UNIVERSITI PUTRA MALAYSIA

CROSS LAYER DESIGN OF NETWORK- BASED FULLY DISTRIBUTED MOBILITY MANAGEMENT FOR HETEROGENEOUS WIRELESS NETWORKS

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By

MUAYAD KHALIL MURTADHA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

December 2016

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DEDICATION

To my parents, for their prayers and endless support

To my beloved wife, for her everlasting love and support

To my precious children, the joy of my life

To my brothers and sisters, for their love and encouragement

…with all love and gratitude…

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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By

MUAYAD KHALIL MURTADHA

December 2016

Chairman : Professor Nor Kamariah Noordin, PhD
Faculty : Engineering

Current mobility protocols; such as MIPv6 and PMIPv6, are deployed in a hierarchical and centralized manner in which a single anchor at the core network handles all mobility signaling and data traffic forwarding. As the core of the mobile network is heavily loaded by inducing excessive traffic, Centralized Mobility Management (CMM) suffers from several issues in scalability, reliability, signaling overhead and non-optimal routing. Therefore, the IETF introduced a Distribution Mobility Management (DMM) working group to overcome these issues.

The DMM paradigm involves a flattened IP network architecture in which the mobility anchor is moved closer to the users and the control and data planes are distributed at the network edge. The DMM is divided into two categories, partially and fully DMMs. The aim of this thesis is to design and develop network-based fully DMM solutions for flat IP architecture by removing any centralized mobility anchor from network infrastructure. Several solutions for heterogeneous wireless networks have been proposed based on the cross layer design of layer2 (data link) and layer3 (network). The IEEE Media Independent Handover (MIH) framework and Logical Interface (LIF) concept are used to abstract the heterogeneity of wireless networks. First scheme is developed using modified MIH framework to carry the addresses of active anchored flows, meanwhile; a modified and extended version of PMIPv6 has been used in the second scheme to carry the addresses of anchored flows. Third scheme is developed based on further modifications in MIH and PMIPv6 protocols by excluding client participation in any L2 or L3 wireless mobility signaling. The LIF concept has been used in the proposing of fourth scheme. Last proposed scheme develops more flattened architecture by distributing both mobility management and authentication process during vertical handover procedure.

The analytical modeling and simulation implementation have been used to evaluate the proposed fully DMM solutions. Analytically, the DMM reports 80% lower data cost compared to CMM, while simulation shows 37% reduction in the end to end

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delay compared to CMM in heterogeneous networks. Moreover, MIH based fully DMM solutions are more complex and show higher signaling cost, handover latency and packet loss compared to LIF based solutions. However, the MIH based solutions can provide Quality of Service (QoS) provisioning of future networks. In particular, MIH based scheme gives an average of 53% lower signaling cost than PDMM, while LIF based scheme reports 102% reduction in signaling cost compared to MIH based scheme with client participation. In addition, MIH based scheme without client participation produces 50% lower handover latency compared to MIH based with client participation. Moreover, distributed mobility and distributed authentication scheme reports 52% and 24% packet loss reduction compared to MIH based without client participation and LIF based schemes, respectively.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

REKA BENTUK LAPISAN SILANG PENGURUSAN MOBILITI TERAGIH PENUH BERASASKAN RANGKAIAN UNTUK RANGKAIAN WAYARLES HETEROGEN

Oleh

MUAYAD KHALIL MURTADHA

Disember 2016

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Protokol mobiliti semasa; seperti MIPv6 dan PMIPv6, dikerahkan dalam hierarki dan berpusat di mana satu peneraju tunggal di rangkaian teras mengendalikan semua pergerakan isyarat dan penghantaran data trafik. Memandangkan teras rangkaian mudah alih banyak dimuatkan dengan mendorong trafik yang berlebihan, Pengurusan Mobiliti Berpusat (CMM) mengalami beberapa isu seperti berskala, kebolehpercayaan, isyarat overhead dan laluan yang tidak optimum. Oleh itu, IETF memperkenalkan kumpulan kerja Pengurusan Mobiliti Teragih (DMM) untuk mengatasi isu-isu ini.

Paradigma DMM melibatkan seni bina rangkaian IP rata di mana peneraju mobiliti diserakkan lebih dekat dengan pengguna dan satah kawalan dan data diedarkan di pinggir rangkaian. DMM dibahagikan kepada dua kategori, DMM separa dan DMM penuh. Tujuan tesis ini adalah untuk mereka bentuk dan membangunkan sepenuhnya penyelesaian DMM berasaskan rangkaian untuk seni bina IP rata dengan mengeluarkan sebarang peneraju mobiliti berpusat daripada infrastruktur rangkaian. Beberapa penyelesaian untuk rangkaian tanpa wayar heterogen telah dicadangkan berdasarkan reka bentuk lapisan silang antara lapisan ke-2 (data) dan lapisan ke-3 (rangkaian). Rangka kerja IEEE Media Bebas Penyerahan (MIH) dan konsep Antara Muka Logik (LIF) digunakan untuk abstrak kepelbagaian rangkaian wayarles. Skim pertama dibangunkan menggunakan rangka kerja MIH yang telah diubahsuai untuk membawa alamat aliran peneraju aktif, sementara itu; versi yang diubah suai dan lanjutan PMIPv6 telah digunakan dalam skim kedua untuk membawa alamat aliran peneraju. Skim ketiga dibangunkan berdasarkan pengubahsuaian lanjutan di dalam protokol MIH dan PMIPv6 dengan mengecualikan penyertaan pelanggan di dalam mana-mana L2 atau L3 pengisyaratan mobiliti wayarles. Konsep LIF telah digunakan dalam mencadangkan skim keempat. Skim terakhir yang dicadangkan membangunkan kerangka lebih rata seni bina dengan mengedarkan kedua-dua pengurusan mobiliti dan proses pengesahan semasa prosedur penyerahan menegak.

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Analisis pemodelan dan pelaksanaan simulasi telah digunakan untuk menilai cadangan penyelesaian DMM penuh. Secara analitikal, DMM melaporkan kos data 80% lebih rendah berbanding CMM, manakala simulasi menunjukkan pengurangan 37% pada kelewatan hujung ke hujung berbanding CMM dalam rangkaian heterogen. Selain itu, penyelesaian DMM penuh berdasarkan MIH adalah lebih kompleks dan menunjukkan kos isyarat yang lebih tinggi, penyerahan kependaman dan kehilangan paket berbanding dengan penyelesaian berasaskan LIF. Walaubagaimanapun, penyelesaian berasaskan MIH dapat menyediakan Kualiti Perkhidmatan (QoS) penyediaan rangkaian masa depan. Khususnya, skim berasaskan MIH memberikan purata kos isyarat 53% lebih rendah daripada PDMM, manakala skim berdasarkan LIF melaporkan pengurangan 102% di dalam isyarat kos berbanding dengan skim berdasarkan MIH dengan penyertaan pelanggan. Di samping itu, skim berdasarkan MIH tanpa penyertaan pelanggan menghasilkan kependaman penyerahan 50% lebih rendah berbanding berasaskan MIH dengan penyertaan pelanggan. Selain itu, mobiliti teragih dan skim pengesahan teragih melaporkan pengurangan kehilangan paket 52% dan 24% masing-masing berbanding berdasarkan MIH tanpa penyertaan pelanggan dan skim berdasarkan LIF.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

5G	5^{th} Generation Mobile Networks
3GPP	3rd Generation Partnership Project
AAA	Authentication, Authorization and Accounting
AAN	Anchor Access Node
AP	Access Point
AR	Access Router
BA	Binding Acknowledgment
BC	Binding Cache
BCE	Binding Cache Entry
BGP	Border Gateway Protocol
BS	Base Station
BU	Binding Update
BUL	Binding Update List
BULE	Binding Update List Entry
CBR	Constant Bit Rate
CLMA	Control plane LMA
CMD	Central Mobility Database
CMM	Centralized Mobility Management
CN	Correspondent Node
CoA	Care-of Address
DAAA	Distributed Authentication, Authorization and Accounting
DC	Data Cost
DHT	Distributed Hash Table
DLMA	Data plane LMA
DMA	Dynamic Mobility Anchoring
DMM	Distributed Mobility Management
DNS	Domain Name System
DPBU	Distributed Proxy Binding Update
DPBA	Distributed Proxy Binding Acknowledgement

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EPS	Evolved Packet System
FA	Foreign Agent
FDMM	Fully Distributed Mobility Management
FMIPv6	Fast handover for Mobile IPv6
FPMIPv6	Fast Proxy Mobile IPv6
FTP	File Transfer Protocol
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
HA	Home Agent
HL	Handover Latency
HNP	Home Network Prefix
HMIPv6	Hierarchical Mobile IPv6
HO	Handover
HoA	Home Address
IE	Information Element
IEEE	The Institute of Electrical and Electronics Engineers
IETF	The Internet Engineering Task Force
IP	Internet Protocol
IPv6	Internet Protocol version 6
L2	Layer 2 (Data Link Layer)
L3	Layer 3 (Network Layer)
LAN	Local Area Network
LGD	Link Going Down
LIF	Logical Interfaces
LM	Location Management
LMA	Local Mobility Anchor
LMD	Localized Mobility Domain
LTE	Long Term Evolution
mSCTP	Mobile Stream Control Transmission Protocol
MAR	Mobility Capable Access Router
MAAR	Mobility Anchor and Access Router

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MAC	Medium Access Control
MAG	Mobile Access Gateway
MIH	Media Independent Handover
MICS	Media Independent Command Service
MIES	Media Independent Event Service
MIHF	Media Independent Handover Functions
MIIS	Media Independent Information Service
MIPv4	Mobile IPv4
MIPv6	Mobile IPv6
MN	Mobile Node
MN-ID	Mobile Node Identifier
MR	Mobility Routing
NAM	Network Animator
ND	Neighbor Discovery
NGWN	Next Generation Wireless Networks
NIST	National Institute of Standards and Technology
NIQ	Node Information Queries
NS2	Network Simulator 2
OTcl	Object-oriented Tool Command Language
PBA	Proxy Binding Acknowledgment
PBU	Proxy Binding Update
PBQU	Proxy Binding Query Update
PBQA	Proxy Binding Query Acknowledgement
PCoA	Proxy Care-of Address
PDMM	Partially Distributed Mobility Management
PGW	Packet Data Network Gateway
PL	Packet Loss
PMIPv6	Proxy Mobile IPv6
PoA	Point of Access
PoS	Point of Service
QoS	Quality of Service

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RA	Router Advertisement
RFC	Request For Comments
RNC	Radio Network Controller
RS	Router Solicitation
RSSI	Received Signal Strength Indicator
SAP	Service Access Point
SC	Signaling Cost
SGSN	Serving GPRS Support Node
SGW	Serving Gateway
SIP	Session Initiation Protocol
SMR	Session to Mobility Ratio
SMS	Short Message Service
TC	Tunneling Cost
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunications System
VAN	Visited Access Node
VNI	Visual Networking Index
VoIP	Voice over IP
WiFi	Wireless Fidelity IEEE 802.11 WLAN
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless LAN

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CHAPTER 1

INTRODUCTION

The highly centralized and hierarchical architecture of the traditional mobile networks has led primarily to deployment of Centralized Mobility Management (CMM) solutions. A single mobility anchor located in the core network performs all the mobility signaling and data forwarding operations. Due to an ever-increasing number of mobile devices and the volume of data traffic, the CMM approach confronts several issues in scalability, reliability, signaling overhead, and non-optimal routing. To overcome the CMM issues, a new architectural paradigm of Distributed Mobility Management (DMM) is proposed to flatten the network architecture. This chapter first highlights the limitations and problems of the current CMM approaches and the general structure of the DMM solution. The chapter then states the thesis main objectives followed by the scope of research and its contributions. Finally, this chapter outlines the thesis organization.

1.1 Background and Motivation

The combined action of broadband mobile access developments, the increasing proliferation of mobile devices such as smart phones and tablets, and Internet cloud services, has sped up the mobile traffic growth in wireless networks. Moreover, the mobile users today demand not only for voice and SMS services, but also for high speed Internet access such as video steaming. As the mobile Internet services incorporated with social networking and instant messaging have become indispensable for a growing number of users, the mobile data traffic is expected to grow about 10 fold from 2014 to 2019 according to the Cisco Visual Networking Index (VNI) report, published in June 2015 [1]. Mobile network operators state that the traffic of mobile devices with mobile IP increased dramatically during the last few years and is expected to exceed that of fixed IP devices in near future. Cisco VNI report also stated that the global mobile data traffic will grow three times faster than global fixed IP traffic from 2014 to 2019. Specifically, global mobile IP traffic was 4% of total IP traffic in 2014, and will be 14% of total IP traffic in 2019 [1].

The current hierarchical wireless mobile networks are heavily burdened by inducing excessive traffic caused by the increasing number of mobile users. Mobile network operators need to cope with tremendous traffic growth as well as the future requirements of mobile users who are interested in unlimited access to Internet at anytime, anywhere. Accordingly, these operators are currently evolving towards a flat architecture with all IP based infrastructure to support ubiquitous service continuity [2]. Given these conditions, mobility management for Next Generation Wireless Networks (NGWN) is increasingly important in supporting ubiquitous service continuity for mobile users. Moreover, considering the heterogeneity of future mobile networks, this mobility support is not only limited to homogenous access networks of similar technology but also caters to the heterogeneous access networks of different technologies.

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However, the current IP mobility management solutions are deployed in hierarchal and centralized manner to support the original centralized architecture, in what is called CMM. Internet Engineering Task Force (IETF) standardized various IP-based mobility solutions such as the host-based MIPv6 [3] and the network-based Proxy MIPv6 (PMIPv6) [4]. The network-based solution of PMIPv6 protocol is developed as an extension of host-based MIPv6 protocol to overcome the drawbacks of Mobile Node (MN) involvement in mobility related signaling [5, 6].

In the existing IP mobility protocols, a centralized anchor is in charge of both the control of the network entities that involved in the mobility management (i.e., a centralized node for the control plane), and the user data traffic routing (i.e., a centralized node for the user data plane). In other words, such mobility management protocols are centralized in both the control plane and the data plane. The CMM scheme is also applied in Third Generation Partnership Project (3GPP) General Packet Radio System (GPRS) networks as well as 3GPP Evolved Packet System (EPS) networks. However, the 3GPP GPRS network comprises a hierarchy of anchors including the Gateway GPRS Support Node (GGSN), Serving GPRS Support Node (SGSN), and Radio Network Controller (RNC). Moreover, Packet Data Network Gateway (P-GW) and Serving Gateway (S-GW) constitute another hierarchy of anchors in the 3GPP EPS network.

As a result of the boom in mobile Internet, the core of the mobile network is heavily loaded, and the CMM architecture encounters several issues in scalability, reliability, and performance. This has triggered both industry and academia to look for new novel mobility management solutions which are more distributed in nature [7, 8]. The standardization committee of IETF introduced a DMM working group to overcome these issues. DMM architecture develops the concept of a flattened system architecture in which the control and data planes are distributed among entities at the network edge and the mobility anchors are moved closer to the users [9]. The IETF working group has been focused on fulfilling the DMM framework requirements and analyzing the deployment of the existing IP mobility protocols in a DMM environment [10]. In general, the DMM is divided into two categories, Partially DMM (PDMM) and Fully DMM (FDMM). PDMM approach involves a distributed data plane on the access routers and a centralized control plane at a central anchor point. Meanwhile, FDMM approach involves distributed control and data planes at the network edge [11]. However, FDMM can be considered the most promising approach because it removes any central entity from the network infrastructure. Therefore, in this thesis, the design of FDMM solution for a flat architecture will be addressed, focused on heterogeneous wireless networks as valuable framework to the next generation mobile networks.

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1.2 Problem Statement

Since the traditional mobile networks have been hierarchical; therefore, the mobility management has primarily been deployed according to a centralized architecture. The CMM is prone to the following problems and limitations [10] which can be addressed by moving to DMM, so the problem statement of the thesis is as follows:

1. Non-optimal routes: in CMM, all the data traffic may pass through a central anchor point since the address of the MN is anchored at this central point. This may lead to increasing the end to end dealy due to non-optimal path which is longer than the direct path between the MN and its communication peer.
2. Lack of scalability: the centralized anchor needs enough processing and routing capabilities to manage all the user's data traffic simultanously. The growing number of the mobile users and the demands for more data bandwidth from one hand, as well as maintaining mobility context for each MN and setting up tunnels through a central anchor from the other, requires more concentrated resources in a centralized design. This may lead to scalability and network design issues.
3. Lack of realiability: the centralized anchor in CMM may be more vulnerable to single point of failure and attacks. The impact of a successful attack on a system with CMM can be far greater as well, hence prone to reliability problems.
4. Lack of granularity on mobility support functions: in CMM scheme, all the MN's are provided with IP mobility support functions. However, it is not always required, and not every parameter of mobility context is always used. Sometimes, the MN may not change the point of attachment during whole application session. Thus, there is unnecessary mobility support to the users that do not need mobility support. Hence, a finer granularity on mobility functions support is necessary to the IP flows that really required it to maintain session continuty.

However, the PDMM may also suffer from the following limitations:

1. Keeping the control plane centralized towards cardinal node used as information store in PDMM can lead to single point of failure and attach issue as in CMM.
2. Considering a huge number of MNs in a single mobile opeartor, updating each MN location with a control messages concentraled in a single mobility anchor at the core network may prone to congestion possibility.
3. Considering very small cells of future mobile networks, the handover probability may increase depending on cell radius and MN speed. Thus, passing the mobility control messages to the core network at each handover in order to update MN location may raise handover latency and causes communication disruptions, especially for real time services..

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Currently, many mobility solutions have been designed and depolyed at different layers of wireless networks. The IETF standardized the host-based MIPv6 and the network-based PMIPv6 protocols with several variants to maintan L3 sessions continuity. However, the upcoming generation of wireless mobile networks is an integration of various wireless technologies including 3GPP systems (e.g., UMTS and LTE) and 802 family (e.g., WiFi and WiMAX) [12]. The IEEE organization standardirzed the 802.21 Media Independent Handover (MIH) protocol as a uniform and media-independent L2 framework to provide seamless vertical handover between different access technologies [13]. Moreover, IETF standarized the LIF architecture to abstarct the heterogeneity of wireless networks. Inter-layer communication using cross layer design between L2 and L3 protocols can improve the performance and Quality of Service (QoS) experience of mobility management solutions, especially in heterogenous wireless networks.

The heterogeneity of future wireless networks should carefully be considered in the design of any mobility management solutions. In particular, the following problems have been addressed throughout this study.

1. The available network-based DMM proposals are mainly focused on PDMM solution, where too little attention has been paid to FDMM architecture. Moreover, the heterogeneous wireless networks has not been considered which requires a cross layer design between network-based PMIPv6 L3 protocol and L2 protocols. In addition, the QoS provisioning (e.g., bandwidth, cost, security) of mobile users which can be provided by L2 MIH protocol may take into account.
2. Even though the FDMM solution can be proposed by modifing L3 and L2 protocols, DMM architecture is mainly focused on modifying L3 network layer protocol and it can keep L2 solution to its standard form.
3. The L2 MIH protocol includes many wireless handover preparation signaling between MN and access network. As a result, the handover latency and power consumption may be increased significantly, especially in crowded networks. In addition, the trend of future networks is to reduce the power consumption of MN.
4. Recently, IETF introduced LIF concept to abstract the heterogeneity of wireless networks. MIH is higher architecture complexity than LIF due to many handover preparation messages. This may cuase higher handover latency and packet loss.
5. Although FDMM solution removes any centralized mobility anchor during vertical handover, the authentication process still centralized to AAA policy server at the core network. This may lead to considerable handover latency.

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1.3 Aim and Objectives

Current protocols consumed a lot of efforts and time to design and develop their operation. Deployment of new mobility management solutions can be challenging, and debugging difficult when they co-exist with solutions already deployed in the field. Moreover, since the DMM is in the early stage of standardization, the DMM charter focuses on the development of the existing IETF protocols to work in a distributed manner. Reuse of existing IETF work is more efficient and less error-prone [10, 14]. Therefore, the aim of this thesis is to design a network-based FDMM scheme for heterogeneous wireless networks by modifying the existing network-based CMM solution. The proposed scheme should remove any dedicated mobility anchor form the core network. Consequently, this thesis aims to achieve the following specific objectives which are listed below:

1. To design a network-based FDMM scheme based on the cross layer design between modified L3 PMIPv6 protocol and extended L2 MIH framework for heterogeneous wireless networks by supporting the QoS provisioning of future mobile networks.
2. To design a network-based FDMM scheme based on modified and extended L3 PMIPv6 protocol and using standard MIH protocol to reduce the time, cost, and complexity of modifications for already established L2 MIH infrastructure.
3. To design a network-based FDMM scheme based on modifications in L3 PMIPv6 and L2 MIH protocols without MN participation in any L2 or L3 mobility signaling in order to reduce MN power consumption.
4. To design a network-based FDMM scheme based on modified and extended PMIPv6 protocol and using Logical Interface (LIF) concept to abstract the heterogeneity of different wireless access networks in order to operate in all sites that do not support MIH infrastructure.
5. To design a network-based FDMM and distributed authentication solution for more flattened architecture by distributing mobility management and authentication procedures at access network in order to obtain further reduction in handover latency.

1.4 Scope of the Study

This research concentrates on mitigating the heavily loaded traffic at the core network in the existing mobile networks. The concept of flat IP mobility architecture based on a DMM paradigm is described as valuable framework to design next generation mobile networks. Figure 1.1 shows the scope of this thesis. The figure shows the mobility protocols that have been used and modified to achieve the objectives of the thesis. The network-based PMIPv6 mobility protocol is considered the favorable solution to overcome host-based approach and to minimize the power consumption of the MN as one of the important goals for future networks [5, 6]. Moreover, the future 5G networks integrates various access technologies and considered heterogeneous in nature, hence vertical handover is a key challenge that allows an MN to transfer its traffic from one interface to another [12]. The MIH protocol facilitates the integration of heterogeneous networks by providing uniform

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link layer information to the upper layers in order to enable seamless vertical handover. In general, this thesis focuses on the design of a network-based FDMM schemes for heterogeneous wireless networks.

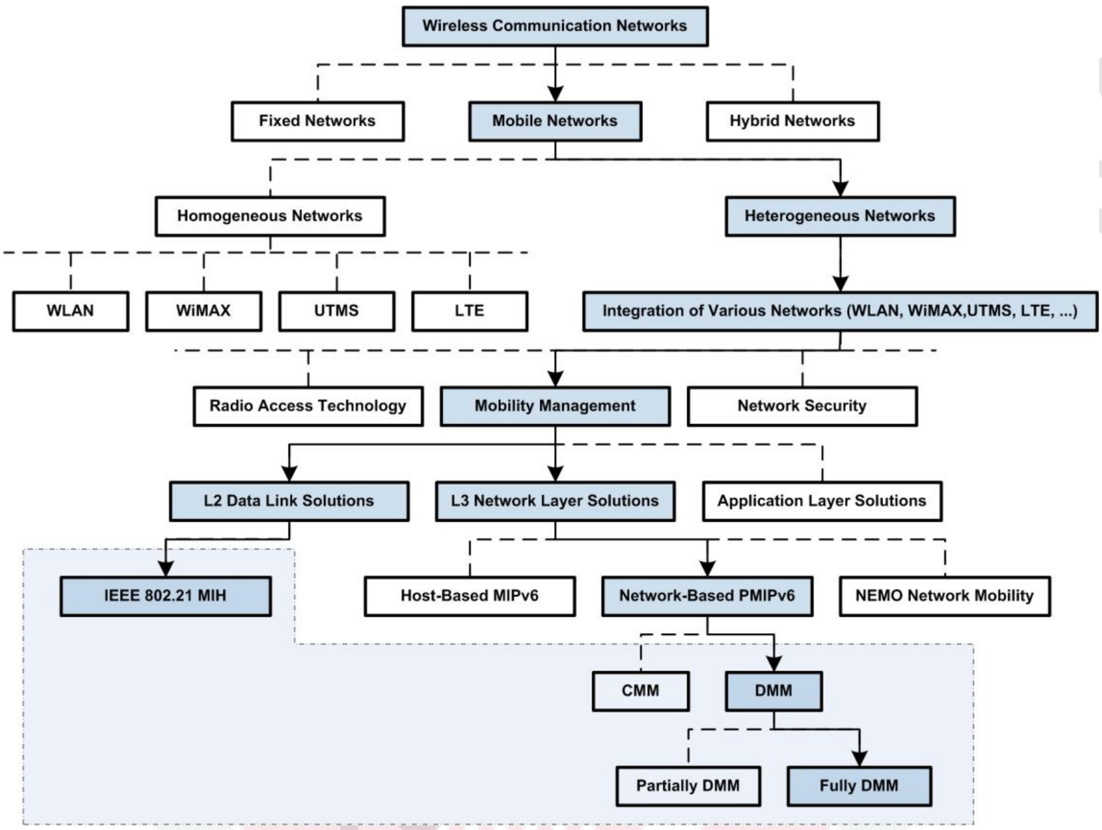

Figure 1.1: Scope of the Thesis

1.5 Significance of the Study

The current 4G LTE system is implemented based on advanced technologies which have been available after decades of extensive research in mobile communications. Mobile network operators search for solutions to increase the available bandwidth per user to cope with the rapid growth of mobile Internet traffic. Simultaneously, to maintain the future 5G deployments, they need to reduce the heavily loaded traffic that pass through the core network. Moreover, the trend today points to implement of extremely dense networks with different wireless access technologies in order to provide ubiquitous high data rates service connectivity. However, the deployments of these requirements posing several challenges in the current heavily centralized architecture when coping with the foreseen explosion of mobile data. To overcome these issues, the DMM is an emerging framework to flattened network architecture for future 5G mobile networks.

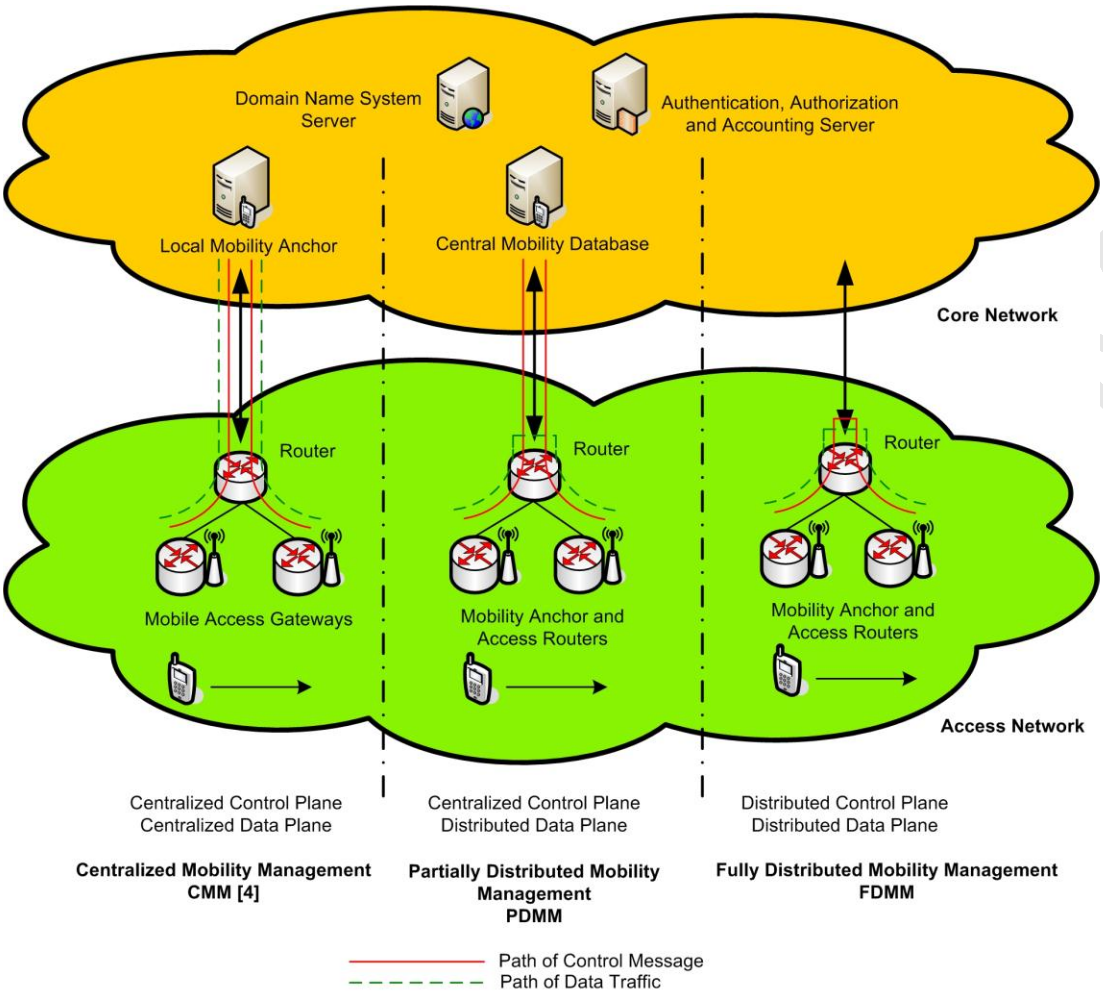

Figure 1.2: Architectures of Mobility Management Solutions

Figure 1.2 shows different architectures of mobility management solutions together with mobility management entities used in each solution. There are two possible solutions for DMM, namely PDMM and FDMM. In PDMM, the data plane is distributed at the network edge and the control plane is kept centralized and managed by a central data base referred by Central Mobility Database (CMD), while FDMM distributed both data and control planes [11]. Hence, in PDMM, every MN registration and movement from one cell to another should be updated with dedicated binding messages with CMD at the core network. Exchanges the binding messages with CMD at the core network in PDMM may add large handover latency similar to CMM scheme. Accordingly, the handover performance will be affected for real time services in future networks. Furthermore, 5G advancing direction is the consistent reduction in the sizes of the deployed wireless networks cells, with sizes that range from macrocells to the modern small femtocells. This direction aims at improving the resources that are deployed (e.g., spectrum) use and the capacity of the cells. Reducing the cell sizes increase the possibilities of handover during MN movement, and hence, raising the number of binding messages with the core network. This adds more handover latency and then causes mobility performance degradation. In addition, the PDMM solutions may prone to single point of failure and attack. Therefore, the FDMM can be considered the most promising for future 5G networks since it distributed both the data and control planes at the network edge.

1.6 Thesis Contributions

Based on the aim and objectives mentioned earlier, the following contributions have been obtained:

A. Re-design of the PMIPv6 Protocol to Work in FDMM Environment

The network-based FDMM is derived from the current architecture of the PMIPv6 protocol, with a modification in the key terms, message formats, and functionalities. The proposed FDMM schemes remove any dedicated centralized mobility anchor.

B. Design of FDMM Based on Cross Layer Design for Heterogeneous Networks

The developed PMIPv6 L3 protocol has been integrated with IEEE 802.21 MIH L2 functionalities to design a FDMM approach for heterogeneous wireless networks. The IEEE 802.21 MIH framework is designed to support seamless vertical handover procedure and Quality of Service (QoS) requirements for multimedia and time-sensitive applications.

C. Design of Fully Network-based FDMM without MN participation in mobility

To overcome the drawback of MN participation in MIH signaling, an efficient solution of network-based FDMM has been developed by excluding the participation of MN in any L2 MIH handover signaling and L3 PMIPv6 mobility signaling. This proposed solution based on further modifications to MIH and PMIPv6 protocols.

D. Design of FDMM based on a Logical Interface Concept

The Logical Interface (LIF) is logical link layer implementation located between L2 and L3 to hide a variety of physical interfaces from IP layer. Inter-technology are possible via simultaneous and sequential network attachment procedures. An MN supported with LIF software and using a developed PMIPv6 protocol is used to design a network-based FDMM for heterogeneous wireless networks.

E. Design of Fully Distributed Mobility and Distributed Authentication Scheme

In the previous proposed FDMM schemes, even though the dedicated centralized mobility anchor has been removed from the architecture, the authentication process

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still centralized to the Authentication, Authorization and Accounting (AAA) server. Thus, the authentication messages are required to move across the core network for each handover. For more flattened architecture, a distributed authentication approach is proposed together with distributed mobility in one solution.

F. Mechanism to Differentiate between First Attachment and Subsequent Handovers

When removing the dedicated mobility anchor in FDMM schemes which maintains a global view of the network status, an issue introduced when the access router needs to know if this is the first MN attachment to the access network or it is a handover from other one. Moreover, the new access router needs to determine all the addresses of the old access routers to update MN current location. Three mechanisms have been proposed depends on the FDMM scheme development:

1. Using a modified IEEE 802.21 MIH messages formats to differentiate between first MN attachment and its subsequent handovers.
2. Using AAA server functions during authentication process to determine if the MN is previously connected to other access router or not.
3. Using a modified version of Neighbor Discovery (ND) messages, specifically modifying Router Solicitation (RS) message to include the MN identifier with the old access router address.

Afterward, either MIH messages or PMIPv6 messages are extended to carry the addresses of all previous access routers that maintain active sessions with MN to the new access router in order to ensure session continuity.

G. Analytical Model to Evaluate the Performance of Proposed Schemes

An analytical model has been developed that used for comparative performance evaluation and analysis of the proposed FDMM against that of CMM, PDMM. The analytical model includes the signaling cost, data cost, tunneling cost, processing cost, handover latency, and packet loss to provide a detailed performance analysis.

H. Simulation Models Implementation to Validate the Analytical Findings

A network-based PDMM and FDMM mobility models have been developed and implemented using NS2 network simulator to compare with the CMM model. Extensive simulations have been conducted through similar simulation scenarios for both CMM and the developed DMM models to validate the analytical findings.

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1.7 Organization of the Study

After a short introduction presented in this chapter, which embeds the statement of the problem and the objectives of this thesis, in addition to the scope and significance of the study, this thesis is organized as follows. In Chapter 2, the existing IETF standardized mobility solutions of the host-based MIPv6 and the network-based PMIPv6 protocols in addition to the IEEE 802.21 MIH protocol are introduced. Previous work related to integrating the PMIPv6 and MIH protocols as valuable work for heterogeneous wireless networks are reviewed and analyzed. After a brief explanation of the current deployed CMM standards, the work on the DMM solutions based on the developments of the existing protocols are reviewed, critically analyzed and compared. This chapter introduces the fundamentals of the host-based, network-based, and hybrid mode DMM solutions to overcome the CMM standards.

The methodology of this thesis has been carefully explained in Chapter 3. This chapter starts with introducing PDMM solution for heterogeneous environment, followed by four proposed solutions of FDMM for heterogeneous wireless networks. Moreover, a proposed solution for distributed mobility and distributed authentication is also presented. These proposed FDMM solutions are developed from the current standards as one of the requirements of the IETF DMM working group. Furthermore, a developed analytical model as well as simulation models implementation for comparative performance analysis of all the described mobility solutions has been detailed out and explained in this chapter also. Chapter 4 presents the results and discussions of the comparative qualitative and quantitative performance evaluation of the proposed DMM solutions compared to current CMM solution in terms of various mobility metrics. The performance evaluation and analysis is carried out based on two directions, analytical evaluations and then simulation validations. In Chapter 5, the thesis is summarized and concluded. Then, several research directions are suggested for further investigation.

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