed MIPv4 model closely follow the results in [7], with a difference of 2 to 5 ms (Figure-16).

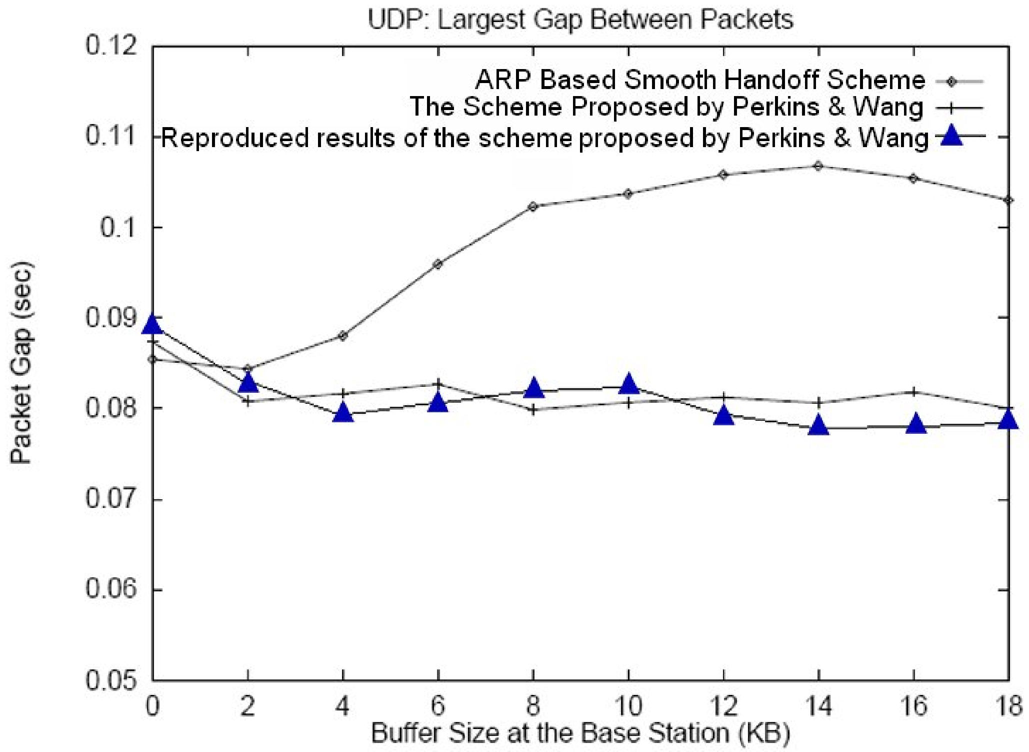

Figure-16 UDP gap vs. buffer size comparison in [7] with reproduced results

3.3.3.4 TCP THROUGHPUT

TCP throughput is very sensitive to packet loss and duplicated packets, where base MIP has a very poor performance. Hence, it is a good indication of improvement for suggested extensions of MIP. Average TCP throughput is given in Figure-17.

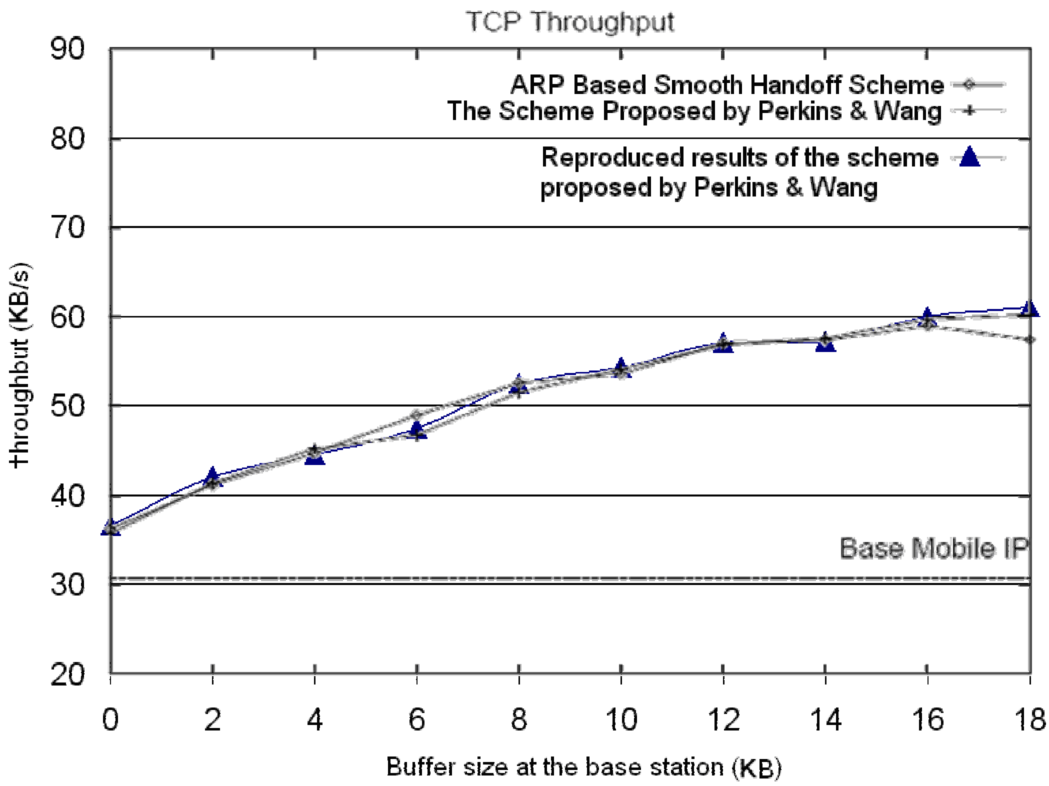

Figure-17 TCP throughput vs. buffer size comparison in [7] with reproduced results

The results consist of 4 curves. ARP Based Smooth Handoff is a scheme offered by C´aceres and Padmanabhan [18]. It is the scheme used by Perkins and Wang for a comparison with their proposed scheme. The curve of this scheme and the reproduced results with the MIPv4 model develop coincide as expected. As can be seen from Figure-17, ARP Based Smooth Handoff Scheme performs as well as the scheme offered in [7], up to the buffer size of 16 KB. As buffer sizes at the base stations increase, duplicated packets result in unnecessary back-offs at CH [7], which is avoided in the scheme offered in [7] by duplicate elimination. The curve at the bottom is the Base MIP, which has the worst TCP performance due to excessive losses during handoffs.

3.3.3.5 BUFFER HANDOVER RATE

Buffer handover rate is defined as the average number of bytes all FA's deliver to the new FA of MH each second. It is a measure of consumed network resources during handoffs [7]. The developed MIPv4 model produces the same results in buffer handover in a TCP scenario (Figure-18).

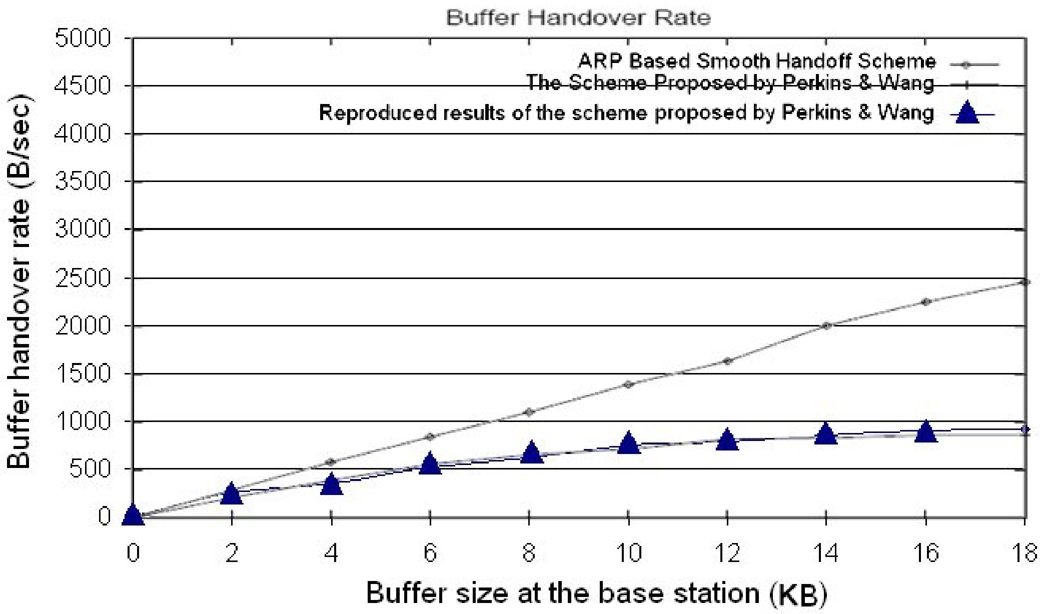

Figure-18 Buffer handover rate vs. buffer size in the TCP scenario [7] with reproduced results

3.3.3.6 EFFECT OF MH SPEED TO TCP PERFORMANCE

Increasing MH speed decreases TCP performance due to more frequent handoffs; hence, it is a good criterion for a handoff scheme to handle increasing frequency of handoffs. The developed MIPv4 model produces similar results as shown in Figure-19 and Figure-20.

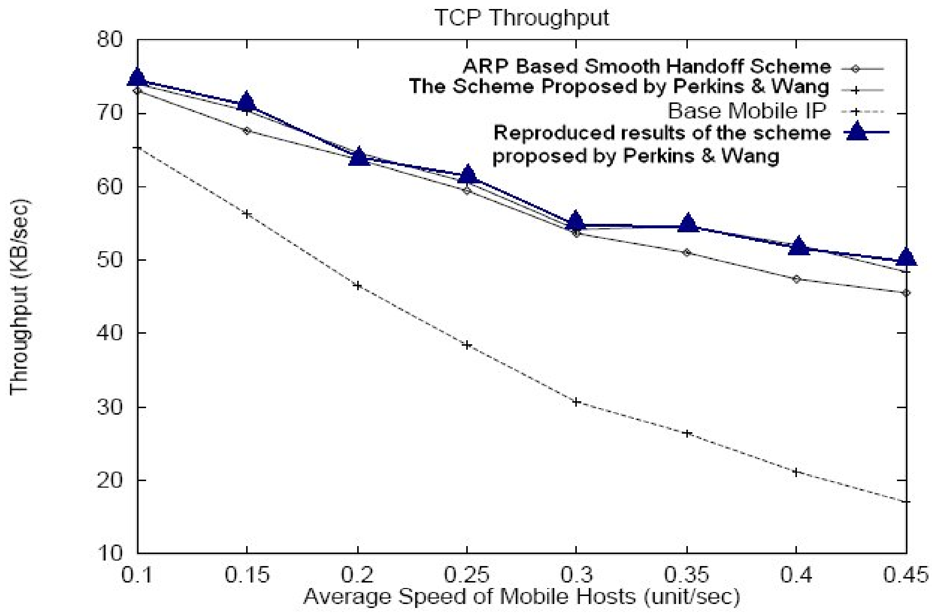

Figure-19 TCP throughput vs. MH speed comparison in [7] with reproduced results (buffer size = 10KB)

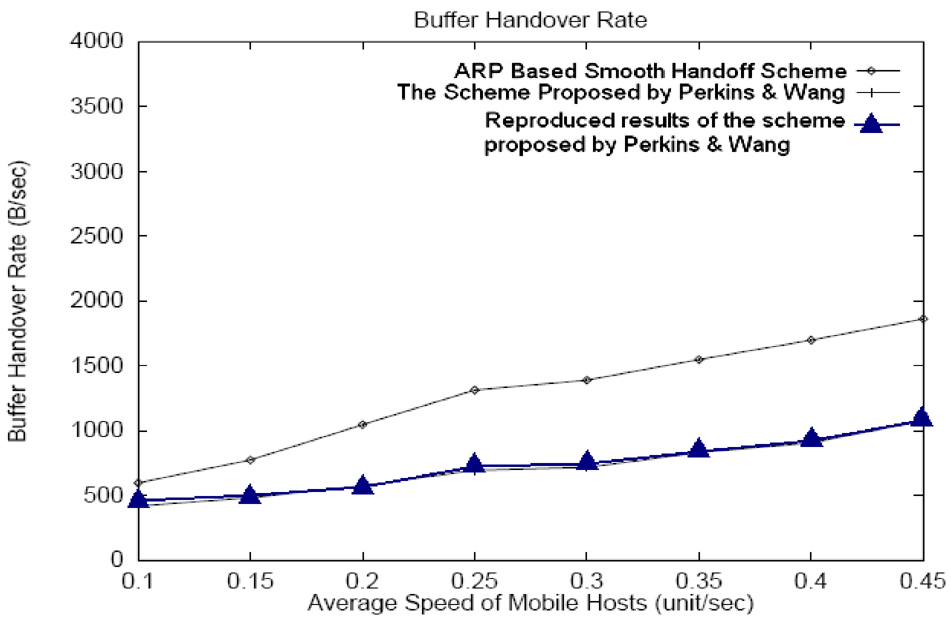

Figure-20 Buffer handover rate vs. MH speed comparison in [7] with reproduced results (buffer size = 10KB)

3.3.4 FAST HANDOFFS

The MIPv4 model developed has proven its accuracy with the reproduced results in subsections 3.3.2 to 3.3.3.6. However, these results do not consider Fast Handoffs (FMIP) (See 2.3). Following subsections compare FMIP performance to the HMIP scheme offered in [7]. In order to simulate FMIP performance, MH is made able to communicate with neighbor FA's and also to detect handoffs and send L2 triggers. In this simulation, handoff is mobile-initiated [12].

3.3.4.1 UDP PACKET GAP

UDP packet gap can be reduced by L2 triggers as results presented in Figure-21 suggest.

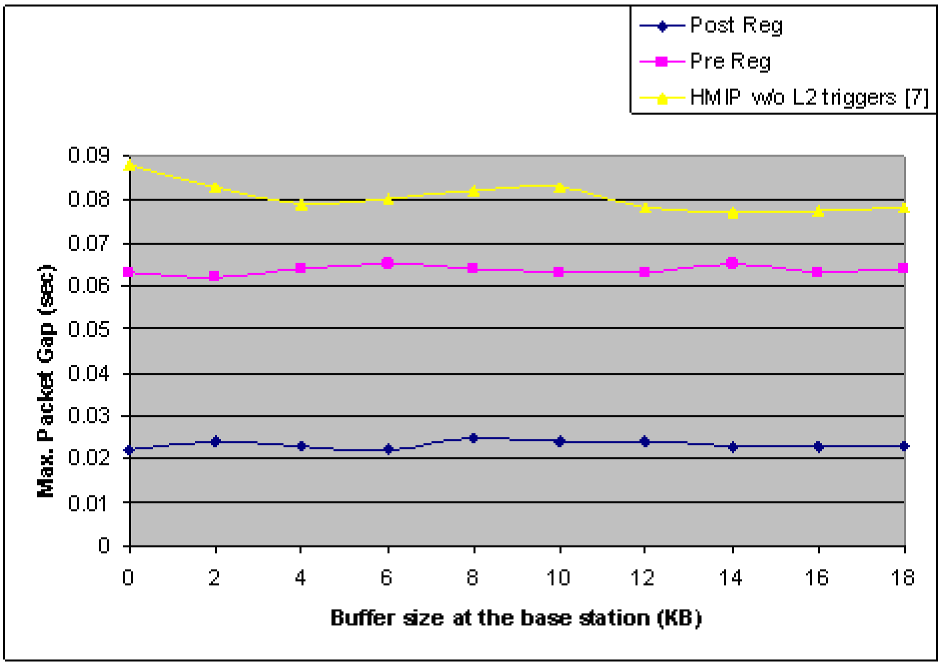

Figure-21 Pre-Reg & Post-Reg packet gap comparison of FMIP

The results show that Post-Reg has better handoff performance, as expected, since it supports tunneling from old FA to new FA during handoff. They both have better performances than HMIP without L2 triggers, in which the gap was around 80ms, since pro-active handoff detection is significantly faster than reactive detection. The results also show that buffer size has little or no effect on UDP packet gap, since duplicates are eliminated. Duplicate elimination allows packet not yet received by the MH to be delivered as soon as the handoff completes.

3.3.4.2 AVERAGE REGISTRATION TIME

Average registration time is an important requirement as it is an indication of signaling overhead. It is also an indication for the duration where MH is unreachable although L2 handoff is complete (except for the FMIP Post-Reg case, in which MH is almost always reachable as soon as L2 is complete). The results are shown in Figure-22.

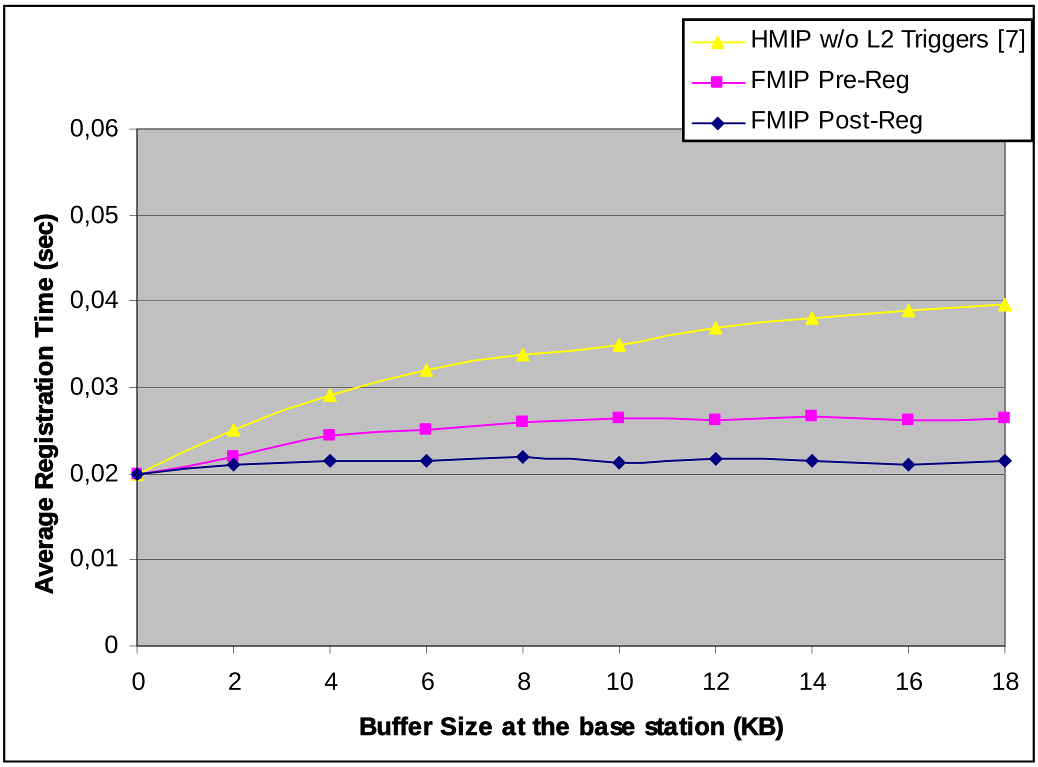

Figure-22 Average registration time vs. buffer size

Results show that Post-Reg bounds the delay that can be experienced during registration. This is accomplished by the tunneling mechanism from old FA to new FA. The tunneling mechanism of Post-Reg almost eliminates the need for delivering buffered packets, hence, lowers the handoff delay. Similarly, FMIP Pre-Reg is less dependent on the buffering mechanism then HMIP w/o L2 triggers; hence, registration requires fewer buffered packets to be delivered to MH, lowering registration delay. On the contrary, HMIP scheme without L2 triggers only relies on buffering to eliminate or at least reduce packet loss. Since delivering buffered packets takes some time, registration time increases with buffer size.

3.3.4.3 INTRA-DOMAIN TRAFFIC

Intra-domain traffic is particularly important when users of a network have frequent conversations, file transfers... etc among each other. For this purpose, the simulation has been repeated for the scenario that two MH's communicate with each other moving inside the same foreign network. The results showing TCP performances are shown in Figure-23. In this figure, TCP goodput indicates the net goodput delivery at the receiver, after re-transmissions due to packet loss are accounted for.

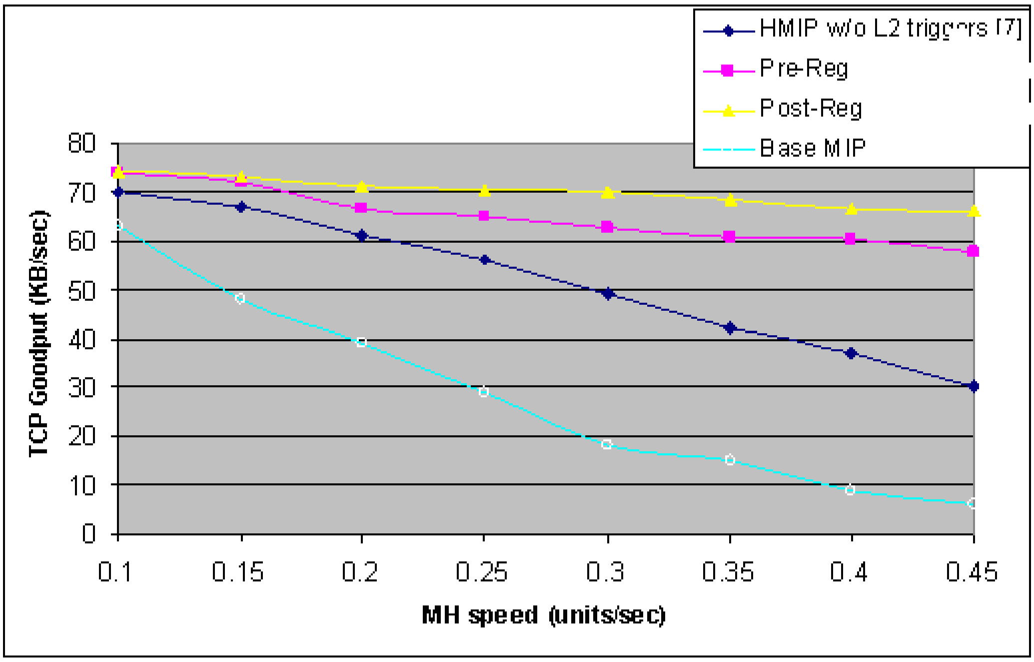

Figure-23 TCP goodput vs. MH speed

It is seen that Post-Reg has the best performance of all, as expected. Pre-Reg comes next and HMIP without L2 triggers is the worst among the three. Naturally, Base MIP does not achieve competitive performance in this context.

CHAPTER IV

CONCLUSION

In this thesis, MIP and offered improvements in the literature have been investigated with simulation results. In order to carry out a simulation study, a MIP model has been developed and tested under some scenarios found in literature. Having validated the MIPv4 model, performances of improvements have been analyzed.

The MIP model developed has been based on INET models by adding physical mobility and access technology support of Mobility Framework into INET models, and then adding network layer support. Although having Mobility and INET Frameworks at hand was helpful, it was not trivial to have working physically-mobile models. Since these two frameworks are seperate projects, they are designed to work in the same simulation. Mobility Framework mainly targets ad-hoc networks while INET Framework models TCP/IP as well as Ethernet and related protocols in this stack. Moreover, in the beginning of the study, INET did not exist. Instead, there was a framework called IPSuite, which had a complicated IPv4 model. Although INET was born with a previously (and seperately developed) Ethernet model, it was not functioning in INET models. An Ethernet network interface has been contributed to the framework by patching the nonfunctional one in it. Adopting Mobility Framework into INET was another important step in our model, since it uses module id's instead of IP addresses. Finally, adding mobility support into the network layer was the final step in our modeling work.

The model has been validated under two scenarios: In subsections 3.3.2 and 3.3.3. Obtaining similar results with the ones found in literature was an important goal to have a reliable MIPv4 model. First a MIP – MIP-RO comparison is attempted and similar results were found comparing to [6]. Then the scenario in [7] has been simulated obtaining very close results with HMIP in UDP packet loss, duplicated packets, packet gap, TCP throughput and buffer handover rate. Effect of MH speed to TCP performance has also been included.

After validation of our MIP model, we investigated the effect of FMIP to UDP packet gap and jitter, which shows that Post-Reg scheme has the best handoff performance among all, Pre-Reg comes next. They both posses a better performance when compared to HMIP. Moreover, TCP performance under intra-domain traffic has also been investigated, since high TCP performance is an important indication of good handoff performance as it is very sensitive to packet loss and duplicates.

Exactly the same number of samples were taken in calculating averages. The confidence interval has been computed for each average and the worst value among them has been given in Section 3.2 (9.53%).

The simulation study tries to compare MIP improvements under frequent local handoffs. Intra-domain traffic was also an interesting scenario in this evaluation. The results show that FMIP Pre-Reg is less dependent to buffering on packet loss prevention then HMIP scheme proposed in [7] is, FMIP Post-Reg is even better. Hence, base station buffer size has little or no effect on UDP gap or registration delay. Results suggest that Post-Reg is a good candidate for the handoff management scheme of the future network layer mobility support protocols.

Although useful results have been obtained at the end, this study can be extended in some ways. Access technology used in this study, for example, is a simple hypothetical network interface card, without noise or interference modeling. The effect of L2 handoff latency on handoff performance could be investigated, since long L2 latency values may result in need for delivering buffered packets to MH, or in the worst case packet loss if buffer size is small. The relation between L2 handoff latency (or L2 blackout duration) and associated minimum buffer size could be a useful extension to this study. In addition to that, a model of an off-the-shelf access technology would be helpful, like 802.11b/g. In addition, case of network initiated FMIP can be simulated and compared with the mobile initiated one presented in this study. Effect of link layer blackouts on performance can be another way of extending this study. Moreover, case of several MH's inside a domain and also several MH's visiting several domains can be simulated.

TCP has several implementations. Some of them are optimized for wireless networks, by not immediately reacting to packet loss and duplicates as a sign of congestion. These TCP implementations can be modeled and added to the simulation. Moreover, combining several TCP implementations and different access technology models, a study for seeking an optimum MIP platform with today's available technology can be carried out as future study, as a guide to portable computer designers and Internet service providers. This study can also be extended to include other mobility related protocols such as MIPv6 and SIP.

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