ANALYSIS AND PERFORMANCE ENHANCEMENTS IN POWER LINE, WIRELESS AND MOBILE NETWORKS

By

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To my parents and my wife Hyuna Kim

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ANALYSIS AND PERFORMANCE ENHANCEMENTS IN POWER LINE, WIRELESS AND MOBILE NETWORKS

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This dissertation focuses on the study of the performance of Powerline Communication (PLC), wireless and mobile networks in conveying multimedia traffic such as Internet Protocol Television (IPTV).

We provide a comprehensive protocol performance comparison for wireless and PLC in-home networks. Our result shows that the throughput of Homeplug AV is at least 18Mbps higher than that of IEEE 802.11 (g and n) because of improved design and the quasi-stationary channel characteristics of PLC. We also show that Homeplug AV outperforms other competing PLC technologies by as much as 17.5% for TCP and 77.7% for UDP at 77% of connections and in addition achieves 100% full home coverage in our performance evaluation.

We also developed and used in this work a network protocol visualization tool, "*Visugator*" for performance evaluation of network protocols. This tool has been made freely available for public use.

For distributing multimedia traffic in mobile networks a mobility management protocol is an essential element of mobile computing including mobile IPTV. We developed a Fast Movement Detection and DAD (Duplicate Address Detection) (FMDD)

scheme for Mobile IPv6 protocol, as well as two improved network-based Proxy Mobile IPv6 protocols over wireless local area network that reduce handover latency and signaling overhead. In the Mobile IPv6 with FMDD scheme, the neighbor cache is used for DAD to reduce the handover latency. To reduce the handover latency and packet loss of Proxy Mobile IPv6, simultaneous L2 & L3 handover procedures and a tunnelling scheme are used. With the help of an Inter Access Point Protocol (IAPP) we decrease the signaling overhead of Proxy Mobile IPv6 significantly. A mathematical analysis is provided to show the benefits of our proposed schemes. Based on our analytical results, the FMDD scheme with Mobile IPv6 can reduce the DAD latency by lookup delay in RAM from the 1 second to just several microseconds. Our proposed Proxy mobile IPv6 protocols also can reduce up to 12.7% of the handover latency, 29.56% of packet loss and 31.6% of signaling overhead compared with the conventional Proxy Mobile IPv6.

The dissertation also presents a MAC scheduling scheme of Bluetooth to improve MAC efficiency.

CHAPTER 1
INTRODUCTION

Until now several technologies for Local Area Network (LAN) have been developed and utilized for many applications. Recently the demand for high speed LAN technologies has increased greatly to support the deployment of high definition video streaming as HDTV has become more wide spread. Wireless LAN technology is gaining attention to provide high speed service at hotspots in public areas like an airport and train station as a part of mobile cellular networks or independent systems using LAN technologies designed for indoor applications.

Home Network

Many LAN technologies have been competing for preeminence as the multimedia home networking technology of choice. HDTV is usually encoded in about 25Mbps, and so to stream one or more HDTV signal requires networks with sustained data rates of more than 30Mbps at the application layer.

While traditional Ethernet networks with appropriate QoS enabled switches may be one desirable choice for this purpose as it is a mature technology that supports very high bit rates, this may not be viable solution for deployment in existing buildings due to the inconvenience in laying the Ethernet cables around the house with the associated drilling through dry walls or even concrete walls. Thus wireless and the so-called ‘no new wires’ solutions become the top contenders for retrofitting a home network in existing buildings

For some time there has been strong interest in the 802.11x wireless LAN technologies as key candidates for home networking as these wireless technologies provide the ultimate convenience and mobility to users. The widely used 802.11b [1] is now considered to be less desirable for streaming HDTV because of its low data rate. However, the IEEE 802.11g [2] provides raw data rates up to 54Mbps which may provide enough application level bandwidth to support streaming HDTV. The IEEE Draft 802.11n standard [3] has also been proposed for higher throughput and QoS enhancements. It is expected to provide raw data rates up to 600Mbps and interoperability with IEEE 802.11a/b/g.

Bluetooth [4] is a wireless technology that allows communication devices and accessories to interconnect using a short-range, low-power, inexpensive radio. While initially developed to eliminate the numerous short-range cables involved in interconnecting mobile devices (laptops, mobile phones, headsets, PDAs, etc) in small networks, usually referred to as PANs (Personal Area Networks), Bluetooth has expanded in scope to encroach on wireless LANs.

In the class of ‘no new wires’ networks, Power Line Communication (PLC), MoCA [5] and HomePNA [6] re-use existing wires for communication and claim multimedia in home streaming capabilities for one or more channels of HDTV. MoCA uses coaxial TV cable for communication and provides raw data rate as high as 270Mbps, however the lack of available access points limits its applications. The HomePNA has similar drawback as the number of telephone jacks in a home are limited and are usually in a very inconvenient locations for installing HDTV players or recorders or the similar devices.

Power Line Communication (PLC) uses the existing in home power circuit to deliver digital data and is considered to be a potentially desirable candidate for home networks as there are plenty of outlets in a home and they are in convenient locations.

In PLC, there are several competing groups – The Home Plug Power Line Alliance and The Universal Power line Association (UPA) as well as Consumer Electronics Power line Communication Alliance (CEPCA).

The Home plug AV [7] standard is the most recent enhancement of the 14 Mbps HomePlug 1.0 standard released by the Home Plug Power line alliance and it provides 200Mbps raw data rate explicitly targeted to support distributing data and high quality, multistream videos like HDTV and SDTV. UPA [8] proposed the Digital Home Specification (DHS) with the chip-sets designed by DS2, Spain. It provides 200 Mbps data rate for AV streaming while the HD-PLC (High Definition power line communication) [9] by Panasonic, is able to support raw data rate up to 190 Mbps.

Mobility Management Protocol

Currently wireless local area network (WLAN) is widely spread as infrastructures for high speed wireless service not only in small indoor area but also in hot spots of public area.

The series of IEEE 802.11 standard are most widely deployed WLAN technology now days. The popularity of WLAN lies on its low cost and high data rate. The IEEE 802.11 b/g [1,2] uses license-free 2.4 GHz Industrial Scientific and Medical (ISM) ratio band. The IEEE 802.11g/a [2, 10] can support data rate up to 54Mbps. Since the IEEE 802.11 standard provides link layer roaming a mobile user (MN) can move to another AP without disruption of current connection within the same network. However WLAN technology cannot support seamless communication when a mobile user moves to another network which has a unique network address.

To provide IP level mobility the Mobile Internet Protocol [11] called MIPv4/v6 was proposed by the Mobile IP working group in the Internet Engineering Task Force (IETF).

Though MIPv6 has been developed it cannot fulfill the QoS requirement of real-time application because of handover latency. In order to reduce the handover latency Fast handover for Mobile IPv6 (FMIPv6) [12] has been also proposed by IEFT. In FMIPv6 a mobile user obtains the new CoA before actual handover. This scheme can reduce delay of Duplicate Address Detection (DAD) which consumes almost handover latency in the MIPv6. Also Hierarchical Mobile IPv6 (HMIPv6) [13] has been proposed to improve performance of MIPv6. This protocol minimizes the signaling cost and latency of location update of MN by adopting a local anchor point called Mobility Anchor Point (MAP). HMIPv6 is more efficient when MNs are frequently changes their point of attachment to the network. While several improved MIP schemes have been proposed until now MIP v6 has not spread widely in practice. MIPv6 and its enhanced schemes called host based mobility management protocol require to modify protocol stack of MN for supporting them. This modification causes incensement of complexity and power consumption of MN.

Recently a network based mobility management protocol named Proxy Mobile IPv6 (PMIPv6) [14] has been proposed by IETF NetLMM (Network-based Localized Mobility Management) working group. In PMIPv6 the serving network performs signaling of IP mobility management on behalf of MN. Therefore no modification of protocol stack in MN is necessary. In the PMIPv6 domain MN recognizes that it is always in home network. Though PMIPv6 is superior it also suffers from packet loss and handover latency.

CHAPTER 2
COMPARATIVE PERFORMANCE ANALYSIS OF LOCAL AREA NETWORK TECHNOLOGIES FOR MULTIMEDIA STREAMING IN HOME

Introduction

A major driving force for the development of advanced high speed in local area networks especially for home is the need to support the ongoing deployment of high definition digital television at rates of about 25 Mbps. HDTV signals may originate at one point in the home from a media center player or via satellite or cable TV. It will then be the necessary to transport the HDTV signal throughout the home for playing the video and audio at multiple locations or for remote recording. Streaming HDTV places very stringent Quality of Service (QoS) requirements on the underlying home networking technology in terms of delays, jitter and packet loss probabilities.

This chapter presents a study of effective technologies for high speed LAN and high definition (HD) video streaming applications in a home or small office environment, without the need for installing new wires. HD videos usually are encoded at a data rate of about 25Mbps and modern LANs offer throughput of 10 – 100Mbps. Thus a practical home networking infrastructure should provide 30Mbps or more at the application layer. Powerline communication (PLC) and wireless networking are among the most desirable choices of building a home network because of easy installation, with no new wires needed.

The main contribution of this chapter is to analyse and conduct a real world performance assessment of the above recent wireless and PLC network technology for home and small office environments.

Overview of Wireless LAN and Powerline communication

This section gives a brief overview of wireless and power line communication technologies considered in the rest of the paper.

IEEE 802.11x Wireless LAN

There are two accessing methods in IEEE 802.11x technology [1,2], one is DCF (Distributed Coordination Function) and the other is PCF (Point Coordination Function). The infrastructure network works with DCF and PCF while ad hoc network uses DCF. The principal approach of DCF is Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The basic DCF Access scheme is shown in Figure 2-1.

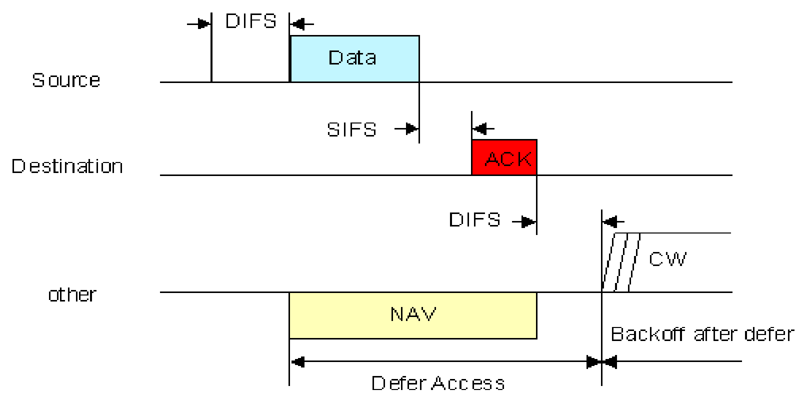


Figure 2-1. DCF access scheme

To avoid collision, physical carrier sense and virtual carrier sense are used and the physical layer uses these techniques to sense whether the medium is busy or idle. Whenever a machine decides to send a frame, a duration is specified in the duration field of the frame to indicate the ending time of the transmission. Other machines that receive the message update their local NAV (Network Allocation Vector) thus avoiding the possible collision resulting from more than one node sending frames at the same time.

The IEEE 802.11g [2] is operated at 2.4GHz band using Orthogonal Frequency Division Multiplexing (OFDM). The use of the same frequency band makes 802.11g interoperability with IEEE 802.11b while providing a compatible data rate with IEEE 802.11a which uses 5 GHz band. The default minimum contention window size in IEEE 802.11b[1] is 31 slots and the slot time is 20µs. IEEE802.11g for compatibility, uses the same parameters. However, when no IEEE 802.11b stations are present in the network, IEEE 802.11g will use 15 slots as the minimum window size and 9 µs for slot time to provide lower protocol overhead and higher throughput.

The IEEE802.11n [3] uses OFDM-MIMO (Multi Input Multi Output) technology and supports not only 20 MHz channel like IEEE 802.11a/b/g standards but also 40 MHz channels in physical layer. The performance at MAC layer of IEEE 802.11n is enhanced by aggregating several frames into one transmission frame. The frame aggregation can decrease the transmission time of preamble and frame header under ideal channel conditions. However, the corruption of aggregation frame will reduce the MAC efficiency as the long channel time is wasted.

Power Line Communication

The Home plug AV [7] operates in the 2-28MHz band and it uses windowed OFDM and Turbo Convolution Code (TCC) in the physical layer. The MAC layer uses a mix of TDMA and CSMA and supports QoS (Quality of Service). There is a Central Coordinator (CCo) in each of the PLC networks. The CCo broadcasts a periodical beacon frame with information of TDMA and CSMA allocations at the beginning of each beacon period. This beacon period is synchronized with the AC line cycle. Figure 2-2 shows the Home Plug AV’s beacon period structure.

The TDMA allocation is for applications that demand QoS while the CSMA allocation is used by applications that do not have strict QoS requirements. The allocations of TDMA slots in Home Plug AV is dynamic. Figure 2-3 shows TDMA allocation of Home Plug AV.

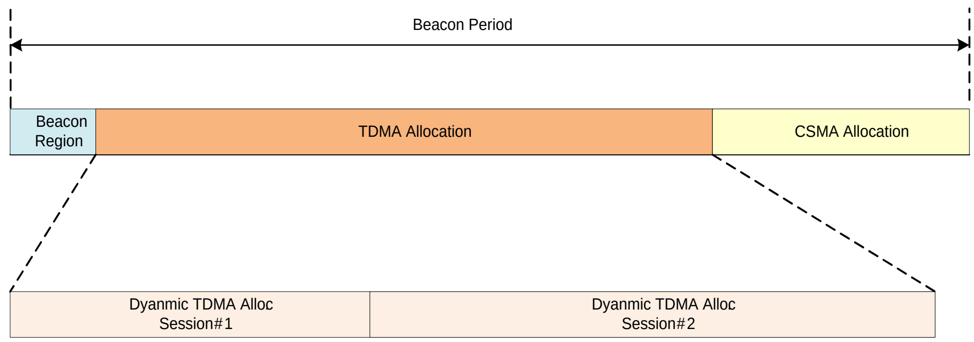


Figure 2-2. Beacon period structure of Home Plug AV

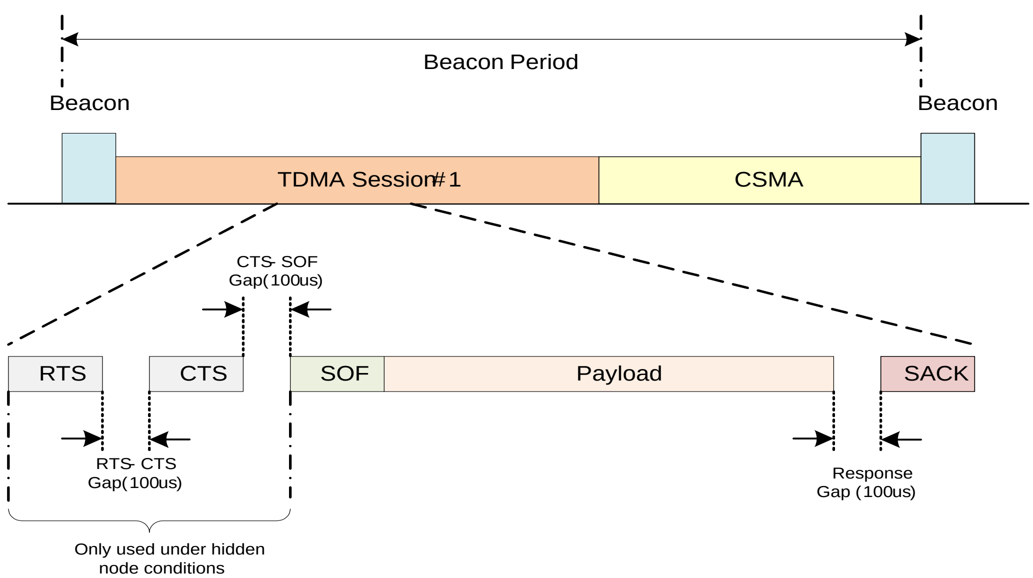


Figure 2-3. TDMA allocation Of Home Plug AV.

The CSMA access scheme in Home plug AV is the same as Home Plug 1.0 [15], which is a modified CSMA/CA protocol with priority that allows Home Plug 1.0 stations to communicate with each other without any centralized coordination. The space between the last frame and the incoming frame is called CIFS (Contention Window

Inter-Frame Spacing) while the space between the last frame and the response is RIFS (Response Inter-Frame Spacing). Home Plug 1.0 provides four priority classes - CA3, CA2, CA1 and CA0. The Priority Resolution Period (PRP) in front of contention window allows higher priority packets to enter the contention window while blocking low priority packets. For the lower two priority (CA1 and CA0) classes, the back off window size is 8-16-32-64 slots, otherwise back off window size is 8-16-16-32 slots for the two higher priority (CA2 and CA3) classes. Figure 2-4 shows CSMA scheme in HomePlug AV.

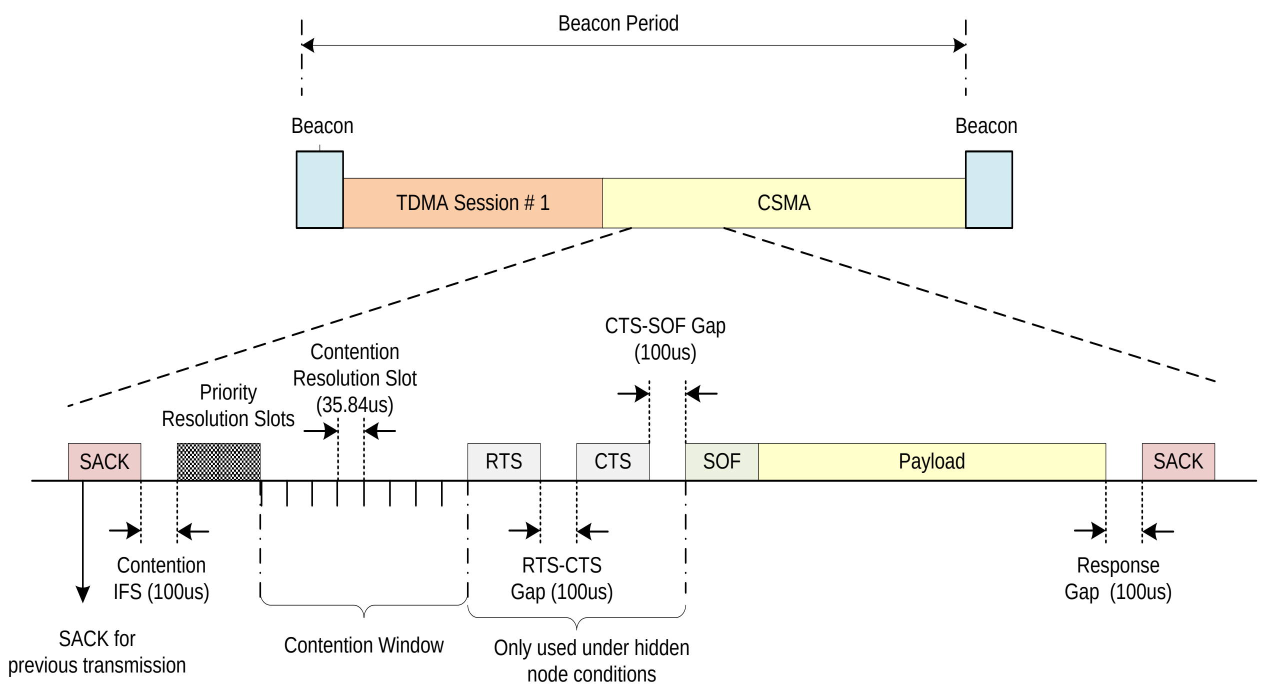


Figure 2-4. CSMA scheme in HomePlug AV

The UPA DHS (Digital Home Specification) [8] uses OFDM modulation technique and is operating in the frequency band of 2-30MHz. The medium Access Control (MAC) Layer of DS2/UPA uses an Advanced Dynamic Time Division Multiplexing (ADTDM) scheme. This ADTDM scheme is essentially a centralized MAC protocol and supports collision free access to PLC channel to all nodes in networks.

There is only master node in the network and this node controls channel access of all other nodes by using a token packet. The Repeater can be placed in network to forward the signal if the signal from master node cannot reach all slave nodes. The slave nodes does not have the right to send any packets unless it is granted this right by the master node.

Only one node has the right to transmit at any moment, however, the possibility of duplicate tokens and token loss is not avoidable. Figure 2-5 illustrates this transmission sequence of UPA/DHS.

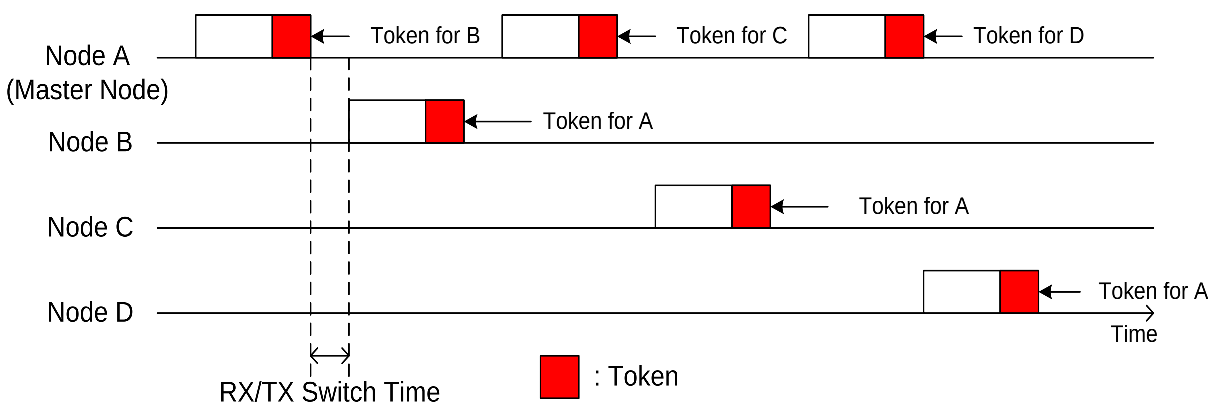


Figure 2-5. Transmission sequence of UPA/DHS

In Figure 2-5 node A starts the transmission process by sending data bursts to its destination and gives the right to control the channel to node B by passing the Token packet. After receiving the token from node A, node B starts transmission. After finishing data transmission, node B returns the token to node A. The node A gives the token to node C and D in order. Every slave node returns the token to node A after finishing data transmission. If a node which has a right to control the channel does not have data to send, this node immediately returns the token to node A.

The HD-PLC (High definition PLC) uses wavelet transform-based OFDM (orthogonal Frequency Division Multiplexing) in the frequency band 4-28 MHz. This wavelet OFDM uses 512 real carriers with symbol lengths of 8.192µs and the carriers are modulated with PAM (Pulse Amplitude Modulation). HD-PLC devices can provide maximum 190 Mbps of physical throughput or more without notches.

The MAC scheme of HD-PLC [9] uses a hybrid medium access protocol composed of Time Division Multiple Access (TDMA) and Carrier Sense Multiple Access (CSMA) in each beacon cycle. The architecture of the HD-PLC hybrid MAC is shown at Figure 2-6.

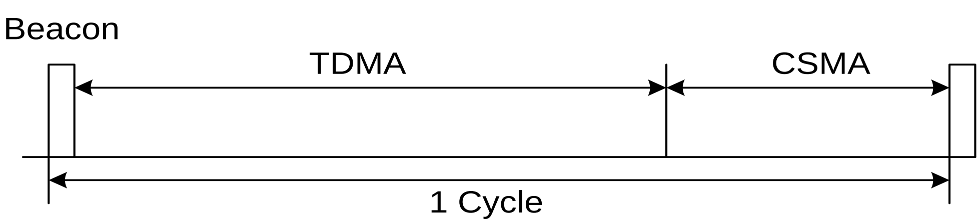


Figure 2-6. Hybrid Medium Access Protocol

In the TDMA region, a centralized channel access management is executed by a central coordination node. The bandwidth schedule is announced to each node by a beacon frame. Distributed channel access management is executed in the CSMA region. In this region bandwidth is not guaranteed and the priority for each link in the CSMA region is determined from the TOS (Type of Service) field in the IP header. If a link has a high priority then a node has short Maximum Back off time.

Experiment Setup

The experiment was conducted in a 2200 square feet house in Gainesville, Florida.

The objective of this test was to determine the performance of recent PLC and wireless technologies in a real world environment. The interior walls of this house are made of wood and drywall. This can give a significant advantage for wireless technology's performance comparing to the same setup in a bricked or concrete wall environment. Figure 2-7 shows the floor plan and the testing locations of this house.

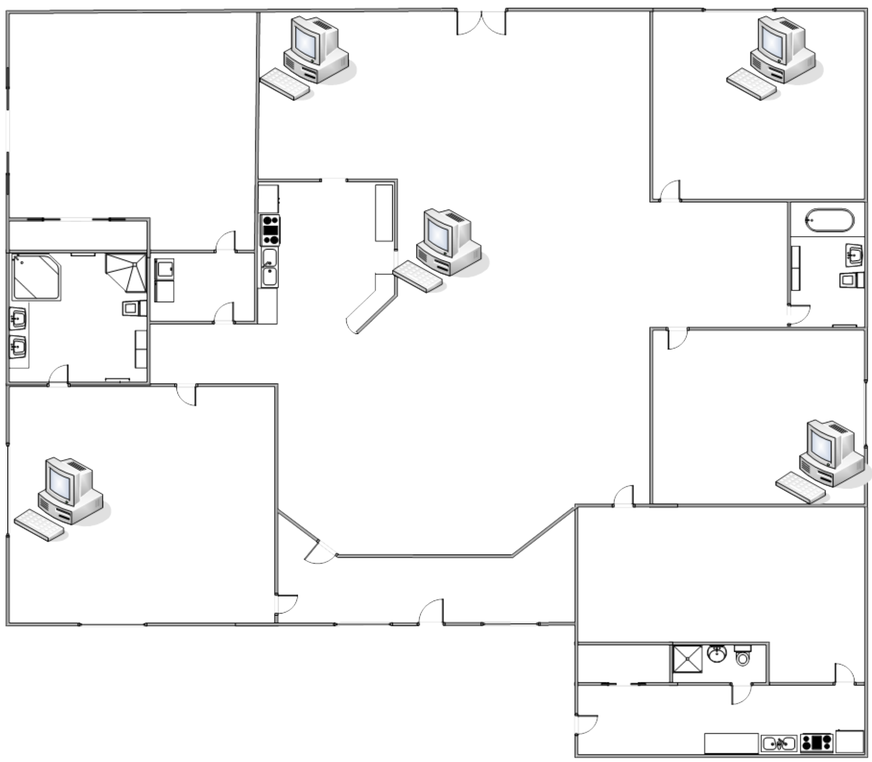


Figure 2-7. Test floor plan

In this experiment, we used one desktop computer as a receiver and one laptop computer as a transmitter. The desktop computer had a 3.0GHz Pentium IV processor with 512 MB Ram and windows XP professional SP2. The laptop was equipped with a 1.87GHz Pentium IV processor, 512MB RAM and running on top of windows XP professional SP2.

The software used for this test was Gatorbytes, a network throughput measurement software developed by the University of Florida and Charleston Southern

University [16]. This program is able to provide real time data visualization that shows the network status in real time. A snapshot of the Gatorbyte output screen is shown in Figure 2-8.

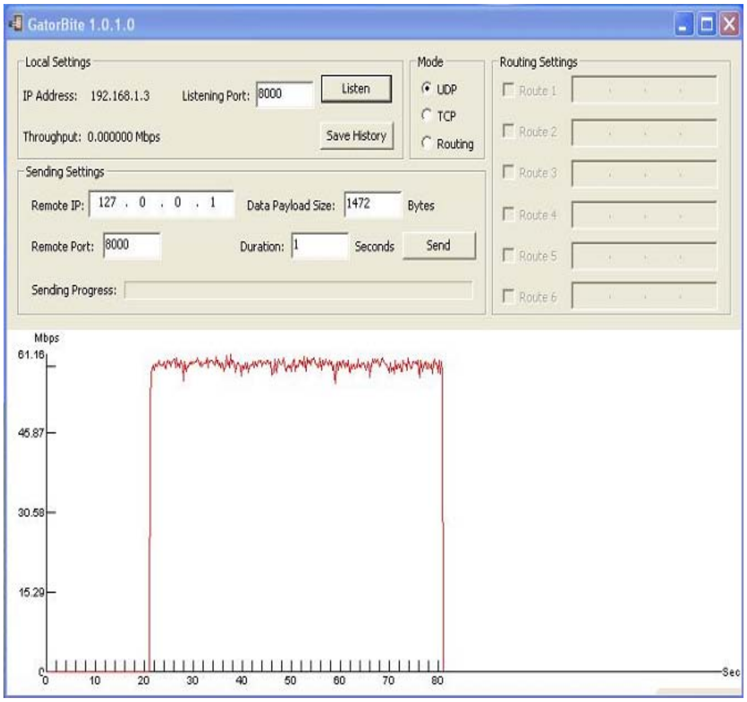


Figure 2-8. Snapshot of Gatorbytes

Both TCP and UDP protocols are used in this test to evaluate the performance of IEEE 802.11g/n and PLC technology. The TCP tests used 64240 byte segments while 1472 bytes packets were sent in the UDP tests. Each test lasts for 60 seconds. This test gives us an idea of the optimal throughput of each technology. The setup for the PLC tests are depicted in Figure 2-9, while the PLC adaptors used in the test are described in Table 2-1.

Table 2-1. PLC Adaptors

Model Name	Maker	Chipset	Technology
RD 6300	Intellon	Intellon	Home Plug AV
HDX101	Netgear	DS-2	UPA-DHS
BL-PA100	Panasonic	Panasonic	HD-PLC

HDX101 and BL-PA100 power line adapter used were the over the shelf products while RD-6300 Homeplug AV power line adaptor is a reference design provided by Intellon corporation.

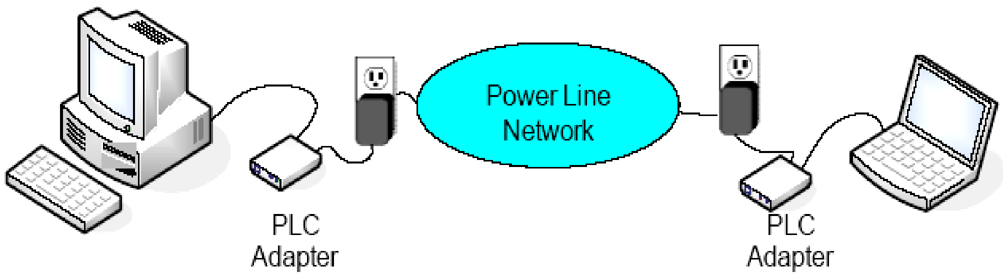


Figure 2-9. PLC test configuration

An Ad-Hoc configuration was used in the wireless network experiments. The configuration is shown in Figure 2-10.

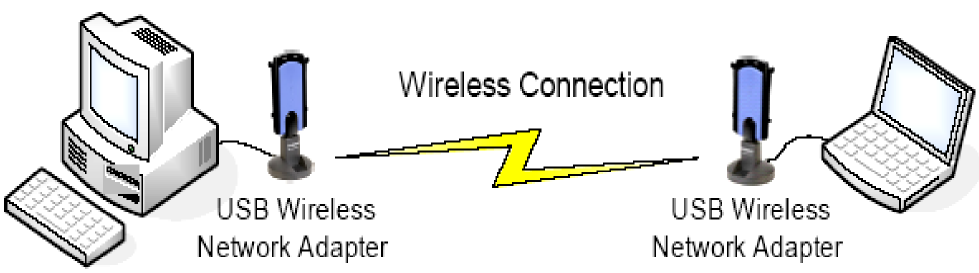


Figure 2-10. IEEE 802.11g/n test configuration

The equipment used in the wireless experiments was Linksys, WUSB300N. Both of the receiver’s and transmitter’s antenna were placed randomly and the manufacturer’s default settings were used.

Test of UDP and TCP Protocol

The experiments were conducted in 18 paths with TCP and UDP protocols. All PLC and IEEE 802.11g/n technologies have full whole house coverage in this test meaning that there was some connection along every path tested. The Netgear’s PLC adapter, HDX101 we used had the amateur radio tones turned on while the other PLC adapters did not use the amateur radio bands. In the results presented, the HDX101 data rates are reduced by 20 % to correct for the amateur radio bands.

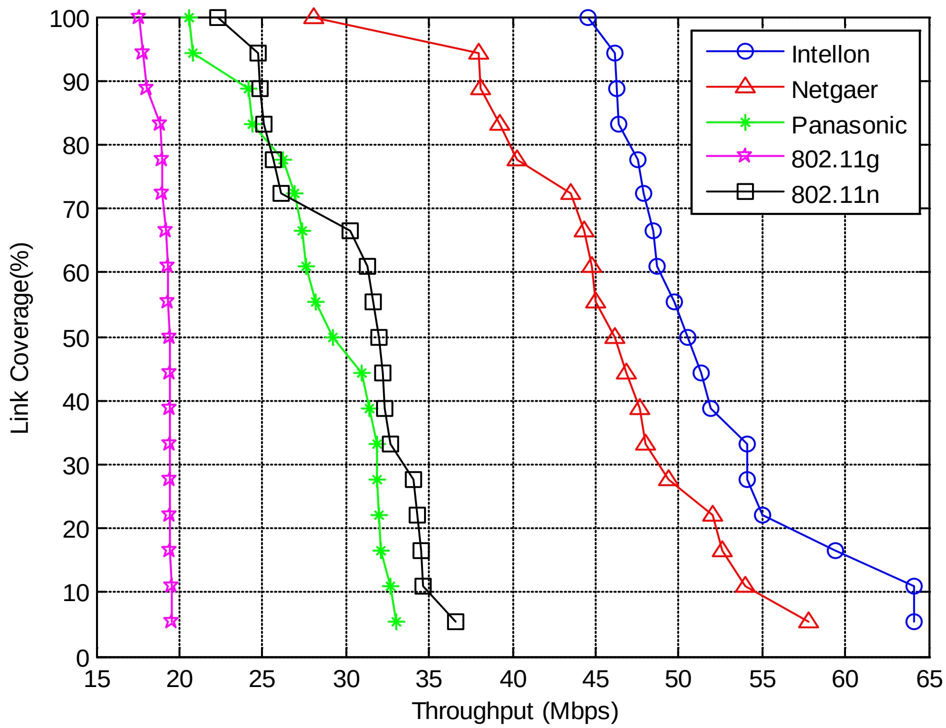


Figure 2-11. Link coverage versus TCP throughput

Figure 2-11 shows the percentage of links that exceed the TCP throughput value noted at the X-axis. The experiment shows that Intellon's PLC adapter RD 6300 has the highest Maximum TCP performance. Figure 2-11 shows that around 77% of connections operated at more than 47 Mbps. For the Netgear's PLC adaptor, HDX101, 77% of the connections operated above 40 Mbps. For IEEE 802.11n ad hoc mode and Panasonic's PLC adapter BL-PA100, 77% of connection operated above 25 and 26 Mbps respectively. IEEE 802.11g ad hoc mode has lower TCP performance compared with other products but gave the most stable output for wireless TCP performance.

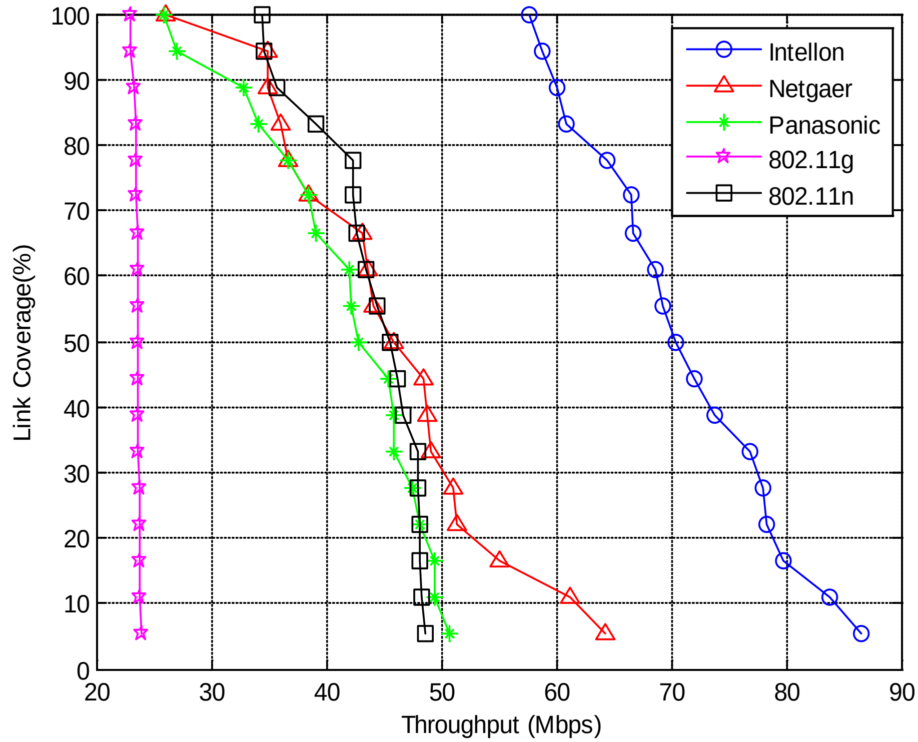


Figure 2-12. Link coverage versus UDP throughput

Figure 2-12 shows the percentage of links that exceed the UDP throughput value indicated on the x-axis. The Intellon's PLC adapter RD 6300 has the highest maximum and minimum UDP throughput. The minimum throughput of RD 6300 observed in the experiment was 57.65 Mbps and 77% of connections operated above 64 Mbps. Notably, this product had highest UDP throughput at all paths. For Netgear's PLC adaptor, HDX101, 77% of connections operated above 36 Mbps for UDP. But our experiment revealed this product is vulnerable to be affected by interference.

As shown in Figure 2-12 the minimum throughput of HDX101 is 25.99 Mbps which is an extremely low value compared with its maximum throughput. For the Panasonic PLC adapter BL-PA100 and IEEE 802.11n in ad hoc mode, 77% of connections operated above 36 and 42Mbps respectively. This experiment shows Maximum UDP throughput of BL-PA100 is higher than that of IEEE 802.11n ad hoc mode but IEEE 802.11n has higher minimum throughput than that of Panasonic's PLC adaptor BL-PA100. IEEE802.11g ad hoc mode has lowest throughput as we know but again gave the most stable throughput. The deviation of maximum and minimum UDP throughput is just 1.07 Mbps. In this experiment the IEEE802.11g/n standards were operated as ad hoc mode. We can expect that the throughput would be reduced to below half of our test values for IEEE 802.11g/n operating in infrastructure mode which is normally used in home and small area networks.

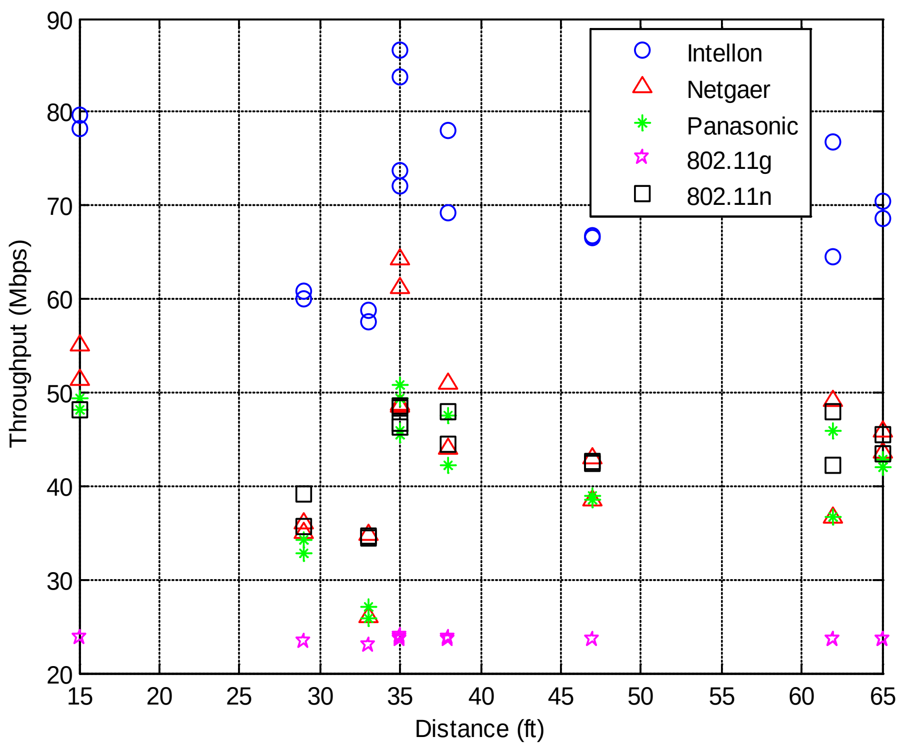


Figure 2-13. TCP throughput versus distance of direct path

The scatter plot of the TCP and UDP throughput as a function of distance is shown in Figures 2-13 and 2-14. Normally wireless communication has direct relation between distance and performance. But in this experiment we could not find any direct relationship between distance and throughput. Especially IEEE 802.11g has almost the same performance irrespective of path distance. The performances of PLC systems have no correlation with the line of sight distance measure in this experiment. This is because PLC signals are transmitted through the convoluted power network cables which reach the destination.

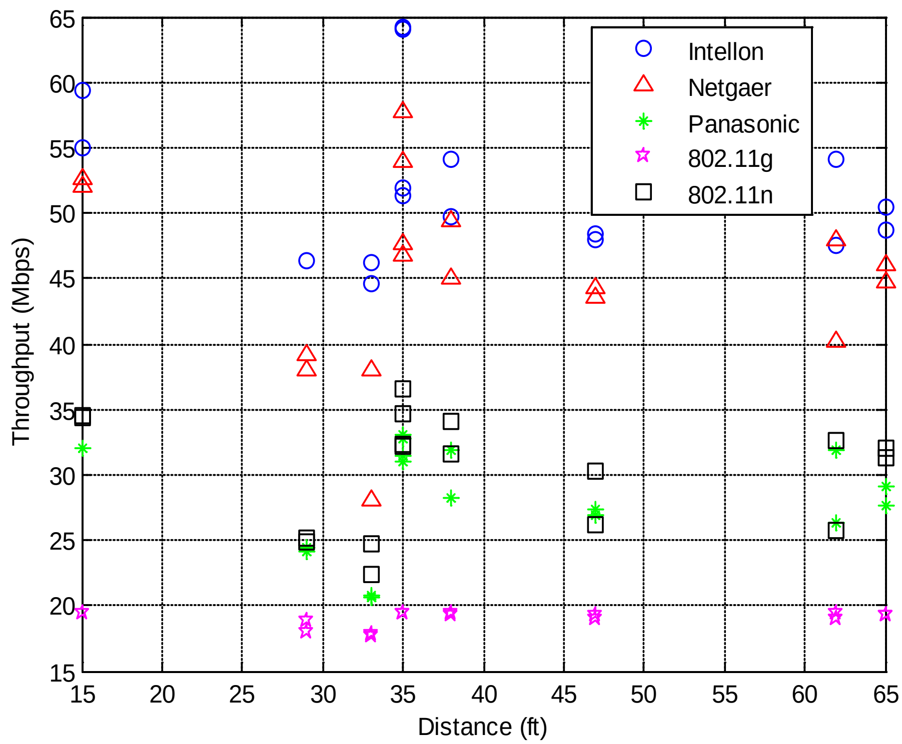


Figure 2-14. UDP throughput versus distance of direct path

HDTV Streaming Test

To assess the feasibility of the distribution of a single HDTV stream in the home, a 25Mbps HDTV stream was transmitted and received using each of the technologies studied. In this experiment we made a connection between the laptop and the desktop computer using PLC and IEEE 802.11g/n technologies and the HDTV stream was played over the power line and wireless network using the PowerDVD multimedia player.

A momentary video freeze phenomenon during playback occurred if the overall bit rate of the videofile was close to or exceeded the capacity the path for the selected technology. We conducted this evaluation on 5 paths in the same house. Table 2-3 shows the quality evolution for HDTV streaming. We evaluated the quality of video streaming in 4 categories of an informal Mean Opinion Score (MOS): “4=Very Good”, “3=Good”, “2=Poor” and “1-Very Poor. Table 2-2 shows the classifications used.

Table 2-2. Classification of video streaming

Classification	Playback condition
4	Very Good: Video streaming is smooth and no packet drop is observed. Or it is hard to realize the packet drop
3	Good: video streaming has slight discontinuity or delay
2	Poor: Video streaming has evident discontinuity or delay but delay is not significant
1	Very Poor: video streaming has serious discontinuity and delay so quality of video is not tolerable.

Table 2-3. Quality of 25Mbps, HD video streaming

Product	Path 1	Path2	Path3	Path4	Path5	Avg.
Intellon RD6300	3	4	2	2	3	2.8
Netgear HDX101	2	1	2	3	2	2
Panasonic BL-PA100	1	2	1	1	1	1.2
Linksys 802.11G	1	1	1	1	1	1
Linksys 802.11N	1	1	1	1	1	1

In the experiment with MPEG-2 file with a bit rate of 25Mbps, we observed a serious video freeze and go (halting) phenomenon with IEEE 802.11g and n technology. The delay of IEEE 802.11g is more serious than that of IEEE802.11n. Panasonic’s BL-PA100 PLC adaptor also shows bad video quality. Intellon’s RD6300 and Netger’s HDX101 PLC adaptor shows better performance than other technologies as we expected. But these could not support a 25 Mbps HD video signal successfully at all paths. (Note: the Negrear HDX101 adapters had the amateur bands turned on for these tests).

Conclusion

This study presents a comprehensive evaluation of the performance of recent wireless and PLC technologies for home and small office environments. The throughput of IEEE 802.11 g/n and High speed PLC technologies in a real world environment was measured. The experiments were conducted along 18 paths with TCP and UDP protocols in 2200 square feet house. HDTV streaming was also evaluated over five paths. All power line and wireless technologies tested in our experiment provide full connectivity with each other.

Our overall experimental results shows the Homeplug AV PLC adapter outperforms other PLC products and the IEEE802.11n/g for UDP and TCP throughput and HDTV streaming performance.

The work reported in this chapter has been published in the Proceedings of 12th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI2008) [33].

CHAPTER 3
A VISUALIZATION TOOL FOR NETWORKING PROTOCOL ANALYSIS

Introduction

Recent decades have seen exponential increase in the amount of digital information flowing across data networks. Digital information goes through several network layers before reaching the intended destination. Each network layer deals with a specific facet of the networking problem. For example, the IP layer is responsible for proper routing while the physical layer deals with the transmission and reception of signals over the medium. Network layers implement a set of protocols or behavior rules that enable them to perform their intended function. Finite State Machines (FSM's) are widely used in modeling and implementation of networking protocols. Typically these FSM's are augmented by means of variables and state transition dependencies based on their values. For example, the modeling of the widely used TCP protocol will include such states as the Slow Start, Congestion Avoidance and variables such as the duplicate acknowledgments counter used for modeling the fast retransmission and fast recovery protocol.

The current generation of networking protocols and hence the FSMs that are used to implement them can are quite complex. Analytical tractability of their behavior is limited to a very small subset of their range of behavior. Network engineers typically use simulations for developing and enhancing the protocols. These simulations output various statistics that can be used to estimate and improve system performance. Several types of statistics can be collected from a simulation based on the parameters of interest. Aggregate statistics provide information over the whole duration of the simulation and hence describe the average system behavior. Dynamic behavior of the system can be captured by means of windowed statistics (i.e., statistics generated over a widow of time) or by means of the detailed trace file. Special events can be captured by means of log files containing the relevant event information such as the time of occurrence, event type, outcome, etc. Typical system/simulation performance verification is accomplished by comparing the system behavior to the expected behavior.

Recently, there has also been an increasing trend to support Quality of Service (QoS) for multimedia streaming both within the Small Office/ Home Office (SOHO) environment as well as more generally over the Interne. There has also been an increasing need for designing intelligent protocols that automatically adjust to changes in network conditions based on cross layer information. Networking protocols required to support such functionality are significantly more complex than the current generation of protocols. The design and verification of such protocols can leverage the statistics gathered from the simulations. However, in several instances it becomes important to go through a long trace file to understand the behavior of the system under certain events.

One such example is the design of contention based medium access control protocols like the CSMA/CA protocol used in IEEE 802.11 Distributed Coordinated Function and in the Powerline HomePlug 1.0 MAC. In CSMA/CA networks, multiple stations use a combination of carrier sensing and back-off algorithm to obtain medium access. Collisions are common in such networks and optimal performance is typically obtained by balancing the collision costs with the time wasted due to idle contention slots. To verify the proper operation of such protocol, one has to go through in detail the trace files of the states of various stations as a function of time, including their internal variables and check if they behave as expected. However, going through a long trace of data is cumbersome and error prone.

To overcome this problem we developed a new Visual Protocol Analyzer named EVGATOR [17] that can juxtapose and plot states of multiple FSMs as a function of time. This utility is configurable so that each state of the FSM is represented by a specific color. The EVGATOR tool proved to be of great advantage in analyzing the new network high speed Powerline protocols.

Requirements

In a generic network protocol simulation, there are multiple instantiations of nodes with each node modeled using a set of FSMs. A subset of state traces of these FSMs at each node can be of interest. Assume there are j nodes on the network and that each node has k FSMs represented as

FSM[1]*_State, FSM*[2]*_State, …… , FSM*[*k*]*_State*

Each FSM contains m_i states that can be denoted by

FSM[*i*][1]*_State, FSM*[*i*][2]*_State, …, FSM*[*i*][m_i]*_State*.

where i represents the i^{th} FSM. At any time, each *FSM*[*i*] *State* contains only one of the m_i available states of the i^{th} FSM. Thus, the general format of the trace file information is,

Time,Node[1]*_States* V_{ec}*,…,Node*[*j*]*_States* V_{ec}

where, *Node*[*j*] *States* V_{ec} is a state vector containing the state of each of the k FSM's at Node j.

Since the set of states for a given FSM is simulation dependent, the FSM state plotter should be easily configurable to any set of states. Further, the number of Nodes, *j*, and the number of FSM's per Node, *k*, and the number of states of each FSM, *mi*, should also be easily to configure.

Apart from these, the following features will be useful to have in the FSM state Plotter,

- Ability to choose the color/texture by which each of the states is displayed,
- Ability to dynamically turn on and off the states that need to be displayed,
- Ability to change the size of time window that is displayed and easy means of zooming in and out of the region of interest,
- Ability to jump to a certain point in time, and
- Ability to print and copy the display region.

EVGator has all the above features. Note that in practice, depending on the way the simulation is designed, it may not be possible to generate a single trace file containing data from all the FSM's. For example, each instantiation of an FSM may independently generate its trace file. In such cases, it would be necessary to preprocess the respective data files to generate a single file containing all the data which could then be analyzed by EVGATOR.

Design and Implementation

The EVGATOR tool was developed using Microsoft Visual Studio .Net platform. The programming language we used was Visual C++, largely due to its wide acceptance in industry and academia. The EVGATOR is an event driven program and thus it reacts only when user commands or system events trigger the associate functions. For example, EVGATOR remains idle until the OS sends a mouse event to it.

The mouse event is then recognized by the gesture recognition function, which then triggers a window re-draw event to the OS to reflect the corresponding mouse gesture. The OS sends mouse events only when the mouse cursor is in the EVGATOR client window and the EVGATOR is the current active window.

Design of the EVGator User Interface

Humans are more sensitive and responsive to graphical data than to text. Especially when analyzing complex situations, people usually use drawings to help themselves to reason. For example, Figure 3-1 shows two modes of the same event transition in a simulation output. People can easily understand the state transition displayed as a rather than the textual description of the same event shown on the figure. This comparison gives us a clear indication of the need of a visual protocol analysis tool - EVGATOR. To meet the requirements, EVGATOR contains the following features:

• Ease and efficiency in communicating with the analyzer.

The manner in which an operator interacts with the analyzer dictates the efficiency and ease of analyzing a simulation result. We choose to use mouse cursor as the major User Interface (UI) for the following reasons. First, using the mouse cursor is an intuitive way of interacting with modern operating systems and people are already familiar with mouse operation. Secondly, using mouse is more effective if the User Interface (UI) is reasonably designed.

However, we did not completely abandon the usage of a keyboard. It is undeniable that under some circumstances the keyboard is more efficient than mouse operations. For example, to jump to a specific time stamp (if the value of the time stamp is known) the operator simply needs to type the value into an edit box and that would be faster than using mouse to browse to the desired time mark.

• Ease to range magnification and contraction (Zoom).

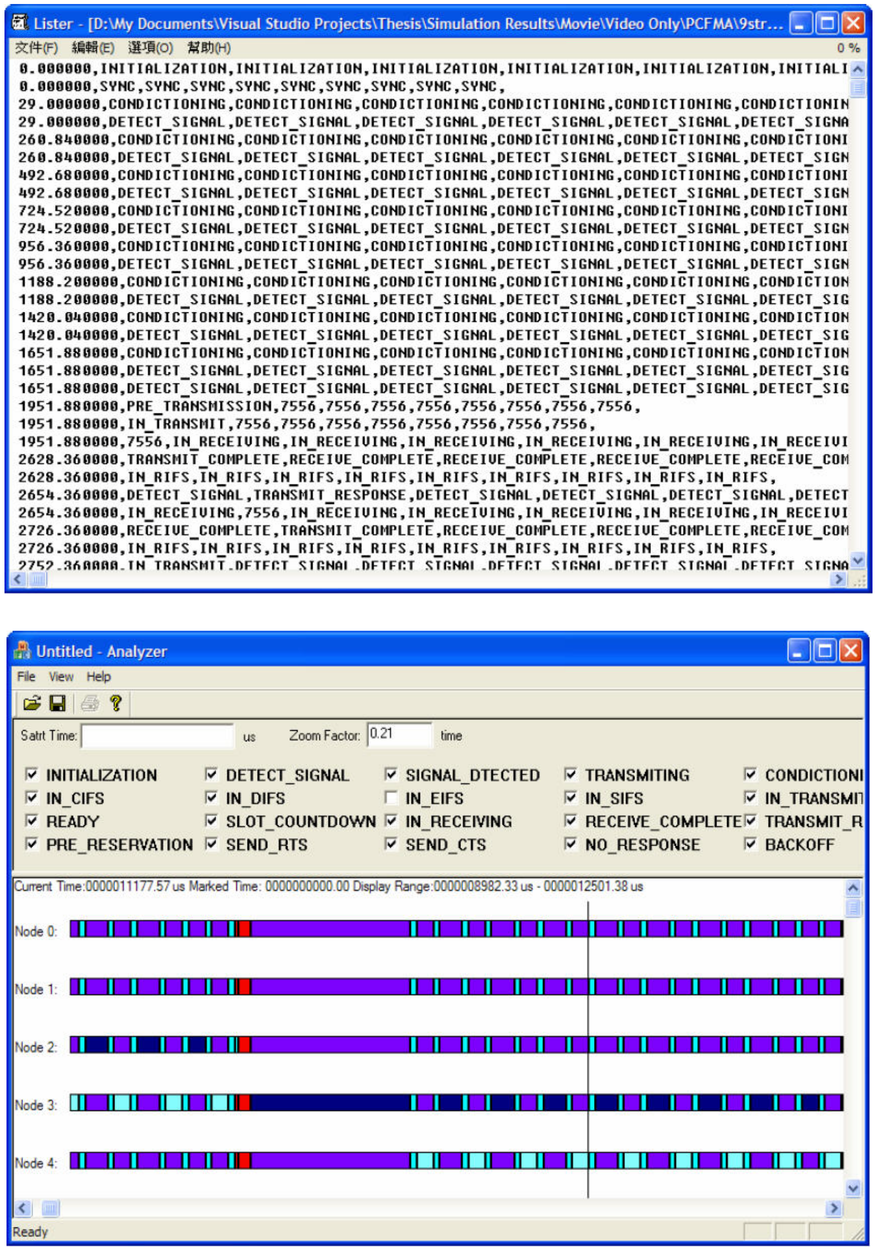


Figure 3-1. Text versus graphical event analyzer

Some events rarely happen except when simulated for a certain amount of time. Thus usually protocol designers will often simulate a scenario for a long time in order to find out the possible design flaws. In this case, the time line in the analyzer could become quite lengthy. Thus an analyzer should be able to zoom into a specific time frame to reveal detailed protocol state transition in that time range. It also should have the ability to zoom out to display a global view of the state transitions to find out the correlations between events.

To achieve this goal, we designed mouse gestures to represent zoom in and out. Designers can use the mouse to mark a range of time which represents the time frame for operation. If designers click within the range, then the analyzer assumes it is a command of ”Zoom In”. Otherwise it will zoom out so that the marked time frame occupies half of the window. Designers can easily mark various lengths of time frames to achieve various zoom factors.

If designers want a specific zoom factor, they can also use the keyboard to type the value into the zoom factor edit box. To prevent ambiguity, the marked time frame is also shown as a text display on the display window.

- Ease of marking a specific time.

When examining simulation results, designers usually have to look at various time stamps to understand the causes of aberrant events. Without the mark function, it would be difficult to move back and forth between time frames.

In the EVGATOR system, designers can achieve this effect by simply clicking on the display window. To help designers understand the marked time, the EVGATOR also shows the marked time value in the display window.

- Ease of navigation throughout the whole time line.

Since the simulation results are usually large, a display window width is not able to display all events at a time. To improve the quality of the event browsing experience, we use scroll bars to travel between time frames. Since scroll bars are elastic to the mouse movements, designers can drastically move the mouse to achieve large step jumps or click on the end arrow box to achieve small scale time line adjustments, either forward or backward.

• Flexibility in changing both event display colors and event names.

Since humans are sensitive to colors, EVGATOR displays different events with different colors. Meanwhile, different protocol designs may have different event naming and thus the EVGATOR is elastic enough to adapt to these minor changes without recompiling the source code.

To achieve the above goals, EVGATOR reads a configuration file before it starts to parse log files. Designers can modify the configuration file to suit their needs. For example, if a protocol has a new state called "Preparation", designers can open the configuration file using a text editor, and add a new line of the event name and the associated representing color. The EVGATOR will automatically add the new event into its control panel and in the representing diagram. The EVGATOR is not only elastic to the offline event representing modifications, but it is also adaptive to real time changes as well. For example, if designers are looking for a specific event, they can turn off other events to make the desired event stand out in the final diagram as shown in the Figure 3-2. The above mentioned EVGATOR features makes using EVGATOR for analyzing protocol events efficient and easy. It can also significantly reduce the time required to debug a simulator.

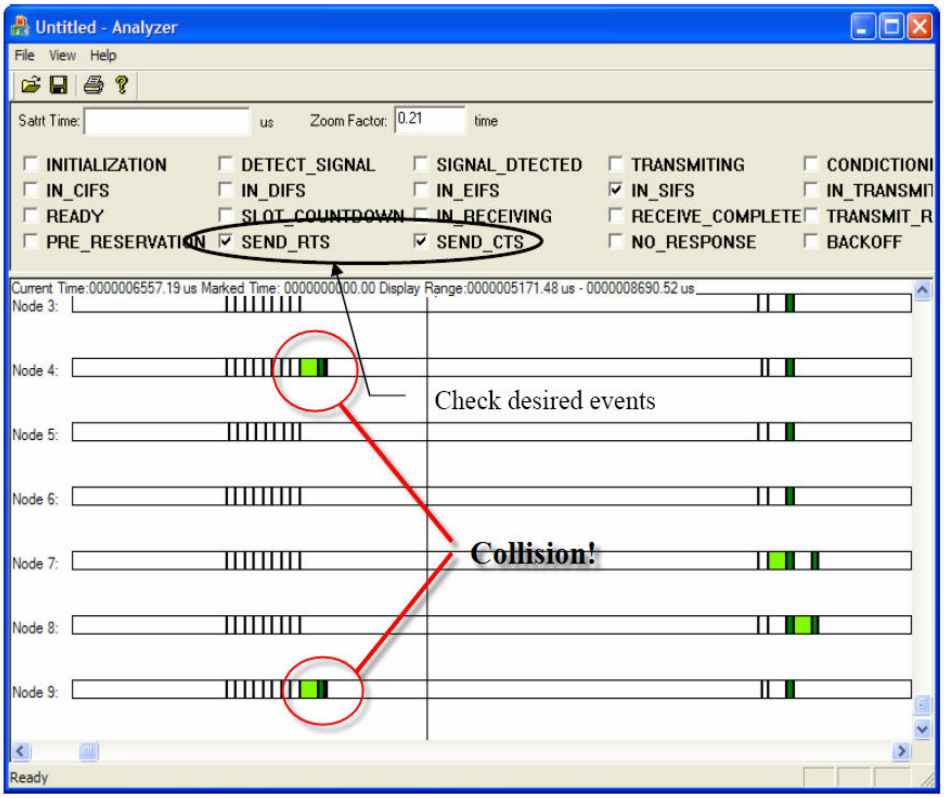


Figure 3-2. Example of selecting desired events.

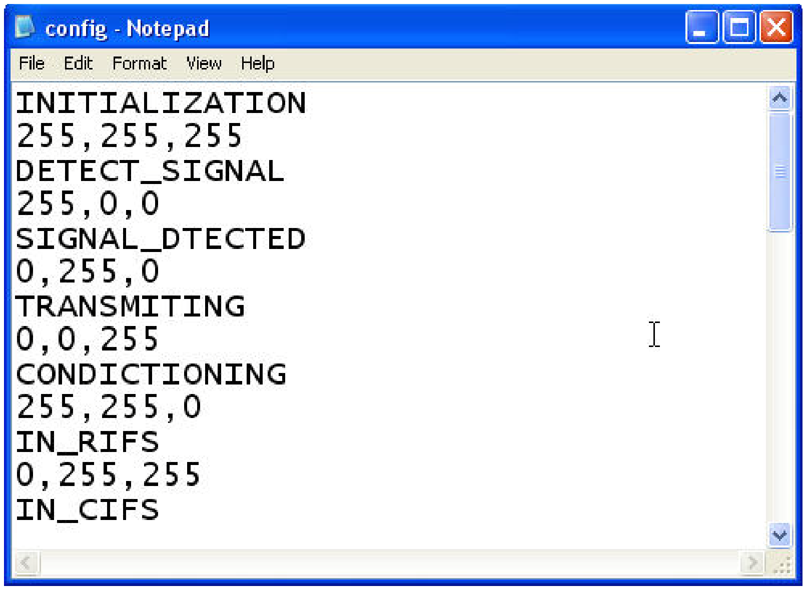
Configuring the EVGATOR

As we mentioned earlier, the EVGATOR requires a configuration file for state presentations. The example is shown in Figure 3-3.

The first line in shows a state name: INITIALIZATION and the second line shows the color that represents this event. Each statement occupies one line. EVGATOR supports 100 different states and 255 nodes. Users do not have to specify the total number of states in the configuration file. EVGATOR will determine the effective state names and number of states.

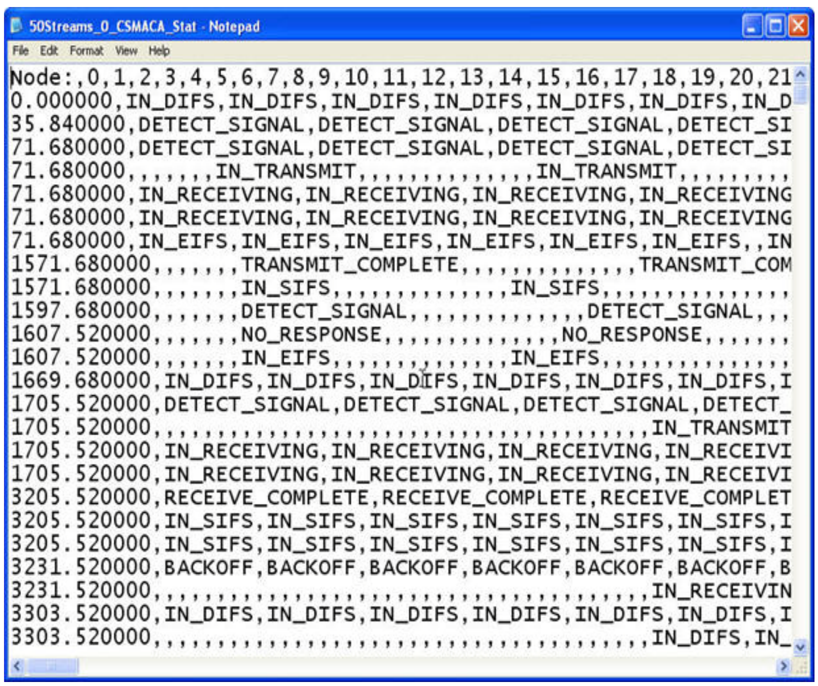
Trace File Format

To translate text log files into diagram forms, EVGATOR has to parse the recorded information. The sample log file format is shown in Figure 3-4.



```
INITIALIZATION
255,255,255
DETECT_SIGNAL
255,0,0
SIGNAL_DTECTED
0,255,0
TRANSMITING
0,0,255
CONDICTIONING
255,255,0
IN_RIFS
0,255,255
IN_CIFS
```

Figure 3-3. EVGATOR configuration format



```
Node:,0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21
0.000000,IN_DIFS,IN_DIFS,IN_DIFS,IN_DIFS,IN_DIFS,IN_DIFS,IN_D
35.840000,DETECT_SIGNAL,DETECT_SIGNAL,DETECT_SIGNAL,DETECT_SI
71.680000,DETECT_SIGNAL,DETECT_SIGNAL,DETECT_SIGNAL,DETECT_SI
71.680000,,,,,,,IN_TRANSMIT,,,,,,,,,,,,,,IN_TRANSMIT,,,,,,,,,
71.680000,IN_RECEIVING,IN_RECEIVING,IN_RECEIVING,IN_RECEIVING
71.680000,IN_RECEIVING,IN_RECEIVING,IN_RECEIVING,IN_RECEIVING
71.680000,IN_EIFS,IN_EIFS,IN_EIFS,IN_EIFS,IN_EIFS,IN_EIFS,,IN
1571.680000,,,,,,,TRANSMIT_COMPLETE,,,,,,,,,,,,,,TRANSMIT_COM
1571.680000,,,,,,,IN_SIFS,,,,,,,,,,,,,,IN_SIFS,,,,,,,,,,,,,,,
1597.680000,,,,,,,DETECT_SIGNAL,,,,,,,,,,,,,,DETECT_SIGNAL,,,
1607.520000,,,,,,,NO_RESPONSE,,,,,,,,,,,,,,NO_RESPONSE,,,,,,,
1607.520000,,,,,,,IN_EIFS,,,,,,,,,,,,,,IN_EIFS,,,,,,,,,,,,,,,
1669.680000,IN_DIFS,IN_DIFS,IN_DIFS,IN_DIFS,IN_DIFS,IN_DIFS,I
1705.520000,DETECT_SIGNAL,DETECT_SIGNAL,DETECT_SIGNAL,DETECT_
1705.520000,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,IN_TRANSMIT
1705.520000,IN_RECEIVING,IN_RECEIVING,IN_RECEIVING,IN_RECEIVI
1705.520000,IN_RECEIVING,IN_RECEIVING,IN_RECEIVING,IN_RECEIVI
3205.520000,RECEIVE_COMPLETE,RECEIVE_COMPLETE,RECEIVE_COMPLET
3205.520000,IN_SIFS,IN_SIFS,IN_SIFS,IN_SIFS,IN_SIFS,IN_SIFS,I
3205.520000,IN_SIFS,IN_SIFS,IN_SIFS,IN_SIFS,IN_SIFS,IN_SIFS,I
3231.520000,BACKOFF,BACKOFF,BACKOFF,BACKOFF,BACKOFF,BACKOFF,B
3231.520000,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,IN_RECEIVIN
3303.520000,IN_DIFS,IN_DIFS,IN_DIFS,IN_DIFS,IN_DIFS,IN_DIFS,I
3303.520000,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,IN_DIFS,IN_
```

Figure 3-4. Generated trace log file format

The tokens are defined in the configuration file. When EVGATOR sees a text string that is equal to a token, the index of the token is stored into an internal state queue associated with the starting time stamps. If a text is not recognizable during parsing, the EVGATOR will skip that text. The EVGATOR will keep parsing every text string in the log file until the end of the file. When a token is recognized, the ending time stamp of the previous state is also decided.

After a whole file is parsed, the EVGATOR will start to display each state with the colors defined in the configuration file. Since the window height and width is limited and is usually smaller than the simulation duration, the real data displayed is a small portion of the whole data as shown in the Fig. 3-5. To help designers browse, a ”Zoom In” and ”Zoom Out” command is required.

Zoom – In/Out

To implement ”Zoom In” and ”Zoom Out”, we need to calculate the Zoom Factor. Initially the Zoom Factor is defined as one. Before calculating the zoom factor, the EVGATOR first translates the marked time frame to coordinates of the display. The translation can be done by Eq.3.1

$$
\begin{aligned}
M1 &= (Mark\_Time_1 - Min\_time) \times Zoom\_Factor \\
M2 &= (Mark\_Time_2 - Min\_time) \times Zoom\_Factor
\end{aligned}
\tag{3.1}
$$

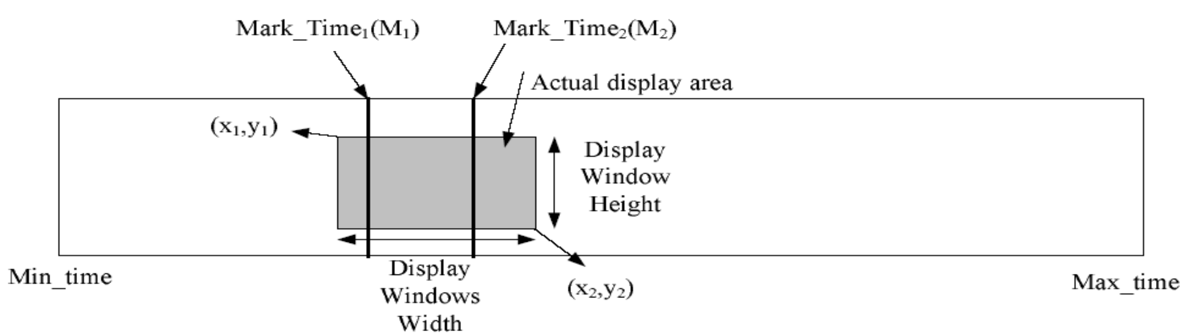


Figure 3-5. Example of actual display window

If the mouse gesture is a “Zoom In” command, that is, the user makes a mouse click within the marked time frame, the zoom factor can be calculated by dividing the current display time frame with the marked time frame as shown in Eq. 3.2.

$$\text{Zoom\_Factor} = \frac{x_2 - x_1}{M_1 - M_2} \tag{3.2}$$

If the command is a “Zoom Out”, the zoom factor is calculated by dividing the marked time frame with the current display time frame as shown in Eq. 3.3.

$$\text{Zoom\_Factor} = \frac{M_1 - M_2}{x_2 - x_1} \tag{3.3}$$

Since the simulation log file is huge, we need a proper data structure to represent state transitions. An event queue is used in EVGATOR. The queue is dynamically allocated and de-allocated in order to minimize the system memory requirement.

To reduce window flickering due to the updating of display contents, we record the areas that are affected by the current operation and update those areas only. This way, only a small portion of the display areas needs to be updated at a time.

Experience

The EVGATOR utility was very useful to us in developing the Medium Access Control protocol of HomePlug AV, which is intended to be the successor to the HomePlug 1.0 Standard [15]. During the development and analysis, we made extensive use of the EVGATOR functions described above.

EVGATOR was particularly useful in the verification of the simulation and in understanding some of the rare/unexpected events that occurred. In the former case, the visual plot of the MAC and Physical Layer state as a function of time proved to be a valuable tool in trying to find any erroneous behavior. In the later case, when an unexpected and very rare event happened, the GUI helped us to quickly go through the set of events that caused the final event. For example, in the process of designing the CSMA/CA protocol, we found that searching for the causes of nodes moving to the back-off state using the text based log file is painful since there are so many different state transitions occurring at the same time. However, using EVGATOR we can easily find the cause using the displayed diagram. In Figure 3-2, we found the cause of the back-off is because of the RTS collisions.

Conclusion

With the help of the EVGATOR, we significantly reduced the protocol design process and the time spent on debugging the simulation results. Designers who work on FSM-based simulators can also benefit from the visualized expressions of state transitions. Though EVGATOR is helpful, it cannot directly parse trace logs from other simulators like NS-2 or Opnet. However, users can readily transform the given log formats to the format EVGATOR accepts. We also expect the inputs from industry and academia to help us keeps developing and improving EVGATOR to meet majority of users' needs, possibly with automatic data format conversion of the most popular simulation environments.

EVGATOR is now available on UF LIST website (*http://www.list.ufl.edu/VisuGATOR*) as a public domain freeware, with some required rights held by the University of Florida to the present source code.

The work reported in this chapter has been published in the International Journal of Software Engineering and Its Applications [17].

CHAPTER 4
ENHANCED LIMITED ROUND ROBIN MECHANISM USING PRIORITY POLICY OVER BLUETOOTH NETWORK

Introduction

The smallest Bluetooth unit is called a piconet, which is composed of one master node and several slave nodes (up to seven).In a piconet a Bluetooth device can be operate in active mode or sleep mode (Sniff, Hold and park mode). However just one master and seven active mode slaves are allowed in a piconet. If some nodes desire to switch the state to active mode, some active nodes should change the state from active mode to sleep mode when seven slaves are already operated in active mode. All nodes in a same piconet should follow same frequency hopping pattern. Multiple piconets can also exist in the same area and be connected via a bridge node, creating a scatternet.

In a Bluetooth system, full-duplex transmission is supported using a master-driven TDD (Time Division Duplex) scheme to segment the channel into 625µs time slots, which are alternatively distributed between the master and the slaves. As such, the master sends a poll or data packet to a slave using the even-numbered slots, then the slave sends a packet to the master using an odd-numbered slot immediately after receiving a packet from the master [4]. Thus, the MAC scheduling in Bluetooth is controlled by the master and executed using master-slave pairs. All Bluetooth devices in a same piconet have to synchronize the clocking exactly and a node which has privilege of using the slot will not release the resource of transmission to other nodes even if it does not have any data to transmit. Hence Bluetooth seems to be inefficient but it can support more reliable connection. So Bluetooth is appropriate for high quality interconnection between mobile devices and many researchers have proposed algorithms to enhance the performance of Bluetooth network [18-22].

Bluetooth systems support two types of virtual data communication link between the master and slave: a Synchronous Connection Oriented (SCO) link and Asynchronous Connection-Less (ACL) link. An SCO connection supports a circuit-oriented service with a constant bandwidth using a fixed and periodic allocation of slots. An SCO connection is suitable for latency-sensitive multimedia traffic like voice traffic, whereas an ACL connection supports a packet-oriented service between the master and slave for data. An SCO connection only uses one time slot, while an ACL connection can use one, three, or five time slots according to the data packet size [4]. The Round Robin (RR) scheme is a default MAC scheduling algorithm for Bluetooth that uses a fixed cyclic order. The POLL packet does not have any information and just gives the polled slave the privilege of transmitting packet in next slot. If the polled slave does not have any data to transmit, it replies to the master by sending a NULL packet which also does not have any information. As a result, numerous slots can be wasted with POLL or NULL packet exchanges in the case of no data to transmit. Despite the introduction of several Bluetooth MAC scheduling algorithms to reduce these slot waste, problems still remain.

Accordingly, this section introduces a simple and efficient MAC scheduling algorithm to reduce slot waste and enhance the performance of Bluetooth.

MAC scheduling scheme of Bluetooth

The principal MAC protocol in Bluetooth is a polling scheme that uses a master-driven time division duplex (TDD). Here, a slave is only allowed to transmit a packet to the master immediately after receiving a packet from the master. Plus, the master can only use an even-numbered slot to send a packet to a slave, while the slave can only reply to this packet using an odd-numbered slot. The MAC scheduling scheme for a

Bluetooth system is shown in Figure 4-1. The TDD slots are shared by the SCO and ACL link in this figure.

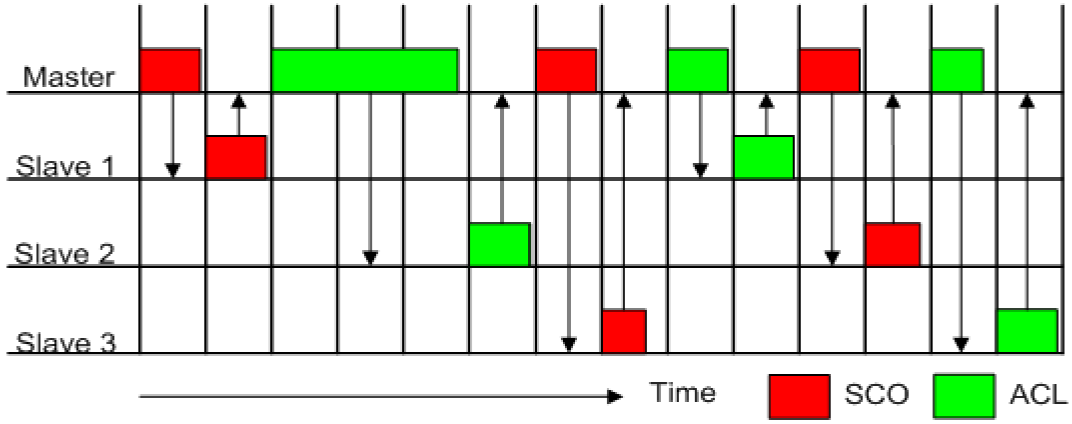


Figure 4-1. MAC Scheduling scheme of Bluetooth

In the Pure Round Robin (PRR) scheme, every slave has the same opportunity to send one data packet even when they have no packet to transmit. Once the master polls a slave, the next time slot is then assigned to the slave without reference to whether the slave has data to transmit or not. Consequently, numerous slots can be wasted when POLL packets are sent by the master and NULL packets are sent by the slaves in the case of no data packets to transmit. Therefore, the PRR scheme is an inefficient scheduling algorithm when the traffic in the network is asymmetric, and several Bluetooth MAC scheduling algorithms have already been proposed to improve the system performance [18-22]. Some works assume that the Master knows up-to-date information of slave's queue status [18-20]. Some approaches do not require this information [22]. Some researchers also proposed low power mode based scheduling policy [21].

In [18], a Master-Slave Queue-State-dependent Packet scheduling algorithm is proposed, where a free bit in the Bluetooth payload header is used by a slave to inform the master of the next available data. Based on this feedback bit, the master classifies all the master-slave pairs into one of four states, and a higher priority assigned to a pair that utilizes the slots more efficiently than the other pairs. However, this algorithm assumes that the master has updated information on the slave queue at all times, which is not actually available given the current Bluetooth specifications, as the slaves can only provide information on their queue state when they send a packet to the master. In addition, a slave starvation problem can occur for low priority pairs when higher priority pairs always have packets to transmit.

In [19], HOL-Priority Policy (HOL-PP) is proposed. This algorithm use similar priority policy with [18]. The master schedules on the basis of the head of line (HOL) packet size at the Master and slave queue. Additional two bits are required to distinguish 4 possible HOL packet size for classifying the master and slave pair into three classes by slot utilization. However this policy assumes the master has up-to-date information of slave queue's status like [18].

In [20], the authors use the similar priority policy as in [18] and [19] to improve the performance of the system considering both throughput and delay on each Master-Slave pair in scheduling decision. They use the amount of link utilization to assign a priority class based on queue status of master and slave pairs. But they also assume that the master knows up-to-date information of the slave-to-master queue status.

Some researchers proposed MAC scheduling policy to optimize power consumption and improve slot utilization by using a low power mode in Bluetooth [21]. In this research authors proposed variable sniff interval and variable serving time on the base of slot utilization. However this scheduling policy is not adequate for dynamic traffic and requires additional information.

In [22], several scheduling algorithms are compared. The Exhaustive Round Robin (ERR) is a simple scheduling policy that uses a fixed order like RR. Yet, since the master does not switch to the next slave until both the master and the slave queues are empty, there is a danger that the channel can be captured by stations generating a higher traffic than the system capacity. Thus, the Limited Round Robin (LRR) was proposed to solve this capture effect Although the LRR also has a fixed cyclic order and is exhaustive, like the ERR, parameter “t” is adopted to limit the number of transmissions (tokens) that can be performed by each pair per cycle. The maximum number of transmissions per cycle then limits the cycle length and avoids the capture effect. Nonetheless, despite an improved throughput and fairness when compared with the RR and ERR, the LRR still suffers from a slot wastage problem under asymmetric traffic conditions.

Accordingly, on the foundation of the MAC scheduling algorithms in [18] and [22], this section introduces an Enhanced Limited Round Robin with a priority policy (ELRR-PP) based on slot utilization to improve the performance. Plus, fairness is maintained using a maximum number of transmissions per cycle.

ELRR-PP Algorithm

The ELRR-PP [23] operates in accordance with the master-slave queue status. As such, four classes of priority are assigned to the master-slave pairs based on the existence of data in the respective queues, which is similar to the method in [18], except the proposed method uses the current queue status for the master and previous queue status for the slave.

Table 4-1. Priority Scheme

Priority	Queue status
Class 1	Master has packets in queue and the slave sent packets to the master during previous turn
Class 2	Master has packets in queue and slave did not send packets to the master during previous turn
Class 3	Master has no packets in queue and slave sent packets to the master during previous turn
Class 4	Master has no packets in queue and slave did not send packets to the master during previous turn

Hence, additional information on the slave queue is not necessary, in contrast to [18]. This priority scheme is described in Table 4-1. Based on the classes, the slave with the highest priority is polled first. It is also assumed that class 2 has priority over class 3, as there is a possibility that the slave has no data to send to the master In the case of several pairs in the same class, the pair with the largest amount of data in the master queue has priority. But for the class 2, the pair with the smallest amount of data in the master queue has priority to relegate this pair to class 4. The ELRR-PP algorithm is described in Figure 4-2.

To avoid starvation of the low priority pairs, a maximum number of transmissions per cycle is adopted for each class, where Max1 is the maximum transmission number for class 1, and Max2, which is smaller than Max1, is the maximum transmission number for class 2 and class 3. Parameter “t” is used to count the number of transmissions. To prevent slot waste, the polling interval for class 4 pairs is modified. For the first cycle, such an inactive pair has the same opportunity to be polled. But, if it still has no packets to send in the next cycle, the polling interval for this pair is increased linearly by one cycle to limit the chances of transmitting packets. Parameter “i” is used for this purpose in Figure 4-2.

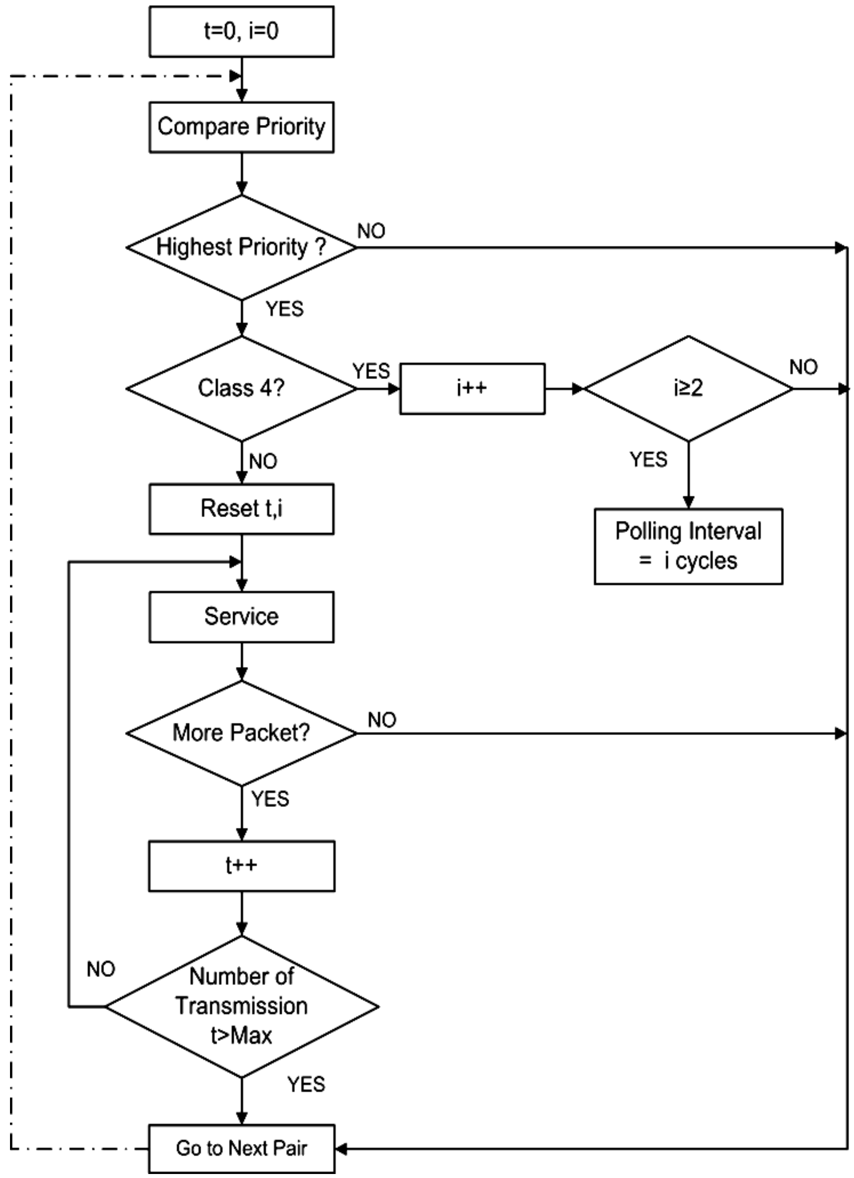


Figure 4-2. Flow chart of ELRR-PP

Performance Evaluation

To evaluate the proposed algorithm, a discrete event simulator was used, and all the simulations were based on a single piconet consisting of one master and six slaves, where the master had a corresponding queue for each slave. The traffic mode considered was ACL. The traffic at the master and each slave was generated independently in accordance with a Poisson process. When comparing the proposed algorithm with other algorithms, the maximum number of transmissions per cycle for the LRR was set at 4, while for the proposed ELRR-PP it was set at 8 for class 1(Max1=8) and 4 for class 2 and class 3 (Max2=4).

Figure 4-3 shows the average delay when each master-slave pair had the same arrival rate. As shown in Figure 4-3, the ELRR-PP produced a lower delay, however, the difference compared to the other algorithms was not significant.

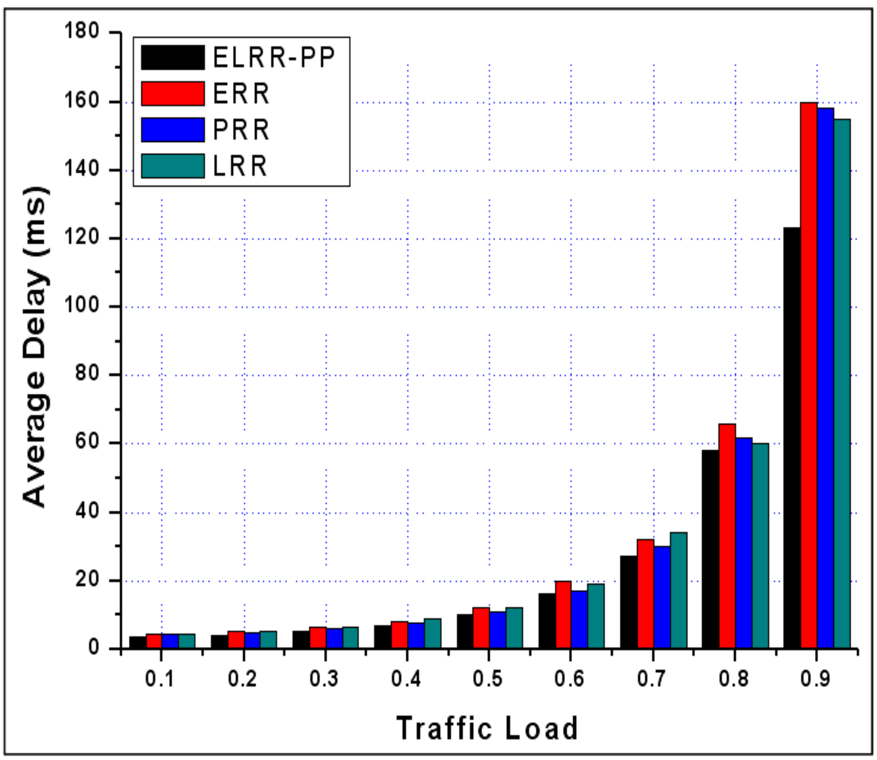


Figure 4-3. Average delay with same arrival rate

To evaluate the delay characteristics when each pair had a different traffic generation rate, the arrival rate was changed, as shown in Table 4-2. The arrival rate of the 6th master-slave pair was changed from 0.03 to 0.27 to increase the system traffic from 0.4 to 0.88. As such, the arrival rate for slave 6 was increased from 0.03 to 0.27, while that for the master was selected randomly between 0.03 and 0.27.

Table 4-2. Traffic Generation Parameter

Piconet	M1	S1	M2	S2	M3	S3
Arrival rate	0.2	0.02	0.05	0.007	0.007	0.05
Piconet	M4	S4	M5	S5	M6	S3
Arrival rate	0.001	0.002	0.002	0.001	Variable	Variable

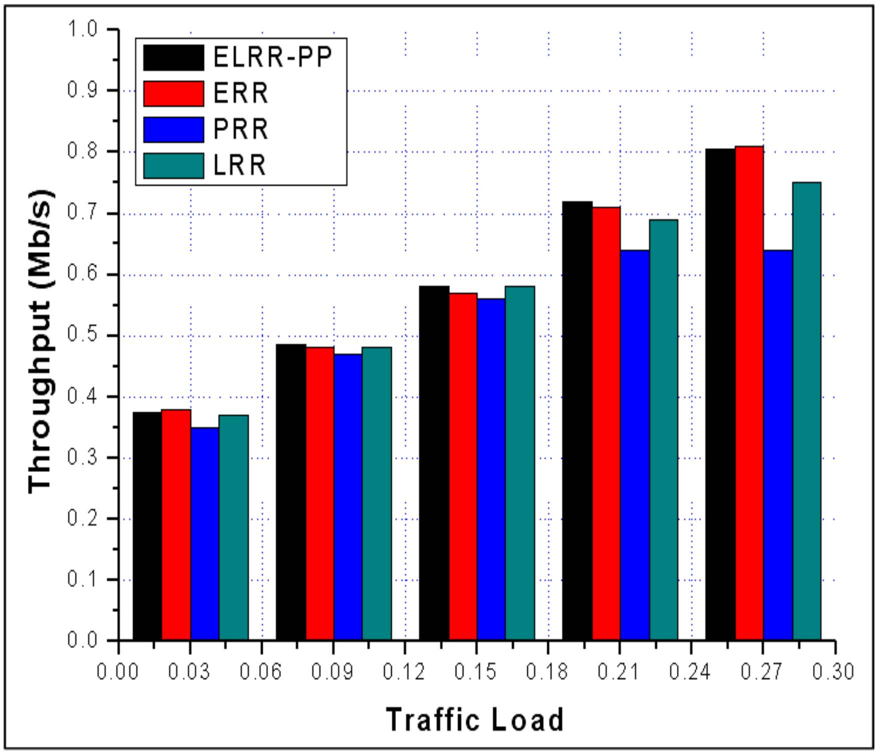


Figure 4-4. Throughput with variant traffic load

Figure 4-4 presents the throughput for the 6th master-slave pair with a variant traffic load. As Expected, the PRR produced a lower throughput than the other algorithms due to the increased traffic load for slave 6. Meanwhile, the ELRR-PP produced a higher throughput than the LRR, and higher or similar throughput to the ERR.

Figure 4-5 shows the average delay with a variant traffic load for slave 6. The delay of the PRR suddenly increased when the traffic load for slave 6 increased. Also, the delay of the LRR increased significantly as the traffic load increased The ELRR-PP produced a lower delay than the PRR and LRR, and comparable performance with the ERR.

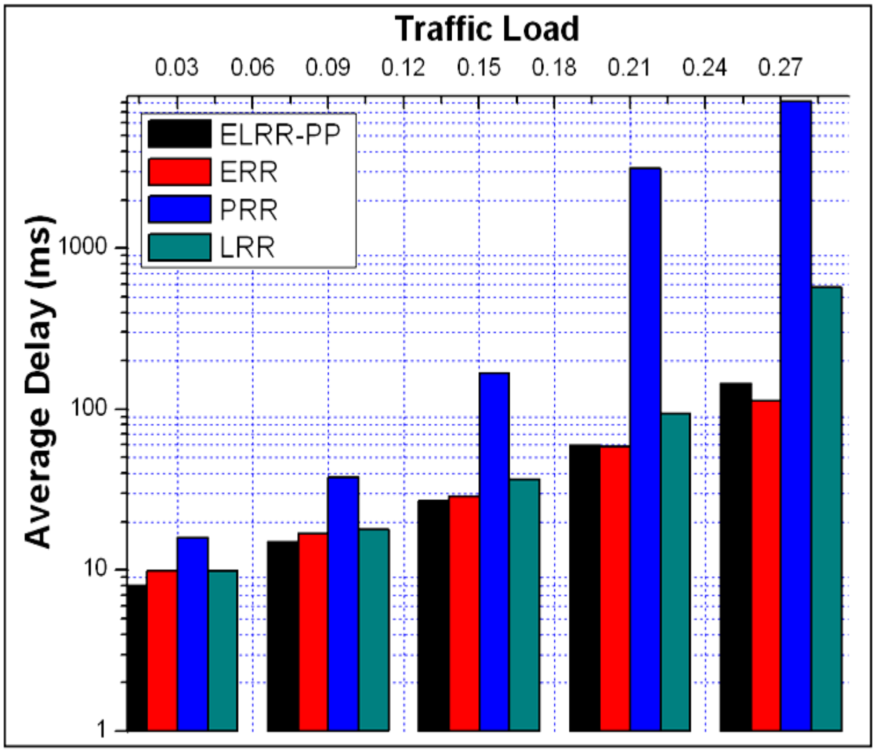


Figure 4-5. Average delay with variant traffic

Conclusion

This paper proposed an enhanced Limited Round Robin with a priority policy for data exchange within a Bluetooth piconet, and its throughput and delay performances were evaluated. The proposed algorithm utilizes the status of the master and slave to schedule the slots effectively, yet additional information on the slave is not necessary. In simulations, the proposed ELRR-PP produced a better performance than the existing PRR and LRR scheme. In comparison between proposed ELRR-PP and conventional

ERR, our proposed ELRR-PP has better or comparable performance when the ERR is vulnerable to a channel capture problems. The work reported in this chapter has been published in the International journal of Advanced Science and Technology [23].

CHAPTER 5
EFFICIENT MOBILITY MANAGEMENT SCHEME OVER WIRELESS LOCAL AREA NETWORK

Introduction

While wireless local area network (WLAN) has been designed and utilized for small area application with limited mobility support, WLAN is gaining attention to support high speed wireless service for wide hotspot area as a part of mobile cellular network such as Universal Mobile Telecommunication system (UMTS) and General packet Radio Service (GPRS) or an independent system.

The mobile Node (MN) can move around among Access Points (AP) which are in the same network without losing current connection because the IEEE 802.11 standard provides a link layer roaming. This process of link layer switch is called L2 hand over and has AP probe, authentication and association phases in IEEE 802.11 based WLAN. However the IEEE 802.11 standard cannot support MN's continuous communication with AP at every time for public user since there are many separate networks which have a unique IP address in wider hot spot area. If the MN moves to an AP which is not in a same network it has to reconfigure its IP address again which makes current connection becomes disabled.

The Mobile Internet Protocol (MIP) supports IP level mobility to provide seamless connectivity to MNs when it moves to another AP which is in a different subnet. The MIPv6 [11] was proposed by the mobile IP working group in Internet Engineering Task Force (IETF) to manage movement of MNs in wireless IPv6 network. In MIPv6 protocol, IP level mobility is provided by binding a Home of Address (HoA) and Care-of Address (CoA) at a Home Agent (HA) and Correspondent Node (CN). When a MN moves to a new Access Router (AR) in different subnet it should obtain a CoA using

Router Advertisement (RA) message from the new AR which is Foreign Agent (FA) in this case and notifies this CoA to the HA and CN to bind the CoA and HoA.

This procedure of network layer switch is called a L3 handover. Packets sent to the MN cannot be delivered until the binding CoA and HoA is finished at HA. So this disruption may degrade the quality of service especially for real time and delay sensitive traffic such as a multimedia streaming and voice over IP (VoIP) service. To improve the handover performance of MIPv6 several schemes have been proposed such as Fast Handover for Mobile IPv6 [12]. To provide the MN's mobility in IPv6 network, the protocol stack of MN is required to be modified for supporting the MIPv6. This modification is too complex considering with limited capacity of the MN and participation of MN in mobility signaling causes increase of power consumption of the MN.

The proxy Mobile IPv6 (PMIPv6) [14] is a network based localized mobility management (NetLMM) protocol which has been proposed by IETF NetLMM working group. In this PMIPv6 the modification of MN's protocol stack is not necessary and MN is not involved in IP mobility related signaling. On behalf of the MN, the network is liable for managing IP mobility. The PMIPv6 guarantees the localized mobility support of MN when MN roams within a local mobility domain region.

Enhanced Handover Scheme of MIPv6 with Fast Movement Detection & DAD

Overview of MobileIPv6 (MIPv6)

The Mobile IPv6 (MIPv6)[11] is a host based mobility management protocol to support global mobility of the MN. The MN uses a permanent HoA and temporary CoA in the MIPv6 protocol. When the MN enters a foreign domain the MN should obtain the new CoA from router advertisement message. After configuration of new CoA Duplicate Address Detection (DAD) procedure is performed. Then the MN registers this CoA with the HA through binding update (BU) message. When the MN moves away from home network the HA works as a stationary proxy.

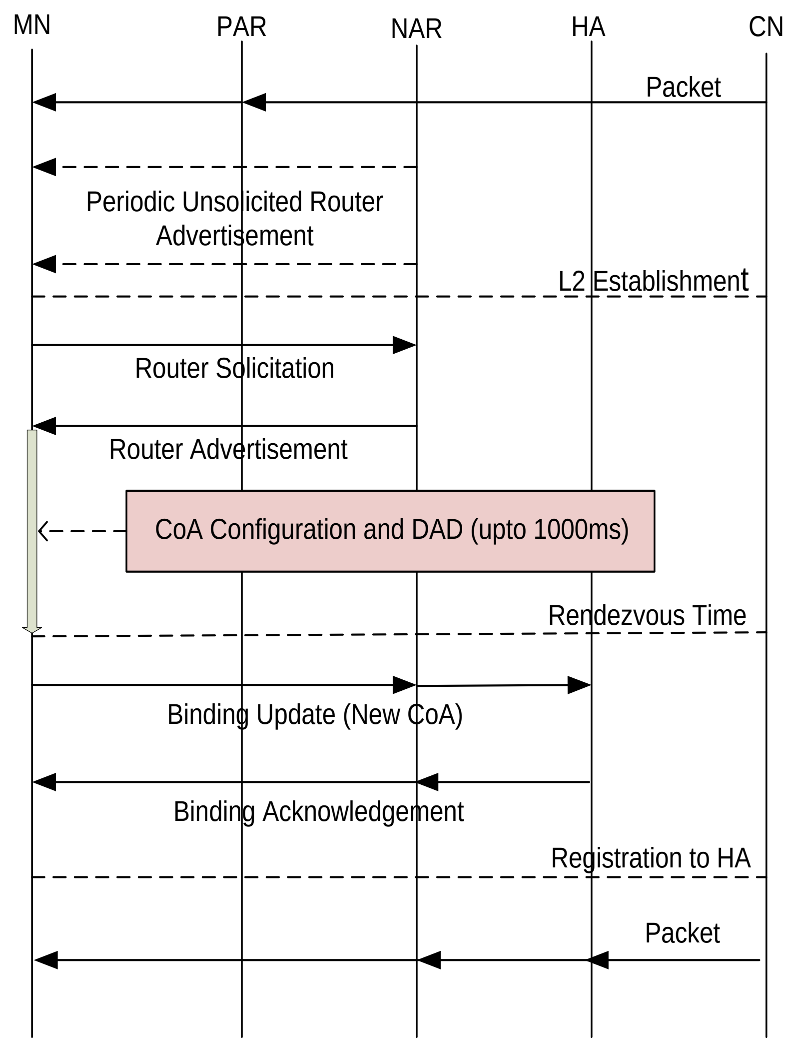


Figure 5-1. Mobile IPv6 handover procedure

The HA intercepts packets destined to the HoA of the MN and forwards these packet by tunnelling to the CoA of the MN. For efficient transmission of packets the Mobile IPv6 has a route optimization scheme. In this scheme the MN sends its new CoA to CN by BU message. After receiving this BU message the CN sends packets to the

MN directly. However packets from CN are delivered to the MN via the HA until the CN receives the new CoA of the MN. Figure 5-1 shows handover procedure of mobile IPv6.

The MIPv6 handover procedure consists of movement detection, new CoA configuration and location update. These procedures cause a long handover latency which can not acceptable for real time multimedia application. In order to improve the handover latency the various extensions of MIPv6 such as fast handover for Mobile IPv6 (FMIPv6) [12] and hierarchical MIPv6 (HMIPv6) [13] have been proposed. Though a lot of enhanced MIPv6 schemes have been reported over the past year the MIPv6 has not deployed widely in practice because of heavy specification which has to be implemented at small mobile node for supporting MIPv6.

Movement Detection Procedure in MIPv6. The primary aim of movement detection is to identify L3 handovers. In MIPv6, movement detection generally uses Neighbor Unreachability Detection to determine when the default router is no longer bi-directionally reachable, in which case an MN must discover a new default router on a new link.

However, this detection only occurs when the MN has packets to send, and in the absence of frequent router advertisements or indications from the link-layer, the MN might become unaware of an L3 handover. After a change of link layer connection the MN must detect any change at the IP layer before it can signal the change to the network. MIPv6 uses RS and RA to detect changes of IP network prefix. This is part of the standard router discovery protocol.

The protocol contains built-in timers, these timers prevent a router from sending immediate responses to RS in order to prevent multiple nodes from transmitting at exactly the same time and to avoid long-range periodic transmissions from synchronizing with each other. These are the significant delays since they interfere with the MIPv6 movement detection algorithm thus preventing mobility signaling for up to 1000ms [11].

Proposed MIPv6 Handover Scheme with FMDD

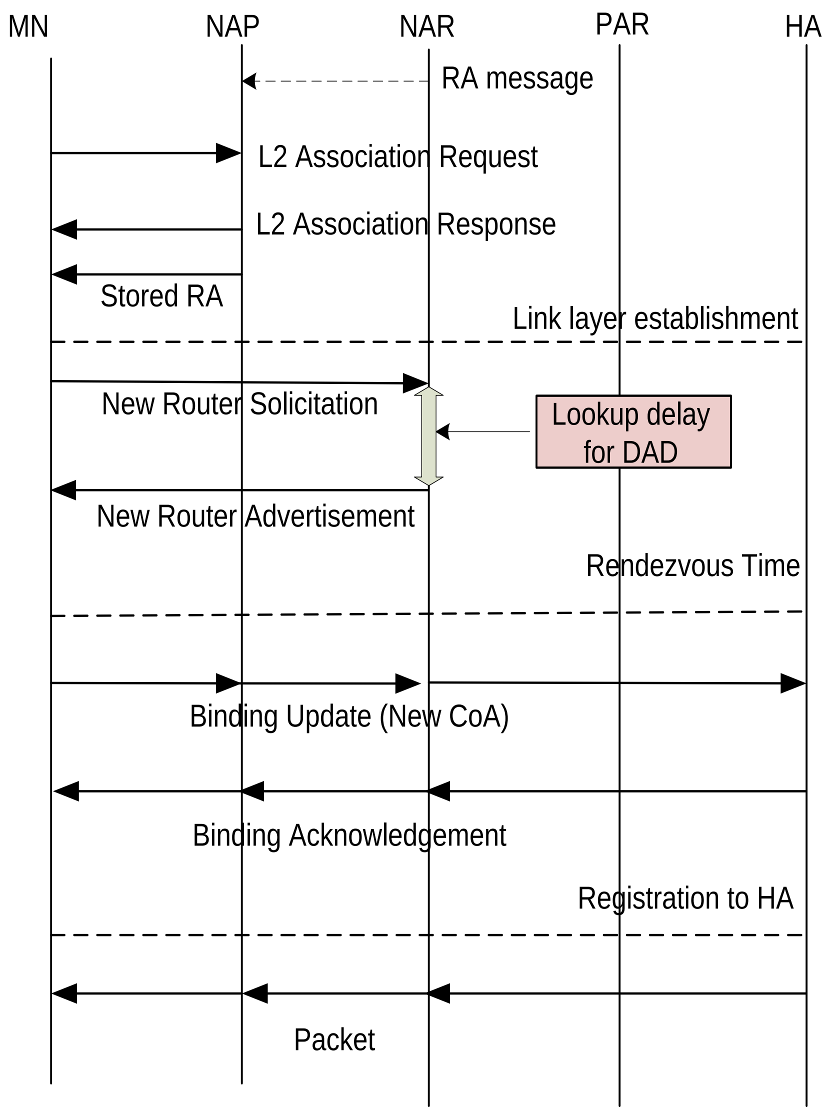


Figure 5-2. Mobile IPv6 handover procedure with FMDD Scheme

Most handover mechanisms for MIPv6 make use of movement detection algorithms, which use received RA information and configuration of new CoA. However, in movement detection, RS delays the transmission for a random amount of time [6]. This time serves to alleviate congestion when many hosts start up on a link at the same time. Also, RA must be delayed by a random amount time. In DAD procedure, after generation of the CoA, an MN has to check CoA's uniqueness [39] [40].

The duration required to complete DAD is up to 1 second. These delays for RS, RA, and DAD are inherent to MIPv6. In this section, we illustrate our proposed fast movement detection and duplicate address detection mechanism for fast handover in MIPv6. Figure 5-2 shows the MIPv6 handover procedure with fast movement detection & DAD (FMDD) scheme.

Movement Detection using Stored RA message

For movement detection, the MN performs a scan to see APs through probes. The result of the scan is a list of AP's information. Authentication is performed, and then the MN sends the (Re) association request message with its MAC address. The AP grants association by sending the Association Response Message. As soon as association is made, the AP sends Stored RA (SRA) to an MN with MAC address in Association Response message [38]. However, in our proposed Movement Detection scheme, when the MN receives the SRA message from an AP during an L2 handover, the MN compares the prefix of the RA message with existing own prefixes in the cache. If the prefix is different, the MN can generate a new care of address (CoA) using the stateless address auto-configuration method and the prefix option allowed in RA messages. Before finishing an L2 handover, the MN sends the RS message by unicast to the new AR using the received SRA's source address included in the Association Response Message. "Unicast" is of great significance since it can reduce the network load and avoid the Random delays attributed to RS and RA.

An MN is able to help smooth proxy handover by adding the new CoA generated by an MN to the RS as an option to provide interoperability with normal nodes. This happens by using a bit in reserved field and notifying the node that follows by the scheme that we offer. We name this bit as the New MN (NMN) and the two options as Previous MN's CoA and previous AR's global address. This modified new RS message is also named as NRS. When the new AR receives the NRS message from an MN, the AR performs DAD as well as movement detection by using the neighbor cache.

DAD configuration and Lookup Algorithm

The proposed DAD method is to use of the neighbor cache of an Access Router (AR) with sufficient buffer size to allow many nodes to attach simultaneously. Firstly, the MN allocates this generated New CoA in its interface without DAD. We need to consider how a neighbor cache and the Neighbor Unreachability Detection procedure perform DAD. As stated [39], a neighbor cache contains one entry for each neighbor to which the node has recently sent messages. Each entry of a neighbor cache may be generated by the RS, the Neighbor Solicitation (NS) or the Unsolicited Neighbor Advertisement (NA) in the case of router. The entries generated in this way are maintained in the state of stale until traffic is sent to the neighbor. Since the neighbor cache has the list of all hosts of the link, which the AR manages, we can compare the entry of the neighbor cache with an MN's MAC address, which is included in each NRS message transmitted from MN to AR. If the addresses of all nodes are generated on the link by stateless auto-configuration, we don't have to consider DAD [40]. However, if the link-local address of a node is changed manually in the middle of use or generated by some exceptional process the ARs cannot maintain the entry of the node in the neighbor cache. We propose that ARs should be able to receive solicited multicast NS messages for normal DAD of exceptional nodes. Since the solicited NS message is sent by multicast, the ARs can receive this message by modification of its interface [40]. The lookup in the neighbor cache on N is the DAD procedure. The DAD consumes an extremely short amount of time, typically a few micro second units, such as Longest Prefix Matching speeds in routing table. The use of neighbor cache for movement detection and DAD gives an additional advantage of obtaining alternative addresses because addresses are managed in the neighbor cache.

If the new AR receives the NRS message from an MN, it can check the entry of the Neighbor Cache for movement detection and DAD. If there is no duplication, an NRS message should also be included in the Neighbor Cache. If not, it must find an alternative address. This alternative address can be chosen in the pre-configured table made by the router. This alternative address is inserted as a new entry in the Neighbor Cache. If this procedure is completed, the AR cans unicast the RA message to the MN's Link-Local Address of the destination address. Certainly this RA can also be modified like the RS message by adding a 2-bit D-flag to the Reserved flag and including the "New MAC address" and "New link-local address" as options in the option field in case of address duplication. We name this new RA message 'NRA'. Table 5-1 defines the D-bits. When an MN receives an NRA the MN has to be operated by D-bits.

Table 5-1. D flag in NRA message

D-flag	Description
00	Must change MAC address (can not apply in IEEE 802.11)
01	Can use the new CoA
10	The new CoA is allocated by other node
11	Cannot used

We denote LD as the address lookup delay, which is the time required to check an MN's MAC address for movement detection and DAD in the Patricia Trie search.

Accordingly the address lookup delay is given as:

$$LD = t_{DA} \times N \tag{5.1}$$

Where t_{DA} is the delay for access and comparison operations in RAM and N is the number of lookups in Patricia Trie. This Patricia Trie has the worst performance in line per minute. We use this algorithm in order to show the lookup time of the worst performance. Under the present circumstance, since a memory access requires from 60 to 100 nsec [41] and a comparison requires 10nsec in DRAM [42], we can use the value of t_{DA} as 70 and 110nsec. In the Patricia Trie case, since lookups require accessing memory 48 times in the worst case, the N value is 48. Hence, LD is 3.36 μsec and 5.28 μsec .The calculated lookup delay is very small.

Efficient PMIPv6 Handover Scheme over Wireless Local Area Network

Overview of Proxy Mobile IPv6 (PMIPv6)

The proxy Mobile IPv6 (PMIPv6) [14] is a network based mobility management protocol to supports localized mobility of the MN in PMIPv6 domain. The Mobile Access Gateway (MAG) and the Local Mobility Anchor (LMA) are main functional constituents of PMIPv6 network.

The MAG performs mobility management on behalf of the MN and it detects the movement of MN and transmits the binding update message to the LMA. The LMA which has functional capabilities of HA as defined in MIPv6 protocol is the topological anchor point for the MN's home network prefix in the PMIPv6 domain. It is responsible for managing the MN's reachability state. The PMIPv6 supports mobility of the MN which does not have MIP function in its protocol stack.

From the help of the MAG and LMN the MN recognizes it is always in the home network whenever the MN roams in the same PMIPv6 domain. Figure 5-3 shows a

PMIPv6 handover process of the MN.

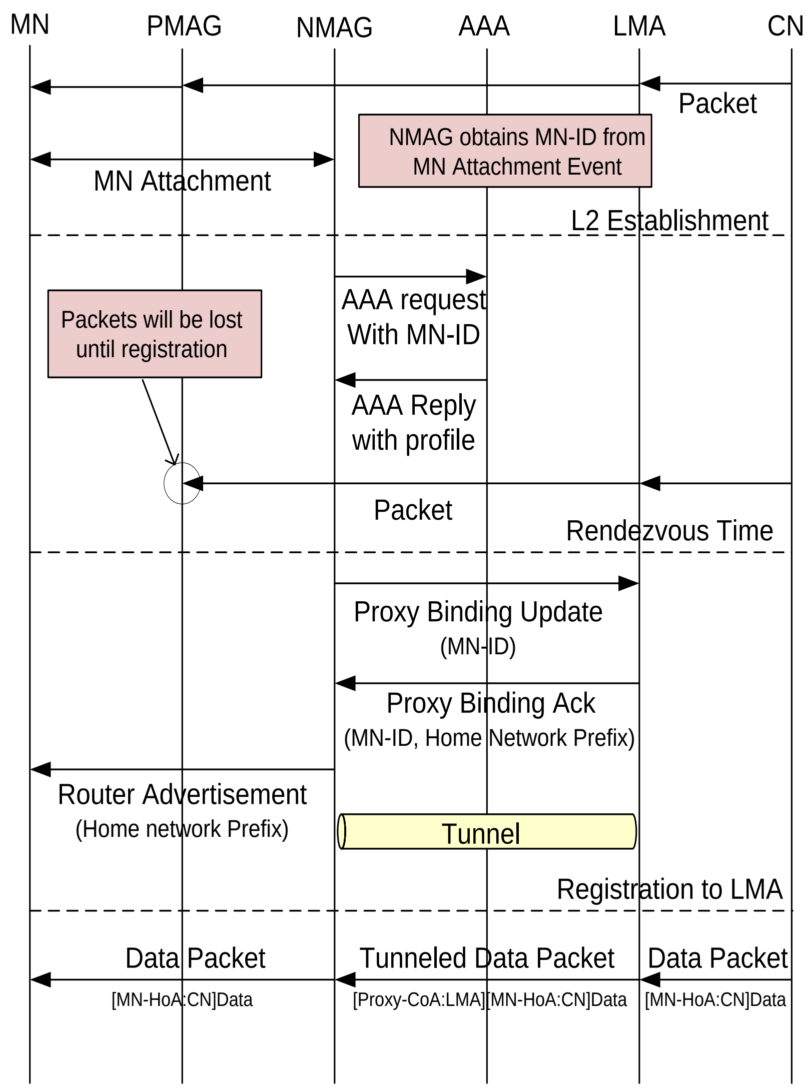


Figure 5-3. PMIPv6 handover procedure

Once the MN enters a region of new MAG (NMAG) the link layer between the MN and the NMAG is established. The MN sends MN-identifier to the NMAG for authentication. Using this identifier the NMAG obtains the MN's policy profile from policy store such as an AAA (Authentication Authorization Accounting) sever. This policy profile has essential parameter like as home network prefix and address configuration mode for providing network based mobility services. The NMAG sends AAA request message to the AAA server then this server performs MN authentication and sends the MN's profile to the MAG. The NMAG sends Proxy Binding Update (PBU) message to the LMA for updating the location of the MN. On receiving the PBU message the LMN establishes a binding between MN's home network prefix and address of MAG's egress interface which is called Proxy care of Address (Proxy–CoA). The LMA sends Proxy Binding Acknowledgement (PBA) message with the MN's home network prefix to the NMAG as a response of the PBU message. By exchange of these messages bidirectional tunnel between the NMAG and the LMA is established. Then the NMAG send Router Advertisement (RA) message which has MN's home network prefix. In the same PMIPv6 domain the MN receives same home network prefix by RA message. So the MN can recognize it stays at the home network.

Proposed PMIPv6 protocol 1

In this section we propose an efficient network based handover scheme on IEEE 802.11 network without changing mobility stack in IEEE802.11 based Mobile node for reducing handover latency. The MN does not need to transmit or receive any management packet to support IP mobility. The same terminology with PMIPv6 is used and MN's localized mobility is considered.

Our assumption of this proposed scheme is that AP can send information of the MN to the MAG directly and place some information in a management packet like a beacon signal. Also we introduce a new signal between NMAG and PMAG.

L2 Handover Procedure

The link layer handover of IEEE 802.11standard has typically three distinct phases: discovery, authentication and reassociation [24]. The MN scans wireless medium to obtain information of APs. From this information the MN selects a candidate AP to establish a new radio link base on the strength of received signal from APs. The MN can broadcast probe request message to get probe reply from AP or wait passively the periodic beacon signal from AP for this purpose.

In this proposed scheme a MAG notifies its address periodically to own APs which are connected directly with the MAG. These APs have a distinct buffer only for an address of the MAG. The AP stores recently received MAG's address periodically in this buffer and puts this address into flexible frame body of periodic beacon message.

A MN measures the strength of signal from neighboring APs and initiates a L2 handover when the strength of beacon signal from the new AP is bigger than that of current AP. From the beacon message the MN knows an address of MAG connected with new AP. If the address of MAG connected with new AP is not changed comparing with that of old AP, the MN needs to do just a L2 handover. Otherwise the MN has to do not only a L2 handover but also a L3 handover. After authentication is made the MN sends reassociation request message to new AP with MN's ID which is a MAC address in IEEE802.11 WLAN and previous AP (PAP)'s address. The AP grants association by transmitting the reassociation response message.

L3 Handover Procedure

In our proposed handover scheme, L3 hand over procedure is performed with L2 handover simultaneously. Figure 5-4 shows proposed handover procedure.

After discover and authentication phase the MN sends reassociation request message to a new AP (NAP) and the NAP delivers this packet to a New MAG (NMAG) to notify attachment of a new mobile node and its information like a MN-identifier and the PAP address. Then the NMAG requests MN's profile by sending AAA request message to the policy store like AAA server. The MN-Identifier is used for this process.

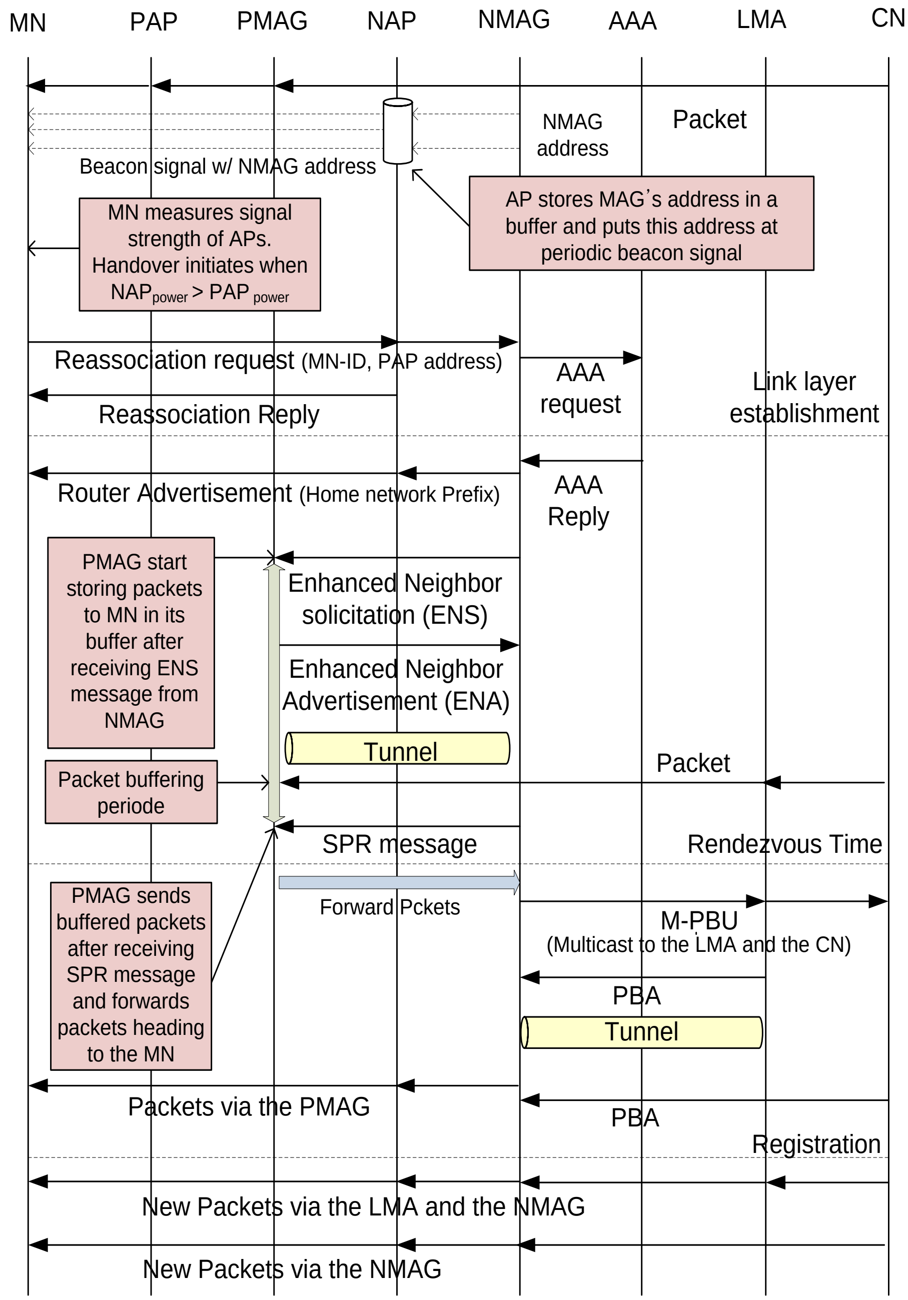


Figure 5-4. Proposed PMIPv6 handover procedure

The AAA server returns MN's profile by AAA reply message. This policy profile contains MN's home network prefix. The NMAG informs NAP of MN's home network prefix information by Router Advertisement message

Based on this information the NMAG notifies the PMAG that the MN are moving from the PMAG and asks to establish a tunnel from the PMAG to the NMAG using Neighbour Discovery (ND) procedure defined in IPv6 protocol [25].

In this ND procedure enhanced neighbour solicitation message (ENS) and enhanced neighbour advertisement (ENA) message are used. The ENS message can be made by adding 2-bits H flag at reserved field and adding the MN's home network prefix and MN-Identifier at option field in neighbor solicitation message frame. Explanation of the 2-bits H flag is described in Table 5-2.

Table 5-2. H flag of ENS message

H-flag	Description
00	MN's home network prefix and Identifier are not included in the ENS message
01	Only MN's Identifier is included in the ENS message
10	Only MN's home network prefix is included in this ENS message
11	MN's home network prefix and Identifier are included in ENS message

By sending the ENS message to the PMAG, the NMAG informs the PMAG of home network prefix and MN-Identifier of MN which has moved to the NMAG and requests the PMAG to perform the L3 handover procedure. If the H-flag in ENS message is “11” the PMAG starts to store packets heading to the MN in its buffer during handover procedure and prepares to establish a tunnel between the PMAG and the NMAG. If the PMAG cannot obtain both of the MN's home network prefix and identifier from ENS message, these procedures for efficient and reliable handover are not performed. The PMAG sends ENA message as an acknowledgment to the NMAG.

Similarly with ENS, ENA message contains 2-bit A flag at reserved field and it can also include MN's home network prefix and MN-Identifier at option field. Frame format of

ENA is same with that of the neighbour advertisement message except A flag. Explanation of the 2-bits A flag is described in Table 5-3. With ENA with 11 A-flag from the PMAG, the NMAG knows the PMAG starts to do the L3 handover procedure and establishes a tunnel between the PMAG and NMAG.

Table 5-3. A flag of END message

A-flag	Description
00	Negative acknowledgement of ENS message because of absence of the MN's home network prefix and Identifier
01	Negative acknowledgement of ENS message because of absence of the MN's home network prefix
10	Negative acknowledgement of ENS message because of absence of the MN's Identifier
11	Positive acknowledgement of ENS message

After finishing tunnel setup the NMAG sends stored packet request (SPR) message to ask the PMAG to send stored packets heading to the MN in its buffer to the NMAG if the NMAG is ready for receiving packet. After receiving this message the PMAG does not store packets but forwards packets heading to the MN to the NMAG. This SPR message is introduced to support more efficient communication between PMAG and NMAG. If the NMAG receives packet from the CN via the PMAG the NMAG sends multicast proxy binding update (M-PBU) message to the LMA and the CN for registering MN's information. Then both the LMA and the CN returns proxy binding acknowledgment (PBA) message to NMAG and the LMA sets a bidirectional tunnel between the NMAG and LMA. This multicast proxy binding update (M-PBU) message can make the CN choose efficient route and avoid the triangle problem. After sending M-PBU message the NMAG forwards packets from the PMAG to the MN. After finishing registration of the MN at the LMN and the CN, packets from CN are delivered to the MN via the LMA and the NMAG or via just the NMAG.

Proposed PMIPv6 Protocol 2

In this section a new scheme for PMIPv6 protocol over IEEE 802.11 network to reduce signalling over head cost with help of IAAP (Inter Access Point protocol). In original PMIP protocol the MAG should obtain the MN's profile from the policy store and check the binding information of the MN after L2 handover completion though the MN still stays in the same MAG area. This useless signalling caused by just L2 handover is significant in the host based mobility management protocol. Our proposed scheme make the MAG know whether the MN is moved from the new MAG or not after the MN is attached to AP. Then no signalling overhead for the obtaining the MN's profile and checking the binding information occurs in the just L2 handover case. The MN is not involved in the any signalling for supporting IP mobility. The same terminology with PMIPv6 is used and MN's localized mobility is considered. We also consider all APs use IAPP defined in IEEE 802.11f[25].

We assume the MAG knows all information which the APs receive simultaneously and these APs know the IP address of the MAG. The MAG sends its address periodically to APs that are connected directly with it. These APs have a distinct buffer that is available only for the address of the MAG. In IEEE 802.11 standard, the handover has typically three distinct phases: discovery, authentication and association. After discover and authentication procedure, a MN send reassociation request message to new AP with previous AP's MAC address. We just consider signals between APs in this paper. Upon receiving reassociation request message new AP starts to communicate with previous AP with IAPP. The new AP send IAPP MOVE notify packet to the old AP. Then the old AP transmits an IAPP MOVE response packet to the new AP.

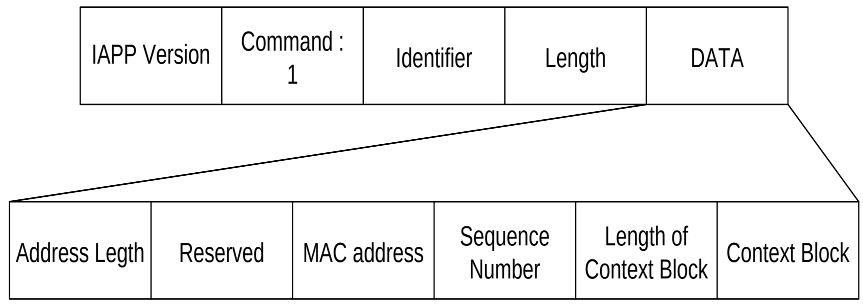


Figure 5-5. IAPP MOVE notify packet format

As shown in Figure 5-5 Move notify message has 8 Reserved bits[25]. We define 1-bit A flag to ask old AP to inform address of MAG which is connected with the old AP with IAPP MOVE respond packet. If A flag is “1” the old AP is requested to send MAG’s address. If A flag is “0” this packet works as a normal MOVE notify message.

Upon receiving MOVE notify packet with “1” A-flag from the new AP, the old AP puts current MAG’s address in context block of MOVE response packet and return it to the new AP. Then the new AP transmits this MOVE response packet to the MAG and reassociation response message to the MN. The MAG checks the address of MAG connected with old AP in context block. If the address of MAG in MOVE response message is different with that of current MAG the MAG recognizes that the MN moved from other MAG region and performs L3 handover procedure. If the address of MAG in MOVE response message is same with that of current MAG the MN performed just L2 handover so no L3 procedures are necessary. Figure 5-5 shows handover procedure of proposed scheme. In this figure PAP and NAP are in the same MAG1 region otherwise NAP2 is in the MAG2 region.

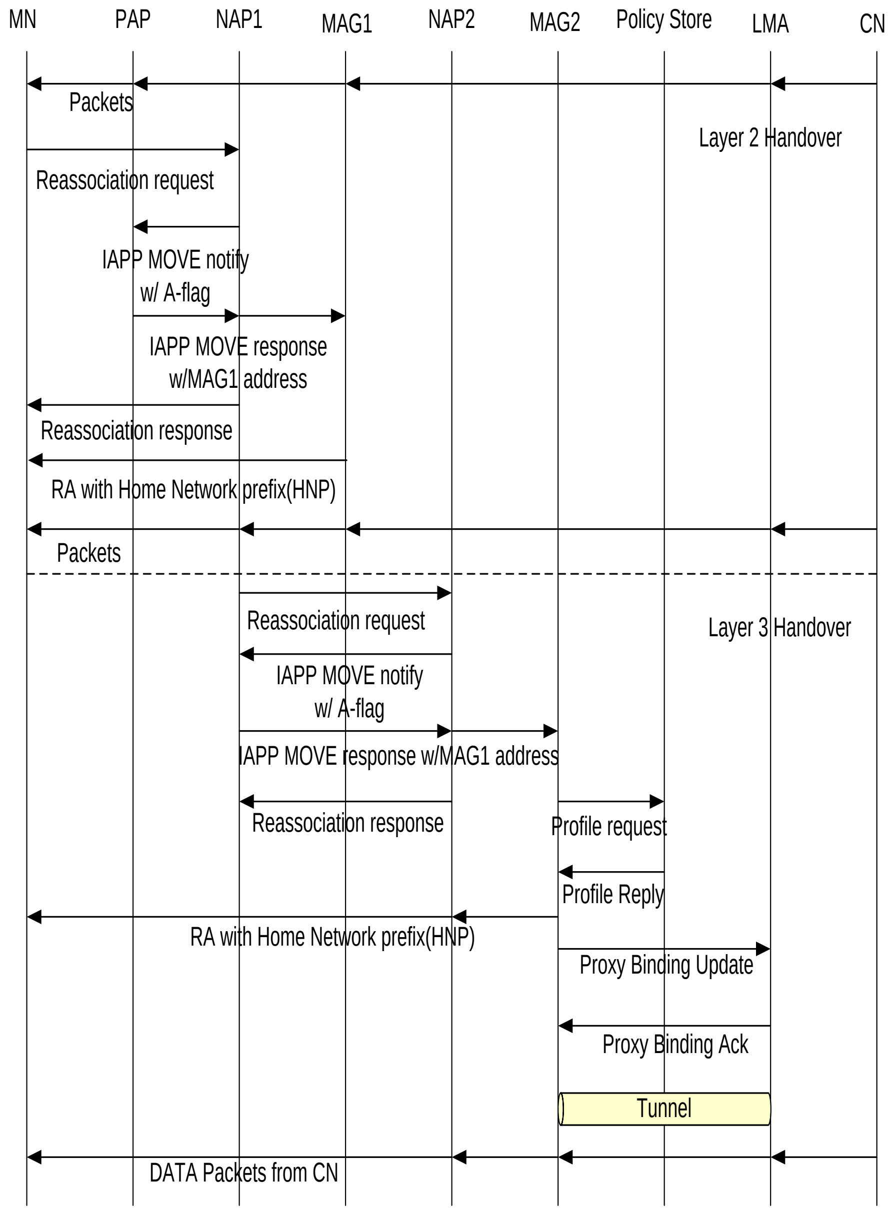


Figure 5-6. The proposed PMIPv6 scheme over IEEE 802.11 network.

Analytical model

We will explain system and user mobility model used in this paper. A common hexagonal cellular network configuration is used in this paper as shown in Figure 5-7. We assume each hexagonal cell is an AP area and every cell has same shape and size. A subnet served by AR/MAG is composed of several layers of cell. The innermost cell is called layer “0” which is surrounded by a layer“1”. And the layer “1” is surrounded by layer “2” and so on. If an outermost layer of a subnet is layer”n-1” this subnet is called “n” layer subnet. A layer i has 6i cells where i>0 and an “n” layer subnet has $3n^2$-3n+1 cells. Also, it is assumed in this analysis that every subnet has same number of layers.

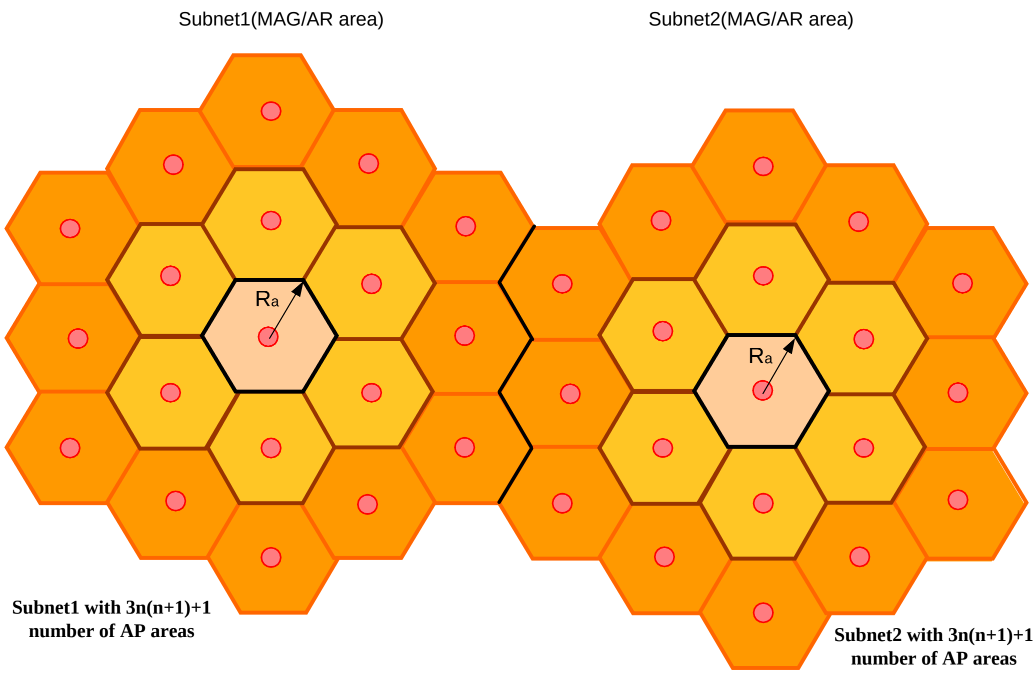


Figure 5-7. Network Configuration

The Domain is composed of several subnets with same manner of subnet composition. We define AP area radius R_a for hexagonal cell as the distance from centre to the vertex of cell. To calculate mean AP area/subnet residence time the hexagonal AP area is approximated by a circle which has same area [35]. The radius of approximating circle for AP area is

$$R_0=\sqrt{\frac{3\sqrt{3}}{2\pi}}R_a \cong 0.91R_a \quad (5.2)$$

The radius of approximating circle for n-layer subnet can be expressed as below

$$R_n = \sqrt{\frac{3\sqrt{3}}{2\pi}(3n^2 - 3n + 1)}\ R_a \qquad (5.3)$$

With a difference with other analysis of mobile IP network [28][31][32], cell area and MN's velocity is considered for a factor of mean AP area and subnet residence time in this mobility analysis. We assume MNs are uniformly distributed in the network and the average velocity of an MN is same in all AP areas and subnets. MNs move in strait line with direction uniformly distributed between [0,2π).

The cell crossing time is just considered as the AP area/subnet residence time for simple analysis. From [34] the mean AP area residence time (μ_a) and mean subnet residence time (μ_s) can be derived as follows:

$$\mu_a = \frac{\pi R_0}{2v} \qquad (5.4)$$

$$\mu_s = \frac{\pi R_n}{2v} \qquad (5.5)$$

Where R_o and R_n are radius of approximating circle for AP area and n-layer subnet respectively. v is an average velocity of the MN.

To obtain the MN's average number of crossing AP areas/subnets we derive the probability α(K), wherein MN moves cross K cells between two sessions. We assume incoming sessions follow the Poisson process. Let t_c be session inter arrival time which is the time interval between two sessions and t_a, t_s be a random variable of the AP area residence time and subnet residence time respectively. Let $f_c(t)$, $f_a(t)$ and $f_s(t)$ be the probability density function of t_c , t_a and t_s respectively. $f_a(t)$ and $f_s(t)$ are the general probability density function. Because incoming session are Poisson process, $f_c(t)$ it is expressed as

$$f_c(t) = \lambda_c\, e^{-\lambda_c t}$$
$$E[t_c] = \frac{1}{\lambda_c} \tag{5.6}$$

where λ_c is session arrival rate.

With these parameters we can derive the probabilities $\alpha_a(J)$ and $\alpha_s(k)$ wherein MN crosses J AP areas and K subnets respectively during a session inter arrival time t_c ,as follows [36]:

$$\alpha_a(J) = \begin{cases} 1 - \frac{\lambda_a}{\lambda_c}[1 - f_a^*(\lambda_c)] & J = 0 \\ \frac{\lambda_a}{\lambda_c}[1 - f_a^*(\lambda_c)]^2 [f_a^*(\lambda_c)]^{J-1} & J > 0 \end{cases} \tag{5.7}$$

$$\alpha_s(K) = \begin{cases} 1 - \frac{\lambda_s}{\lambda_c}[1 - f_s^*(\lambda_c)] & \mathrm{K} = 0 \\ \frac{\lambda_s}{\lambda_c}[1 - f_s^*(\lambda_c)]^2 [f_s^*(\lambda_c)]^{K-1} & K > 0 \end{cases} \tag{5.8}$$

where $f_a^*(s)$ and $f_s^*(s)$ is the Laplace transform of $f_a(t)$ and $f_s(t)$ respectively.

For simplicity of analysis, we assumed that the AP residence time t_a and the subnet residence time t_s follow exponential distribution with parameter λ_a $(1/\mu_a)$ and λ_s $(1/\mu_s)$ respectively [28]. The Laplace transform of $f_a(t)$ and $f_s(t)$ is expressed as

$$f_a^*(s) = \frac{\lambda_a}{s + \lambda_a} \tag{5.9}$$

$$f_s^*(s) = \frac{\lambda_s}{s + \lambda_s} . \tag{5.10}$$

From (5.6)-(5.10), We have

$$\alpha_a(J) = \frac{\lambda_c}{\lambda_c + \lambda_a}\left(\frac{\lambda_a}{\lambda_c + \lambda_a}\right)^J \qquad J \geq 0. \tag{5.11}$$

$$\alpha_s(K) = \frac{\lambda_c}{\lambda_c+\lambda_s}\left(\frac{\lambda_s}{\lambda_c+\lambda_s}\right)^K \qquad K \geq 0 \tag{5.12}$$

From (5.11)-(5.12), We can easily derived the MN's average number of crossing AP areas ($E(N_a)$) and subnets ($E(N_s)$) as follows:

$$E(N_a) = \sum_{J=0}^{\infty} J\alpha_a(J) = \frac{\lambda_a}{\lambda_c} \tag{5.13}$$

$$E(N_s) = \sum_{K=0}^{\infty} K\alpha_s(K) = \frac{\lambda_s}{\lambda_c} \tag{5.14}$$

Since an MN which crosses AR/MAG coverage area also crosses AP area simultaneously we can obtain the MN's average number of crossing AP areas when the MN still stays in the same AR/MAG coverage area ($E(N_l)$) as:

$$E(N_l)=E(N_a)-E(N_s)=\frac{\lambda_a-\lambda_s}{\lambda_c} \tag{5.15}$$

Performance Analysis

The performance of the MIPv6 with FMDD and proposed PMIPv6 scheme1 are evacuated in the terms of the handover latency and packet loss. The proposed PMIPv6 scheme 2 is evaluated in the terms of signalling cost. For comparison conventional MIPv6 and PMIPv6 protocols are analyzed as well. We do not consider any security scheme in both host and network based MIP protocols.

However the procedure of obtaining the MN's profile from the policy store like AAA server is necessary in network based MIP protocol to make the MN feel in the home network. Also we just consider intra domain handover for network based MIP protocol in this analysis. The parameters used in the analysis are shown in Table 5-4.

Table 5-4. Parameters

Symbol	Description
$T_{X\text{-}Y}$	Transmission delay between node X and Y
$d_{X\text{-}Y}$	Average number of hops between node X and Y
B_w	Bandwidth of the wired link
B_{wl}	Bandwidth of the wireless link
L_w	Latency of the wired link
L_{wl}	Latency of the wireless link
$C_{X\text{-}Y}$	Transmission cost of packet between node X and Y
PC_X	Processing cost in node X
ε	Unit transmission cost over wired link
κ	Unit transmission cost over wireless link

Analysis of Handover Latency and Packet Loss

The handover latency is defined as an interval from the time the MN has lost L2 connection with previous AP until the time the MN receives the first packet delivered from CN in this analysis. The handover latency consists of the L2 handover latency (T_{L2}) and L3 handover latency (T_{L3}). Therefore the total handover latency (HL) can be given :

$$HL = E(N_a)T_{L2} + E(N_s)T_{L3} \tag{5.16}$$

The L2 handover is composed of 3 procedures as discovery, authentication and reassociation in IEEE 802.11standard [24]. In discovery procedure two types of scanning are exist: active and passive scanning. In active scanning the MN try to find a candidate AP with sending probe request message to neighbouring APs. In passive mode scanning the MN listens to periodic beacon from neighbouring APs [27]. This latency for finding candidate AP is called probe delay (T_{scan}) which consumes almost L2 handover latency. The average L2 handover latency varies about 40-400ms [27]. If the MN has selected an AP to move the MN sends authentication request message to the AP and receives authentication response message from the AP. This process is called authentication and the latency for this process is called authentication delay ($T_{auth.}$).

After authentication the MN sends reassociation request message to the AP and receives reassociation response message and then L2 handover is completed. This procedure is called reassociation and the duration of this procedure is called reassociation delay (T_{reas}). The L2 handover latency T_{L2} can be expressed as:

$$T_{L2} = T_{scan} + T_{auth} + T_{reas} \tag{5.17}$$

We assume passive scanning is used and the MN listens beacon message from 3 neighbour APs. If the APs are configured only on channel 1,6 and 11 and the beacon interval is 10 msec as describe in [26], the probe delay T_{scan} is 90 msec. We define the authentication delay and reassociation delay as the round trip time of IEEE 802.11 control packet between the MN and AP, $2T_{MN\text{-}AP}(sl)$. The one-way transmission delay between nodes X and Y for a message of size s via one hope wireless and $d_{X\text{-}Y}$ -1 hops wired links is expressed as follows:

$$T_{X\text{-}Y}(s) = \left(\frac{sl}{B_{wl}} + L_{wl}\right) + (d_{X\text{-}Y} - 1) \times \left(\frac{sp}{B_w} + L_w\right) + d_{X\text{-}Y}\, p \tag{5.18}$$

where p is average processing delay of each node.

The size of IEEE 802.11 control packet and IP mobility management packet is “sl” and “sp” respectively. For simplicity of the analysis we assume network is symmetric and all the IEEE 802.11 control packets have same size. Also the size of control packets for IP mobility management is same in this analysis.

Mobile IPv6.

The IP handover latency (T_{L3}) of Mobile IPv6 protocol can be composed of Movement detection latency(T_{MD}), address configuration latency ($T_{add.}$) and location update latency (T_U) as shown in Figure 5-8 [20].

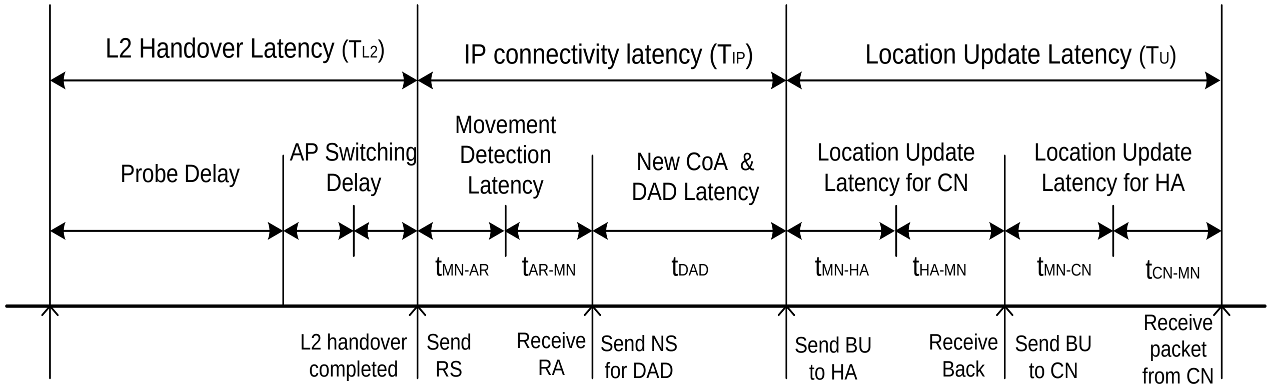


Figure 5-8. Timing diagram of MIPv6

In movement detection procedure the MN sends RS message right after L2 handover completion and receives RA message from the AR. Then T_{MD} is same with $2T_{MN\text{-}AR}(sp)$. After movement detection the MN obtains a new CoA. If we assume all MNs obtain a CoA by means of stateful address autoconfiguration and DAD procedure is not necessary in the analysis. The address configuration latency, $T_{add.}$ can be roundtrip time between the MN and DHCP server, $2T_{MN\text{-}DHCP}$ (sp). If we assume all MNs obtain a CoA by means of stateless address the address configuration latency, $T_{add.}$ can be the delay for DAD procedure T_{DAD} (1s). With Fast movement detection & DAD (FMDD) scheme the address configuration latency, T_{add} can be a just look up delay in neighbour cache of AR.

Then MN registers its location at HA and CN. Therefore the total handover latency of MIP protocol with DHCP server can be expressed as follows:

$$HL(MIP) = E(N_a)[T_{L2}] + E(N_s)[T_{L3}] \qquad (5.19)$$

where $T_{L2} = T_{scan} + 4T_{MN\text{-}AP}(sl)$ and $T_{L3} = 2T_{MN\text{-}AR}(sp) + T_{add.} + T_{MN\text{-}CN}(sp) + T_{CN\text{-}MN}(sd)$. The sd is size of data packet.

Since there are no special scheme to protect packet loss under ongoing handover in MIPv6 protocol packets sent to the MN are lost during the handover latency. The number of packet loss is proportional with handover latency. So the total number of packet loss can be given as:

$$PL(MIP) = \lambda_p HL(MIP) \qquad (5.20)$$

where λ_p is average packet arrival rate.

Proxy Mobile IPv6

Unlike the host based mobility management protocol, PMIP does not need to perform the movement detection procedure. However the procedure for obtaining policy profile of the MN is inevitable in network based MIP protocol.

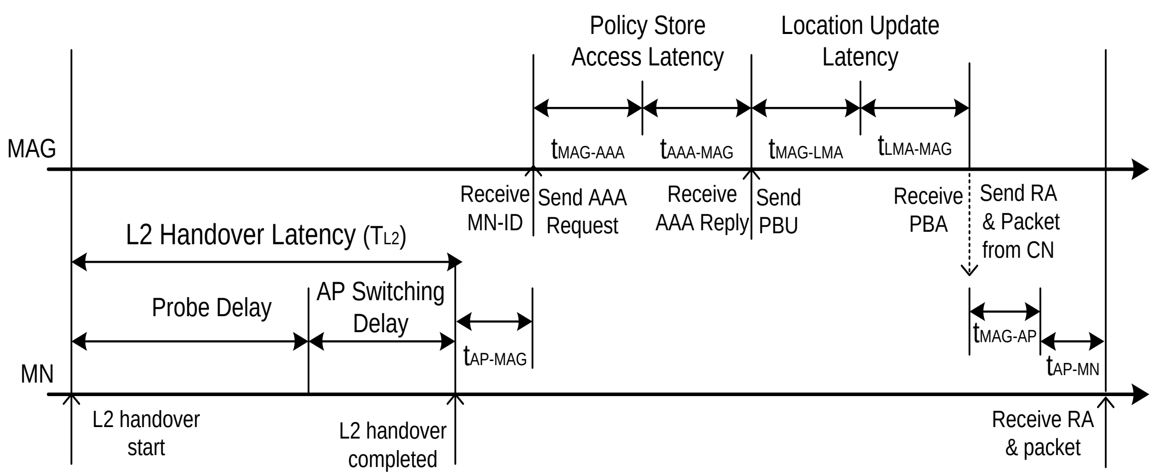


Figure 5-9. Timing diagram of PMIPv6

The MAG gets the MN's profile from the policy store like AAA server then it can send RA message with same home prefix to the MN. Therefore the MN believes it is always on the home domain. The delay for obtaining profile is $2T_{MAG\text{-}AAA}(sp)$. After the MAG has the MN's profile the MAG performs location update to the LMA. The MAG sends PBU message to the LMA then the LMA sends PBA message and data packet to the MAG. The total handover latency of PMIPv6 can be given as follows:

$$HL(PMIP) = E(N_a)[T_{L2}] + E(N_s)[T_{L3}] \qquad (5.21)$$

where $T_{L2} = T_{scan} + 4T_{MN\text{-}AP}(sl)$ and $T_{L3} = 2T_{MAG\text{-}AAA}(sp) + T_{MAG\text{-}LMA}(sp) + T_{LMA\text{-}MAG}(sd) + T_{MAG\text{-}MN}(sd)$

Since the PMIP protocol does not support any packet loss protection scheme the number of packet loss is given as:

$$PL(PMIP) = \lambda_p HL(PMIP) \tag{5.22}$$

Proposed PMIPv6 Protocol 1

In Figure 5-10 the timing diagram of our proposed scheme is illustrated. The NMAG obtains the MN's profile by MN-ID from reassociation request message at L2 handover procedure. After receiving the MN's profile the NMAG sends RA to the MN with home prefix in profile and asks PMAG to establish tunnel by sending ENS message simultaneously.

The PMAG replies with ENA message and starts forwarding packets to the NMAG after receiving SPR message. Then the MN can receive packets from the NMAG via the PMAG. The MN can receive packets from CN not via the PMAG after location update to the LMA. The weight of packet transmission delay (τ=1.2) by tunnel is used in the analysis. The total handover latency of our proposed PMIP protocol can be expressed as follows:

$$HL\ (P\text{-}PMIP1) = E\ (N_a)\ [T_{L2}] + E\ (N_s)\ [T_{L3} - T_{reas}] \tag{5.23}$$

where $T_{L2} = T_{scan} + 4T_{MN\text{-}AP}(sl)$ and $T_{L3} = T_{MN\text{-}NMAG}(sl) + 2T_{NMAG\text{-}AAA}(sp) + 3T_{NMAG\text{-}PMAG}(sp) + \tau T_{PMAG\text{-}NMAG}(sd) + T_{NMAG\text{-}MN}(sd)$

After receiving the ENS message from the NMAG the PMAG starts to store packets heading to the MN. So packets are not lost from this point. The number of packet loss is given as:

$$PL\ (P\text{-}PMIP1) = \lambda p\ \{E\ (N_a)\ [T_{L2}] + E\ (N_s)\ [T_{Loss} - T_{reas}]\} \tag{5.24}$$

where $T_{L2} = T_{scan} + 4T_{MN\text{-}AP}(sl)$ and $T_{Loss} = T_{MN\text{-}NMAG}(sl) + 2T_{NMAG\text{-}AAA}(sp) + T_{NMAG\text{-}PMAG}(sp)$

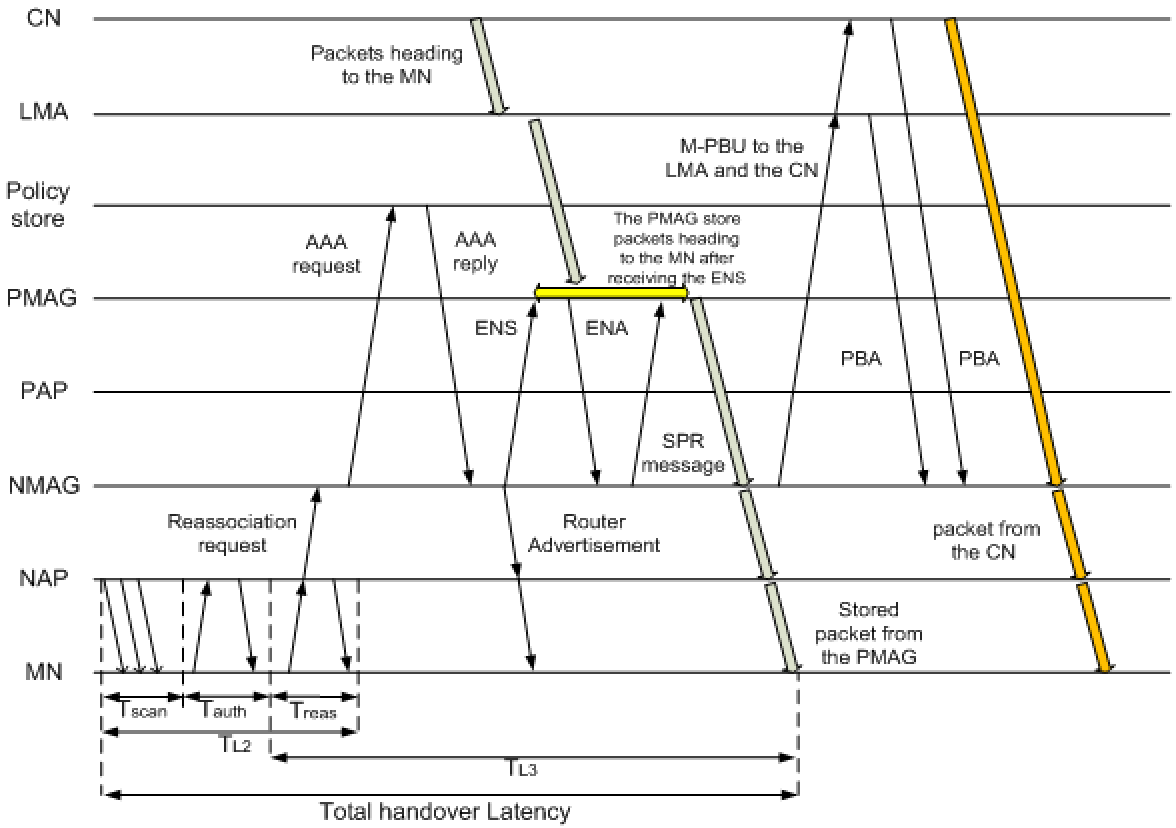


Figure 5-10. Timing diagram of proposed scheme1

Analysis of Signaling Cost

The signalling cost is composed of the signalling cost caused by inter-AP roaming with staying in the same AR/MAG area (C_A) and by inter-AR/MAG roaming (C_S). Then the total signalling cost C_T can be expressed as:

$$C_T = E(N_I)C_A + E(N_s)C_S \qquad (5.25)$$

The inter AP roaming can cause the inter AR/MAG area roaming but not always cause it. If the MN crosses the AP area within the same AR/MAG area the IP configuration and location update procedures are not necessary. However the MN in host based MIP and the MAG in network based MIP do not know whether the location update is needed or not although the MN just performs L2 handover.

In host based MIP protocol the MN knows whether it is in the same AR coverage area by receiving RA message from the AR after crossing an AP area. This procedure is called movement detection. We assume the MN sends RS rather than just waits the RA message right after L2 handover. This movement detection procedure is also performed in just L2 handover case and same in host based MIP protocols except the FMIP. In FMIP protocol the MN communicates with AR before crossing the AP area to get information of the candidate AR. The impact of inter AP handover in host based MIP protocols are well analyzed in [37].

In network based MIP protocol, PMIP, the movement detection of the MN is not necessary within same domain. The MN recognizes it always stays in the same MAG coverage area. However the MAG has to do location update of MN to the LMA if the MN has been moved from the other MAG area. So the MAG has to obtain the MN's profile from policy store by MN-ID. With the MN's home network prefix the MAG checks whether the MN needs location update or not then sends the RA message to the MN in just L2 handover case. However the MAG cannot know whether the MN moves from the same MAG region or not the MAG performs L3 handover procedures in just L2 handover case.

In this analysis we just consider signalling cost for L3 handover because L2 handover procedures are same in every protocol. The cost by inter AP roaming with staying in the same AR/MAG area, C_A is composed of the cost by the procedure until receiving RA after L2 handover.

The packet transmission cost is proportional to the hop distance and packet size. We use packet size ratio η (transmitting packet size/sl) instead of real packet size. The transmission cost of IEEE802.11 control packet between the X and Y via a wired link can be expressed as $C_{X\text{-}Y} = \eta\varepsilon d_{X\text{-}Y}$ where ε is the unit transmission cost over wired link. We use κ as the unit transmission cost over wireless link and the κ is generally larger than ε.

The cost by crossing AR/MAG area, C_S is composed of the binding update cost (C_B) and packet delivery cost (C_P). Then C_S is expressed as:

$$C_S = C_B + C_P \tag{5.26}$$

The control message for IP mobility management such as RA and BU causes binding update cost C_B. The packet delivery cost C_P is induced by data packet transmission in handover procedure during ongoing session. The costs of forwarded packet ($C_{forward}$) and lost packet (C_{loss}) are considered for the packet delivery cost and the C_P can be calculated as follows:

$$C_P = \alpha C_{forward} + \beta C_{loss} \tag{5.27}$$

Where α and β are weighting factors and the sum of α and β is 1.

Mobile IPv6 Protocol

The movement detection procedure is always performed after L2 handover in both case of L2 and L3 handover. Otherwise the IP configuration, DAD and location update procedures are required only for L3 handover . We assume the MN sends RS and receives RA from the AR in MIP. The cost by inter AP roaming with staying in the same AR/MAG area, C_A is given by :

$$C_A(MIP) = 2\eta_p C_{MN\text{-}AR} + PC_{AR} + PC_{MN} \tag{5.28}$$

where $\eta_p = sp/sl$.

The binding update cost C_B are given by :

$$C_B(MIP) = 2\,\eta_P\,(C_{MN\text{-}AR} + C_{MN\text{-}HA} + N_{CN}C_{MN\text{-}CN}) + \eta_P\,\omega C_{MN\text{-}AR} + 2PC_{AR} + PC_{HA} + N_{CN}PC_{CN} \quad (5.29)$$

where ω is the weighting factor for multicast transmission of NS in DAD procedure. We define the number of CN, N_{CN} is the number of active MNs and PC is process cost of node.

$$N_{CN} = \gamma\rho 2\sqrt{3}R_0^2 \times \left(3n^2+3n+1\right)m \quad (5.30)$$

where ρ is density of MN in AP area and m is number of AR in the domain in the n layer subnet. The γ is ratio of active MNs to total number of MNs in AR area [31].

In MIPv6 there is no forwarding scheme during handover then the packet delivery cost, C_P is induced by just packet loss and given as follows:

$$C_P(MIP) = \eta_d\,(C_{CN\text{-}PAR} + C_{PAR\text{-}MN}) \times \lambda_p\,HL(MIP) \quad (5.31)$$

where η_d = sd/sl.

Proxy Mobile IPv6 protocol

The MN in network based MIP does not required to participate in any IP mobility management procedure. After L2 handover the MN does not send any signal on the other hand the MAG should obtain the MN’s profile from policy store using MN-ID, MAC address in IEEE802.11 standard from L2 attachment and sends RA message to the MN in both case of inter AP roaming and inter MAG roaming. The location update procedure is required for just inter MAG roaming. The cost by inter AP roaming with staying in the same MAG area, C_A is given by:

$$C_A(PMIP) = C_{AP\text{-}MAG} + \eta_P\,(2C_{MAG\text{-}PS} + 2C_{MAG\text{-}LMA} + C_{MAG\text{-}MN}) + 3PC_{MAG} + PC_{PS} + PC_{LMA} \quad (5.32)$$

The binding update cost C_B are given by :

$$C_B(PMIP) = C_{AP\text{-}MAG} + \eta_P\,(2C_{MAG\text{-}PS} + 2C_{MAG\text{-}LMA} + C_{MAG\text{-}MN}) + 3PC_{MAG} + PC_{PS} + PC_{LMA} \quad (5.33)$$

Since the PMIPv6 has no forwarding scheme during handover the packet delivery cost is just induced by packet loss. The packet delivery cost C_P is

$$C_P(PMIP) = \eta_d\,(C_{CN\text{-}LMA} + C_{LMA\text{-}PMAG} + C_{PMAG\text{-}MN})\,\lambda_p\,HL(PMIP) \quad . \quad (5.34)$$

Proposed PMIPv6 Protocol 2

In the proposed PMIP we assume all APs use IAPP. Using this IAPP new AP can get an address of the MAG which is connected with the old AP. The new AP sends this information to the MAG then the MAG can recognize that the MN performs L2 or L3 handover. So the signalling for obtaining the MN's profile and sending RA message does not occur in the just inter AP roaming case. And L3 handover signalling cost is same with the PMIPv6. The signal flow of proposed scheme is shown at Figure 5-6. The signalling cost by inter AP roaming with staying in the same MAG area, C_A is expressed as follows:

$$C_A(P\text{-}PMIP2) = C_{AP\text{-}MAG} + \eta_P\,C_{MAG\text{-}MN} + PC_{MAG} \quad (5.35)$$

The binding update cost C_B is given by :

$$C_B(P\text{-}PMIP2) = C_{AP\text{-}MAG} + \eta_P\,(2C_{MAG\text{-}PS} + 2C_{MAG\text{-}LMA} + C_{MAG\text{-}MN}) + 3PC_{MAG} + PC_{PS} + PC_{LMA} \quad (5.36)$$

The packet delivery cost C_P is

$$C_P(P\text{-}PMIP2) = \eta_d\,(C_{CN\text{-}LMA} + C_{LMA\text{-}PMAG} + C_{PMAG\text{-}MN})\,\lambda_p\,HL(PMIP) \quad (5.37)$$

Numerical Result and Comparison

This section presents numerical result of the analysis shown in previous section. Parameters and default value used in this analysis are referred from [28, 29]. Table 5-4 presents these values.

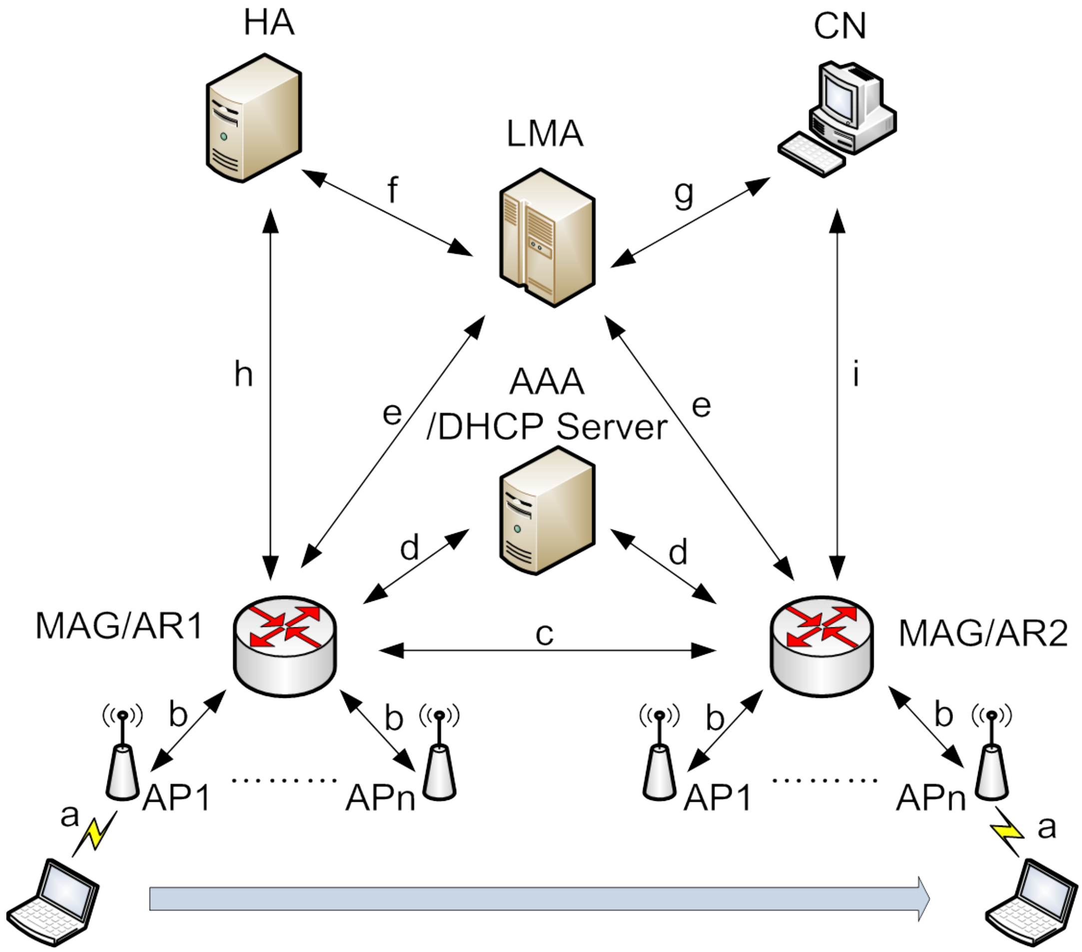


Figure 5-11. Network topology

Figure 5-11 shows network topology used in the analysis. We assume hop distance from every AR/MAG to HA, CN, AAA/DHCP server and LMA is same respectively. We set a= b=1, c=2, d=5,e=7 ,f=g=10 and h=i=15. Also we define process cost as follows :

PC_{HA} = 24,PC_{CN} = 4, PC_{AAA} = 12, PC_{LMA} = 12 and $PC_{MAG/AR}$ = 8

Table 5-4 Parameters for analysis

Parameters for analysis	Symbol	Value
Wired link bandwidth	B_w	100 Mbps
Wireless link bandwidth	B_{wl}	11 Mbps
Latency of the wired link	L_w	2 msec
Latency of the wireless link	L_{wl}	5 msec
IEEE 802.11control packet size	sl	48 bytes
IP mobility Control packet size	sp	96 bytes
Data packet size	sd	200 bytes
Process and queuing delay of node	p	0.5msec
Packet arrival rate	λ_p	20 packets/sec
Unit transmission cost over wired link	ε	1
Unit transmission cost over wireless link	κ	2

Numerical Result of MIPv6 with FMDD

These numerical results show the total handover latency of Mobile IPv6 protocols during an inter-session arrival time (1/ λ_c) as function of several parameters. Figure 5-12 illustrates the total handover latency according to subnet layer. Total handover latency is decreased abruptly as subnet layer is increased. In the case of 1 subnet layer, AR/MAG has just one AP. Thus inter AP roaming causes L2 and L3 handover simultaneously. As the number of AP area in subnet is increased the number of L3 hand over is reduced. It means the portion of L2 handover in total handover latency becomes bigger as layer of subnet is larger. If the subnet layer is too large as MN's AR/MAG residence time is longer than session duration, the total handover latency is only composed of L2 handover latency. The Figure 5-12 shows the handover latency of Mobile IPv6 with FMDD scheme and DHCP server is less than 5.4 sec. Otherwise the handover latency of conventional MIPv6 protocol is around 27sec at 1 subnet layer because of a long duplicate address detection delay.

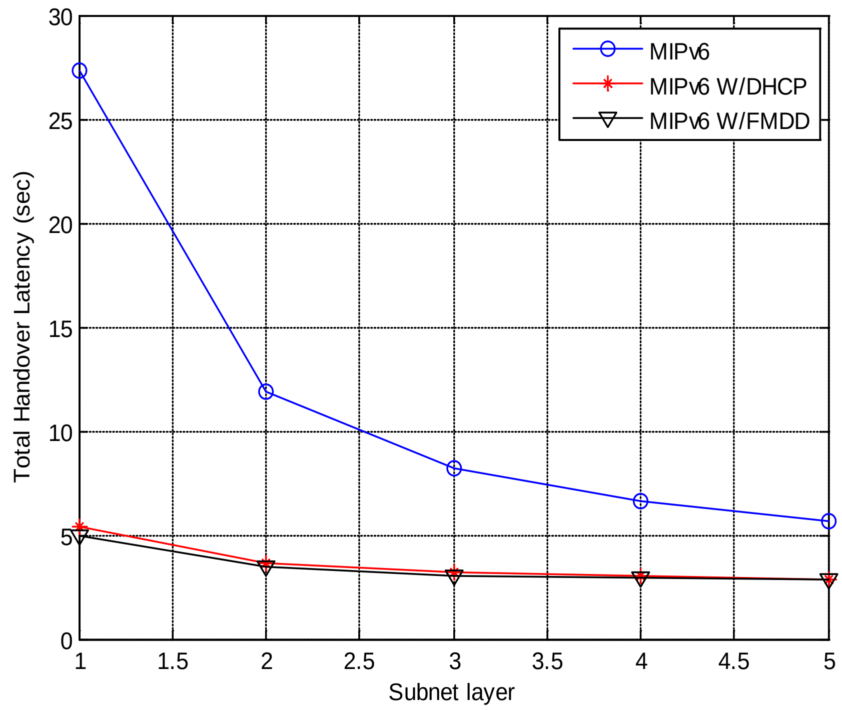


Figure 5-12. Mobile IPv6 handover latency comparison 1

Figure 5-13 shows the total handover latency as function of AP area radius. As radius of AP area becomes larger the number of handover is decreased in session duration. Consequently total handover latency is decreased as radius of AP area increases. And the difference of latency among each protocol is reduced as AP area radius is increased. The Figure 5-13 shows the handover latency of Mobile IPv6 with FMDD scheme and DHCP server is less than 4.5 sec. Otherwise the handover latency of conventional MIPv6 protocol is around 15sec when radius of AP area is 50m.

Figure 5-14 presents the relationship between total handover latency and MN's average velocity. The total latency is augmented linearly according to ascent of MN's velocity. The gap of handover latency among protocol is larger as augmentation of MN's velocity. When the average velocity of the MN is 5m/s the gap of handover latency between MIPv6 and MIPv6 with FMDD is around 21.2 sec.

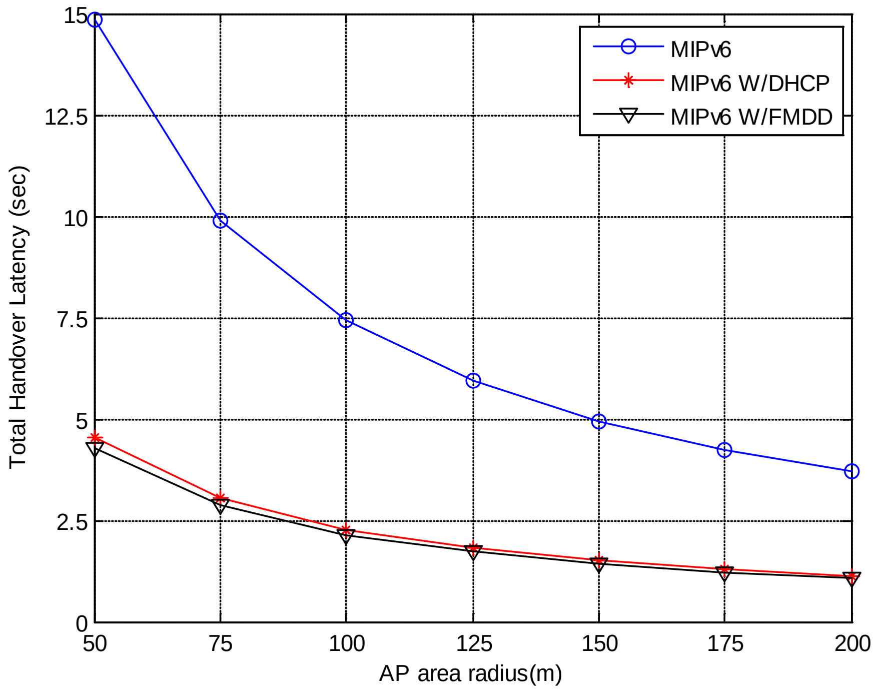


Figure 5-13. Mobile IPv6 handover latency comparison 2

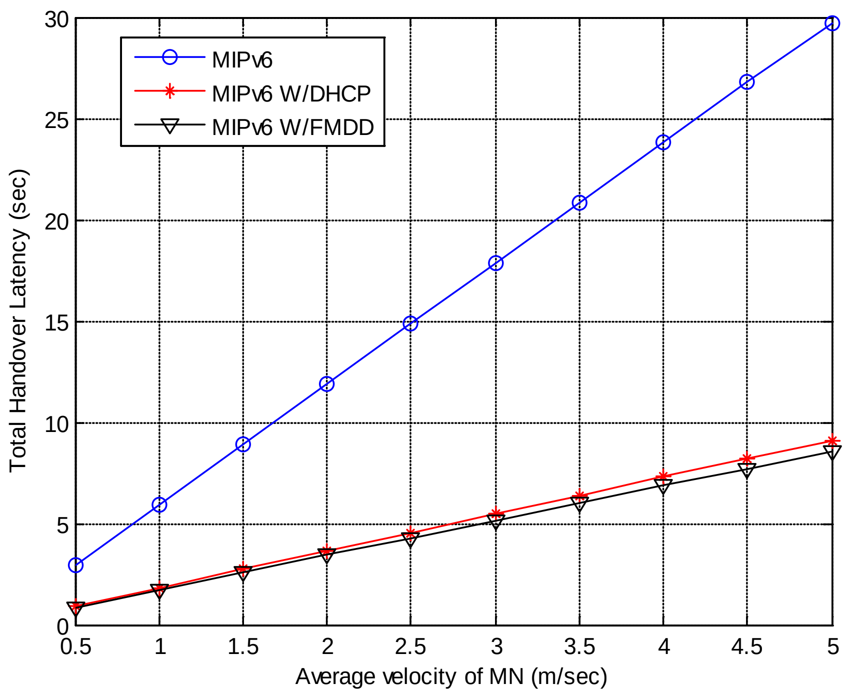


Figure 5-14. Mobile IPv6 handover latency comparison 3

Numerical Result of Proposed PMIPv6 Scheme 1

Figure 5-15 shows the total handover latency of proposed PMIPv6 scheme according to subnet layer. For the comparison this figure presents the handover latency of a conventional PMIPv6 and MIPv6 with DHCP server. Our proposed scheme combined L2 and L3 handover procedures however; it affects mostly L3 handover latency. Therefore improvement of proposed scheme becomes less as subnet layer is increased. Our scheme reduces 12.7 % of total handover latency at 1 subnet layer comparing with PMIP protocol.

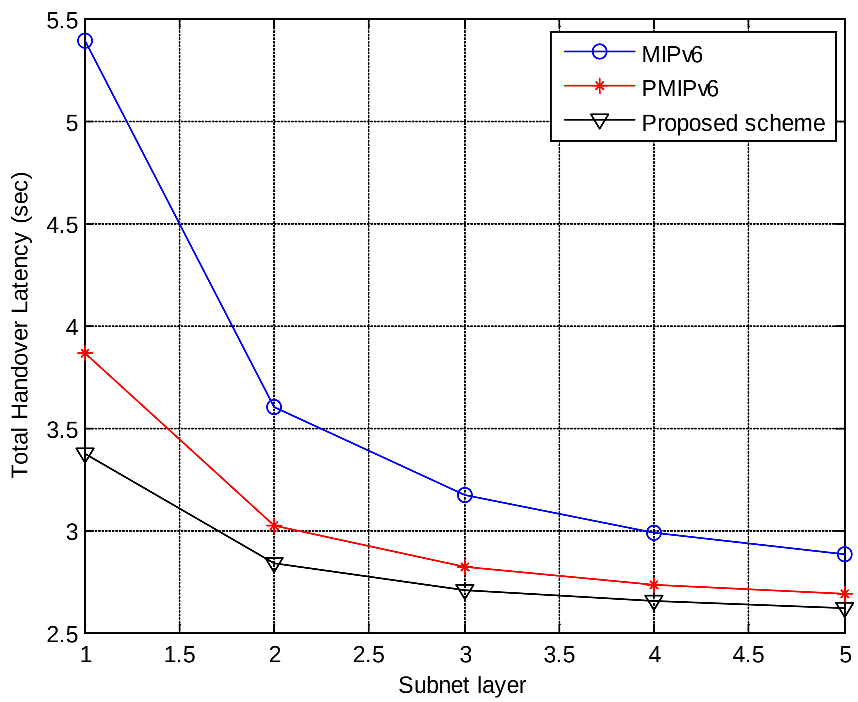


Figure 5-15. PMIPv6 handover latency comparison 1

Figure 5-16 shows the total handover latency of PMIPv6 as function of AP area radius. As radius of AP area becomes larger the number of handover is decreased in session duration. Consequently total handover latency is decreased as radius of AP area increases. And the difference of latency among each protocol is reduced as AP area radius is increased.

Figure 5-17 presents the relationship between total handover latency and MN's average velocity. The total latency is augmented linearly according to ascent of MN's velocity. The gap of handover latency among protocol is larger as augmentation of MN's velocity.

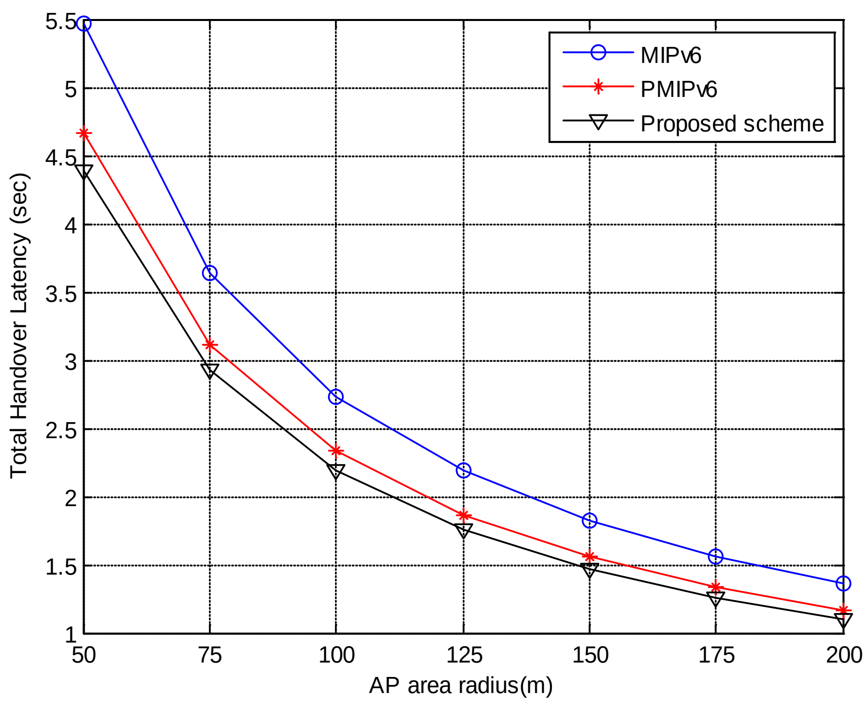


Figure 5-16. PMIPv6 handover latency comparison 2

Figure 5-18 shows the number of packet lost according to subnet layer. As shown in the figure, the number of packet lost is reduced as subnet layer is increased. The number of Packet lost is diminished by buffering & forwarding scheme in the proposed algorithm during an ongoing session. Proposed scheme decreased the packet lost as 29.56 % in the case of 1 layer subnet and 11.14% in the case of 2 layer subnet compared with PMIP protocol respectively. Not only Packet loss but also disparity among protocols is decreased as AP area becomes wider as shown in Figure 5-19. Figure 5-20 shows the impact of MN's velocity on packet loss. The number of packet lost is proportional to MN's velocity. The gap among protocols also becomes larger as augment of MN's velocity.

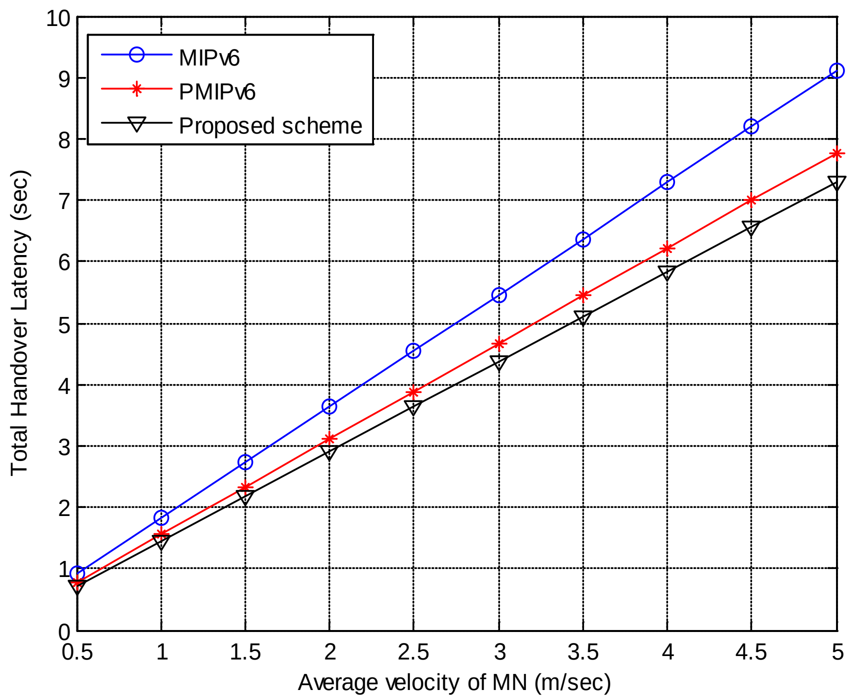


Figure 5-17. PMIPv6 handover latency comparison 3

Figure 5-21 illustrates data packet delay from CN to MN according to packet size during ongoing session. In the proposed scheme the MAG sends multicast PBU message to the LMA and the CN simultaneously. This M-PBU message make CN determine the shortest way to the MAG not via the LMA contrast with PMIP protocol. The maximum transmission unit (MTU) of IPv6 in the Internet is 1280 bytes or greater [30]. The data packet size varies from 200 byte to 1400 byte. The proposed scheme reduces data packet delay around 15ms.

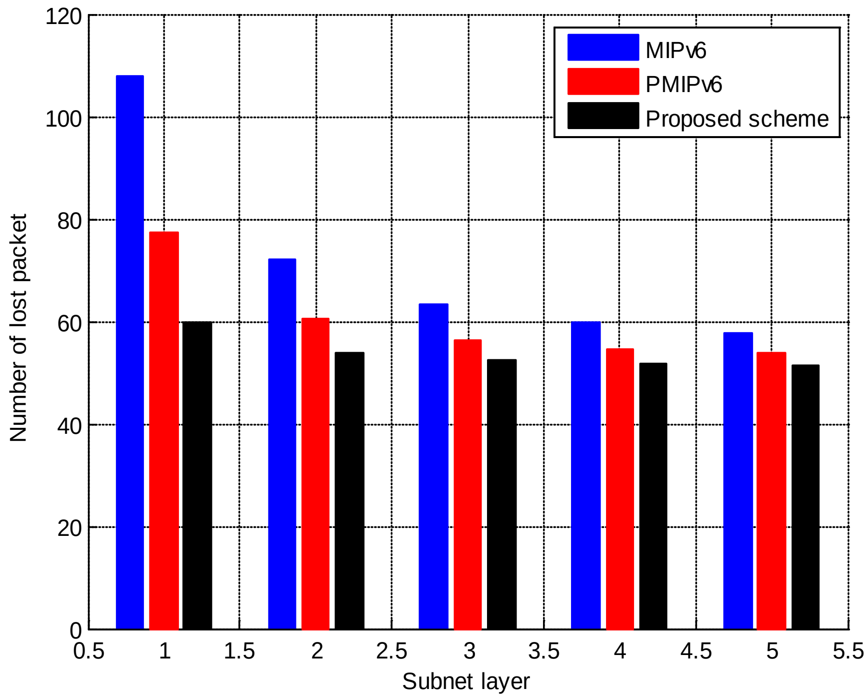


Figure 5-18. PMIPv6 packet loss comparison1

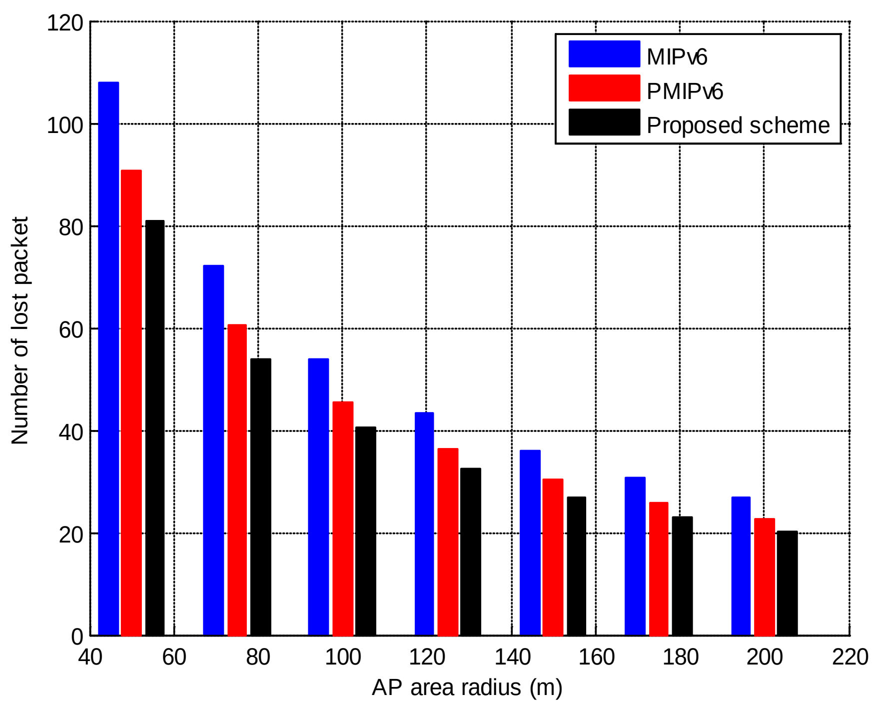


Figure 5-19. PMIPv6 packet loss comparison 2

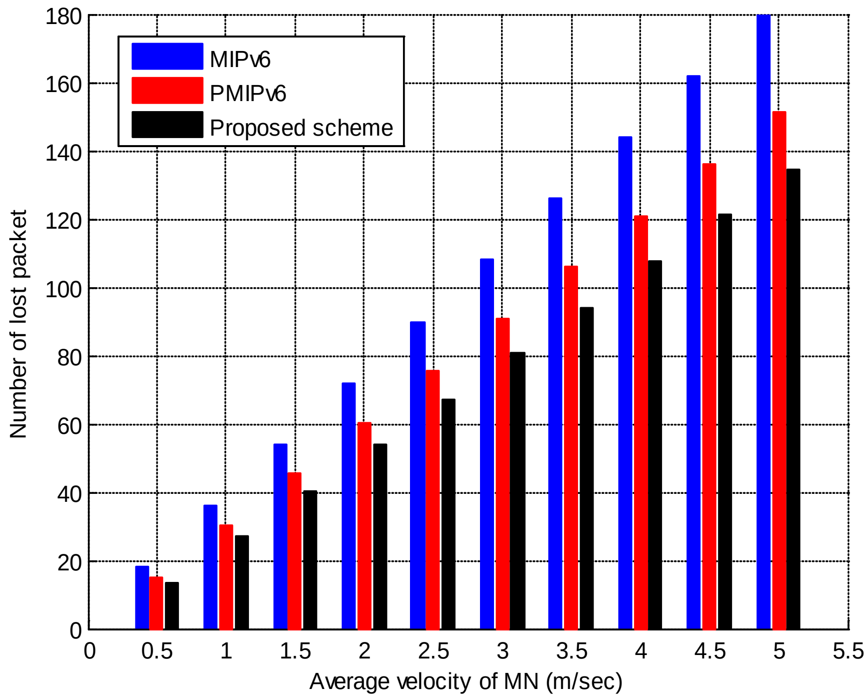


Figure 5-20. PMIPv6 packet loss comparison 3

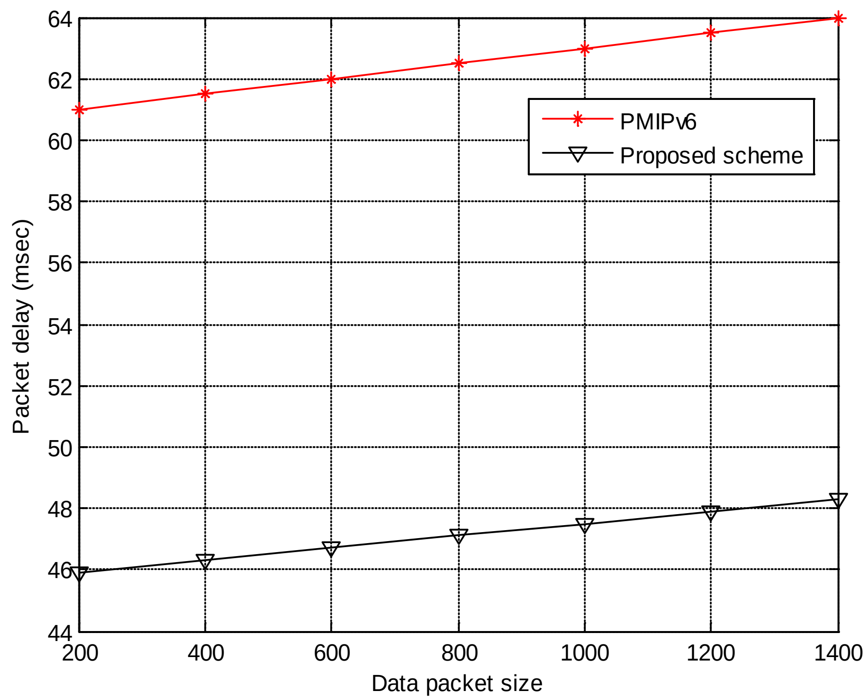


Figure 5-21. Packet delay in session time

Numerical Result of Proposed PMIPv6 scheme 2

Figure 5-22 shows total signaling cost as function of subnet layer. At subnet layer 1 inter AP roaming always cause inter MAG roaming. Therefore the handover procedure needs much signalling overhead at 1 layer subnet. However as subnet layer increased the signalling cost for handover procedure is decreased. At 3 layer subnet PMIP and MIP protocols have almost same signalling cost and from 4 layer subnet PMIPv6 protocol needs more signalling for handover comparing with MIPv6. At 2 layer subnet proposed scheme reduce 31.6 % of signalling cost comparing with the conventional PMIPv6.

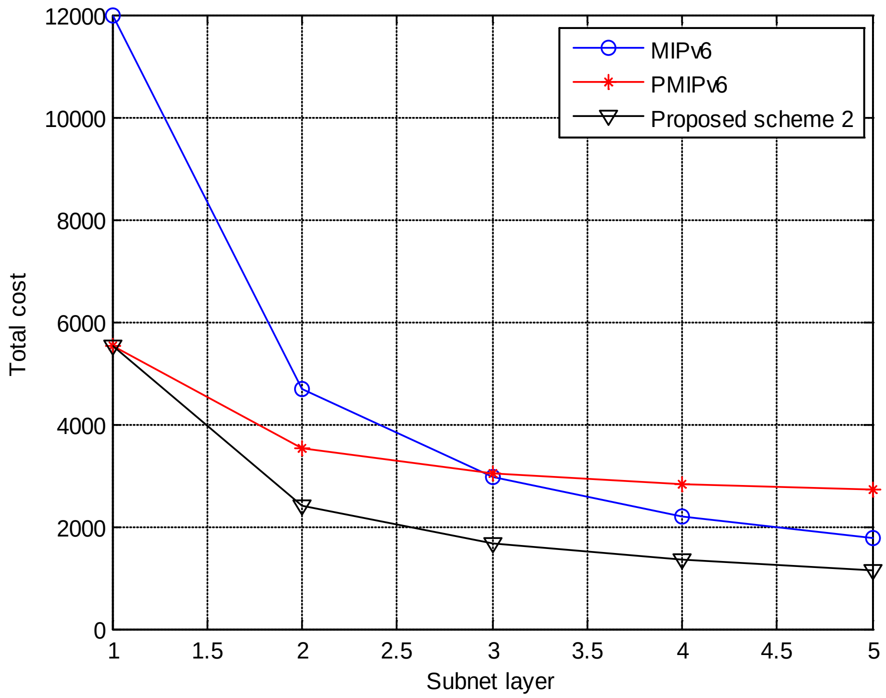


Figure 5-22. PMIPv6 cost comparison 1

Figure 5-23 presents the relationship between total cost and MN's average velocity. The total cost is augmented linearly according to ascent of MN's velocity. The gap of total cost among protocol is larger as augmentation of MN's velocity.

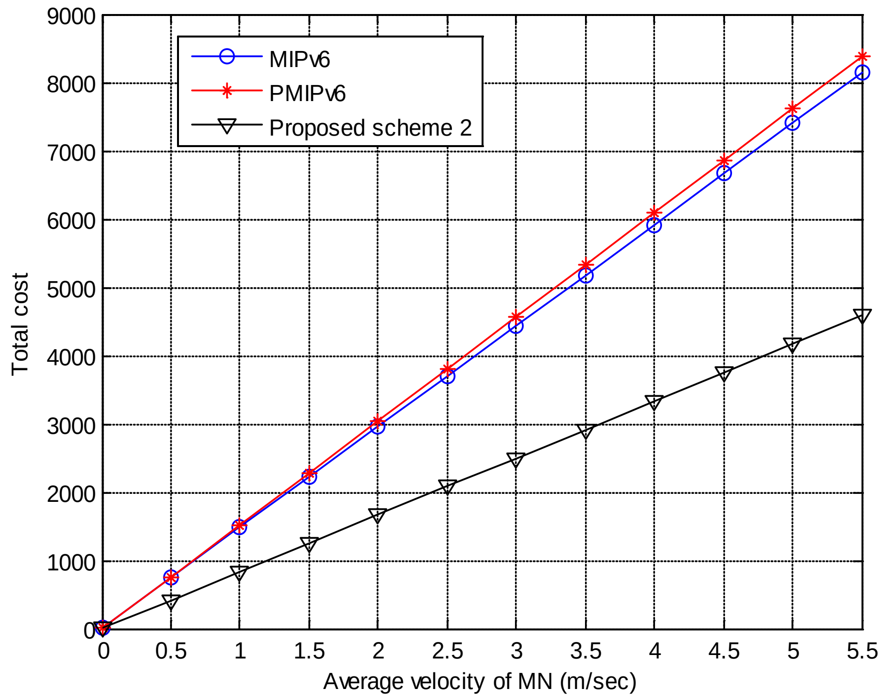


Figure 5-23. PMIPv6 cost comparison 2

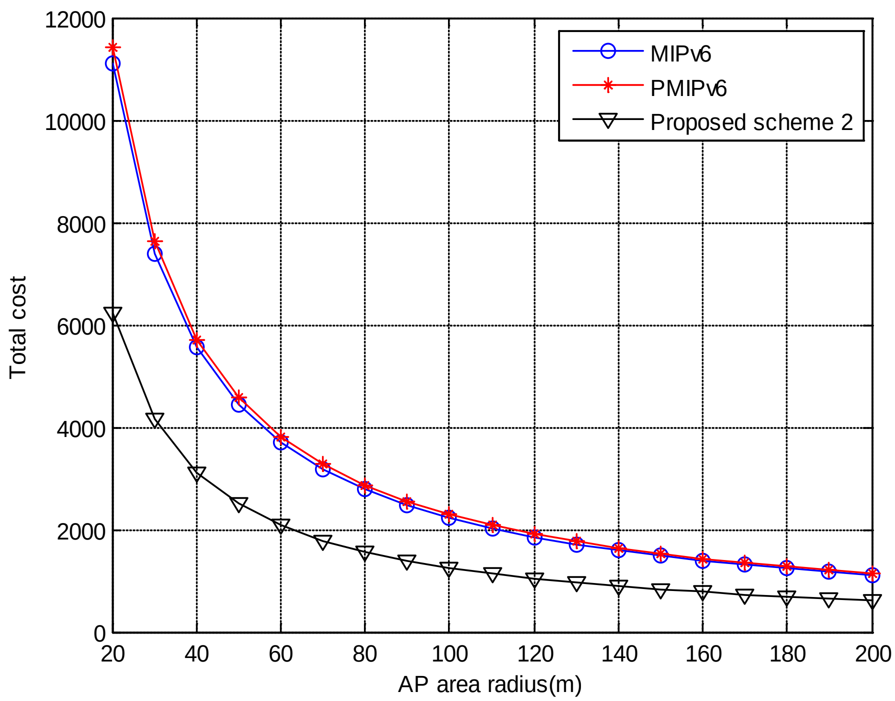


Figure 5-24. PMIPv6 cost comparison 3

Figure 5-24 shows the total cost as function of AP area radius. As radius of AP area becomes larger the signalling cost is decreased in session duration. Consequently total signalling cost is decreased as radius of AP area increases. And the difference of signalling cost among each protocol is reduced as AP area radius is increased.

Conclusion

In this chapter, a fast movement detection & DAD (FMDD) scheme for Mobile IPv6 and 2 efficient Proxy Mobile IPv6 protocols on IEEE 802.11 standard are proposed. The FMDD scheme for Mobile IPv6 use neighbor cache at access router for duplicate address detection procedure which takes at least 1 sec in handover procedure. This proposed FMDD can reduce the latency taken by the movement detection, address configuration and confirmation from the whole handover latency. Our propose PMIPv6 scheme1 performs L2 and L3 handover simultaneously to diminish total handover latency and packet forwarding scheme through the tunnel between the NMAG and PMAG by enhanced ND messages is introduced to reduce packet loss during handover. Moreover multicast PBU message make our scheme can decrease data packet delay from the CN to MN. The analysis result shows our scheme1 can reduce the total handover latency and number of packet lost compared to the existing mobile management protocols.

The proposed scheme 2 uses MOVE notify and response message in IAPP defined in IEEE 802.11f. Using these messages the MAG can recognize whether the MN moves from different MAG or not. Therefore we can reduce unnecessary signalling cost caused by just L2 handover. The analysis result shows our scheme2 can reduce signalling cost significantly.

CHAPTER 6
CONCLUSIONS

This dissertation introduced our proposed schemes and shows the analysis and performance enhancement of home network and mobile network technologies. We provide a comprehensive performance analysis of recent wireless and powerline technologies for home. The recently developed 200Mpbs Powerline modems (HomePlug AV, UPA-DHS and HD-PLC); IEEE 802.11g and 802.11n wireless technologies are compared and evaluated. The results of comprehensive experimental measurements and testing of these technologies with the UDP and TCP protocols as well as with High Definition TV streaming media at 25 Mbps are shown. We have proposed an enhanced Limited Round Robin with a priority policy for data exchange within a Bluetooth piconet. The proposed algorithm utilizes the status of the master and slave to schedule the slots effectively, yet additional information on the slave is not necessary. Also, we introduce EVGATOR, a protocol visualization tool. EVGATOR is flexible and configurable to display key trace data as space time diagrams with color coding for local protocol states. This visualization tool can significantly reduce the protocol design process and the time spent on debugging the simulation results.

We have introduced fast movement detection & DAD (FMDD) scheme for Mobile IPv6 and two efficient network based mobility management schemes over wireless local area network for reducing handover latency and signaling overhead. The FMDD scheme uses neighbor cache for DAD procedure and can reduce handover latency of Mobile IPv6 significantly. To reduce service disruption time and packet loss of Proxy Mobile IPv6 simultaneous L2 and L3 handover scheme is proposed and modified message in Neighbour Detection procedure is used for handover management. Also, enhanced binding update message can reduce the packet delivery delay. To reduce signalling overhead of PMIPv6 we use MOVE-notify message defined in IEEE802.11f. The proposed scheme makes the MAG know whether the MN is moved from the new MAG or not after the MN is attached to AP. Then, no signalling overhead for the obtaining the MN's profile and checking the binding information occurs in L2 handover case. For performance analysis, we developed network configuration and mobility model by using several parameters to analyze handover latency, packet loss, signalling overhead cost. Our analyzed results show that our proposed schemes have a better performance than conventional mobility management protocols.

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BIOGRAPHICAL SKETCH

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