An Enhanced Scheme to Support High Level Nested Network Mobility

منهجية محسنة لدعم الشبكات المتحركة ذات الدرجة العالية من التداخل

BY

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ABSTRACT

Recently, wireless devices have been used significantly due to the continuous and enormous services that they provide. The mobility support protocols have been designed to achieve a permanent and continuing access to the Internet while the mobile network are roaming and changing their points of attachment. One of the major challenges that arise is how to achieve seamless mobility and high network performance. However, one of the major requirements of a protocol supporting network mobility is to achieve continuous and uninterrupted communication to the mobile network during moving. Network Mobility (NEMO) (RFC3963), developed by Internet Engineering Task Force (IETF), is introduced for this purpose but it still suffers from some limitations, especially when the level of nesting increases. To overcome these drawbacks, this dissertation proposes an enhanced scheme using hierarchical structure to support high level nested network mobility. This proposed scheme aims to reduce packet transmission delay and handoff latency in high level nested network to achieve seamless mobility and high network performance. This can be achieved by dividing a network domain under top-level mobile router into multiple sub domains. The evaluation technique followed in this dissertation is by using simulation and analytical model approach. The simulation carried on by using OPNET to measure performance metrics (based on simulation time) such as delay, throughput, traffic, and response time. In addition to simulation, analytical model approach has been used to measure performance metrics (based on nesting degree) are handoff latency and packet transmission delay. The proposed scheme enhancement is benchmarked with NEMO protocol and Route Optimization Using Tree Information Option (ROTIO) approach witch it based on IETF standards. The result obtained had shown that the proposed scheme has better performance than the benchmark.

مستخلص البحث

أصبحت اجهزة الاتصالات اللاسلكية تستخدم بصورة كبيرة نظرا للخدمات المستمرة الهائلة التي تقدم من خلالها . صمم دعم قابلية الحركة للشبكة المتحركة للحصول علي إتصال دائم بالانترنت اثناء الحركة وتغيير نقطة إتصالها بالانترنت . من أعظم المشاكل التي تواجه هي كيفية الحصول علي حركة سلسلة ذات كفاءة عالية . إن أحد أهم متطلبات أي بروتوكول يدعم الشبكة المتنقّلة أن يحقق اتصالات مُثلى ومستمرة من وإلى جميع المستخدمين. ولتحقيق هذا الغرض فقد قام فريق مهام هندسة الانترنت بتطوير الشبكة المتنقلة لكنها لا تزال تعاني من بعض القصور، خاصة بزيادة درجة التداخل . لتدارك هذه العيوب، فإن هذه الأطروحة تقترح طريقة محسنة تستخدام الهيكل الهرمي لدعم الشبكات المتحركة المتداخلة ذات الدرجة العالية من التداخل . هذا المخطط المقترح يهدف لتقليل نسبة التأخير الناجم عن الانتقال، وتأخير ارسال حزم المعلومات في الشبكات المتحركة المتداخلة ذات الدرجة العالية من التداخل .هذا يمكن تحقيقه عن طريق تقسيم المجال الكلي للشبكة الي عدة مجالات جزئية . وسيلة تقييم الأداء المتبعة في هذه الأطروحة هي باستخدام نظام محاكاة الشبكات والتحليل الرياضي. نظام المحاكاة تم بإستخدام برنامج "أوبنت" لقياس معايير الأداء (على اساس الزمن) وهي: التأخير، الإنتاجية وحركة السير وزمن الإستجابة. بالإضافة للمحاكاة، فقد تم استخدام التحليل الرياضي لقياس معايير الأداء (على اساس درجة التداخل) وهي: التأخير الناجم عن الانتقال، وتأخير ارسال حزم المعلومات. أظهرت النتائج كفاءة عالية في الاداء مقارنة بمنهجية (الشبكات المتحركة) و منهجية (الطريق المخطط الأمثل مع خيار معلومات الشجرة الممتدة) المبنية علي مقاييس فريق عمل هندسة الانترنت . وقد أظهرت النتئج التي تم الحصول عليها أن المنهجية المقترحة لديها أداء أفضل مقارنة بالمنهجيات الاخري.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigation, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at Sudan University of Science and Technology or other institutions.

Mohammed Babiker Ali Mohammed

Signature________________ Date___________________

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LIST OF ABBREVIATIONS

AR: Access Router.

BU: Binding Update.

CN: Correspondent Node.

CoA: Care of Address .

HA: Home Agent.

HMIPv6: Hierarchical Mobile Internet Protocol Version 6.

HoA: Home of Address.

IETF: Internet Engineering Task Force.

MIPv6: Mobile Internet Protocol Version 6.

MN: Mobile Node.

MNN: Mobile Nodes Network.

MNP: Mobile Network Prefix.

MR: Mobile Router.

NEMO ES: Network Mobility Extended Support.

NEMO: Network Mobility.

NERON: Nested Route Optimizations.

PAN: Personal Area Network.

PMIPv6: Proxy Mobile Internet Protocol Version 6.

RBU: Recursive Binding Update.

RFCS: Request for Comments.

ROHC: Robust Header Compression.

ROTIO: Route Optimization using Tree Information Option

SD-TLMR: Sub Domain Top Level Mobile Router

TCoA: Tree -Based Care of Address.

TLMR: Top Level Mobile Router.

TuCP: Tunneling Compression Protocol.

VAN: Vehicle Area Network.

VMN: Visited Mobile Network.

LIST OF SYMBOLES

N	The degree of nesting of whole domain
M	The degree of nesting inside sub domain
$N_{SD-TMLR}$	The number of sub domains
D^{i}_{MR}	The Processing delay of MR
$LD^{i,i+1}_{MR}$	The link delay between MR i and MR i+1
D^{i}_{HA}	The processing delay of HA
$LD_{CN-ROUTER}$	The link delay between correspondent node and MR
$D_{SD-ROUTER}$	The processing delay of SD_TLMR
$LD_{HA-ROUTER}$	The link delay between home agent and MR
LD_{MR-MN}	The link delay between MR and Mn
$LD_{AR-ROUTER}$	The link delay between AR and MR
$LD_{AR-TLMR}$	The link delay between AR and TMLR
D_{MD}	The processing delay of movement detection
D_{DAD}	The processing delay of duplicate address detection

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

Wireless devices and wireless networking technologies are drastically grows recently, consequently, many electronic devices are capable to connect to the Internet using their own IP addresses. Mobile networking becomes more applicable to various scenarios. So the users are expected to be connected anywhere at any time. However, network mobility is not supported as core functionality in the TCP/IP stack, so additional mechanisms are required to support network mobility. Internet Engineering Task Force (IETF) has initiated many protocols to support connectivity to these devices. This keeps the connection while the users are moving, not only to single device but also to Mobile Networks that are moving as a single unit. Mobile Network contains multiple mobile nodes and other wireless devices (routers, switches and hosts) that are capable to exchange the data between them, the topology of network defers from network to another depending on the number and complexity of nodes. The architecture of mobile network can be Vehicular Area Network (VAN), a Personal Area Network (PAN) or a Body Area Network (BAN), which require access to the Internet. Hence, an efficient mobility management scheme is needed to provide continuous services for mobile network as it changes its point of attachment to the Internet. To provide the mobility support, IETF has proposed MIPv6 for host mobility and network mobility Basic Support Protocol (NEMO- BS) (Devarapalli, Vijay and Wakikawa, Ryuji and Petrescu, Alexandru and Thubert, Pascal, 2004), for whole network mobility. NEMO enables mobile nodes to move together as mobile network using mobile router (MR) (Al-Surmi, Ibrahim and Othman, Mohamed and Ali, Borhanuddin Mohd, 2012). Moreover, it allows MRs from different mobile network to connect each other in form known as nested mobile network (Nested Nemo). In NEMO (Ernst, Thierry, 2007). Any MR is mainly designed to be connected to a particular network or home network. Then the MR is given a permanent IP address known as a home address (HoA). The MR's HoA, it is a constant address and it is not changing regardless of its attachment point in the Internet. When the MR is move from its home network, and join another network, packets addressed to the nodes of the home network are routed to the home network and a home agent (HA), a router in the home network manages all these packets. When the mobile router attached to the foreign network, it gets an address known as care-of address (CoA) in foreign mobile network. Then the mobile router sends a binding update (BU) message to its HA with the purpose of map the CoA with its HoA, after that, a bi-directional tunnel between MR and HA is established. All packets are encapsulated and transferred to the mobile node (MN) in home network through this tunnel. MR receives the encapsulated packet and extracts the original packet to MN. The main problem here is the additional IP header that are added and removed for purpose of tunnelling occur between MRs and Home Agents, which may causes a lot of problems directly affects the network performance. when there are many routers connected together, they are create hierarchical form known as Nested Network Mobility , which is suffer from the Bi-directional tunnelling overhead that are occurs multiple time depending on level of nesting.

Network mobility (NEMO) manages the movement of MR during it changes the point of attachment of the mobile network in order to be connected to the internet (Devarapalli, Vijay and Wakikawa, Ryuji and Petrescu, Alexandru and Thubert, Pascal, 2004). Therefore, it is very significant to acquire the high performance of mobility management protocol to accomplish fast and seamless handoff with lower delay and packet losses in NEMO environment (Perera, Eranga and Sivaraman, Vijay and Seneviratne, Aruna, 2004). Network Mobility Support protocol is based on creating bi-directional tunnel between MR and its Home Agent (HA), only MR should send the binding update message (BU) with the network prefix to provide Internet connectivity to all MNs. Following this technique MR hide the mobility of MNs and limited the repeated registration of the MNs (Perera, Eranga and Sivaraman, Vijay and Seneviratne, Aruna, 2004). However, establishing of bi-direction tunnelling between the MR and it’s HA for all communications causes on an increasing message size because it is done by

(IP-in-IP) encapsulation. This increases handoff latency, packet loss, signalling cost and tunnelling overhead especially when the level of nesting is becomes high.

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

Mobile routers can move freely and attach to other mobile network using its original IP address. Mobile router in foreign mobile network gets care of address and sends this new address to its home agent, and then the bi-directional tunnel between mobile router and its home agent is established. All data packets to and from MNs must go through this tunnel even though a shorter path may exist. This tunnel is done by IP-in-IP encapsulation, which means additional IP header will be added at each operation. When there are multiple networks connected together, they make hierarchal structure known as Nested Network mobility. This hierarchy of mobile routers increases the complexity of route because a bidirectional tunnel is formed at each level of nesting. The additional IP header will increase the size of the message at each level. This consequently increases tunnelling overhead, handoff latency and packet transmission delay leading to inefficient performance of mobile network.

1.3 RESEARCH OBJECTIVES

The main aim of this research is to enhance the performance of high-level nested mobile network to achieve seamless mobility. The detailed objectives to be achieved by this research are:

- To investigate the current mobility management protocols and identify their limitations.
- To develop a novel scheme using hierarchical structure to address the high-level Nested Network Mobility limitations.
- To evaluate proposed scheme using analytical method and simulation.

The Performance metrics that will be used in evaluation are: handoff latency, packet transmission delay, throughput, traffic, and response time.

1.4 RESEARCH QUESTIONS

This research will be conducted to answer the following questions.

- How the drawbacks of NEMO can affect its efficiency and functionality?
- Is it possible to get optimal routing with minimal handoff latency and packet transmission delay?
- How to address the problems caused by encapsulation and de capsulation process for any degree of nesting?
- What rule can hierarchical structure play for enhancing the performance of nested NEMO?

1.5 RESEARCH HYPOTHESIS

Behind its simplicity, NEMO Basic Support Protocol faces many challenges in term of performance that may significantly affect its reliability and interrupt the communications between the connected entities. In order to reduce signalling overhead, packet loss and handoff latency that the Mobile Network suffers this thesis will develop a novel scheme that use hierarchical architecture in the nested Mobile Network with dividing a domain under TLMR into multiple subdomains in order to reduces visited mobile router registration path. In addition, this scheme should reduce packet transmission delay as well as reduce handoff latency. Furthermore, to achieve seamless mobility, hierarchal Mobile IPv6 concept will be used in nested NEMO to allow direct tunnelling between HA and MR without nested tunnels which result in multi-levels of nested mobile networks. Mobility management at the level of sub domain rather than a whole domain reduces the overall overhead.

1.6 RESEARCH METHODOLOGY

To achieve the research objectives, this thesis carry out the following steps:

1. Investigate the current research works that dealt with the nested network mobility issues and limitations.
2. Determine the open issues that need to be addressed.
3. Development of An Enhanced Scheme to Support high level Nested Mobile Networks
4. Evaluate the scheme using analytical model and simulation.
5. Benchmark the proposed scheme with the standard NEMO BSP and ROTIO.

1.7 RESEARCH SCOPE

The focus of this research is to support nested network mobility performance. The performance metrics that used for the evaluation are handoff latency and packet transmission delay. This work, focus on layer three solutions with some support from layer two. The implementation and evaluation are carried out using Opnet 14.5 simulator and mathematic model.

1.8 RESEARCH ORGANIZATION

The organization of the following chapters in this research as follows:

Chapter 2: presents an overview of Network Mobility (NEMO), the literature review that related to the research topic, gives more details about the research problem, and critically investigates the existing solutions, which they proposed to address the research problem and discusses its advantages and limitations..

Chapter 3: explains the research methodology and presents the design of the proposed scheme and its operations.

Chapter 4: presents the evaluation of the proposed scheme using analytical model and simulation and discuss the results.

Chapter 5: presents the conclusion, the thesis contribution and the future recommendations.

CHAPTER TWO
LITERATURE REVIEW

2.1 INTRODUCTION

Nowadays wireless technologies and mobile devices are widely used in IPv6 communication. Mobile IP and Mobile IPv6 (Perkins, Charles and Johnson, David and Arkko, Jari, 2011)aim at maintaining Internet connectivity while a host is roaming, as users anticipate to be able to access the Internet from "anywhere" at "anytime". Mobile IPv6, as Mobile IPv4, provides transparency to a node's mobility (i.e., change of IPv6 address) to the upper layer applications and protocols on the mobile node in addition to correspondent nodes (CN). Every Mobile IPv6 node belongs to a home network and has an IPv6 home address (HoA) appointed to the MN within its home network's prefix. Regardless where the MN is, its IPv6 HoA does not have to be modified. Packets from CN can be directed to the IPv6 home address of MN. Regardless where the MN is, Mobile IPv6 guarantees that a MN can get the packets directed to its HoA (Chen and Zhang, 2004). This chapter presents literature review of Mobile Network protocol (NEMO Basic Support) especially nested mobile networks. In addition, the chapter discusses the related researches and IETF contributions are mentioned with comparison of various protocols that are proposed to solve the drawbacks of nested network mobility.

2.2 NETWORK MOBILITY TERMONOLOGIES

Mobile Node (MN):

A node that has MIPv6 capability and it can move around the networks.

Corresponding Node (CN):

A node who wants to communicate with Mobile Node.

Home Address (HoA):

It is permanent address of mobile node that remains same and does not change with mobility of node.

Care of Address (CoA):

It is temporary address of mobile node that is acquired when mobile node connected to new network. It will change as mobile node joins any new network.

Home Agent (HA):

It is a router at home location of the mobile node. It has the HoA and maintains it. Home Agent also do the packet forwarding and mapping when mobile node is away from it.

Foreign Agent (FA):

It is a router at far location through which mobile node get itself connected. It will assign CoA to mobile node. Mobile node will undergo a procedure of registration with Home Agent and let HA knows its CoA.

Mobile Network (MN):

A network that is mobile and changes its location.

Mobile Route (MR):

A Router that is mobile and serving mobile nodes.

Local Fixed Node (LFN) :

A Mobile Network Node that remains fixed but attached in Mobile Network.

Local Mobile Node (LMN):

A Mobile Network Node that is attached to MN but it can also move and change its position.

Visiting Mobile Node (VMN):

A node that is visiting current Mobile Network.

Top Level Mobile Router (TLMR):

Mobile Router at the top in hierarchy of Nested Mobile Network. It is connected to internet via Access Router (AR). TLMR is connected to AR through wireless medium (e.g. 3G, WiMAX) whereas AR is directly connected to Internet through wireline

Packet Transmission Delay:

Packet delay is defined as the difference between time the packet sent from the source and the time the packet received at the destination for each packet.

Handoff Latency:

The handoff latency is defined as the amount of time where the MN probably cannot be reached. Usually, it is resulted by the time required to be attached to a new network, get and configure a new CoA, a wait authorization to approach the new network, decide that a handover have to be started, and lastly, carry out the handover, which results on informing the HA about the new CoA and obtain the acknowledgement from the HA .

Throughput:

Network throughput is a measure of the total amount of data the network delivers during a selected time interval. In other words, throughput is known as the average amount where the data packet is sent successfully from a node and received from another node through a transmission path. A throughput with a bigger value is usually a best selection in any network.

End-to-End Delay:

End-to-end delay is the total delay time of data packets received at all nodes of a particular type in the network. It is the period between when a packet is sent from the source host and received by the destination host. End-to-end delay estimates the strength of the routing protocols regarding their efficient use of the network resources.

Average TCP Delay:

TCP delay is a delay for all connections (in seconds) of packets arriving at the TCP layers in the entire network. It is calculated from the time a data packet is sent from the TCP layer of the sender to the time it is totally arrived at the TCP layer of the receiver.

Average Download Response Time:

The download response time (sec) defines the measured time spent from a request sent by the source node to the time of the response packet received by the destination node. This statistic includes all response packets that are sent from a server to an application.

Average Traffic Sent:

The HTTP/FTP traffic sent describes the average bytes per second submitted to the transport layer by all HTTP/FTP applications in the network.

Average Traffic Received:

The HTTP/FTP traffic received represents the average bytes per second forwarded to the HTTP/FTP Application by the transport layer.

2.3 MOBILITY SUPPORT

The Mobility Support is generally designed to achieve a permanent and continuing access to the Internet, while the wireless devices are roaming and changing their point of attachment. This Mobility Support can be classified into two main forms: Host Mobility (MIPV6), which concerns mobile node mobility, and Network Mobility (NEMO Basic Support) which concerns the whole Network Mobility (Mobile Router & Mobile Nodes) as a single unit.

2.3.1 Host Mobility

The Host Mobility Support is a mechanism that maintains session continuity between mobile node and their Correspondent Node whereas the mobile host changes the point of attachment. (Ernst, Thierry, 2007).It can be achieved in using one of these techniques: (MIPv6), (Hierarchical Mobile IPv6 (HMIPv6), or (Proxy Mobile IPv6 (PMIPv6), which are defined as follows:

2.3.1.1 Mobile IPv6 (MIPv6)

A MIPv6 is a protocol that allows mobile node move from one network to another while retaining the MN's home address. Therefore, packets are routed to the MN using the home address regardless of the MN's current point of attachment to the Internet (Prakash, Arun and Verma, Rajesh and Tripathi, Rajeev and Naik, Kshirasagar, 2009). The key advantage of MIPV6 is, even though the mobile node moves to other network, the current connection of the original mobile network is still saved and maintained.

2.3.1.2 Hierarchical Mobile IPv6 (HMIPv6)

A HMIPv6 is an extension of the MIPv6, which designed to minimize signalling overhead between the mobile node with its correspondent nodes, and its home agent when the MNs are roaming locally (Mosa, Ahmed A and Abdalla, Aisha H and Saeed, Rashid A, 2012).

Mobile IPv6 protocol considers intra domain and inter domain are having same mobility features. This may result in some problems such as data packets loss and inefficient network bandwidth. Hierarchical Mobile IPv6 (HMIPv6) improves the performance of Mobile IPv6 by dividing mobility management into micro and macro mobility thus fastening responses and minimizing message traversing in the network backbone. (Eddy, Wesley, Terry Davis, and Will Ivancic, 2009)

In Mobile IPv6, when the MN is away from it's HA, the registration delay will be high. However, many data packets might get lost during the registration process. In HMIPv6, when the MN moves within a subnet, the registration process is handled locally and not transmitted to the HA. This reduces handover latency and location management cost. (Cho, Hosik and Paik, Eun Kyoung and Choi, Yanghee, 2004).

Hierarchical Mobile IPv6 presents a new conceptual entity known as Mobility Anchor Point (MAP) which is a router that keeps a binding with the MN recently locating in its domain. Within a visited network, one or more MAPs may exist. MAP behaves in its local domain as a proxy home agent for mobile nodes. However, HMIPv6 (using MAP) is responsible for the mobility management in the MAP domain (local domain) whereas MIPv6 manages the mobility between MAP domains. (Eddy, Wesley, Terry Davis, and Will Ivancic, 2009).

When a MN moves to a new MAP domain, it configures two care of addresses: Local Care of Address (LCoA) and Regional Care of Address (RCoA). The RCoA is fixed for a specific MAP domain. Whenever the MN changes its point of attachment within the MAP domain, it obtains a new LCoA. The RCoA is used by the MN to update its HA and active CNs about its new location whereas LCoA is used to acquire an address within MAP domain. However every movement of MN within the MAP domain, it requires to register with its current MAP. Hence the RCoA of a MN will not be changed in this case, no binding update will be sent to its HA and CNs. (Cho, Hosik and Paik, Eun Kyoung and Choi, Yanghee, 2004).

When a MN moves to a new network, it receives Router Advertisement (RA) consisting of details about one or more local MAPs such information are: the existing MAPs and their locations from the MN. After choosing a proper MAP, the MN gets RCoA on the MAP domain and LCoA from AR. Then, the MN initializes a Binding Update to the MAP in order to bind LCoA and RCoA. MAP store the mapping between LCoA and RCoA in a binding cache. Sending BU to HA and CN are only necessary when the MN crosses the MAP domain boundaries. In such case, the Mobile Node has to send a Binding Update to HA and CN in order to map the home address with the new RCoA. (Eddy, Wesley, Terry Davis, and Will Ivancic, 2009).

When a packet sent to a MN arrives at the local domain, MAP encapsulates it and by using its binding cache it will forward the packet to MN’s LCoA. By this way, all data packets sent from other networks are received by MAP and forwarded to the MN. However, the MN is always able to send data directly to the CN (Cho, Hosik and Paik, Eun Kyoung and Choi, Yanghee, 2004). The MN periodically sends BU messages to MAP or whenever it configures a new LCoA in order to keep current mappings in MAP. The HA and CNs do not get binding updates upon location change but get periodic binding updates. A MN can register at the same time with more than one MAP. In case the MN changes its point of attachment frequently, it's important to improve the average time between a message transmission by a CN and its reception (Eddy, Wesley, Terry Davis, and Will Ivancic, 2009). Figure 2-1 illustrate this operations numbered from 1 to 9 as follows:

Step 1 - and 2- shows the normal sending and receiving between CN and MN before MN leave his home network.

Step 3 – shows the transition from home network to the foreign network.

Step 4, 5 and 6 shows the binding update message and acknowledgment between MN and its Ha and message exchange between MN and HA.

Step 7- shows the tunnel between CN and MN established by ha.

Step 8 and 9 clearly shows the normal sending and receiving message between CN and MN after MN change its point of attachment after moving.

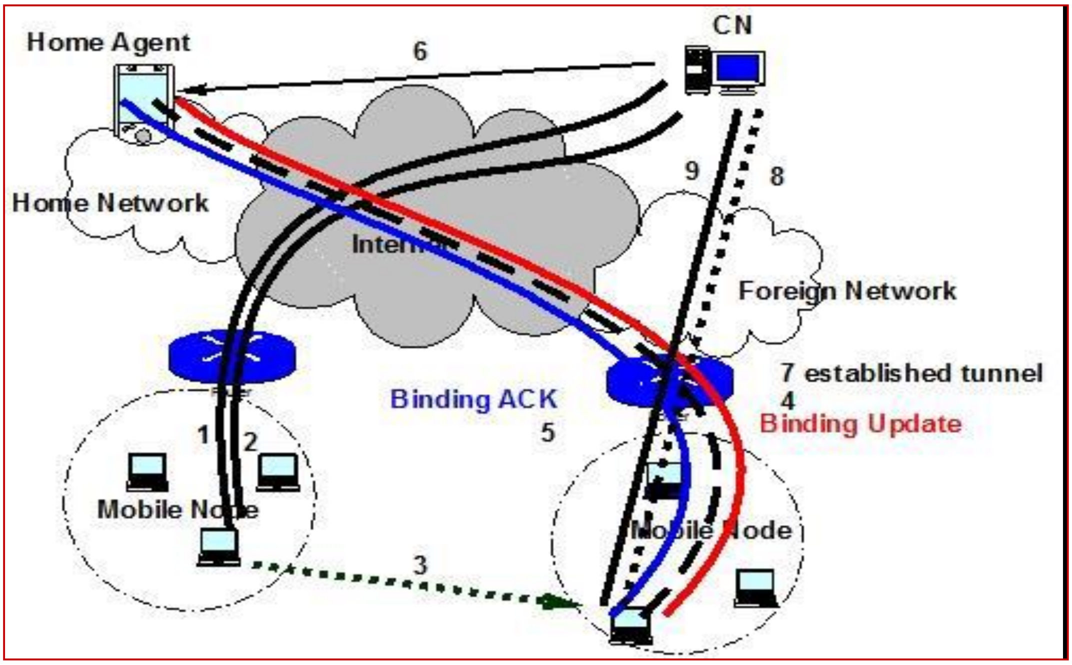

Figure 2.1: Host Mobility Operations

2.3.1.3 Proxy Mobile IPv6 (PMIPv6)

A PMIPv6 consists of the network entities, that are responsible for controlling mobility signals in the MIPv6, and therefore provides the network based mobility management service. (Tuncer, Hasan and Mishra, Sumita and Shenoy, Nirmala, 2012)

2.3.2 Network Mobility

A Network Mobility Support is a mechanism that maintains session continuity between the mobile network nodes (MNNs) and their CNs while the MR's change their point of attachment (Devarapalli, Vijay and Wakikawa, Ryuji and Petrescu, Alexandru and Thubert, Pascal, 2004). Internet Engineering Task Force (IETF) as an extension of host mobility has proposed Network Mobility Basic Support Protocol to support network (MNs & MR) mobility management, and to ensure that the continuing communication for all nodes in the mobile network are well established. Network mobility looks like a single MN, moving as a unit containing its peripherals, and it needs one or more MR to connect to Internet (Devarapalli, Vijay and Wakikawa, Ryuji and Petrescu, Alexandru and Thubert, Pascal, 2004). The MR uses its Ingress interface to transmit the packets to the Mobile Nodes and use its Egress Interface to the mobile network internet connectivity. The MR in its home network connects directly to the HA; therefore, delivering and sending packets to or from mobile network are done via HA and MR. When the MR moves to another network, it obtains a care-of-address (CoA). Binding update (BU) message is sent from MR to HA to bind Care-of-Address with its Address, and Binding acknowledgment (BA) is sent from HA to MR to specify the current states of the connection. Then a tunnel between CoA and HA is established. Data between mobile node and internet is transmitted through this tunnel. In this technique, an MR in a foreign Network is capable of supporting internet connectivity to its MNs and correspondent Nodes. The MNs are unaware of MR position and does not need any mobility management (Petander, Henrik and Perera, Eranga and Lan, Kun-Chan and Seneviratne, Aruna, 2006). MRs advertises their prefix home address. A bidirectional tunnel between MRs and their home agents is used to transmit all packets between MNs; packets are tunnelled to the HAs and to the relevant CN (Senan, Shayma and Hashim, Aisha Hassan A and Rashid, A Saeed and Daoud, Jamal I, 2011).

When the mobile network relies on another mobile network to access the Internet, it gives a new structure known as nested network. Although there are several advantages provided by the Nemo Basic Support, but there are still some problems related to the nested network need to be addressed, especially when there are several mobile routers connected with each other. In this scenario, the number of mobile routers increases the complexity, whereas each level of mobile network need new tunnel between the MR and it's HA. Figure 2.2 illustrates network mobility operations.

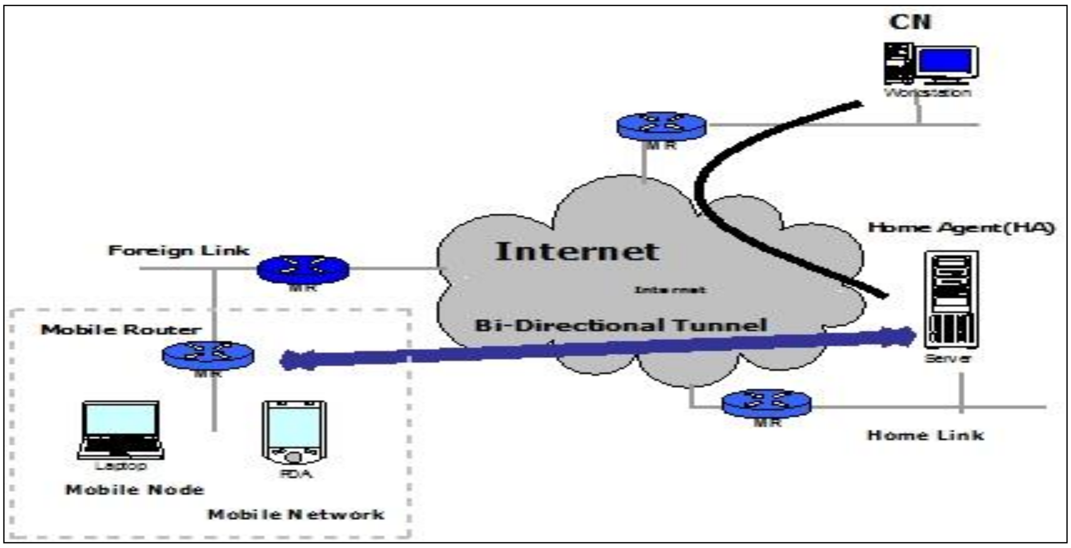

Figure 2.2**:** Network Mobility Operations

2.3.2.1 Network Mobility Basic Support (NEMO BS).

As an extension of the MIPv6, IETF established Nemo Basic Support Protocol for the purpose of mobility management in the network, as if is a single unit (Devarapalli, Vijay and Wakikawa, Ryuji and Petrescu, Alexandru and Thubert, Pascal, 2004). It is also concerned with internet connectivity for all MNs. Figure 2.2 illustrates main operations on Nemo Basic Support Protocol.

2.3.2.2 Nemo Extended Support (NEMO ES).

NEMO ES concerned with performance optimization for (Multihomming, route Optimization and Nested Network Mobility), which are defined bellow:

- Multihomming: when an MR has multiple Addresses.
- Route optimization: Approach to select the optimal path between nodes.
- Nested Network Mobility: a form occur when Mobile router connecting with another mobile router in different Mobile network

2.3.2.3 Network Mobility Operations

This subsection describes functions and operations performed by the mobile router and the home agent.

MR operation:

All information sent in BU messages to MR. Tunnels between MR and HA is established through using this information. The main tasks of MR is sending BUs, receiving binding acknowledgements, building bi-directional tunnels, error processing, neighbour discovery for the MR, and so on. (Devarapalli, Vijay and Wakikawa, Ryuji and Petrescu, Alexandru and Thubert, Pascal, 2004)

A MR obtains a CoA on each foreign link. This address is sent via a BU message to its HA once the MR moves to a new network. As a result, a MR-HA tunnel is set up in order to connect them. Upon receiving the encapsulated packets by the HA, the MR will forward these packets to the mobile network nodes. When the MR receives packets from the mobile network nodes, it would encapsulate these packets and forward them to HA via MR-HA tunnel according to certain routing rules.

HA Operation:

Every MR has a Binding Cache in HA once it is registered. The format of Binding Cache in HA and the BUL in the MR is similar. When the HA receives a BU, it will check the Prefix table which is used for preventing a MR from configuring MNPs related to other MRs. (Mohammadi, Nafiseh, 2005)

The validity check will be performed when a HA receives a BU. Upon passing this validity check, the HA will create, based on the information provided in the BU message, a new entry in its Binding Cache. Then it will send back the binding acknowledgement to HA. (Eddy, Wesley and Davis, Terry and Ivancic, Will, 2009)

Once the HA receives a packet from a CN, it will search its binding cache and compare this destination address with its entries. In case the destination address is found in the binding cache, the corresponding CoA will be sent back. Resulting from that, the packet will be sent to the CoA of the MR. Once a message is sent through the tunnel, the outer IP header of the encapsulated packets would be removed by the HA and forward the packet to the destination node. (Devarapalli, Vijay and Wakikawa, Ryuji and Petrescu, Alexandru and Thubert, Pascal, 2004)

So in NEMO, once a MR and its mobile subnet attached to a new network, the MR will send BU containing its new CoA to the it's HA in order to register both itself and MNNs. After that a bidirectional tunnel will be established to connect the MR and it's HA. The mobile nodes in the MR's mobile network would be unaware about this movement, however they would not need to configure a new CoA or register anything at the HA. The connecting tunnel between the MR and the HA will pass all the traffic. (Sharma, Vishal and Singh, Harsukhpreet and Kaur, Mandip and Banga, Vijay, 2013)

2.3.3 Nested Network Mobility

As previously mentioned, when a mobile router is connected to another one in another mobile network, it makes new structure known as Nested Mobile Network. This structure suffers from several problems in performance, due to its complexity. In each level of connected routers, a Bi-directional tunnel between each pair of MRs and their Home Agents must be performed. This increases packaging, leads to an increment in the size of the message, which in turn lead to other problems such as tunnelling overhead, need of message fragmentation, complex route known as pinball routing problem, delay and packet losses. Figure 2.3 is a simple illustration of nested Mobile Network after three MR moves from home network to foreign network and connected together as follows.it consist of three MRs connected in hieratical form and each MR communicate with its HA through MRs in between.

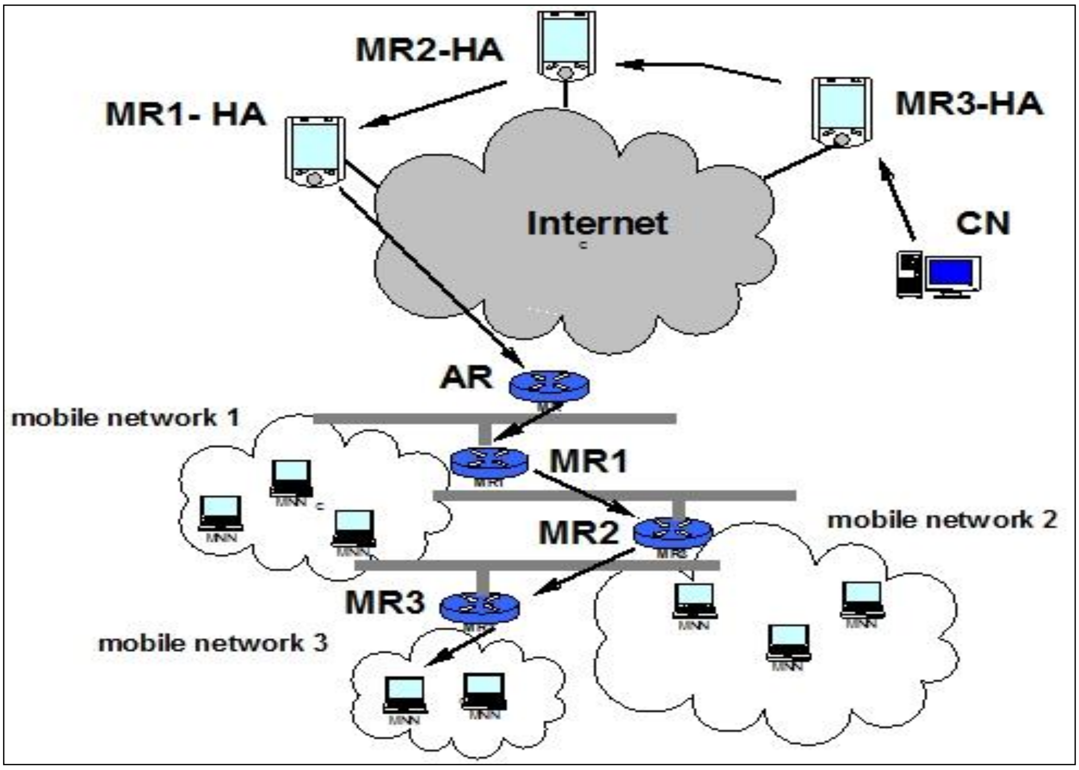

Figure 2.3 : Nested Mobile Network

2.4 RELATED WORKS

This section explains and analyses different techniques that have been proposed to give a solution for the nested mobile network problems. there are many approaches have been conducted to solve the problems facing the nested network mobility, this section briefly describe some of the Internet Engineering Task Force (IETF) contributions as well as highlighting some Approaches based on IETF .

2.4.1 The Internet Engineering Task Force (IETF) contributions

In addition to the standard documents of Nemo Basic support Protocols, the IETF is continuing its support by providing several informational documents (RFCs) to specify features and drawbacks of Nemo Basic Support. Furthermore, many related Internet Drafts issued by others (Bhasin, Kul and Hayden, Jeffrey, 2004), the following subsections explain some of them.

- RFC 3963 Network Mobility (NEMO) Basic Support Protocol (Petrescu, Alexandru and Wakikawa, Ryuji and Thubert, Pascal and Devarapalli, Vijay,

2005) . Proposes a protocol, which allows Mobile Networks to access the Internet by different points. This extended Mobile IPv6 protocol ensures the reachability and session continuity of every node in the Mobile Network as the network move around. The NEMO Basic Support protocol is ran at the Mobile Router connecting the network to the Internet and its Home Agent. In this protocol, the mobility of the network is intended to be transparent to the nodes inside the Mobile Network.

- RFC4885 Network Mobility Support Terminology (Ernst, Thierry, 2007)describes the terms for outlining network mobility (NEMO) problem space, issues, solution requirements, and design goals. It initiates terms to describe the architecture, and later explains terms wanted to highlight the distinct implementations of the architectural components. Furthermore, terms related to Multihomming, nested mobility, and diverse configurations of mobile networks at home are stated, in addition to the different mobility types.
- RFC4886 Network Mobility Support Goals and Requirements (Ernst, Thierry, 2007) .summarizes the objectives from network mobility support and describes the NEMO Basic Support solution's requirements. The main objective of the NEMO efforts is to find a solution for mobile network nodes (MNNs) to be continuously reachable and to keep connected to the Internet as the mobile router which serves the mobile network transfers its access point. Another objective is to analyse the effects of network mobility on different features of Internet communication like the implications of fast handovers and real-time traffic, routing protocol changes, and optimizations. This analysis should support the main goal of the reachability for mobile network nodes. Furthermore, the security is also an important challenge and the current security solution should be modified if they are appropriate for mobile networks.

- RFC4887 Network Mobility Home Network Models (Thubert, P and Wakikawa, R and Devarapalli, V, 2007) . Outlines some of the associated issues and usage patterns of installing an enabled and conforming Mobile Routers to the NEMO Basic Support for the Home Network of Network Mobility (NEMO). The goal in particular as to offer some organization examples of the Home Network. The Home Network in NEMO is including the Home Link and all the other Links which the Mobile Routers (MRs) hold with them. The relation in a deployment between the two concepts follows the management of the Home Network, as explained in this document.
- RFC4888 Network Mobility Route Optimization Problem Statement (Ng, C and Thubert, P and Watari, M and Zhao, F, 2007) . Examines the sub-optimal routing problems specifically with nesting Mobile Networks and stimulate the Route Optimization (RO) of NEMO. There is already Route optimization mechanism in Mobile IPv6 and it improves the end-to-end path from the Mobile Node to Correspondent Node and vice versa. The load is also reduced in the Home Network. More issues are also presented in NEMO Basic Support and complicate the problem, so the Route Optimization was addressed separately. In this situation, the Route Optimization mechanism may allow connectivity which likely is broken otherwise, and the predictable benefits will be more dramatic. So the Route Optimization became more important in this sense to NEMO Basic Support rather than Mobile IPv6.This document explains the drawbacks in NEMO Basic Support with their consequences on communications between the corresponding node and the Mobile Network Node.
- RFC4889 Network Mobility Route Optimization Solution Space Analysis [28] describes different types of NEMO Route Optimization which are used to avoid

the drawbacks of using (MR-HA) tunnel and examines the trade-offs and benefits in various aspects of NEMO Route Optimization. It also generally categorizes the proposed approaches related to solving the Route Optimization problems for NEMO. It analyses the benefits, the solutions scope, and the impacts to the current implementations and deployments. It helps the NEMO WG to deeply understand the strengths and drawbacks of each approach in order to choose where to concentrate its Route Optimization effort.

- RFC5177 Network Mobility (NEMO) Extensions for Mobile IPv4 (Leung, K., et al. , 2008). Documents a Mobile Networks supporting protocol between the Mobile Router and its Home Agent by Mobile IPv4 extended protocol. The mobility of network segments and subnets is the responsibility of the Mobile Router. The Mobile Router mobility is transparent to the Mobile Network Nodes. The Mobile Network Nodes can be fixed relating to the Mobile Router or they may be not mobile. This document is aimed to introduce the extensions to Mobile IPv4 those are made to support Mobile Networks to equip mobility scenarios with groups of nodes and routers transfer homogeneously (all together). All the hosts and routers in the Mobile Network need to be reachable to the Internet, and execute applications linking to the Internet.
- RFC5488 Network Mobility (NEMO) Management Information Base (Gundavelli, S., et al. , 2009). Describes a Management Information Base (MIB) that is a part of the Network Mobility (NEMO) support MIB. It will be used in the Internet community with the network management protocols. The NEMO MIB will specially be used to control a Mobile IPv6 node with NEMO implementation.
- RFC5522 Network Mobility Route Optimization Requirements for Operational Use in Aeronautics and Space Exploration Mobile Networks (Eddy, Wesley,

Terry Davis, and Will Ivancic, 2009) . Explains the wanted properties and requirements of Network Mobility (NEMO) Route Optimization techniques to be used in international interconnected systems for space and aeronautics exploration.

- RFC4980 Analysis of Multihomming in Network Mobility Support (Ng, C and Ernst, Thierry and Paik, E and Bagnulo, Marcelo, 2007) . Investigates Multihomming under network mobility (NEMO) in IPv6. The possible configurations are categorized since the mobile network may be multihomed in many situations. The multihomed mobile networks' scenarios with the associated problems when NEMO Basic Support is used, as well as the recommendations are to address these issues are explained.
- RFC6089 Flow Bindings in Mobile IPv6 and Network Mobility (NEMO) Basic Support (Tsirtsis, George and Soliman, Hesham and Montavont, Nicolas and Giaretta, Gerardo and Kuladinithi, Koojana, 2011). Proposes Mobile IPv6 extensions that allow nodes binding a care-of address to one or more flows. With these extensions, the home agents and the other Mobile IPv6 entities are instructed by multi-homed nodes so that the inbound flows will be directed to specific addresses. The flow is defined in this document as a group of IP packets corresponding to a traffic selector. A traffic selector may recognize the transport protocol number, source and destination IP addresses, and the source and destination port fields in IP and other-layer headers. This specification defines the traffic selector sub-option format that may be used in any specific traffic selector. However, it does not describe traffic selectors that are going to be characterized in other specifications.
- RFC6276 DHCPv6 Prefix Delegation for Network Mobility NEMO (Droms, R and Thubert, P and Dupont, F and Haddad, W and Bernardos, C, 2011). States

the DHCPv6 prefix delegation which is used for setting the prefixes or prefix on the links in order to use the mobile router in the mobile network. The home agent plays the role of delegating router, while the mobile router functions as the requesting router. In addition, the mobile router plays the role of DHCPv6 relay agent when it is outside its home network, co-located with the function of requesting router.

- RFC 6312 Mobile Networks Considerations for IPv6 Deployment (Koodli, Rajeev, 2011). Describes the considerations in using IPv6 in mobile networks. Therefore, this document is a useful reference for network designers and service providers. It does not suggest new protocol specification or propose new protocols.
- RFC 6521 Home Agent-Assisted Route Optimization between Mobile IPv4 Networks (Makela, Antti and Korhonen, Jouni, 2012) explains a new function of home agent-assisted route optimization for the Network Mobility IPv4 Protocol. It is enabling route optimization when all nodes are attached to one home agent. Therefore, it uses optimal routing within similar entity or single organization. It also helps the discovery of appropriate peer nodes and their network prefixes (based on information sent by the home agent), and establish a direct tunnel between them.
- RFC 6626 Dynamic Prefix Allocation for Network Mobility for Mobile IPv4 (NEMOv4) (Tsirtsis, George and Park, Vincent and Leung, Kent, 2012) .describes the specification of dynamic prefix allocation mechanism for the extended Mobile IPv4 based on Network Mobility (NEMOv4).

2.4.2 Approaches based on IETF

This section explains and analyses different techniques that have been proposed to give a solution for the nested mobile network problems. there are many approaches have been conducted to solve the problems faced the nested network mobility, such as multi-tunnelling overhead, which is called pinball route problem, many approaches of Route Optimization have been proposed to solve this problem and other performance issues.

The authors in (Cho, Hosik and Paik, Eun Kyoung and Choi, Yanghee, 2004) proposed RBU+ Recursive Binding Update for End-to-End Route Optimization in Nested Mobile Networks. In this proposal, the optimal route to the Top Level Mobile Router (TLMR) will be maintained by updating its binding information recursively when it receives a binding update (BU) message (Cho, Hosik and Paik, Eun Kyoung and Choi, Yanghee, 2004). This approach provides end-to-end delivery, improves performances significantly by reducing transmission delay and decreasing tunnelling, but it consumes bandwidth by periodic control overhead for maintaining the operations in cache entry. In addition, it is not tested for high level of nesting.

In (Priyanka R., Jean-Marie B., Laurent T., 2007)**,** the authors proposed an end-to-end tunnel header compression solution for nested mobile networks by using the TuCP, which is a novel tunnelling compression protocol that provides an end-to-end tunnel header compression technique. TuCP can be used to compress the tunnel header (outer encapsulation) without the need to modify the existing header compression scheme and it does not compress the IP header of the tunnel to be used for routing purposes. Although this approach reduces the message size, it still shows some challenges for context transfer between the MR and the HA in nested mobile networks. In addition, this approach takes more time to perform compression operation, which it makes it not suitable for multi-level of nesting.

In (Kim, Jaewoo and Jung, Hyunduk and Lee, Jaiyong, 2009)**,** authors proposed route optimization for network mobility with tree-based care of address, a new scheme to reduce end-to-end packet and handoff delay by using structure of Tree-based Care of

Address (TCoA) and Mobile Network Prefix (MNP). This scheme reduced end-to-end packet and handoff delay but it has high signalling cost and suffers from Bottleneck that may occurs on tree root.

In (Senan, Shayma and Hashim, AishaHassan and Saeed, Rashid and Hameed, Shihab and Zeki, Akram M and Daoud, Jamal and others, 2012), a new route optimization scenario based on nested mobile network has been proposed. This approach uses the hierarchal structure with binding update tree (BUT), and configured two care of address: (i)- Regional care of address (RcoA), which is based on the mobile node prefix of the TLMR. (ii)- Local care of address (LcoA), which is based on the mobile prefix of its access router (Senan, Shayma and Hashim, AishaHassan and Saeed, Rashid and Hameed, Shihab and Zeki, Akram M and Daoud, Jamal and others, 2012). This scheme has reduced packet overhead, handoff latency, packet transmission delay and enhanced the routing. However, additional research effort is needed to complement the previous findings contributions in high level of nesting.

In (Kabir, Md Humayun and Mukhtaruzzaman, Mohammad and Atiquzzaman, Mohammed, 2013), the authors proposed an “efficient route optimization scheme for nested network mobility”, which uses two care of addresses for each mobile router as well as two types of entries in the mobile routers caches (Kabir, Md Humayun and Mukhtaruzzaman, Mohammad and Atiquzzaman, Mohammed, 2013). This scheme completely removed the tunnelling on the nested Nemo in a single step and transmitted only one BU message. However, this scheme has introduced high signalling cost at each level of nesting because of the operations of the two addresses and the two types of entries. Therefore, this scheme is not suitable for multiple level of nesting.

The author in (Gao, Tianhan and Guo, Nan, 2011) presented “a novel route optimization scheme (HRS) based on local management architecture that combined nested NEMO and HMIPv6”. This scheme had eliminated the bi-directional tunnelling by setting up one-way tunnel between (TLMR) and Home Agent (Gao, Tianhan and Guo, Nan, 2011). Moreover, it had reduced registration overhead because it is based on hierarchal local management architecture (Gao, Tianhan and Guo, Nan, 2011). Whenever the domain under the MAP becomes high, the efficiency of the scheme significantly decreases. Problems of BU storm appear and lead to high hand-off latency and issues of performance efficiency is persisting in the high level of nesting.

The author in (Wu, Hu and Lu, Jian-de, 2011) proposed “an (HRO), a routing optimization Scheme based on hierarchical MIPv6”. In this scheme, a MAP was introduced and deployed to manage the mobile network in its domain. Most registration messages are kept in MAP domain, and the packets in MAP domain are forwarded along with the optimized routing path (Wu, Hu and Lu, Jian-de, 2011). This scheme avoids encapsulation between intermediate Mobile Routers along with the transmission path and reduces the registration overhead. However, similar to consequences of the HRS scheme it increases handoff latency and registration overhead whenever the number of nesting becomes high.

In (Chuang, Ming-Chin and Lee, Jeng-Farn, 2011), A DRO scheme for nested mobile Networks has been proposed. The scheme based on domain-based network architecture, which adapts ad hoc routing techniques to reduce handoff latency, prevent the out-of sequences packet delivery as well as the minimization of packet transmission delay. Although the result of this technique is better in comparison with the other techniques, but it is clear that, the handoff latency is still increasing in the case of multiple nesting.

In (Ng, C and Zhao, Fan and Watari, Masafumi and Thubert, Pascal, 2007), Reverse Routing Header (RRH) is proposed to avoid the nested tunnels overhead. It uses a type 4 routing header from the MN to record the Home Address (HoA) of each intermediate MR in the nested NEMO. This routing information is stored in its binding cache to determine the optimal route of packets back to the MN in a type 2 routing header. In this way, RRH only needs to build a bidirectional tunnel between the MN’s serving MR and the MR-HA, which resolves the pinball routing problem. However, RRH introduces high processing overhead for the routing header of each packet, which increases with the number of levels of the nested mobile network.

In (Senan, Shayma and Hashim, Aisha Hassan A and Rashid, A Saeed and Daoud, Jamal I, 2011), An Advanced Handoff Scheme (AHS) is proposed to enable the improvement of micro-mobility. This approach combines the Hierarchical Prefix Delegation protocol (HDP) and the Hierarchical Mobile IPv6 (HMIPv6) functionality. This is done in order to use the functionality of a Mobility Management Router (MMR). MMR is allowed to update the binding information of all MNNs in a mobile network without getting Binding Update messages (Bus) from the MNNs as the MMR receives a BU from the MR in the mobile network when the MR moves locally within the MMR domain. The result of this scheme shows improvements in term of handoff latency, signalling overhead and transmission delay, although the packet overhead in AHS is higher than in HDP. Additionally, the packet overhead increases relevant to the level of nesting.

This section briefly summarize some of them as shown in table 2.1

Table 2-1: Qualitative Comparison for the Related Approaches

Research Work	Approach	Advantages	Limitations
“RBU+”Recursive Binding Update for End-to-End Route optimization in nested Mobile Network (2004)	Using methods that defining the route between a Top Level Mobile Router (TLMR) and the destination Mobile Node (MNN)	- Provide end -to-end delivery - improve performances - reduce Delay - decrease tunneling and message size	-Periodic routing control overhead - Consuming bandwidth - CN overhead - operation in cache -CN cache size
NEMO BS (Devarapalli et al., 2005)	- Bi-directional tunneling	- Location privacy	- Route optimization - packet overhead - the pinball routing problem in nested NEMO
" a cost-effective mobility modeling in nested network mobility" (2006)	based on binding update multi-cast by various mobility patterns of mobile nodes in nested Network Mobility	- Minimizes binding update cost	- High packet overhead
“Seamless Handoff Solution For Nested Mobile Networks” (2006)	Adding an entry for the MR prefix at the MRs located on the egress path .and swapping the source address of the packet by its CoA. The next hop of this entry will be the source address of the BU.	- minimize the registration delay component - reduce handoff latency	- effort overhead - operation overhead -increase massage size
ROTIO (Cho et al., 2006)	routing optimization scheme with the extended tree information option	- Location privacy - mobility transparency - seamless handoff support - solve the pinball routing problem	- the non-optimal transmission path - increased packet overhead - increased TLMR/MR binding cache sizes - Binding Update storm
“An End-to-End Tunnel Header Compression Solution for Nested Mobile Networks” (2007)	Using of TuCP, a novel tunneling compression protocol which provides an end-2-end tunnel header compression when several nested tunnels are used	- provides an end to end tunnel header compression - reduce massage size	- operation overhead - High delay - undesirable increasing size
RRH (Thubert and Molteni, 2007)	similar to the MIP Loose Source Routing	- resolves the pinball routing problem - avoids the nested tunnels overhead	- handoff disruption - packet overhead - Binding Update storm
" route optimization for network mobility with tree-	using structure of Tree-based Care of Address (TCoA) and	reduced end-to-end packet delay and handoff –delay	-Bottleneck may be occurs - Periodic routing

based care of address " (2009)	Mobile Network Prefix (MNP).		control overhead
HRO (Wu and Lu, 2011)	hierarchical MIPv6 + multi-layer packet encapsulations	- solves pinball route problem - reduces handover latency	increase in MAP overhead and binding registration time
FHCoP-B (Chang, Ing-Chau and Lu, Ciou-Song, 2011)	HCoP-B + fast handoff	Solves some problems of HCoP-B related to handoff	increased TLMR binding cache size
OwR (Kong et al., 2013) (Kong, Ruoshan and Feng, Jing and Gao, Ren and Zhou, Huaibei, 2013)	combining optimized route cache protocol with reverse routing header and using a quota for optimized sessions	Decreases the cost of optimal routing	route optimization is not always applicable
Scheme in (Kabir et al., 2013) (Kabir, Md Humayun and Mukhtaruzzaman, Mohammad and Atiquzzaman, Mohammed, 2013)	two CoAs for each MR and two kinds of entries in the routing table in each MR, that are fixed and visiting	- achieves an optimal route - solves binding update storm	Expected problems during TLMR's handoff
BBUS (Yeh et al., 2013) (Yeh, Lo-Yao and Yang, Chun-Chuan and Chang, Jee-Gong and Tsai, Yi-Lang, 2013)	NEMO in VANET + elliptic curve cryptography (ECC)	Solves some security issues for route optimization	- Binding Update storm - the non-optimal transmission path
EfNEMO (Ryu et al., 2014) (Ryu, Seonggeun and Park, Kyung-Joon and Choi, Ji-Woong, 2014)	Fast handover + NEMO	reduces packet loss and handover latency	- Packet overhead - Increased TLMR binding cache

2.5 SUMMARY

This chapter has provided an overview of the previous research on nested network mobility. We discuss the proposed IETF protocols and their extensions proposals to overcome the mobility issues in nested network mobility. A comparative table shows these approaches and presents the advantages and disadvantages of each one. The following chapters describe the proposed scheme of this research to continue the enhancement of previous researches.

CHAPTER THREE

DESIGN OF THE PROPOSED SCHEME FOR HIGH LEVEL NESTED NETWORK MOBILITY

3.1 INTRODUCTION

Network Mobility manages the movement of MR when changing its point of attachment. It establishes a bidirectional tunnel between the mobile router and its original home agent to re-establish the connection (Devarapalli, Vijay and Wakikawa, Ryuji and Petrescu, Alexandru and Thubert, Pascal, 2004). Therefore, it is very important to acquire the high performance of mobility management protocol to accomplish fast and seamless handoff with lower delay in NEMO environment (Perera, Eranga and Sivaraman, Vijay and Seneviratne, Aruna, 2004) . Network Mobility Support protocol is based on creating a bi-directional tunnel between MR and its Home Agent (HA). Only MR should send the binding update message (BU) with the network prefix to provide internet connectivity to all MNNs; by this technique MR hide the mobility of MNNs and limited the repeated registration of the MNNs (Perera, Eranga and Sivaraman, Vijay and Seneviratne, Aruna, 2004). However, establishing a bi-direction tunnel between the MR and it's HA for all communications causes an increase of message size because it is done by (IP-in-IP) encapsulation. Mobile networks form a hierarchal architecture consisting of multiple mobile routers and one Top-Level Mobile Router (TLMR) in (HMIPv6). Multiple MRs can exist under a TLMR in nested form. Increasing the number of mobile routers under TLMR, increases the problems related to nested networks (High Level Nested Mobile Network). Figure 3-1 shows traditional HMIPv6 when there are multiple level of nesting and illustrates the challenges they face. Figure 3-1 contains of multiple Mrs connected together under TLMR in side MAP domain. MAP consist of all Mrs Information that are necessary for communication to each Ha.

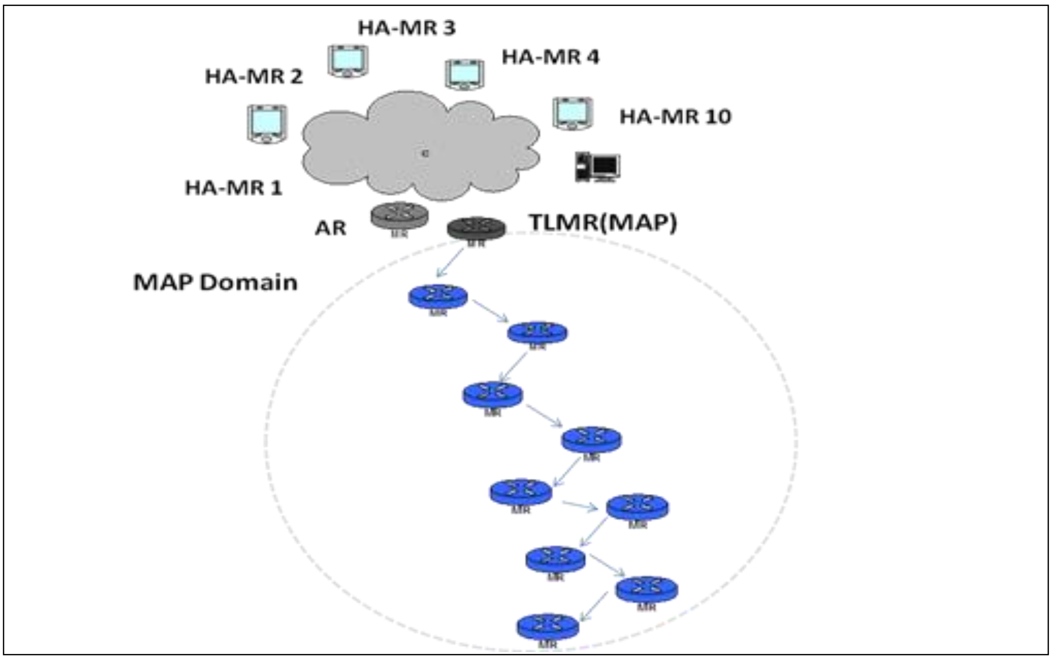

Figure 3.1: The High Level Nested Network Architecture

Figure 3-1 illustrates the nested network with multiple nested routers. The TLMR manages all routers inside MAP domain, so each mobile router arrives inside the map domain receives a message from the AR containing the TLMR address. The mobile router after that performs registration operations through all mobile routers in between to get CoA. The TLMR saves all MR addresses using its own cache. When a correspondent node send a message to the mobile router, the TLMR search its cache firstly , if the MR address exist in the TLMR cache, then the message is routed directly to its destination through MRs in between . When the level of nesting becomes high, a performance metric such as handoff latency and transmission delay significantly increases due to the registration overhead. Figure 3.2 shows the path between TLMR and visiting MR in high level of nesting network and describes the related performance metrics status. It is clearly shows long path between visited MR and TLMR which is caused High handoff latency, high transmission delay, high messaging cost, high registration overhead, high binding update storm and high signalling cost (Mohammed, Mohammed Babiker Ali and Hashim, Aisha Hassan A, 2015).

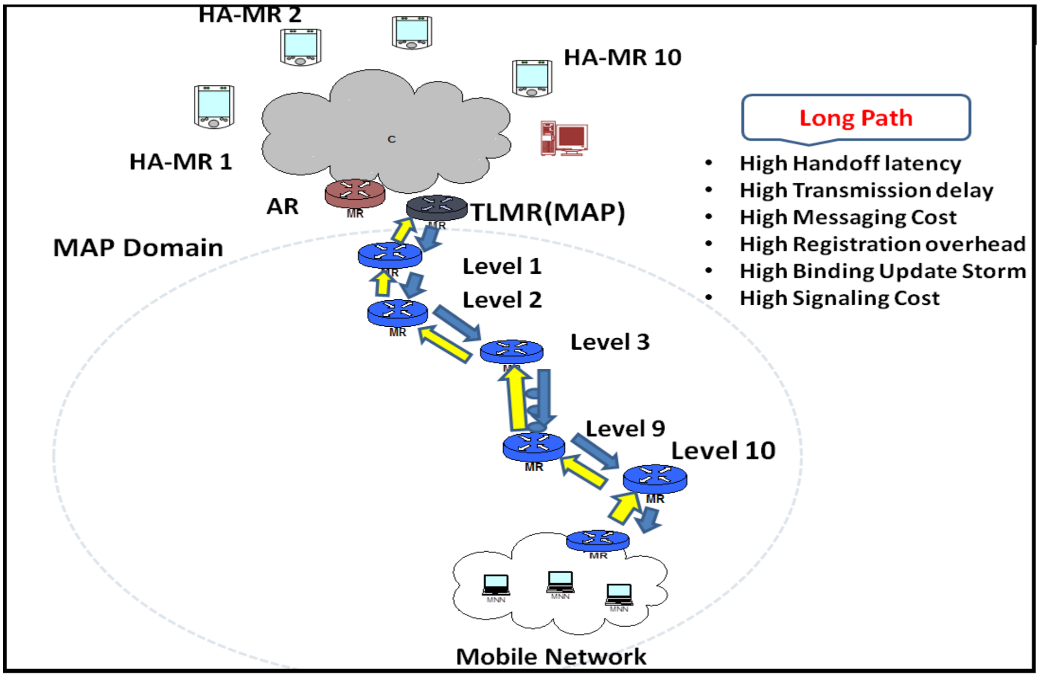

Figure 3.2: The Path of Registration in High Level of Nesting

Figure 3.3 shows the signalling flow as expected for this structure. It is clearly shows the traffics of each MR after receive a message from AR and determine TLMR in purpose of registration operations. After that MN and CN can exchange the message through this complex structure.

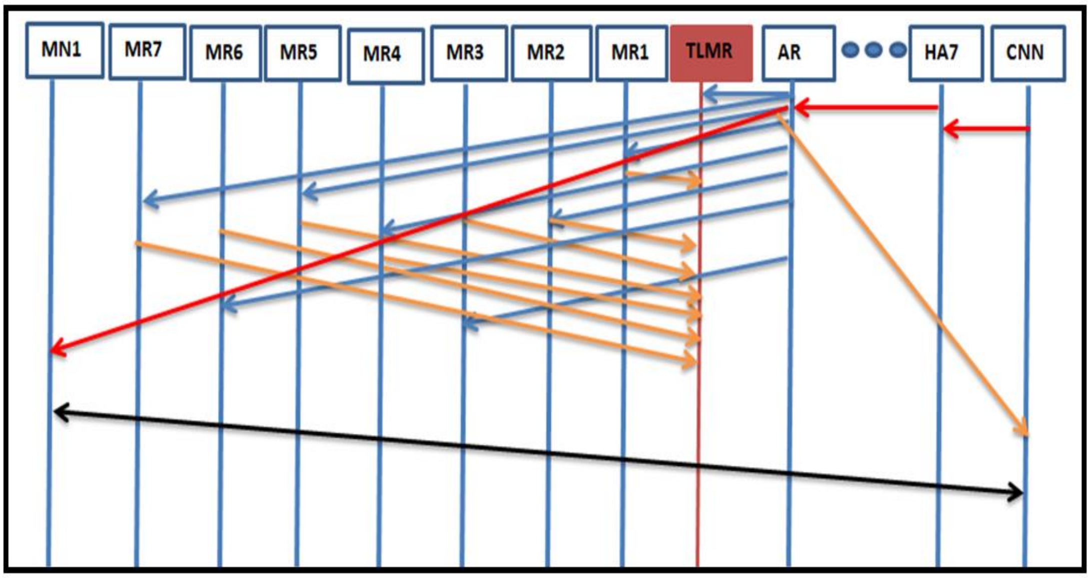

Figure 3.3 : The Signalling Flow of The Nested Nemo.

This research proposes a novel enhanced scheme to support high-level nested mobile routers under TLMR, which reduces handoff latency and packet transmission delay to achieve seamless mobility inside MAP domain.

3.2 THE PROPOSED SCHEME

In order to address the issues related to the nested network mobility especially in case of high level nesting, an enhanced hierarchal scheme have been proposed to overcome the overall performance issues and support seamless mobility . The proposed scheme uses Hierarchal architecture that divides the domain under MAP into multiple sub domains depending on the level of nesting. Each subdomain consist of three level of nested , because the IETF prove that the better performance in nested network mobility was achieved in maximum three level of nesting (Sornlertlamvanich, Parin and Elz, Robert and Kamolphiwong, Sinchai and Angchuan, Touchai, 2008). Therefore, this technique reduces the transmission cost, decreases the nested tunnels, enhances Intra domain routing perfectly; in addition to improving Message Delay, and enhancing Handoff latency and Binding Update. This scheme is simple to implement, as it requires only slight change in the implementation of mobile routers and mobile nodes which is defined in the proposed scheme, no change is required on home agents, correspondent node or any other network components. Figure 3.4 shows the proposed scheme.

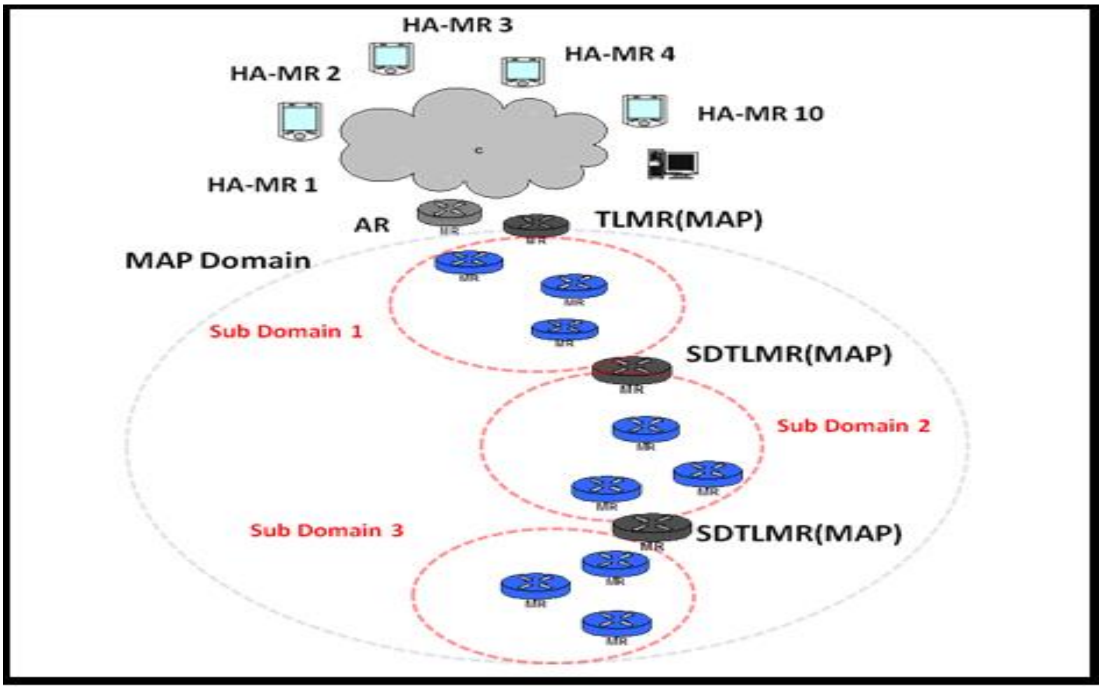

Figure 3.4: The Proposed Scheme

Figure 3.4 shows the map domain under TLMR, which is divided into multiple sub domains, so after each three levels of nesting a first arriving MR acts as sub domain TLMR (SDTLMR) that inherits all the features of original TLMR in order to save high performance at each sub domain [5]. So all the operations are done locally inside a sub domain rather than on a whole domain. By this way, the path in between MR and a near TLMR becomes shorter which gives an important advantage as illustrated in the next figure. Each SDTLMR sends its cache's contents to the original TLMR using suitable cache strategy technique. When correspondent node sent a message to its MR the original TLMR search its cache's contents and set which SDTLMR to receive a message, then the SDTLMR route the message to the MR.

3.3 PROPOSED SCHEME OPERATIONS

When MR visits a network, it receives a "Router Advertisement" message from AR. the Advertisement message contains MAP option of last SDTLMR to allow the MR to discover SDTLMR address. Once the MR receives Router Advertisement messages with the MAP option that contains prefix information for RCoA, it configures two addresses, RCoA and LCoA by the stateless address configuration mechanism. Then As the MR builds RCoA, the MR sends Local Binding Update message to the

SDTLMR. Upon receiving Local Binding Update message, SDTLMR performs Duplicate Address Detection (DAD) for RCoA. Then The SDTLMR returns a Binding Acknowledgement message to the MR, to indicate the result of the binding update to the SDTLMR. Finally The MR receives acknowledgement packet from SDTLMR containing RCoA. Once the binding update in SDTLMR is successfully completed, the SDTLMR updates the original MAP cache. Hence, the original MAP now is up to date with the sub- domain’s map contents. When HA and CNs sends a message to the MR, the original MAP receives the message and searches its cache to determine which SDTLMR receives this message. The targeted SDTLMR directly routes the message to the MR. Figure 3-5 shows the scenario of operations in proposed scheme numbered from step 1 until step 6. Step1 present the arrival of MR inside foreign network domain, in step 2 the MR received router advertisement from the access router to determine which TLMR will be chose to complete the registration. Step 3 and 4 explains the registration operations and selecting of SDTLMR or TLMR. Step 5 present the map cache update operation which keep the MAP cache updated when a new MR complete its registration. In step 6 home agent registration operation was done by sending BU to the HA to share the new address of its MR. finally in step 7 the message can be exchanged between CN and MR.

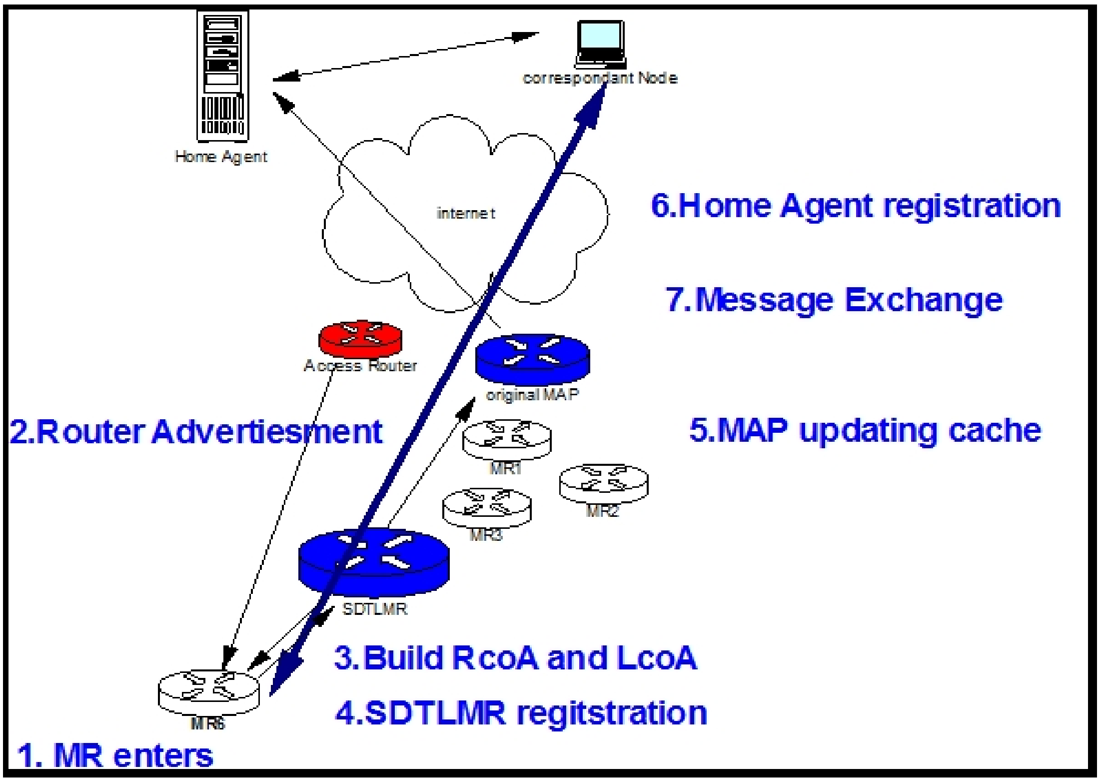

Figure 3.5: The Scenario of Proposed Scheme Operations

The proposed scheme provides a short path to complete these operations, so it gives low handoff latency, low transmission delay, low messaging cost, low registration overhead and low signalling cost in comparison with the previous scenarios. Figure 3.6 shows the operation of registration on the SDTLMR and snapshot of operation in sub domain rather than a whole domain.

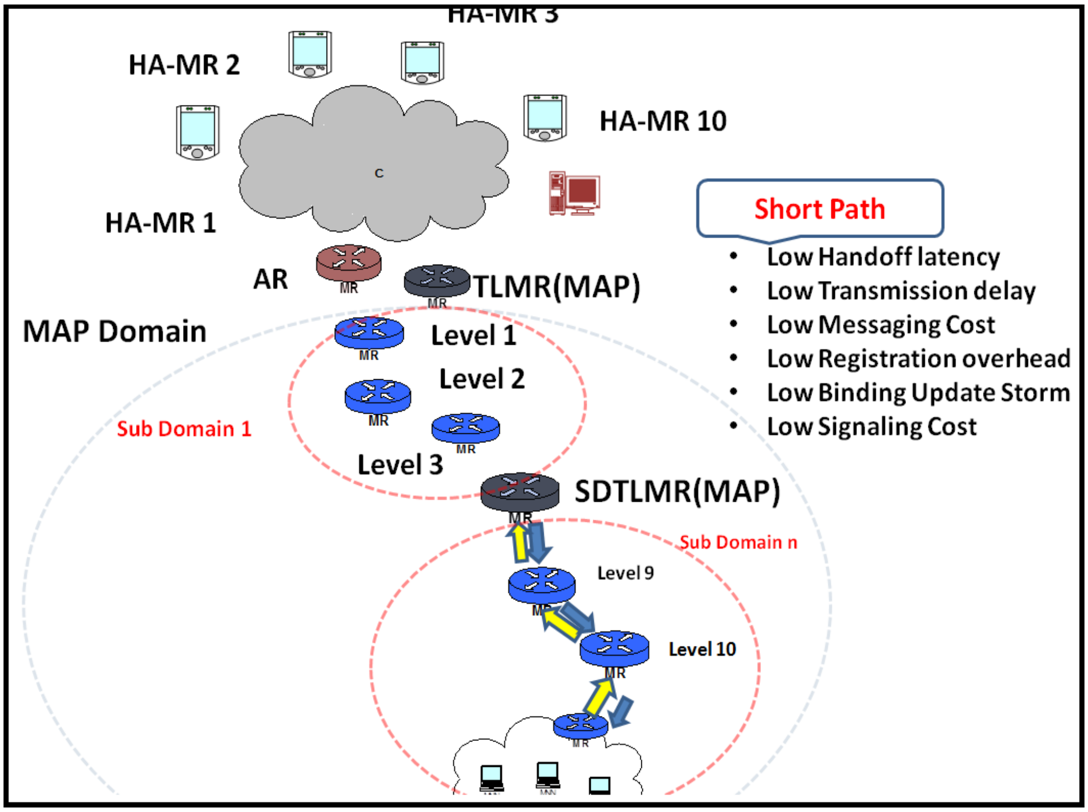

Figure 3.6: The Operations on Sub Domain

Figure 3-7 is clearly shows the signalling flow of the proposed scheme that is divided a total signalling flow of TLMR to multiple areas under the SDTLMR. SDTLMR keep out the traffic of MR5, MR 6 and MR7 from TLMR. Therefore the overall signalling is reduced.

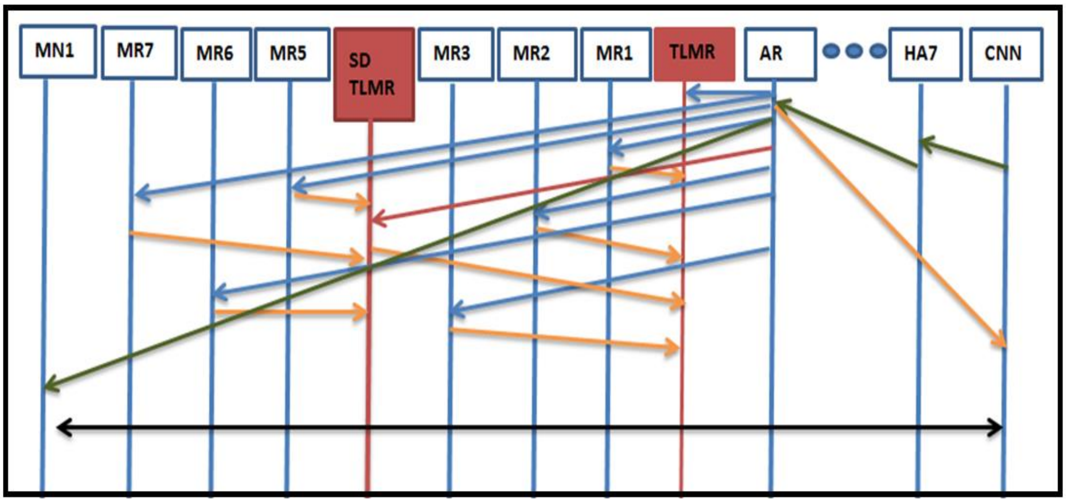

Figure 3.7: The Signaling flow of The Proposed Scheme

3.4 PROPOSED SCHEME ALGORITHM AND FLOW CHARTS

This section presents the proposed scheme algorithm and basic operations flow charts.

3.4.1 Proposed scheme algorithm.

The proposed scheme algorithm consist of multiple stages listed as follows:

1- Mobile router entrance.
2- Mobile router Registration.
3- TLMR registration.
4- MAP updating cache.
5- Home agent registration.
6- Message exchange.

These stages are discussed in details as they shown in the next paragraphs:

3.4.1.1 Mobile router entrance.

When mobile router enter inside the MAP domain, it receives a message from Access router, this message contains the registration information which include the TLMR address , after that mobile complete the registration as in next stage .

3.4.1.2 Mobile router registration

After the MR receive the RA message from access router, it will be able to determine which TLMR selected to complete the registration process. If the process of registration completes, the SDTLMR updates its cache. After that, the SDTLMR sends its cache information to the original TLMR. The original TLMR updating its cache and will be ready to send BU to the home agent. So the home agent can communicate with MR in it new situation. Figure 3-8 shows the scenario that happens after MR registration. so when the mobile router arrive and enter inside MAP domain it will perform registration operations , if the registration complete successfully the TLMR cache updated , after that the home agent will be able to communicate with the mobile router.

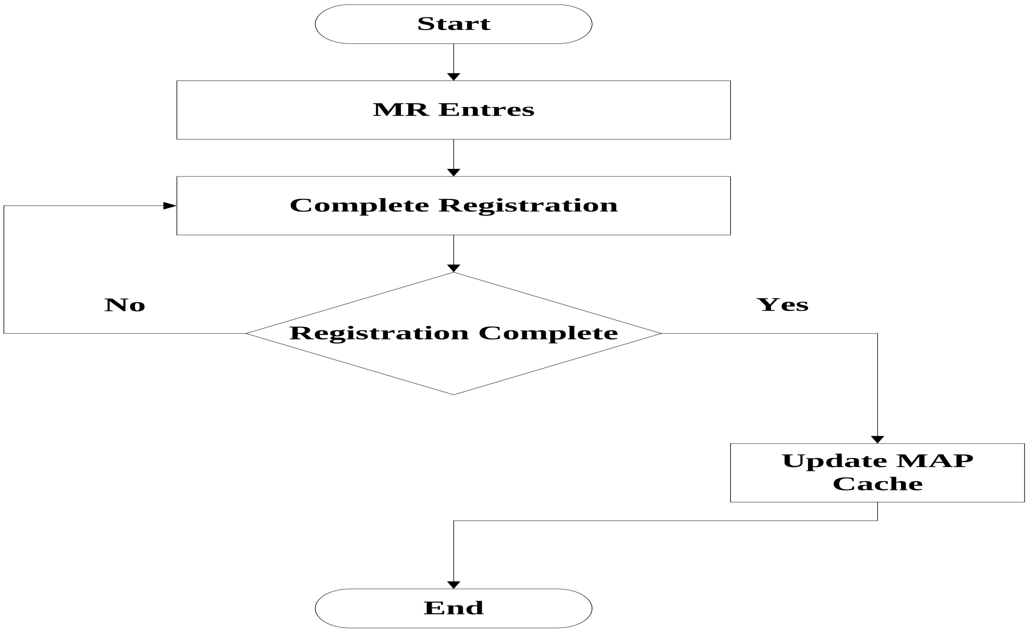

Figure 3.8: MR Registration Scenario

Figure 3-9 shows the pseudo code for MR registration stage.

```
Begin:
Checking RA message Info (  );
Extract SDTLMR address (  );
Starting MR – Registration (  );
If (MR - Registration complete)
   {
       Update TLMR cache (  )
       Received Ack;
    }
Communicate with MR_HA (  );
End.
```

Figure 3.9: MR Registration Pseudo Code

3.4.1.3 Operation of dividing global domain.

AR sends a RA to the MR when it arrives and enters inside MAP domain. The RA message consists of the information of the TLMR address for the MR to complete registration. The proposed scheme extends the role of RA to divide the whole domain into multiple sub-domains depending on the number of MR inside. Figure 3-10 illustrates the operation of dividing TLMR domain into multiple subdomains.

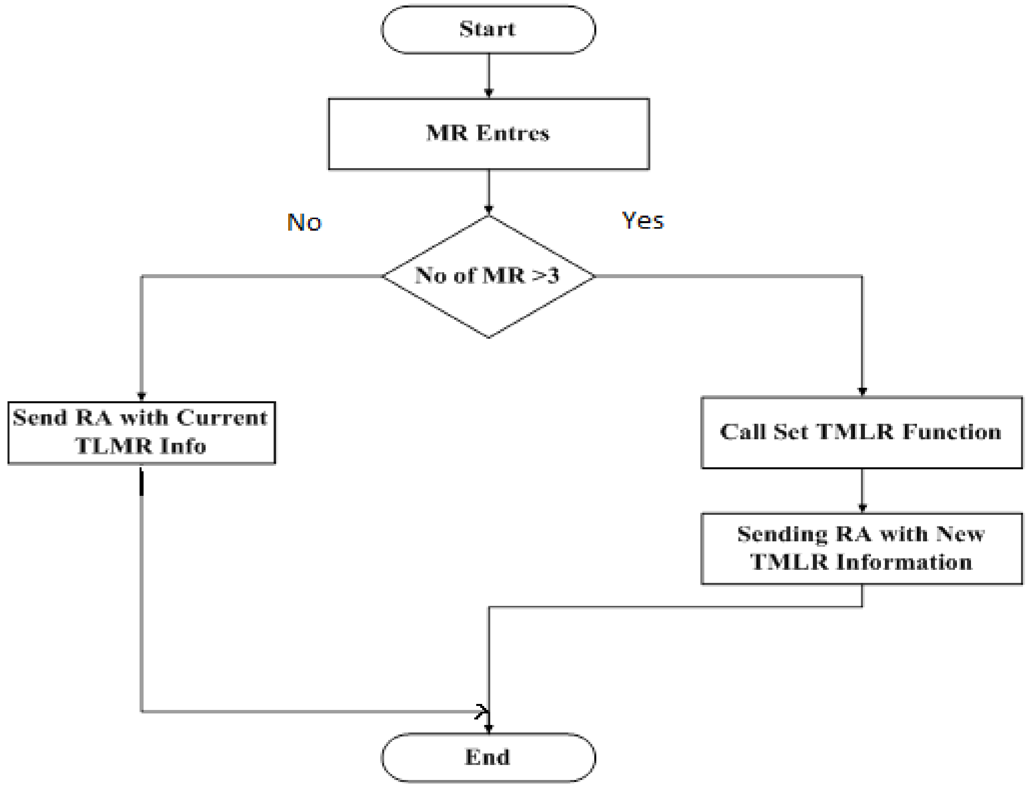

Figure 3.10 : Dividing Domain Flow Chart.

Figure 3-11 below shows the pseudo code of dividing a global domain into multiple subdomains.

```
 begin
Checking –New –MR-enteres ();
Calculate –No-of associate MR();
If ( No of associate MR > 3)
   {
      Set New - Subdomain();
      Update route advertisement info ();
    }
Sends Route advertisement info() ;
End;
```

Figure 3-11 The Pseudo Code of Dividing a Domain Into Multiple Subdomains.

3.4.1.4 Home Agent Registration and Message Exchange.

When the TLMR updates its cache after the last MR registration has been completed, the TLMR sends BU message to the HA informing it about the current MR address. Therefore, the HA is capable of sending the message received from the CN to the target MR. when the message arrives to the TLMR, it searches its local cache to determine if the MR address is there or not. If the MR address exists, the message is routed to the target SDTLMR and then to the MR. figure 3-12 shows the details of this operation.

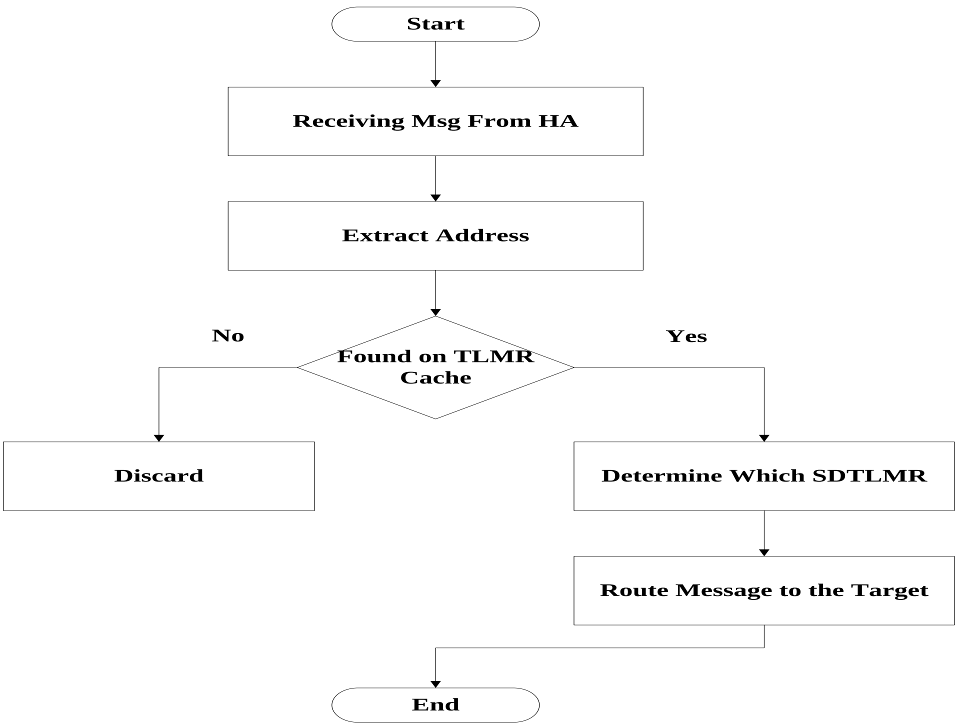

Figure 3.12 Home Agent Registration and Message Exchange

3.5 SUMMARY

This chapter introduces a new scheme to support nested network mobility in high-level. We show that the handoff latency and packet transmission delay have been minimized by dividing the MAP domain into multiple sub-domains. The following chapter describes the method used to evaluate and study the performance of the proposed scheme.

CHAPTER FOUR

EVALUATION OF THE PROPOSED SCHEME

4.1 INTRODUCTION

In this chapter, two evaluation methods are used to evaluate the proposed scheme, simulation and analytical approach. In the simulation part, the performance metrics and simulation scenario are discussed. The performance of the proposed scheme is compared with hierarchical mobile ipv6 (HMIPv6) and other selected benchmark. The scenario considered is that the MAP domain is distributed into multiple sub domains depending on the level of nesting. The performance metrics considered during the evaluation are packet transmission delay and handoff latency. In the analytical part, analytical models are developed to evaluate performance metrics. This chapter ends up with the discussion of both the simulation and analytical results.

4.2 ANALYTICAL EVALUATION OF THE PROPOSED SCHEME

Analytical model has been developed to compare the packet transmission delay and handoff latency of the proposed scheme with selected benchmark. A packet transmission delay was calculated by summing up the link delay between CN and MR, link delay between HA and MR, processing delay at home agents, link delay between AR and MR, link delay between AR and TLMR, link delay at each sub domain and the link delay between MR and MN. Also handoff latency was calculated by summing up the total delay of movement detection, the total delay of duplicate address detection at each sub domain TLMR and the total processing delay at each MR and link delay between each MR.

4.2.1 Notations

The analytical model uses the notation shown in table 4.1

Table 4-1:The Notations of The Analytical Model

N	The degree of nesting of whole domain
M	The degree of nesting inside sub domain
$N_{SD-TMLR}$	The number of sub domains
D_{MR}^{i}	The Processing delay of MR
$LD_{MR}^{i,i+1}$	The link delay between MR i and MR i+1
D_{HA}^{i}	The processing delay of HA
$LD_{CN-ROUTER}$	The link delay between correspondent node and MR
$D_{SD-ROUTER}$	The processing delay of SD_TLMR
$LD_{HA-ROUTER}$	The link delay between home agent and MR
LD_{MR-MN}	The link delay between MR and Mn
$LD_{AR-ROUTER}$	The link delay between AR and MR
$LD_{AR-TLMR}$	The link delay between AR and TMLR
D_{MD}	The processing delay of movement detection
D_{DAD}	The processing delay of duplicate address detection

4.2.2 Packet transmission delay

As previously mentioned packet transmission delay was calculated by summing up the link delay between CN and MR, the link delay between HA and MR, and processing delay at home agents, the link delay between AR and MR, the link delay between AR and TLMR, link delay at each sub domain and link delay between MR and MN. This section shows the equation used to calculate the packet transmission delay for each approach.

4.2.2.1 Packet transmission delay in NEMO.

Equation (4.1) (Cho, Hosik and Kwon, Taekyoung and Choi, Yanghee, 2006) calculates the packet transmission delay for NEMO approach as follows:

$$PD_{NEMO} = 2\,LD_{MR\text{-}MNN} + \sum_{i=1}^{N}\left(D_{MR}^{i} + LD_{MR}^{i,i+1} + D_{HA}^{i}\right) + 2\,LD_{AR\text{-}TLMR} + 2\,LD_{AR\text{-}Router} + 2\sum_{i=1}^{N} LD_{HA\text{-}Router} + \sum_{i=1}^{N} LD_{Router}^{i,i+1} + 2\sum_{j=1}^{M} LD_{HA\text{-}Router} + \sum_{j=1}^{M} LD_{Router}^{i,i+1} + \sum_{j=1}^{M}\left(D_{MR}^{i} + LD_{MR}^{i,j+1} + D_{HA}^{i}\right) \quad \ldots\ldots\ldots\ldots \quad 4.1$$

Equation 4-1 Packet Transmission Delay in NEMO

4.2.2.2 Packet transmission delay in ROTIO.

Equation (4.2) (Cho, Hosik and Kwon, Taekyoung and Choi, Yanghee, 2006) calculates the packet transmission delay in ROTIO approach as follows:

$$PD_{ROTIO} = (LD_{CN\text{-}Router} + LD_{HA\text{-}Router}) + 2\sum_{i=1}^{a-1} LD_{HA\text{-}Router} + \sum_{i=1}^{a-1} LD_{Router}^{i,i+1} + \sum_{i=1}^{a-1}\left(D_{HA}^{i}\right) + LD_{AR\text{-}Router} + LD_{AR\text{-}TLMR} + \sum_{i=1}^{N}\left(D_{MR}^{i} + LD_{MR}^{i,i+1}\right) + LD_{MR\text{-}MNN} \quad \ldots\ldots\ldots \quad 4.2$$

Equation 4-2 Packet Transmission Delay in ROTIO

4.2.2.3 Packet transmission delay in LBU+.

Equation (4.3) (Senan, Shayma and Abdalla Hashim, Aisha-Hassan and Hameed, Shihab A and Daoud, Jamal Ibrahim and Zeki, Akram M, 2014) calculates the packet transmission delay in LBU+ approach as follows:

$$PD_{LBU+} = (LD_{CN\text{-}Router} + LD_{HA\text{-}Router}) + \sum_{i=1}^{a}\left(D_{HA}^{i}\right) + LD_{AR\text{-}Router} + LD_{AR\text{-}TLMR} + \sum_{i=1}^{N}\left(D_{MR}^{i} + LD_{MR}^{i,i+1}\right) + LD_{MR\text{-}MNN} \quad \ldots\ldots\ldots\ldots\ldots \quad 4.3$$

Equation 4-3Packet Transmission Delay in LBU+

4.2.2.4 Packet transmission delay in proposed scheme.

Equation (4.4) (Mohammed, Mohammed Babiker Ali and Hashim, Aisha Hassan A, 2015) calculates the packet transmission delay in proposed approach as follow:

$$PD_{proposed} = (LD_{CN-ROUTER} + LD_{HA-ROUTER}) + \sum_{i=0}^{u}(D_{HA}^{i}) + LD_{AR-ROUTER} + LD_{AR-TLMR}$$

$$(\sum_{i=1}^{N}(D_{MR}^{i}) + LD_{MR}^{i,i+1}) / N_{SD-TMLR} + D_{SD-ROUTER} + LD_{MR-MN} \cdot \quad \ldots\ldots \; 4.4$$

Equation 4-4 Packet Transmission Delay in proposed Scheme

4.2.3 Handoff latency

The handoff latency is calculated by summing up the total delay of movement detection and total delay of duplicate address detection at each sub domain TLMR, the total processing delay at each MR, and the link delay between each MR. This section shows the calculation of the handoff latency for each approach.

4.2.3.1 Handoff latency of NEMO.

Equation (4.5) (Cho, Hosik and Kwon, Taekyoung and Choi, Yanghee, 2006) calculates the handoff latency in NEMO approach as follow:

$$HL_{NEMO} = D_{MD} + D_{DAD} + LD_{AR\text{-}HA} + LD_{AR\text{-}MAP} + \sum_{i=1}^{n}(D_{MR}^{i}) + \sum_{i=1}^{n-1}(LD_{MR}^{i,i+1}) \quad \ldots . \; 4.5$$

Equation 4-5 : Handoff latency in NEMO

4.2.3.2 Handoff latency of ROTIO.

Equation (4.6) (Cho, Hosik and Kwon, Taekyoung and Choi, Yanghee, 2006) calculates the handoff latency in ROTIO approach as follow:

$$HL_{ROTIO} = D_{MD} + D_{DAD} + \sum_{i=1}^{n}(D_{MR}^{i}) + \sum_{i=1}^{n-1}(LD_{MR}^{i,i+1}) \quad \ldots . \; 4.6$$

Equation 4-6 : Handoff Latency in ROTIO

4.2.3.3 Handoff latency of LBU+.

Equation (4.7) (Senan, Shayma and Abdalla Hashim, Aisha-Hassan and Hameed, Shihab A and Daoud, Jamal Ibrahim and Zeki, Akram M, 2014) calculates the handoff latency in LBU+ approach as follow:

$$HL_{LBU+} = D_{MD} + \sum_{i=1}^{n}(D_{MR}^{i}) + \sum_{i=1}^{n-1}(LD_{MR}^{i,i+1}) \quad \ldots\ldots \; 4.7$$

Equation 4-7: Handoff Latency in LBU+

4.2.3.4 Handoff latency of proposed scheme.

Equation (4.8) (Mohammed, Mohammed Babiker Ali and Hashim, Aisha Hassan A, 2015) calculates the handoff latency in proposed scheme as follow:

$$HL_{proposed} = D_{MD} + D_{SD-TLMR-DAD} + \sum_{i=1}^{M} D_{MR}^{i} + \sum_{i=1}^{M-1} lD_{MR}^{i,i+1} \quad \ldots\ldots \ 4.8$$

Equation 4-8 : Handoff Latency in Proposed Scheme

4.3 NUMERICAL ANALYSIS AND SIMULATION RESULTS.

This section discusses the numerical analysis based on analytical models and the simulation results in comparison with the benchmark. The performance metrics that have been considered in the comparison are packet transmission delay, handoff latency, packet loss, and media access delay. Table 4.2 shows the system parameters values that are used to evaluate the proposed scheme. (Cho, Hosik and Kwon, Taekyoung and Choi, Yanghee, 2006)

Table 4-2: The System Parameters Values

Parameter	value
D_{MR}^{i}	10 ms
$LD_{MR}^{i,i+1}$	5 ms
D_{HA}^{i}	10 ms
$LD_{CN-ROUTER}$	50 ms
$D_{SD-ROUTER}$	10 ms
$LD_{HA-ROUTER}$	10-100 ms
LD_{MR-MN}	5 ms
$LD_{AR-ROUTER}$	5 ms
$LD_{AR-TLMR}$	100 ms
$LD_{CN-ROUTER}$	50 ms
D_{MD}	10 ms
D_{DAD}	10 ms

4.3.1 Packet transmission delay

Figure 4.1 presents the packet transmission delay in the proposed scheme compared with the selected benchmark approaches. It is clearly shown the packet transmission delay in the proposed scheme is less than NEMO approach by 54% and less than ROTIO approach by 42%, finally the packet transmission delay in proposed scheme is also less than LBU+ approach by 36 %. Table 4.3 summarise these percentages.

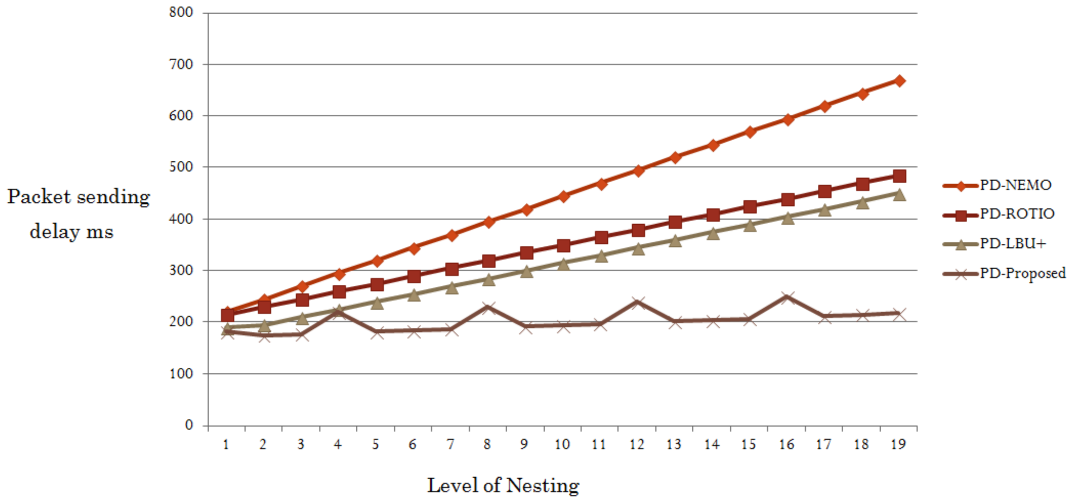

Figure 4.1: Comparison of Packet Transmission Delay

Table 4-3 Packet Transmission Delay Percentages Comparison

Approach	Average	Percentage *
NEMO BS	445	54%
ROTIO	350	42%
LBU+	315	36%

$$* \ \text{percentage} = \frac{Average_{\ Proposed} - \ Average_{Benchmark}}{Average_{Benchmark}}$$

$$* \ Average_{Proposed} = 203$$

4.3.2 Handoff latency.

Figure 4.2 presents the Handoff latency in the proposed scheme compared with the selected benchmark approaches. It is clearly shown the Handoff latency in the proposed scheme is less than NEMO approach by 55% and less than ROTIO approach by 47%, finally the packet transmission delay in proposed scheme is also less than LBU+ approach by 43 %. Table 4.4 summarise these percentages.

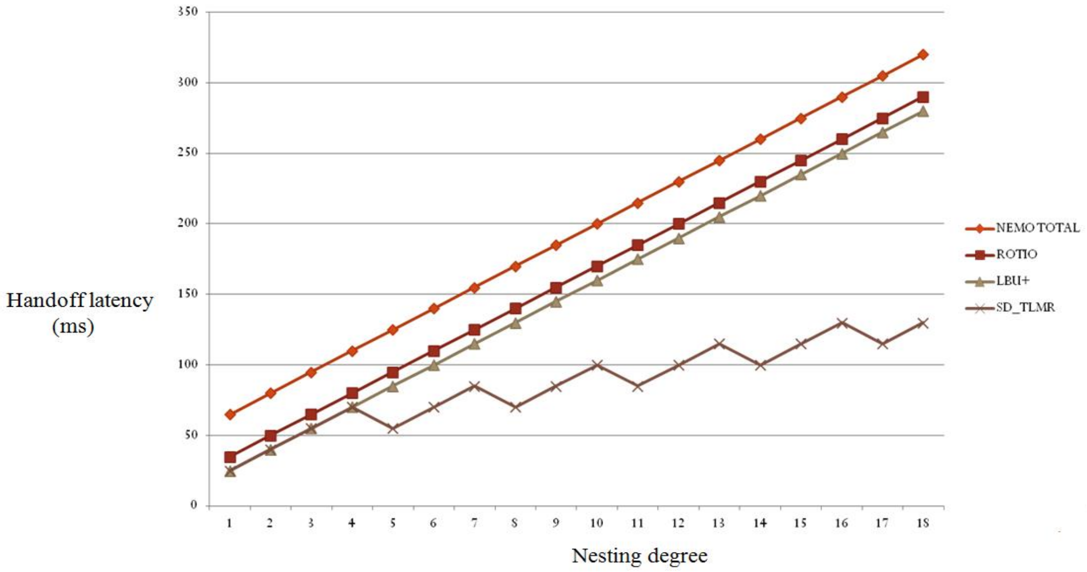

Figure 4.2 : Comparison of Handoff Latency

Table 4-4 : Handoff Latency Percentages Comparison

Approach	Average	Percentage *
NEMO BS	192.5	55%
ROTIO	162.5	47%
LBU+	152.5	43%

$$* \ \text{percentage} = \frac{Average_{\ Proposed} - \ Average_{Benchmark}}{Average_{Benchmark}}$$

$$* \ Average_{Proposed} = 85.5$$

4.4 SIMULATION

4.4.1 Simulation performance metrics

The simulation parameters used to evaluate the improvement of the proposed scheme are as follows:

- Average traffic sent.
- Average traffic dropped.
- Average media access delay.

4.4.2 Simulation environment.

Optimized Network Engineering Tools (OPNET) is heavily used in the simulation of network routing. OPNET support several network protocols and offers simulation result for different types of network. OPNET is written in C++ language and supports network mobility. OPNET 14.5 used as evaluation tools for the proposed scheme for many reasons listed below:

- An extensive set of pre-built models, protocols and algorithms
- A good level of acceptance from the scientific community
- An excellent scalability
- A rather good, highly modular, software design
- A satisfactory level of usability, modifiability and expandability
- Advanced graphical and mathematical tools for experiment building, monitoring and post-processing
- Possibility to execute and monitor several scenarios in a concurrent manner.

4.5 ANALYSIS OF THE SIMULATION RESULT

This section describes simulation scenario considered and discusses performance results obtained.

4.5.1 Simulation scenario

The network topology used is shown in Figure 4.3 that consists of all the components of the nested network mobility. The figure shows multiple mobile networks connected together under an access router, which is connected to the internet. These mobile networks move freely and change the point of attachment by connecting through other MR. Next figures discuss the result obtained by this scenario.

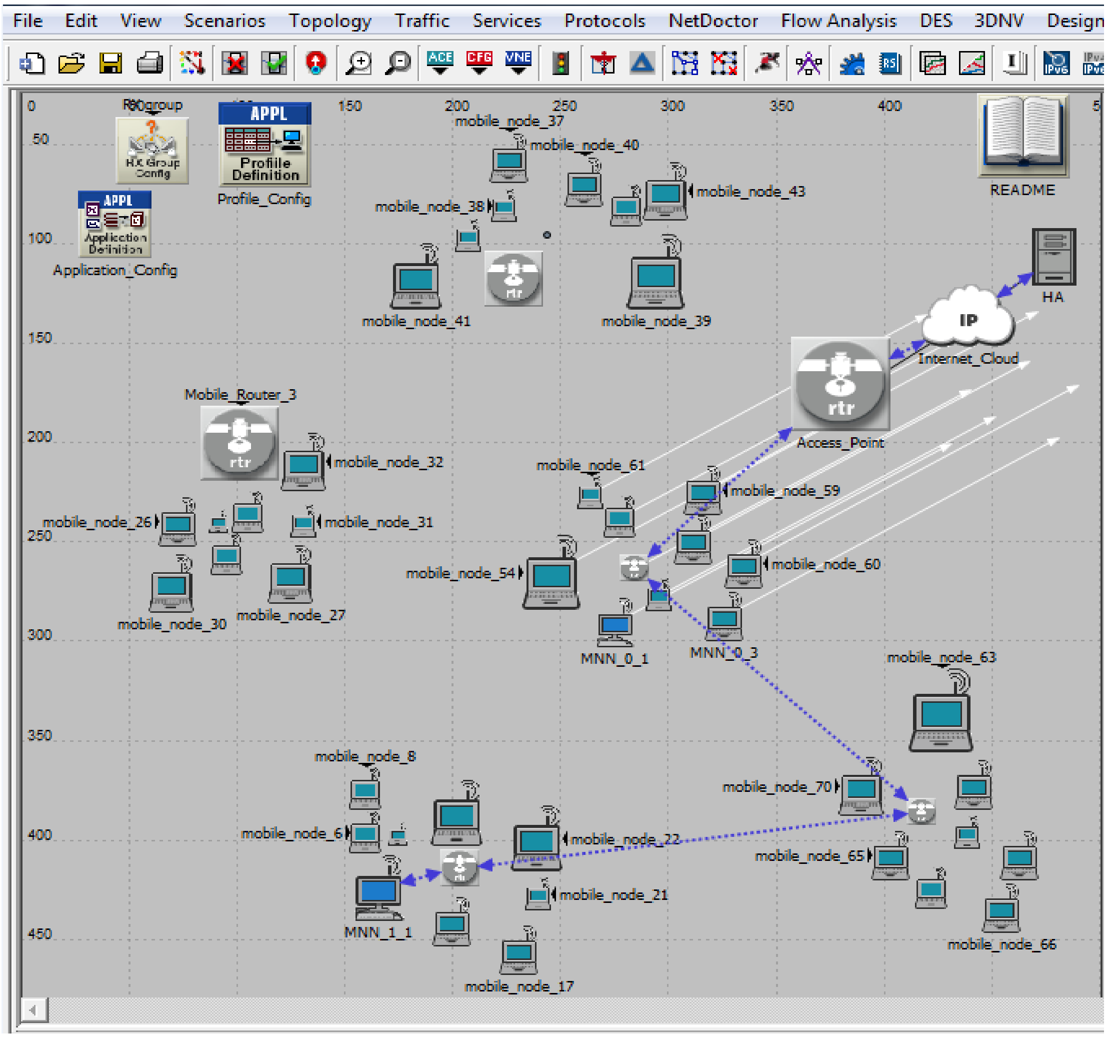

Figure 4.3 : The Network Scenario in Simulation Environment

4.5.2 Average traffic sent.

Figure 4.4 shows the average traffic sent compared to benchmarks. It shows that the proposed scheme reduces the average traffic sent by 41% than NEMO and 19% than ROTIO approach. Table 4.5 summarise these percentages.

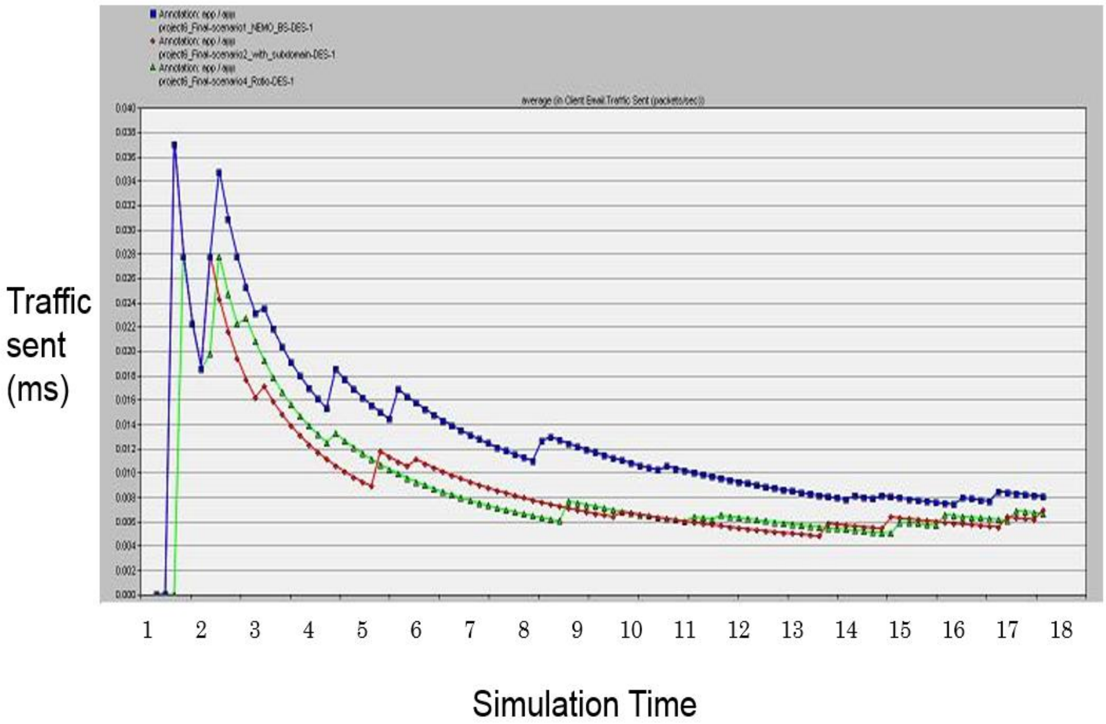

Figure 4.4 : The Average Traffic Sent Comparison

Table 4-5: The Average Traffic Sent Percentages Comparison

Approach	Average	Percentage *
NEMO BS	116	41%
ROTIO	84.3	19%

$$* \ \text{percentage} = \frac{Average_{\ Proposed} - \ Average_{Benchmark}}{Average_{Benchmark}}$$

$$* \ Average_{Proposed} = 67.6$$

4.5.3 Average traffic dropped .

Figure 4.5 shows the average traffic dropped (packet loss). It is clearly shown that the proposed scheme have minimum average traffic drop than NEMO and ROTIO. The proposed scheme reduces the average of packet loss by 15% less than NEMO and 7 % less than ROTIO.

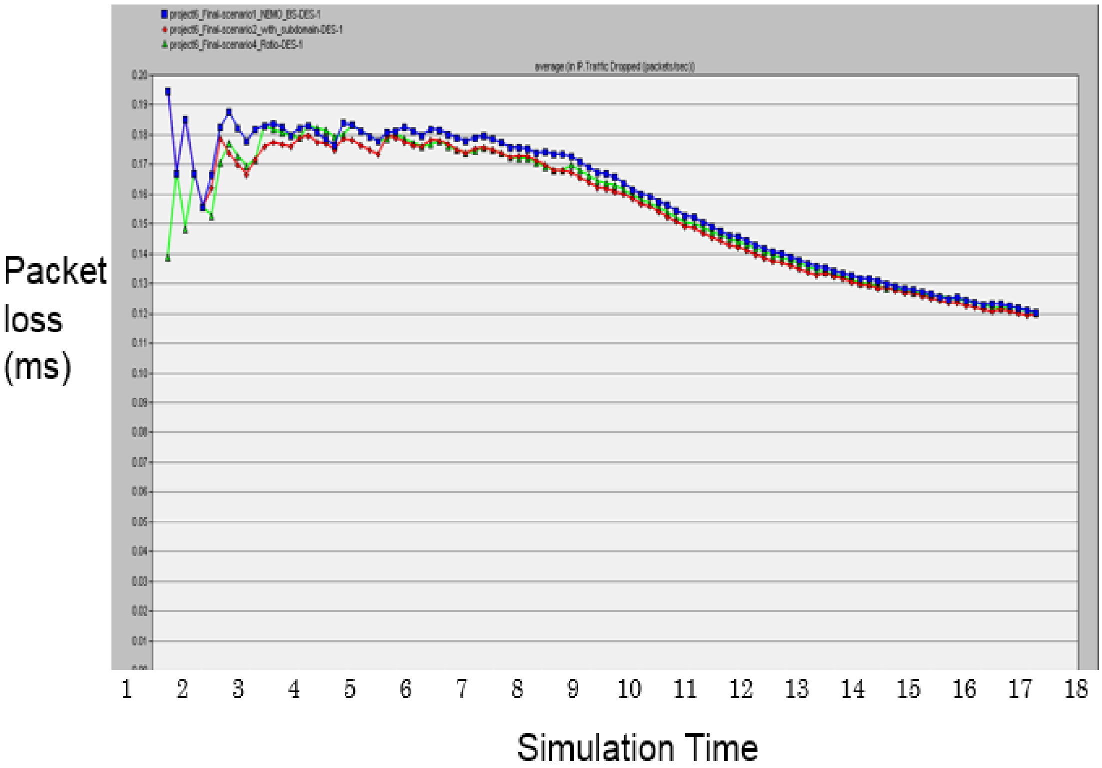

Figure 4.5: The Average Traffic Dropped Comparison

Table 4-6: The Average Traffic Dropped Percentages Comparison

Approach	Average	Percentage *
NEMO BS	48.3	15%
ROTIO	44.5	7%

$$* \ \text{percentage} = \frac{Average_{\ Proposed} - \ Average_{Benchmark}}{Average_{Benchmark}}$$

$$* \ Average_{Proposed} = 41.1$$

4.5.4 Average media access delay .

Figure 4.6 illustrates the average delay of media access; it shows that the proposed scheme has reduced the media access delay by 17% than NEMO and 0.9 % than ROTIO.

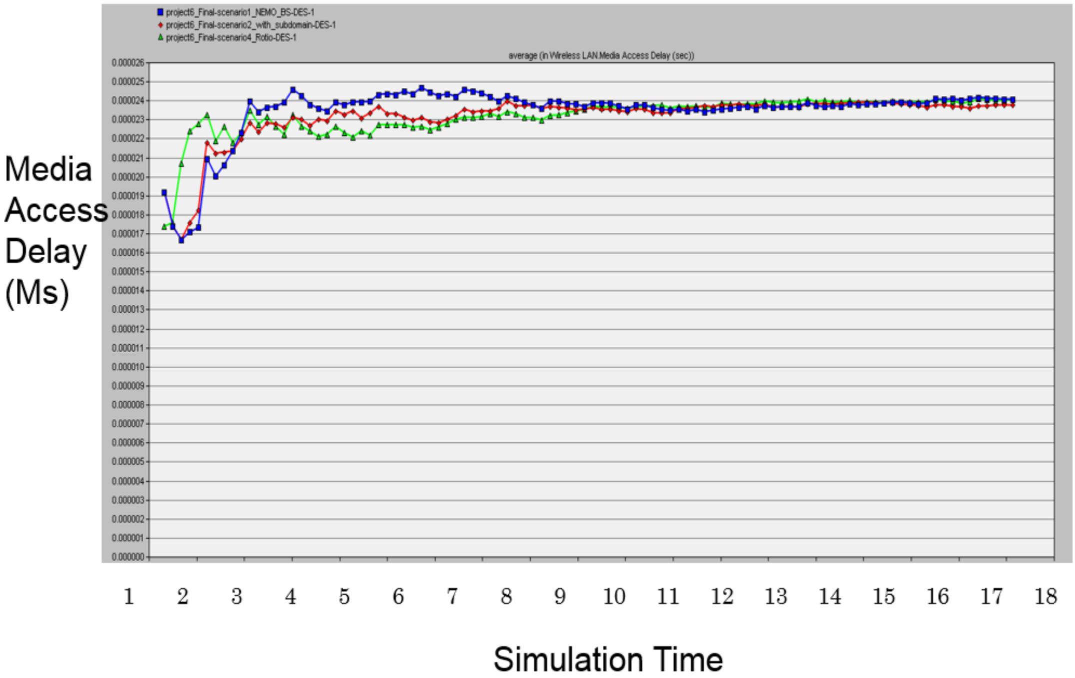

Figure 4.6: the average Media Access Delay Comparison

Table 4-6: The Average Media Access Delay Percentages

Approach	Average	Percentage *
NEMO BS	.000370	17%
ROTIO	.000345	0.9%

$$* \ \text{percentage} = \frac{Average_{\ Proposed} - \ Average_{Benchmark}}{Average_{Benchmark}}$$

$$* \ Average_{Proposed} = .000310$$

Finally, the parameters used to evaluate the proposed scheme in the simulation environment have proved that the proposed scheme was better than previous approaches.

4.6 DISCUSSION

The proposed scheme is designed to minimize packet transmission delay as well as handoff latency in nested network mobility when the level of nesting becomes high. The simulation results show that the proposed scheme has introduced an enhancement of performance metrics compared with the benchmark. The analytical model for proposed scheme introduced packet transmission delay and handoff latency less than benchmark; this is because of using the concept of distributing the network domain into multiple sub domains.

4.7 SUMMARY

The performance evaluation of the proposed scheme has been presented in this chapter. Both the simulation and the analytical models were used for the evaluation. For the simulation model, comparative performance analysis for the proposed scheme compared to benchmark has been shown. Two metrics, the packet transmission delay and handoff latency, have been considered in the analytical evaluation.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This dissertation investigates the current mobility management protocols and identifies their limitations. In this thesis, a novel scheme using hierarchical structure has been proposed to overcome the performance problems that occur in nested network mobility in case of high degree of nesting level. An analytical model for packet transmission delay and handoff latency are developed and evaluated compared to the benchmarks. The simulation environment has been used to compare network utilization with the benchmark. The result obtained had shown that the proposed scheme has better performance than the benchmark. The proposed scheme reduced the packet transmission delay by 55% than NEMO and 47% Than ROTIO. It has also reduced the handoff latency by 54% than NEMO and 41% than ROTIO.

5.2 DISSERTATION CONTRIBUTION

This thesis aimed to tackle the limitation associated with performance in nested network mobility in case of high level of nesting. A new scheme has been developed to overcome the shortcomings facing nested network mobility and provide seamless mobility. The result of evaluation shows that the packet transmission delay and handoff latency in proposed scheme are significantly improved compared to benchmark. The following conference papers are presented at international conferences, titled as bellow:

- An Enhanced Scheme To Support Nested Network Mobility , ICOM13 Kuala Lampur, July 2013 (selected to be published in IOP journal) , this paper introduced a novel scheme that support the nested network mobility by reducing tunnelling overhead , handoff latency and end-to-end delay. Therefore, this scheme enhanced nested network mobility performance.
- Investigation of Nested Nemo Schemes in mobile network environment: IEEE international conference – Khartoum Aug 2013. (Published in IEEE explore).

This article investigates and surveys the current approaches that deal with nested network mobility problems, the outcome of this paper shows that the related research introduced valuable results, however they still suffer from drawbacks especially in case of high level nested network mobility.

- Evaluation of Nested Network Mobility Approaches**,** ICCCE2014, IIUM, Kuala Lumpur, Sept 2014 (published in IEEE explore). This paper evaluates the current approaches that take the nested network mobility problem. Thus, it tries to test the performance metrics in case of high level of nesting.

Two journal papers was published in international journal titled as bellow;

- Improving Message Delay, Handoff latency and Binding Update in High level Nested Network Mobility, International Journal of Computer Science and Network Security, 2014. This paper presents the proposed scheme that is used in this research. This paper shows an improvement in message transmission delay, handoff latency and binding update in high level nested network mobility.
- Evaluation of an Enhanced Scheme for Support high level Nested Mobile Networks , International Journal of Computer Science and Network Security, IJCSNS, Korea , October 2015. This paper presents evaluation of the proposed scheme using analytical model approach and simulation.

5.3 FUTURE WORK

From the observation of this study, the following recommendations are made for further work in the mobility management research area:

- To develop a cache strategy to keep SDTLMR updated with TLMR in efficient manner.
- More work need to be done in the security issues, studying security approaches associated with mobility management.
- To develop intelligent approaches and manipulate the network mobility when the selected SDTLMR move out the MAP domain.

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