# REDUCING HANDOVER LATENCY USING CROSS LAYER PROTOCOL IN MIPV6-BASED WIRELESS LOCAL AREA NETWORKS

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*To my father Muhammad Amin, who always wanted his children to get the best education and be proud of their achievements. His hard work, especially restless days and nights has resulted in his being the proud father of three engineers. I pray to Almighty Allah to shower blessings on him and place him in Jannah*

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# ABSTRACT

The rapid development of wireless technologies has resulted in a movement towards total mobility. Mobility is an essential and necessary feature for roaming users who connect to different wireless networks via APs. Mobility provides users with the freedom of movement and real-time communication such as VoIP and video between mobile and stationary users. The application of such communication requires an efficient protocol to provide seamless connections. Existing protocols such as MIP, MIPv6, FMIPv6 and HMIPv6 provide mobility to users. These protocols suffer from handover latency, delivery ratio, packet loss and signal overhead due to data link and network layer process execution. Besides these problems, wireless networks also suffer from unnecessary handovers due to the mobility pattern, cell structure and variable mobile node speed. However, handover latency has become an important issue in the research world that needs to be resolved through the design of an efficient cross layer protocol and topology by considering wireless network characteristics. This research first proposed an enhancement to the Layer 2 reassociation signal based on passive scanning called Enhanced Reassociation (EN-ReAS). The enhancement will allow a mobile node to transmit a previous IP address during the reassociation process. Secondly, an Efficient Mobile IPv6 (EF-MIPv6) is proposed in order to reduce the average delay, packet loss and total handover latency by enhancing the router advertisement and router solicitation signals. Finally, an Efficient Wireless Topology Design (EF-WTD) is proposed based on cell structure and minimum overlapping area to enable the mobile node to make a proper handover decision. The designed EnReAS, EF-MIPv6 and EF-WTD solutions were implemented and then compared with standard and cross-layer mobility solutions. Multiple practical test-bed and simulation experiments were carried out with different scenarios at Layer 2, Layer 3 and in the topology design. The simulation results showed that EN-ReAS performed better than the standard Layer 2. Secondly EF-MIPv6 improved handover latency and packet drop rate in comparison to MIPv6, FMIPv6, SFMIPv6 and EnFMIPv6. Thirdly, the EF-WTD model provides better handover rate, less packet loss, while keeping the same handover latency. The proposed design has proven that the handover latency could be reduced significantly and this would lead to the enhancement of mobility in wireless networks.

# ABSTRAK

Perkembangan pesat teknologi tanpa wayar telah menyebabkan perubahan ke arah mobiliti secara menyeluruh. Mobiliti merupakan ciri yang penting dan perlu untuk perayauan pengguna yang disambungkan kepada rangkaian tanpa wayar yang berbeza melalui AP. Mobiliti menyediakan pengguna dengan kebebasan bergerak dan berkomunikasi secara masa nyata seperti VoIP dan video antara pengguna mudah alih dan pengguna pegun. Aplikasi komunikasi tersebut memerlukan satu protokol yang cekap bagi menyediakan sambungan yang lancar. Protokol yang sedia ada seperti MIP, MIPv6, FMIPv6 dan HMIPv6 telah dicadangkan untuk menyediakan mobiliti kepada pengguna. Walaubagaimanapun, protokol ini masih mengalami penyerahan kependaman, nisbah penghantaran, kehilangan paket dan limpahan isyarat disebabkan oleh pautan data dan proses pelaksanaan lapisan rangkaian. Selain daripada masalah yang dinyatakan, rangkaian tanpa wayar setempat juga mengalami masalah dari kependaman yang tidak perlu disebabkan oleh corak pergerakan, struktur sel dan perubahan kelajuan nod mudah alih. Oleh itu, penyerahan kependaman telah menjadi salah satu isu yang penting dalam dunia penyelidikan yang perlu diselesaikan, iaitu dengan cara merekabentuk protokol lapisan silang yang cekap dan merekabentuk topologi dengan mempertimbangkan ciri-ciri rangkaian tanpa wayar. Kajian ini pada permulaannya mencadangkan peningkatan kepada penyatuan semula isyarat pada lapisan kedua berdasarkan pengimbasan pasif yang dipanggil peningkatan penyatuan semula (ENReAS). Peningkatan ini akan membolehkan nod mudah alih menghantar alamat IP sebelumnya semasa proses penyatuan semula. Kedua, pergerakan mudah alih IPv6 yang cekap (EF-MIPv6) dicadangkan untuk mengurangkan purata kelewatan, kehilangan paket dan jumlah penyerahan kependaman dengan menambahbaik proses pengiklanan router dan isyarat ajakan router. Akhirnya, tesis ini mencadangkan pembangunan satu rekabentuk topologi tanpa wayar yang cekap (EF-WTD) berdasarkan struktur sel dan kawasan bertindih yang minimum bagi membolehkan nod mudah alih membuat keputusan penyerahan dengan betul. Penyelesaian EnReAS, EF-MIPv6 dan EF-WTD yang dilaksanakan dan kemudian dibandingkan dengan penyelesaian mobiliti standard dan rentas lapisan. Pelbagai tapak uji praktikal dan eksperimen simulasi telah dijalankan dengan senario yang berbeza di lapisan kedua, lapisan ketiga dan dalam rekabentuk topologi. Keputusan simulasi pertama menunjukkan pretasi EN-ReAS lebih baik daripada standard lapisan kedua. Kedua, EF-MIPv6 telah memperbaiki prestasi dari sudut penyerahan kependaman dan kadar pembuangan paket berbanding dengan MIPv6, FMIPv6, SFMIPv6 dan EnFMIPv6. Ketiga, model EF-WTD menyediakan kadar penyerahan yang lebih baik, kurang kehilangan paket, di samping mengekalkan penyerahan kependaman yang sama. Rekabentuk yang telah di cadangkan terbukti dapat mengurangkan penyerahan kependaman dengan jayanya dan ini membantu dalam peningkatan mobiliti rangkaian tanpa wayar.

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| | | |
|---|---|---|
| 1G | – | First Generation |
| 2G | – | Second Generation |
| 3G | – | Third Generation |
| 4G | – | Fourth Generation |
| AP | – | Access Point |
| AP1 | – | Access Point 1 |
| AP2 | – | Access Point 2 |
| ARP | – | Address Resolution Protocol |
| AAA | – | Authorization, Authentication and Accounting |
| AID | – | Association ID |
| ACK | – | Acknowledgement |
| AH | – | Authentication Header |
| AR | – | Access Router |
| BS | – | Base Station |
| BSS | – | Basic Service Set |
| CN | – | Correspondent Node or Core Network |
| CoA | – | Care-of Address |
| CDMA | – | Code Division Multiple Access |
| CTS | – | Clear to Send |
| CSMA/CD | – | Carrier Sense Multiple Access with Collision Detection |
| CSMA/CA | – | Carrier Sense Multiple Access with Collision Avoidance |
| CA | – | Collision Avoidance |
| CoTi | – | A care of test init cookie sent to the Correspondent Node |

| | | |
|---|---|---|
| CN | – | Correspondent Node |
| DS | – | Distribution System |
| DCF | – | Distributed Coordination Function |
| DAD | – | Duplicate Address Detection |
| DHCP | – | Dynamic Host Configuration Protocol |
| DiffServ | – | Differentiated Service |
| DIFS | – | Distributed InterFrame Space |
| DNA | – | Detecting Network Attachment |
| DoS | – | Denial of Service |
| ESS | – | Extended Service Set |
| ESP | – | Encapsulated Security Payload |
| ESSID | – | Extended Service Set Identifier |
| FA | – | Foreign Agent |
| FMIPv6 | – | Mobile IPv6 Fast Handoff |
| FH-MIPv6 | – | Fast Hierarchical MIPv6 |
| FFHMIPv6 | – | Flow based Fast Hierarchical MIPv6 |
| FF-HMIPv6 | – | Fast Handover for Fast Hierarchical MIPv6 |
| HA | – | Home Agent |
| HN | – | Home Network |
| HO | – | Handover (or Handoff) |
| HMIPv6 | – | Hierarchical Mobile IPv6 |
| HoA | – | Home Address: A unicast routable address assigned to a Mobile Node |
| IEEE | – | Institute of Electrical and Electronics Engineers |
| IETF | – | Internet Engineering Task Force |
| IP | – | Internet Protocol |
| IEEE 802.X | – | Wireless LAN standards |
| ISDN | – | Integrated Service Digital Networks |
| IFS | – | Inter Frame Space |
| IBSS | – | Independent Basic Service Set |

| | | |
|---|---|---|
| ICMP | – | Internet Control Message Protocol |
| IKE | – | Internet Key Exchange |
| IPSec | – | IP Security |
| IPv4 | – | IP version 4 |
| IPv6 | – | IP version 6 |
| IrDA | – | Infrared Data |
| ISP | – | Internet Service Provider |
| LAN | – | Local Area Network |
| LA | – | Location Area |
| LLC | – | Logic Link Control |
| L2 | – | Layer 2 |
| L3 | – | Layer 3 |
| L2 handoff | – | Layer 2 handoff |
| L3 handoff | – | Layer 3 handoff |
| L2 trigger | – | Information from L2 that informs L3 of particular events before and after L2 handoff |
| LEAP | – | Lightweight Extensible Authentication Protocol |
| MN | – | Mobile Node |
| MAC | – | Medium Access Control |
| MH | – | Mobile Host (same as MN) |
| MG | – | Mobility Gateway |
| MAN | – | Metropolitan Area Network |
| MAP | – | Mobility Anchor Point |
| MS | – | Mobile Station |
| MAHO | – | Mobile Assisted Handover |
| MIPL | – | Mobile Implementation for Linux (for Mobile IPv6) |
| Mobile IPv4 | – | Mobility Support in IPv4 |
| Mobile IPv6 | – | Mobility Support in IPv6 |
| MIH | – | Mobile-initiated handoff: L3 handoff in which the Mobile Node initiates the handoff |

| | | |
|---|---|---|
| MTU | – | Maximum Transmission Unit |
| NS2 | – | Network Simulation 2 |
| NA | – | Neighbor Advertisement |
| NAR | – | New Access Router |
| NAT | – | Network Address Translation |
| NAP | – | New Access Point |
| NCoA | – | New Care of Address |
| ND | – | Neighbor Discovery |
| NEMO | – | Network Mobility |
| NEH | – | Network-initiated handoff: L3 handoff in which oFA or nFA initiates the handoff |
| NFA | – | New Foreign Agent |
| NS | – | Neighbor Solicitation |
| NUD | – | Neighbor Unreachability Detection |
| OAP | – | Old Access Point |
| OAR | – | Old Access Router |
| OCoA | – | Old Care of Address |
| OFA | – | Old Foreign Agent |
| OSI | – | Open System Interconnection |
| PAR | – | Previous Access Router |
| PSC | – | Personal Communication Services |
| PS | – | Packet Switching |
| PDC | – | Personal Digital Cellular |
| PCF | – | Point Coordination Function |
| PCoA | – | Previous Care of Address |
| QoS | – | Quality of Service |
| RSS | – | Received Signal Strength |
| RTT | – | Round Trip Time |
| RTS | – | Request to Send |
| RA | – | Routing Area |

| | | |
|---|---|---|
| RA | – | Router Advertisement |
| RFC | – | Request For Comments |
| RR | – | Return Routability |
| RS | – | Router Solicitation |
| RSVP | – | Resource Reservation Protocol |
| SIFS | – | Short Inter Frame Space |
| SCTP | – | Stream Control Transmission Protocol |
| SSID | – | Standard Service Set |
| TCP | – | Transmission Control Protocol |
| TCL | – | Tool Command Language |
| ToS | – | Type of Service |
| UDP | – | User Datagram Protocol |
| VoIP | – | Voice over IP |
| VPN | – | Virtual Private Network |
| WLAN | – | Wireless Local Area Network |
| WAP | – | Wireless Application Protocol |
| WCDMA | – | Wideband Code Division Multiple Access |
| WISP | – | Wireless Internet Service Provider |
| WEP | – | Wired Equivalent Privacy |
| Wi-Fi | – | Wireless Fidelity |
| WPA | – | Wi-Fi Protected Access |

## LIST OF SYMBOLS

| | | |
|---|---|---|
| $T_{scan}$ | – | Scan Delay |
| $T_{Probe}$ | – | Probe Delay |
| $T_{auth}$ | – | Authentication Delay |
| $T_{Assoc}$ | – | Association Delay |
| $T_{mvd}$ | – | Movement Detection Delay |
| $T_{IP}$ | – | IP Registration Delay |
| $T_{DAD}$ | – | Duplicate Address Detection Delay |
| $T_{BU}$ | – | Binding Update Delay |
| $\mu$ | – | Signal Power in dB |
| d | – | Distance of the MN to the AP |
| $K_1$ | – | Gain of the transmission |
| $K_2$ | – | Environment-specific attenuation |
| D | – | Distance between the access points |
| v | – | Velocity of the mobile node |
| $v_{max}$ | – | Maximum Velocity |
| $v_{min}$ | – | Minimum Velocity |
| $p_a$ | – | Probability of False Handover |
| $p_f$ | – | Probability of Failure Handover |
| T | – | Time to overcome the average interval |
| $T_v$ | – | Velocity in Time |
| $T_{Layer2}$ | – | Layer 2 Delay |
| $T_{Layer3}$ | – | Layer 3 Delay |
| b | – | Average interval distance |

| | | |
|---|---|---|
| $\delta$ | – | Hystersis Handover Delay |
| $\beta$ | – | Probability Density Factor |
| p | – | Experienced Handover Delay |
| R | – | Cell Radius |
| O | – | Celle Overlap Area |
| a | – | Cell Boundary |
| h | – | Radio Signal in dB |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

Traditionally, people used to make use of network services using cables plugged into a wall jack and these were considered to be stationary (Saltzer *et al.*, 1984). This has led researchers to invent wireless technology, which allows users with wireless devices to move freely from one place to another. These users stay connected to the network during movement; hence, being referred to as mobile users. Wireless technology allows users to move within set boundaries of the network, which is restricted by the transmission signal range. Once the wireless client is out of the range it should connect to a different network to maintain communication, and this process of moving from one wireless network to another is called handover. The handover process requires a number of signals to be exchanged between network devices, which cause delays.

Internet Protocol (IP) was originally designed for fixed networks (Postel, 1981a). IP addresses were associated with fixed network computers and were required to be unchanged for the current session; however, if the user moves to a different network, the computer is rebooted to gain network connectivity by obtaining a new IP address. Therefore, to satisfy the requirements of the mobile users, Mobile IP (MIP) (Perkins, 1996) was proposed by the Internet Engineering Task Force (IETF).

Current solutions are based on either reducing Layer 2 or Layer 3 handover latency individually. Layer 2 solutions focus only on reducing the scan, authentication and association delays individually (Yoon *et al.*, 2011). Therefore, these solutions do not help to reduce Layer 3 delays, but only contribute in reducing the total handover latency; however, the Mobile Node (MN) still suffers from handover latency because Layer 3 handover delays continue to exist. Some other solutions such as pre-scanning of the Media Access Control (MAC) layer (Mustafa *et al.*, 2005), smooth MAC layer handoff (Liao and Cao, 2006) and make-before-break MAC layer handoff (Ramachandran *et al.*, 2006) are proposed to enhance Layer 2 handover. However, these methods produce processing and signalling load on the MN and therefore require extra configuration of the operating system.

On the other hand, Layer 3 solutions, such as Mobile IPv4 (MIPv4) (Perkins, 2002), were developed to provide mobility to IPv4 users, which were mainly fixed-node users. However, due to the address space restriction in IPv4, the IETF began to work on a new protocol version of IP called IP version 6 (IPv6) (Deering and Hinden, 1998). IPv6 follows the Internet-addressing architecture, which allows nodes to communicate freely with another node regardless of their physical location (Hinden and Deering, 2006). Since MIPv4 did not get commercially deployed due to the limitations in the IPv4 addressing architecture, mobility in IPv6 was considered from the beginning of IPv6 design; hence, MIPv6 was developed as an extension in the header of the IPv6 protocol (Johnson *et al.*, 2004) to provide mobility to IPv6 wireless clients. Commercial deployment of native IPv6 has only begun in a few regions, with Asia as the fastest and North America as the slowest. However, ISPs have also started to deploy IPv6 websites and fewer than 1,581,774 are listed on the website of the IPv6 portal with 310 top-level domains up to the present (Leber, 2012).

MIPv6 networks cannot handle frequent handovers efficiently due to layer separations. A standard handover consists of Layer 2 handover and Layer 3 handover. Frequent handovers can severely interrupt on-going communication within an MIPv6 network, thus significantly downgrading the performance. Even a single handover is large enough to drop large numbers of packets, thus disconnecting the wireless client for a few seconds from the network. As modern communication, which includes real-time applications such as Voice over IP (VoIP), require more bandwidth and time accuracy, reducing handover delays has become very important. To overcome deficiencies in MIPv6, MIPv6 extensions were developed (McCann, 2005; Soliman *et al.*, 2005; Koodli, 2008), but all of these extensions mainly focus on reducing Layer 3 handover delay only.

As discussed above, there is a need for a handover method which can execute at both Layer 2 and Layer 3. Therefore, in this research, a cross layer design based on the Enhancement of Link Re-association Signal (EN-ReAS) and Layer 3 Router Advertisement (RA), Router Solicitation (RS) signals are proposed. This method is referred to as Efficient Mobile IPv6 (EF-MIPv6), which is based on standard MIPv6 and Enhanced MIPv6 (Mun and Ryu, 2005). This method involves a modification in the Layer 2 process which enables an MN, to form an IPv6 address faster than the standard MIPv6 protocol. The proposed method is fully backward compatible to the standard MIPv6 protocol, therefore if the MN does not use the EF-MIPv6 process, it can still perform standard MIPv6 handover.

In addition to the proposed method, an Efficient Wireless Topology Design (EF-WTD) is also proposed based on cell structure to provide a minimum cell overlap area for an MN to perform handover efficiently using linear, random and circular mobility. The EF-WTD aims to aid in reducing the total handover latency and smooth mobility. The impact of the number of MNs and MN speed on the handover is also discussed and analyzed.

To validate the proposed solution and to verify that the example implementation does improve communication and reduce handover delay, a set of simulation tests have been designed. The thesis also covers a test-bed environment in a lab to evaluate handover delays in a real network environment. The test-bed results reveal that Layer 2 delay has greater impact on the total handover delay in MIPv6. However, it also reveals that through the use of the cross layer, handover delay can be reduced drastically.

## 1.2 Motivation

The development of real-time applications such as VoIP and IP-based data in the context of mobile devices demands mobility support at the Layer 3. These mobile devices include wireless laptops and 3G/4G mobile phones, which use access technologies such as WLAN, Long Term Evolution (LTE), Worldwide Interoperability for Microwave Access (WiMAX) and High Speed Packet Access (HSPA). The main requirement of these technologies is to allow MNs to keep communication with other hosts while roaming between different networks. Roaming occurs when a node moves from one access network to another; it involves physically moving from one network to another. This process is also referred to as the, handover process, which includes moving between Access Points (APs).

Consider the IEEE 802.11 WLAN structure shown in Figure 1.1. Network connectivity is provided to the MN through an AP1, which connects to an AR1, the AR 1 connects to a backbone router, which belongs either to the same organization or

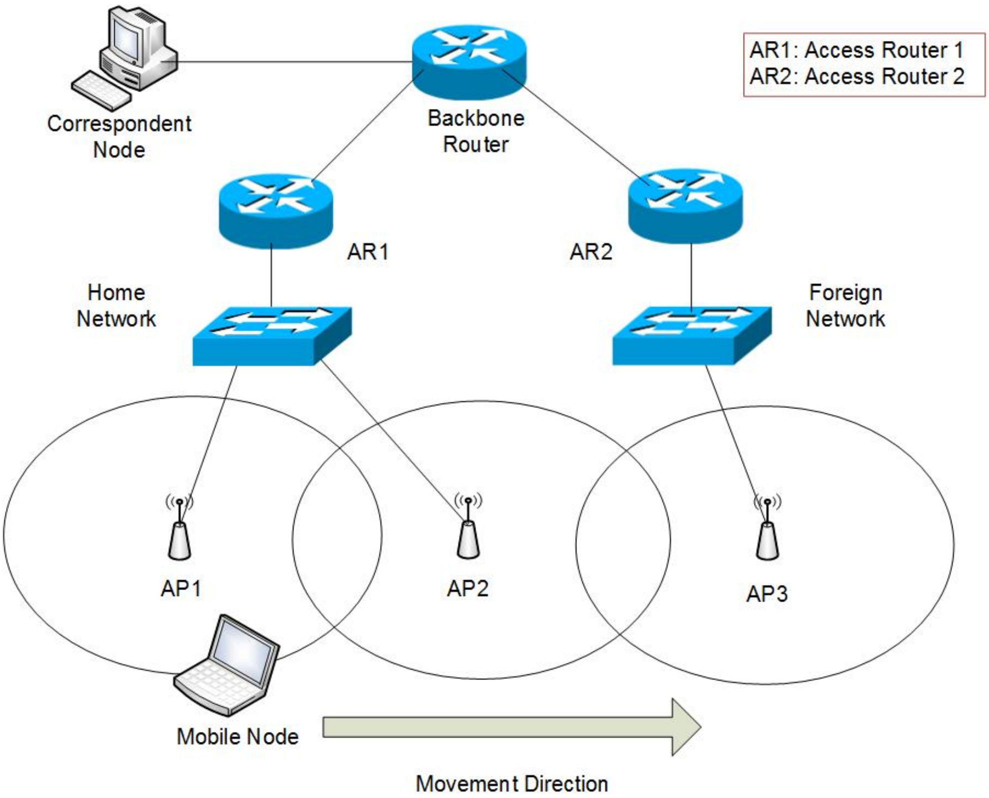


**Figure 1.1**: Mobility/Handover Process

to the Internet. When the MN moves out of the coverage area of AP1, it may attach to AP2, which is connected to the same AR1. In this case, the handover will occur only at Layer 2, therefore the MN continues the communication to the Correspondent Node (CN) without any change in the IP configuration parameters. However, if the MN continues its movement, it will then enter into the coverage area of AP3 and will try to connect to AP3 by initiating Layer 3 handover. Since AP3 is connected to a different AR2, the IP configuration parameters will change and Layer 2 hence Layer 3 handover, will also occur and the communication between the MN and CN will break for a few seconds.

As indicated by Postel (1981a), traditional networks maintain host IP address and host identity with respect to their network topological location. Host movement often results in a new location with respect to network IP topology. This results in a demand to acquire a new IP address in order to route packets to a host's new location. Standard protocols such as IPv4 and IPv6 will result in disconnection of on-going communication. MIPv6 allows for the MN to perceive minimum disruption during movement and then continue communication. Since the host IP address is used in transporting the application data to the different layers in Transmission Control Protocol/Internet protocol (TCP/IP) suite (Braden, 1989), it is likely that when the IP address changes, the upper layer may disconnect (for example TCP and User Datagram Packet (UDP) sessions). Packets sent to the previous IP address will be lost, and a host's previous peers will not be able to communicate because these peers are unaware of the new IP address assigned to the host.

Many applications such as VoIP, Virtual Private Networks (VPNs), database applications, and real audio and video streaming do not react actively when the IP address changes. Therefore, these applications need to re-start the session. Additionally the binding of the host name to an IP address in the Domain Name Server (DNS) (Postel, 1994) has to change based on the movement.

MIPv6 provides mobility by introducing two IP addresses for the MN; the first is a static IP address referred to as the Home Address (HoA), which is assigned by the home network, and with this IP the host is recognized globally. The second IP is referred to as the Care of Address (CoA), which is a temporary IP address assigned by the visiting network while the node stays in the foreign network. A special mechanism of mapping between these two IP address is used to send packets to the host's CoA to allow communication between previous peers and new peers. To communicate between two networks, ARs must be configured with special parameters to handle mobility functions. Therefore, the AR at the home network is referred to as Home Agent (HA). The function of the HA is to keep track of the MN by mapping the HoA to the current CoA, so that any CN communicating with the MN can forward packets.

## 1.3 Problem Background

The convergence of wireless networks has made mobile communications achieve rapid growth. With the increase in the number of mobile subscribers, mobility has emerged as one of the most important and challenging problems for wireless networks. Mobility enables the serving networks to locate a MN's point of attachment for delivering data packets (i.e. location management), and maintaining a MN's connection as it continues to change its point of attachment (i.e. handover management) (Sun and Sauvola, 2002; Akyildiz *et al.*, 2004; Nazir *et al.*, 2007; Al-Surmi *et al.*, 2010). Mobility in IEEE 802.11 wireless networks requires an MN to move between different APs which results in handover. Due to the number of signals exchanged and the involvement of multiple devices, the MN suffers delays during handovers, which result in disconnection of the real-time applications such as

VoIP (Yasukawa *et al.*, 2001, 2002), 802.11 phones, mobile video conferencing, video streaming and audio streaming (Mishra *et al.*, 2003). The handover process consists of Layer 2 and Layer 3 delays (McCann, 2005), which result in a large number of signals and packet loss. Thus, each time an MN performs Layer 2 handover, it is possible that a change in IP address will take over, which is a Layer 3 handover. The change in the subnet also involves a change in the IP address and the default gateway that forwards the traffic to the Internet. In order to make these changes, the IP module has to detect the new network, realize that the old configuration is no longer valid, and obtain new configuration parameters.

In MIPv6, the detection phase is based on Layer 3 movement detection, which is itself based on an advertised prefix (Johnson *et al.*, 2004). These Layer 3 parameters are not readily available immediately after Layer 2 handover because the Layer 3 handover cannot be processed until the Layer 2 handover is finished successfully (Koodli and Perkins, 2007), causing high latency. If a part of the Layer 3 information could be gathered at Layer 2, then the signalling load and latency could be greatly improved (Mcnair *et al.*, 2005). Since handover is the outcome of the co-operation of different layers, focusing only on Layer 2 or Layer 3 individually is not sufficient. Layer 2 handover requires from several tens of milliseconds to 8 seconds to complete, the length of this time being determined by the number of users attached to the APs, the number of applications running on the MN, access equipment and link access protocols (Montavont and Noel, 2002; Mills *et al.*, 2007). As a result, a lot of effort has been made to optimize the 802.11 handover latency at Layer 2 (Velayos and Karlsson, 2004; Issac *et al.*, 2006). Another problem that IEEE 802.11 WLAN faces is its mobility pattern and cell structure, which cause unnecessary and unwanted handovers by the MN (Ariyakhajorn *et al.*, 2006; Prabhakaran and Sankar, 2006; Tie-yuan *et al.*, 2009; Zola and Barcelo-Arroyo, 2009). Therefore, the focus of this research is to develop an efficient protocol based on the cross layer model, which can reduce the total handover latency. In particular, the most common problems are addressed such as number of signals, packet loss, Layer 2 and Layer 3 handover latencies and avoiding unnecessary handovers. The following sections discuss how these problems significantly affect the handovers in IEEE 802.11 WLANs.

### 1.3.1 Layer 2 Assisted Handover Protocols

In IEEE 802.11-based WLANs, the movement of the MN can be detected after its wireless interface card detects the decrease in the signal strengths of the current

AP. It then compares the signal strength with the other AP in the same area. If the signal strength is higher than the current AP, the MN initiates a Layer 2 handover. In IEEE 802.11 cards, this Layer 2 handover logic is built into the firmware of the wireless interface card, and does not generate any interrupts to notify the system. The wireless interface cards do not provide any information to notify the system about Layer 2 handover; however, there is a hardware control functionality that allows software to probe the identity of the AP with which a wireless interface card is currently associated. The decision regarding when to associate with a new AP at Layer 2 may not be the optimal decision considering Layer 3 performance. A Layer 2 handover results in re-associating with the new AP. A Layer 2 handover requires scan and authentication processes to finish before a re-association can occur, causing individual probe, authentication and association delays as shown in Figure 1.2; therefore, the total Layer 2 handover latency is the sum of these individual delays, as shown in Equation 1.1. During this time, Layer 3 is unaware of changes occurring to the MN; therefore, it is very difficult to detect the MN movement or change in the point of attachment that adds up to the total handover latency.

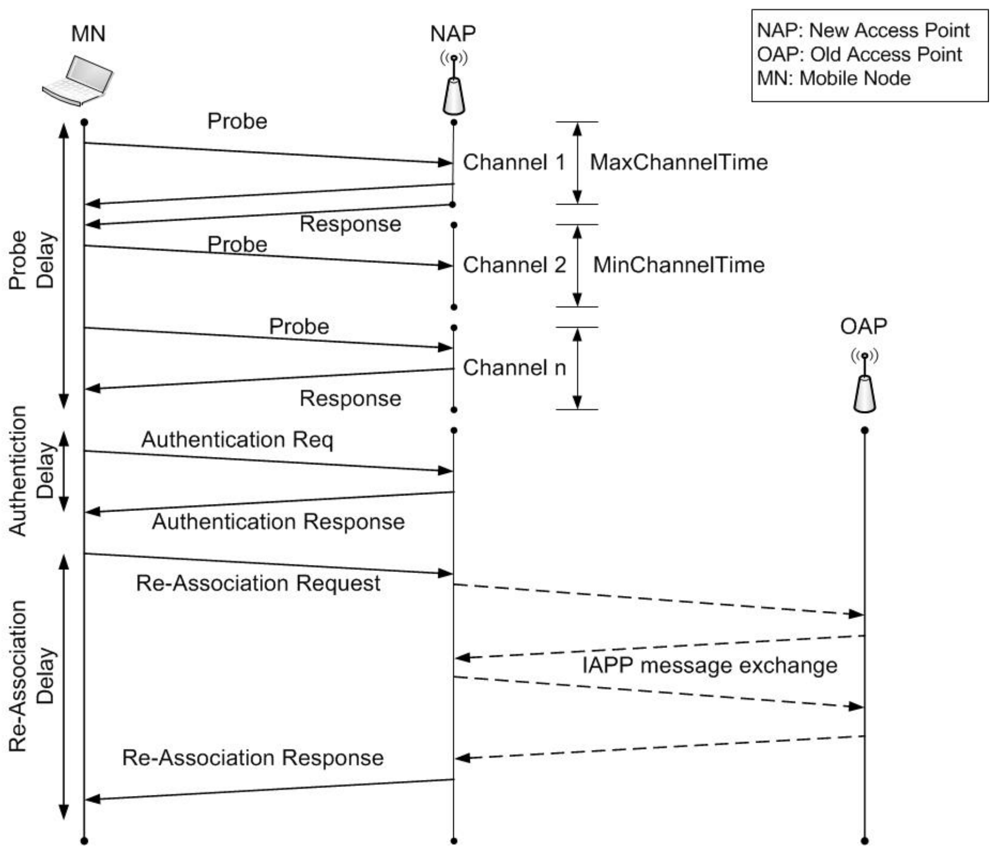


**Figure 1.2**: IEEE 802.11 Layer 2 Handover Process

$$T_{(Layer2)} = T_{probe} + T_{auth} + T_{assoc} \tag{1.1}$$

To assist movement detection in the MIPv6 handover process, different techniques that use Layer 2 hints are presented by Yokota *et al.* (2002), Buddhikot *et al.* (2003) and Oh *et al.* (2006). In this type of protocol, a Layer 2 hint is used to pass information to Layer 3 before a handover can take place. The basic idea behind this approach is to provide link-up and link-down triggers based on the Received Signal Strength (RSS) information to indicate the MN movement (Seunghun *et al.*, 2007; Malki, 2007). Although these types of protocol anticipate the possibility of handover in advance in the intra-system handover and significantly reduce the Layer 2 handover latency (Akyildiz *et al.*, 2004), but do not work efficiently in inter-system handover due to the lack of trigger prediction. Techniques such as pre-registration and post-registration are also proposed to anticipate Layer 3 handover by executing the Layer 3 process before movement, and the post-registration process involves tunneling to forward data without delays (Geunhyung and Cheeha, 2004). Both of these methods are not suited in the high density and high mobility area because the pre-registration process would require large amounts of data to be executed by the AP and the post-registration process includes tunnels, which consume high bandwidth. Moreover, the existing Layer 2 assisting handover protocols do not consider the influence of the number of users, bandwidth and speed of the MN.

Layer 2 assisted handover protocols that can pass important information to Layer 3 are very much suited to the IEEE 802.11 wireless networks. Such protocols include pre-authentication (Issac *et al.*, 2006) and policy-based handover (Lee *et al.*, 2007; So-In *et al.*, 2010). However, these solutions do not constitute the mobility pattern and speed of the MN; therefore, unnecessary handover can occur and create load on the network. A Layer 2 assisted handover based on a re-association signal is suitable for WLANs. This type of solution will transmit current registration information to the new AP and before Layer 2 handover finishes and Layer 3 handover starts. Passing this information will allow the New Access Router (NAR) to form a new IP address of the MN and prepare it to be registered when the MN initiates Layer 3 handover. This will reduce handover latency significantly during the Layer 2 and Layer 3 process.

### 1.3.2 Layer 3 Handover Protocols

The process of Layer 3 handover requires a change in the IP address of the MN which involves infrastructure devices and special configuration. The process of Layer 3 handover involves network devices sending signals to other devices when the MN moves (between old and new networks). These devices are called ARs, and are connected through a common network; thus are able to send MN information. Sending packets to the MN during roaming is possible if the IP address of the MN is within the same hierarchy of the home network, but this is not possible because the MN may change its location to a different network with a different address space. To perform the process of handover, the AR must be configured with additional features that allow packets to move continuously to the foreign network, always keeping the MN in contact. To achieve successful handover requirements such as link detection, link establishment, network detection, IP address acquisition, and access authorization must be fulfilled (Koodli and Perkins, 2007). To cater for mobility, the concept of the mobile IP protocol was standardized by the IETF (Perkins, 1996), which performs handover during the change in the network and was mainly designed for fixed nodes. MIP is simple to implement because it is based on IPv4, but has several shortcomings such as a non-hierarchical IP structure, signaling load and high handover latency. Although MIP has provided some satisfactory functionality to the fixed-node mobile users, there can be delays for the mobile user during wireless networking. Some of these delays are detection delays, address configuration delays and registration delays (Perkins, 1998).

MIPv4 (Perkins, 2002) was developed to overcome the problems encountered in MIP by introducing the concept of a foreign agent as an external body to communicate with the home network and maintain connectivity by providing the IP address automatically, or a third-party source such as a Dynamic Host Configuration Protocol (DHCP) server (Droms, 1997). MIPv4 remains a good candidate for wireless mobility. However, it can also result in problems such as a shortage of IPv4 addresses, movement detection delay, discovery delay and triangular routing. MIPv4 suffers from an ingress filtering (Ferguson and Senie, 2000), which prohibits communication from other network sources based on the private addressing scheme (Rekhter *et al.*, 1996). This is due to the shortage of public IPv4 addresses, as stated by the Internet Society in a newsletter (ISOC, 2011). Some of the MIPv4 problems have been resolved by providing reverse tunneling (Montenegro, 2001), route optimization (Perkins, 1998) and smooth handover.

MIPv6 is a header extension in the IPv6 protocol to provide mobility. MIPv6 was expected to overcome all the issues related to mobility. However, it has still been a victim of delays such as through movement detection, automatic IP address registration and Binding Updates (BUs). In MIPv6, the movement detection process is based on the RAs sent periodically every 35 to 70 ms by the AR (Johnson *et al.*, 2004). When the MN moves between networks, it detects changes in the network by investigating the network prefix advertised within the RA frame. To detect that the MN has moved out of the current network, it has to miss at least three RA signals from the current AR. Moreover, to detect movement into a new network, it has to listen to at least three RAs from the NAR. Once the RA has been listened to, the MN forms an IP address based on the stateless auto-configuration process (Thomson *et al.*, 2007) or stateful address configuration process (Droms *et al.*, 2003), and it then performs a Duplicate Address Detection (DAD) process on that particular IP address to verify its uniqueness (Narten *et al.*, 2007). To overcome DAD process delays, Optimistic DAD (ODAD) (Moore, 2006) was introduced, but the ODAD process assumes that the node is an optimistic node carrying a unique IP address. However, this does not guarantee uniqueness. The original MIPv6 protocol was not designed to handle rapid change in a network. In addition, with all the modifications to previous protocols, it did not provide promising results in terms of handover delays. In the worst case scenario, the MN will keep doing handover rather than communication. Since the handover takes a longer time to complete, packets are lost or dropped, especially for real-time applications. Both connectionless UDP (Postel, 1980) and connection-oriented TCP (Postel, 1981b) protocols will be susceptible to the delays and, hence, will provide poor communication.

To overcome the deficiencies of the MIPv6 protocol, fast handover/smooth handover and hierarchical handover solutions are proposed. The fast/smooth handover solution is based on Fast Handover in MIPv6 (FMIPv6) protocol (Koodli, 2009). The fast handover solution is based on the Layer 2 triggers to predict the MN movement detection and perform fast RAs but lack movement prediction, irregular mobility pattern, unnecessary handovers and signalling overload. However, the hierarchical handover solution is based on the hierarchical structure of the network. The Hierarchical MIPv6 (HMIPv6) (Soliman *et al.*, 2008) protocol was developed by the IETF to handle intra-domain MIPv6 handovers. This solution attempted to solve the handover latency problem in the intra-system networks and introduce extra devices such as a Mobility Anchor Point (MAP). A hybrid solution based on the fast and hierarchical handover is also proposed as Fast Handover in Hierarchical MIPv6 (F-HMIPv6) (Mun and Lee, 2010). This solution provided smooth handover in the intra-system network structure only. Most of the MIPv6 extensions solve particular issues related to the delay. However, these extensions do not reduce the overall latency during handover. The total handover in the MIPv6 network is based on the sum of Layer 2 and Layer 3; delays, therefore, co-operation between these layers can reduce the latency. The total MIPv6 handover latency, $Total_{Handover}$ is the sum of individual Layer 2 handover latency, $T_{Layer2}$ and Layer 3 handover latency, $T_{Layer3}$, as shown in Equation 1.2. The Layer 2 handover is the sum of time required to complete the probe scan, $T_{probe}$, authentication, $T_{auth}$ and association, $T_{assoc}$, as shown in Equation 1.3. The Layer 3 handover latency is the sum of time required to complete movement detection, $T_{mvd}$, IP address registration, $T_{IP}$, DAD, $T_{DAD}$ and BU, $T_{BU}$, as shown in Equation 1.4. The mathematical representation of the total MIPv6 handover latency is shown in Equation 1.5. The total MIPv6 handover time line is shown in Figure 1.3, which shows that the handover process starts with the Layer 2 trigger and finishes with the completion of association signal in the Layer 2 handover. The Layer 3 process starts with movement detection and finishes with the BU signal to the CN.

$$Total_{(Handover)} = T_{Layer2} + T_{Layer3} \tag{1.2}$$

$$T_{(Layer2)} = T_{probe} + T_{auth} + T_{assoc} \tag{1.3}$$

$$T_{(Layer3)} = T_{Mvd} + T_{IP} + T_{DAD} + T_{BU} \tag{1.4}$$

$$Total_{(Handover)} = T_{probe} + T_{auth} + T_{assoc} + T_{Mvd} + T_{IP} + T_{DAD} + T_{BU} \tag{1.5}$$

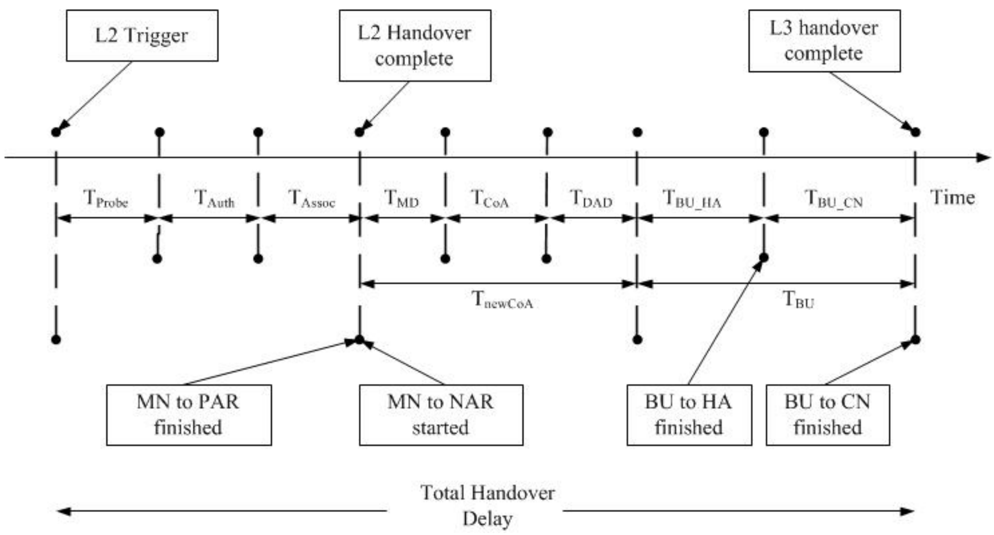


**Figure 1.3**: Handover Delay Timeline of MIPv6

### 1.3.3 Cross Layer Handover Protocols

From the discussion in the previous Sections 1.3.1 and 1.3.2, it is obvious that focusing only on reducing Layer 2 and Layer 3 handover latency does not solve the problem. Therefore, a cross layer design, which is based on Layer 2 and Layer 3, is required to reduce the total handover latency in MIPv6-based WLANs. From Equation 1.5, it is clear that the MIPv6 handover constitutes movement detection, IP address registration and DAD delays. Therefore, it is very important to develop a method in which these delays can be reduced via the co-operation of the Layer 2 and Layer 3 functions. A parallel execution method is required at Layer 2 and Layer 3 so that most of the handover functions are carried out before the actual handover takes place.

Existing cross layer solutions aim to achieve Layer 3 handover with help from Layer 2, mainly by obtaining RSS reports and movement detection information from the Layer 2 in advance. The system can then make better preparation for the Layer 3 handover so that the packet loss is eliminated and the handover latency is reduced. A solution based on User Mobility Profiles (UMP) (Akyildiz and Wang, 2004) to support enhanced handover management in intra-system and inter-system network structure is proposed. This solution does not specify any particular mechanism for obtaining the Layer 2 triggers. Another solution based on cross layer design is Cross Layer Handoff Management Protocol (CHMP) (Mohanty and Akyildiz, 2006) to reduce the intra and inter-system handover. The method is based on the HMIP protocol, which includes extra devices in the network to support handover. All of these existing solutions aim to reduce the latency and packet loss; however, these solutions also add load either to the network devices or MN and so are not very suitable for dynamic and high mobility environments.

A cross layer design (Layer 2 + Layer 3) in which a Layer 2 hint is provided to Layer 3 reduces the overall latency. The Layer 2 assisted hint provides the previous IPv6 address of the node to the NAR before Layer 2 handover finishes. The NAR detects MN movement based on the received IP address and movement detection. The AR based on the MIPv6 forms the new IPv6 address of the MN, performs the DAD process and keeps the IP address in the cache. The MN on arriving in the new network requests the IP address based on the modification in the MIPv6 process and continues the communication. This type of method will reduce the packet loss and handover latency significantly.

### 1.3.4 Wireless Topology Design Impact on Handover Latency

Wireless topology design plays a key role in analysis of handover in WLAN. Since MNs in a WLAN facility are allowed to move freely, it is important to note that the MNs can and will move in different directions at different speeds. Multiple issues such as resource allocation, user location updating, AP placement and channel holding time are important in planning WLAN infrastructure. Even after thorough planning of WLAN infrastructure, it is difficult to predict if the MN will perform handover.

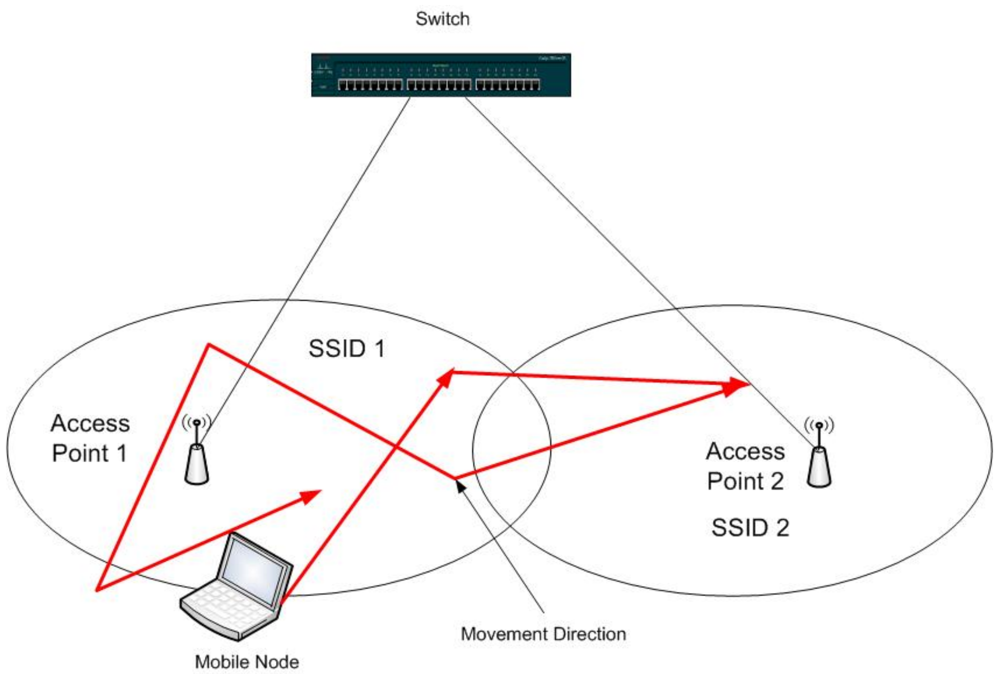


**Figure 1.4**: Random Mobility

A comprehensive survey of existing mobility patterns is discussed by Camp *et al.* (2002), which proves, through simulation, that MN movement has a noticeable impact on the handover latency, which includes end-to-end delay, data packet delivery ratio and quality of service (QoS). Similar studies have been done by Ariyakhajorn *et al.* (2006) and Tie-yuan *et al.* (2009), and show the impact of the Random Waypoint and Gauss Markov's Mobility Model on network performance, as shown in Figure 1.4. The only difference found is when the node moves faster than the walking pedestrian. A dynamic construction of the mobility pattern is proposed by Geunhyung and Cheeha (2004) to use as a history to predict future location and reserve resources for the handover. However, this technique cannot be implemented in a heavily populated WLAN in which multiple nodes are moving in random motion. The impact of the handover process decreases the network performance due to the high bandwidth utilization. However, performance can vary when the connection rate increases and the duration decreases, although the overall traffic is maintained. With a WLAN infrastructure in which APs are placed properly with 20% to 25% overlap, it is predicted that the faster the MN movement, the higher the handover rate (Hong and Lu, 2000; Qin *et al.*, 2002).

It is assumed that adding more APs to cover more area does allow for better handover and provides adequate time to the MN for exchanging handover signals. The consequences of a large number of APs is better coverage, reliability and traffic capacity, but this increases complexity due to the large number of handovers. Therefore, it is essential to design a WLAN topology that can allow the MN to roam freely and provide proper handover.

Handover in WLAN infrastructure depends on the MN's velocity as well. MNs moving at high speed perform faster handover, so it is possible that before an MN can exchange all the handover signals, it moves away from that particular AP. Therefore, proper cell coverage and structure are required to accommodate proper handover. This will allow MNs moving at pedestrian speed, a bicycle, motor bike, or a vehicle moving around the campus to handover properly without packet loss and delay.

## 1.4 Problem Statement

To reduce overall handover latency in a WLAN consisting of multiple MNs, an efficient protocol development is required. Since the Layer 3 handover can only be performed after Layer 2 handover, a protocol is required which can perform parallel signal execution by integrating Layer 2 and Layer 3 to reduce the handover delay. Moreover, an EF-WTD based on WLAN infrastructure, cell coverage and cell overlap is required to reduce handover latency of the MNs with variable velocity and random motion.

## 1.5 Research Questions

This research addresses the problem of handover latency in MIPv6-based wireless networks. In this study, IEEE 802.11 wireless networks were selected because of their low cost and high bandwidth provision (Mills *et al.*, 2007). WLANs are an emerging technology, which aim to provide freedom of access, but fail to provide seamless real-time communication due to handover latency. Therefore, to provide discontinued real-time communication, a cross layer approach with EF-WTD is required. Thus the purpose of this thesis is to answer the following research questions:

(i) How to design a re-association signal at Layer 2 in an IEEE 802.11 WLAN that can forward an IP address to the new network?

(ii) How to design a RS and an RA signal to improve Layer 3 handover latency in an IEEE WLAN?

(iii) How to improve cell structure by designing a wireless topology that can provide better coverage and handle irregular movement of MNs?

## 1.6 Research Aim

The aim of this research is to design a cross layer protocol and a EF-WTD that can reduce total handover latency in an MIPv6 based WLAN during the MNs movement between different networks. The reduction in handover latency will provide reliable, efficient, smooth handover and allow the MN to connect faster to the new network, thus reducing the disconnection time and the packet loss during handover.

## 1.7 Research Objectives

The following objectives are in place to design an EN-ReAS, EF-MIPv6 protocol and EF-WTD in IEEE 802.11 WLANs:

(i) To design a re-association signal at Layer 2 in an IEEE 802.11 WLAN that can forward an IP address to the new network.

(ii) To design an RS and an RA signal to improve Layer 3 handover latency in an IEEE WLAN.

(iii) To design a wireless topology that can provide better coverage and handle irregular movement of MNs.

(iv) To evaluate Layer 2, Layer 3 and their combination in a wireless topology design.

## 1.8 Research Contributions

The overall contribution of this thesis is to develop an EF-MIPv6 protocol to reduce the total handover latency in IEEE 802.11 wireless networks. A re-association frame modification at Layer 2, AP modification and AR functional modification are carried out to handle enhancement in the protocol. To perform a smooth handover based on the cell size and overlap area, in addition to reducing packet loss, a topology design is proposed to allow the MN to predict handover and avoid unnecessary handover due to random motion and variable speed. The main contributions of this thesis are as follows:

(i) Design of a re-association signal at Layer 2 in an IEEE 802.11 WLAN that can forward an IP address to the new network.

(ii) Design of an RS and an RS signal to improve Layer 3 handover latency in an IEEE WLAN.

(iii) The improvement in cell structure by designing a wireless topology that can provide better coverage and handle irregular movement of MNs.

## 1.9 Scope of the Research

The research presents an EF-MIPv6 protocol to reduce overall handover latency in wireless LANs. It also focuses on the design and development of WLAN topology that allows MN to adopt variable speed and random motion within the WLAN infrastructure. To provide an efficient handover protocol and topology design, different modifications at Layer 2 and Layer 3 were required. Multiple scenarios, mathematical models and evaluation processes were required to validate the performance of the designed protocol and topology. The research aims to take account of the following points:

(i) The Layer 2 and Layer 3 signal designing and validation is done using an xMIPv6 module.

(ii) The performance of the proposed protocol is evaluated and validated using an OMNET++ 4.1 network simulator.

(iii) The WTD and proposed protocol do not include any obstacles during simulation.

(iv) The proposed protocol and model are limited to IEEE 802.11 b/g standard.

(v) The proposed protocol and model are tested using one fixed node and one or more MNs.

(vi) No security is considered during Layer 2 and Layer 3 authentication.

(vii) Pre-placed APs with fixed channel numbers are used to avoid unnecessary channel scans.

## 1.10 Significance of the Study

One of the crucial issues relating to mobility is handover latency in IEEE 802.11 WLANs. Large handover latency causes real-time applications to disconnect. It therefore requires re-connection with the CN. A complete handover process requires Layer 2 handover and Layer 3 handover to be completed individually so that the MN can resume communication with the CN. A Layer 2 handover process consists of scanning, authentication and association. A Layer 3 handover process consists of movement detection, IP address registration, DAD and BU signals. Each of these signals at Layer 2 and Layer 3 causes delays and packet loss during motion. In addition to the signal delays, an MN also experiences unnecessary and unwanted delays due to the unpredicted movement pattern and variable velocity. Multiple solutions are proposed individually at Layer 2 and Layer 3; however, could only reduce latency for the data packets.

To provide a solution to the aforementioned problem, this research provides a comprehensive solution based on Layer 2 and Layer 3, which can reduce the total handover latency. The proposed solution modifies the re-association signal in the Layer 2 frame to handle the previous IP address and send it to the NAR. The AR then deduces the MAC address of the MN and forms a new IP address, performs DAD and keeps the IP address in the memory. A modification in the RA signal is proposed to indicate the use of the EF-MIPv6 protocol so that the AR can understand that the MN is requesting a pre-formed IP address. In addition, an EF-WTD is also proposed to handle random motion and variable speed in MNs.

## 1.11 Thesis Organization

The remaining chapters of this thesis are organized as follows:

Chapter 2 provides an intensive literature review of the study area, background, handover protocols, problems and potential solutions. At the end, a discussion of proposed solutions and a comparison table of the protocols are presented. Chapter 3 focuses on the research methodology flow used in this research. It discusses the test-bed setup, simulation setup and problem formulation based on the literature review. At the end, it describes the WTD and the protocol design used in this research. Chapter 4 outlines the design details for modifying the Layer 2 re-association signal (EN-ReAS) and EF-MIPv6 protocol and its algorithm. Chapter 5 outlines the proposed EF-WTD and implementation of the proposed protocol in the model. The chapter also describes the velocity impact and density of nodes on handover latency. Chapter 6 presents a simulation of experiments to measure handover latency for MIPv6, FMIPv6 and the proposed cross layer method based on EN-ReAS and EF-MIPv6. It also presents a comparison of these protocols, latency and packet loss. It also describes the impact of density of nodes and velocity on handover during mobility. Chapter 7 summarizes the thesis, re-states the contributions, and suggests directions for future research.

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# APPENDIX B

## PUBLICATIONS

Muhammad Arif Amin, Kamalrulnizam Abu Bakar, Abdul Hanan Abdullah, Hamad Odhabi. ”Emerging Wireless LAN Mobility Protocols”, International Conference of Resource Management (IRM 2009), May 21-23, 2009. Dubai, UAE.

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Muhammad Arif Amin, Kamalrulnizam Abu Bakar, Abdul Hanan Abdullah, Mahesh Nair, Rashid Hafeez Khokhar. ” Handover Latency Measurement of Mobile

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