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A MOBILITY MANAGEMENT SCHEME FOR PROXY MOBILE IPv6 WIRELESS SENSOR NETWORKS

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By

SAFWAN MAHMOOD YAHYA GHALEB

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

January 2019

DEDICATIONS

I would like to dedicate this thesis to :
my family who encourage me to study well in order to help the people.
My great father and mother for their patient, encourage and prayers for me.
my late Uncle "Ahmed" who support me in the beginning of my study till his death.
My late grandmother "Fatemah" who loved me unconditionally .
My great brother "Mukhtar" who always help me when I need.
My best cousin I ever met "Barraq" who always support me in my study.
This thesis is dedicated also to my lovely wife who always stand beside me with her help to achieve my live objectives.

To my brothers, my sisters and my wonderful kids (Ramez and Rami).
To my supervisor and entire committee.
To all my honest friends whom taught me to be brave and patient.
I would like to dedicate this thesis to my beloved motherland.
Finally, To All whom I love.
"=====".

&

To All whom I love.

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

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January 2019

Chairman: Shamala Subramaniam, PhD
Faculty: Computer Science and Information Technology

Internet of Thing (IoT) or also referred to as Internet Protocol (IP) enabled Wireless Sensor Network (IP-WSN) is a rich area of research. This is due to the rapid growth in a wide spectrum of critical application domains. However, the properties within these systems such as memory size, processing capacity and power supply has led to imposing constraints on IP-WSN applications and its deployment in the real world. Consequently, IP-WSNs is constantly faced with issues related to the complexity which arises due to IP mobility management. IP mobility management protocols, which have evolved from host-based to network-based protocols, are utilized as a mechanism to resolve these issues. The presence of both types of solutions is dominant but depended on the nature of systems being deployed. Features of IoT are inclined more towards the network-based solutions due to the objective of reducing involvement of the Mobile Node(MN) especially in the mobility signaling. The wide spectrum of strategies derived to achieve enhanced performance evidently displays superiority in performance.

Proxy Mobile IPv6 (PMIPv6) and its derivation protocols are designed to achieve a seamless handover when the MN moves among two different networks by transferring the mobility management responsibility to new mobility entities, named the Local Mobility Anchor (LMA) and Mobile Access Gateway (MAG). However, PMIPv6 heavily relies upon manipulating the MNs that are associated to a specific MAG individually. In addition, the PMIPv6 protocol lacks the support

of efficient buffer resource utilization mechanisms. Such mechanism does not appear to be enough to solve the issue of latency of the mobility-related signaling during the MNs motion,thus, resulting in increasing the MAG load probability, inevitable packet loss, session disruption and negative effect on the MN's communication performance.

Accordingly, the goal of this research is to improve the efficiency of MNs and hence the overall system performance via addressing the latency issue. Associating the MNs to a specific MAG inside the PMIPv6 network and ignoring the multi-level domain increase the MAG load probability. Thus, designing an efficient load balancing mechanism on the Clustered PMIPv6 (LB-CSPMIPv6) to balance the loads equally between the MAGs within the PMIPv6 domain is necessary. Hence, by means of load distribution among the MAGs, this mechanism is able to avoid the overloaded issue among the MAGs by utilizing the load status of the MAGs, the domain number and the strength signaling. The LB-CSPMIPv6 mechanism has been proven to improve the system performance latency by reducing the queuing delay when compared with the previous works.

In addition, the mobility-related signaling is processed individually for each MN that enters the PMIPv6 domain. Thus, if the MNs come simultaneously or moving in a group, the PMIPv6 still have to process them separately one after another, which causes serious issues such as long handover latency and high singling cost. Hence, the MN's session might be affected negatively. Accordingly, this work proposes a new scheme named, an Enhanced Cluster-based PMIPv6 protocol (E-CSPMIPv6), which combines the mobility-related messages in one message for a group of MNs instead of performing it individually. This Scheme achieves a better performance in terms of handover latency and signaling cost compared with to the base work.

Furthermore, to achieve an effecting buffer utilization, we propose an Enhanced PMIPv6 (AE-PMIPv6) scheme. AE-PMIPv6 manages the MNs information in one Binding Cash Entry (BCE) instead of creating a BCE for every MN inside the PMIPv6 domain. The AE-PMIPv6 efficiently addresses the memory occupation inside the PMIPv6 domain, which leads to improve the overall system performance. Hence, by means of the proactive load MAGs status with the respective LMAs in the LB-CSPMIPv6, manipulating a group of MNs simultaneously and efficiently utilizing the buffer resources in the PMIPv6 domain respectively, these schemes are able to balance the load among the MAGs, provide a seamless handover and utilize the MNs binding information as well as enhancing the perceived quality of communication during the MN roaming. The superiority of this scheme has been achieved in terms of buffering cost compared to the counterpart works.

Extensive simulation experiments and analytical analysis models through the Network Simulator (NS2) have been developed and performed with respect to various PMIPv6 wireless network environments and scenarios. The simulation

results demonstrate that the proposed schemes significantly increase the overall system performance. This enhancement satisfies the mobile users Quality of Service (QoS) requirements in terms of handover latency, buffer cost, signaling cost, queuing delay and load balancing.

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

SKIM PENGURUSAN MOBILITI UNTUK RANGKAIAN PENDERIA WAYARLES IPv6 MUDAH ALIH PROKSI

Oleh

SAFWAN MAHMOOD YAHYA GHALEB

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Pengerusi: Shamala Subramaniam , PhD
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Internet Benda (IoT) atau juga dikenali sebagai Rangkaian Penderia Wayarles (IP-WSN) dilengkapi Protokol Internet (IP) adalah suatu bidang penyelidikan yang kaya. Ini disebabkan oleh pertumbuhan yang pesat dalam spektrum yang luas dalam domain aplikasi kritikal. Walau bagaimanapun, sifat-sifat dalam sistem ini seperti saiz ingatan, kapasiti pemprosesan dan bekalan kuasa telah menyebabkan kekangan terhadap aplikasi IP-WSN dan penggunaannya di dunia nyata. Akibatnya, IP-WSN sentiasa menghadapi masalah yang berkaitan dengan kerumitan yang timbul disebabkan oleh mobiliti pengurusan IP. Protokol pengurusan mobiliti IP yang telah berkembang dari suatu protokol yang berasaskan hos kepada berasaskan rangkaian, telah digunakan sebagai mekanisma untuk menyelesaikan masalah ini. Kehadiran kedua-dua jenis penyelesaian adalah dominan tetapi bergantung kepada jenis sistem yang digunakan. Ciri-ciri IoT yang lebih cenderung ke arah penyelesaian berasaskan rangkaian kerana ianya bermatlamat untuk mengurangkan penglibatan Nod Mudah Alih (MN) dalam isyarat yang berkaitan dengan pergerakan. Spektrum strategi yang luas yang diperoleh untuk mencapai prestasi yang dipertingkatkan dengan jelas memaparkan keunggulan prestasi.

Proksi Mudah Alih IPv6 (PMIPv6) dan protokol derivasinya direka untuk mencapai penyerahan lancar apabila MN bergerak di antara dua rangkaian yang berbeza dengan memindahkan tanggungjawab mobiliti pengurusan kepada entiti

mobiliti baru yang bernama Mobiliti Sauh Tempatan (LMA) dan Gerbang Laluan Mobiliti (MAG). Walau bagaimanapun, PMIPv6 sangat bergantung kepada memanipulasi MN yang dikaitkan dengan MAG tertentu secara individu. Di samping itu, protokol PMIPv6 tidak mempunyai sokongan mekanisme penggunaan sumber buffer yang cekap. Mekanisme sedemikian tidak nampak cukup untuk menyelesaikan masalah latensi isyarat berkaitan pergerakan semasa pergerakan MN, oleh itu, mengakibatkan peningkatan kemungkinan beban MAG, kehilangan paket yang tidak dapat dielakkan, gangguan sesi dan kesan negatif terhadap prestasi komunikasi MN.

Sewajarnya, matlamat penyelidikan ini adalah untuk meningkatkan kecekapan MN dan oleh itu prestasi sistem keseluruhan melalui menangani masalah latency. Bersekutu MN ke MAG tertentu di dalam rangkaian PMIPv6 dan mengabaikan domain pelbagai peringkat meningkatkan kemungkinan beban MAG. Oleh itu, mereka bentuk mekanisme mengimbangi beban yang cekap pada PMIPv6 Cluster (LB-CSPMIPv6) untuk mengimbangi beban sama antara MAGs dalam domain PMIPv6 adalah perlu. Oleh itu, dengan cara pengedaran beban di kalangan MAGs, mekanisme ini dapat mengelakkan isu kelebihan di kalangan MAGs dengan menggunakan status beban MAGs, nombor domain dan isyarat kekuatan. Mekanisme LB-CSPMIPv6 telah terbukti dapat meningkatkan latency kinerja sistem dengan mengurangkan kelewatan beratur bila dibandingkan dengan kerja sebelumnya.

Sebagai tambahan, isyarat berkaitan pergerakan yang diproses secara individu untuk setiap MN yang memasuki domain PMIPv6. Oleh itu, jika MNs datang serentak atau bergerak dalam kumpulan, PMIPv6 masih perlu memprosesnya secara berasingan satu demi satu, yang menyebabkan isu-isu yang serius seperti latensi penyerahan panjang dan kos yang tinggi. Oleh itu, sesi MN mungkin terjejas secara negatif. Oleh itu, kerja ini mencadangkan skim baru yang dinamakan, protokol PMIPv6 yang berasaskan Cluster Enhanced (E-CSPMIPv6), yang menggabungkan mesej yang berkaitan dengan mobiliti dalam satu mesej untuk sekumpulan MN dan bukannya melaksanakannya secara individu. Skim ini mencapai prestasi yang lebih baik dari segi latensi penyerahan dan kos isyarat berbanding dengan kerja asas.

Tambahan pula, untuk mencapai penggunaan penampan yang berkesan, kami mencadangkan skim PMIPv6 (AE-PMIPv6) yang Diperkaya. AE-PMIPv6 menguruskan maklumat MN dalam satu Kemasukan Tunai Mengikat (BCE) dan bukannya membuat BCE untuk setiap MN di dalam domain PMIPv6. AE-PMIPv6 cekap menangani pekerjaan memori di dalam domain PMIPv6, yang membawa kepada peningkatan prestasi keseluruhan sistem. Oleh itu, dengan menggunakan status MAG aktif beban dengan LMAs masing-masing di LB-CSPMIPv6, memanipulasi sekumpulan MNs secara serentak dan dengan cekap menggunakan sumber penampan di domain PMIPv6 masing-masing, skim ini dapat mengimbangi beban antara MAGs, menyediakan penyerahan lancar dan menggunakan maklumat pengikatan MN serta meningkatkan kualiti komunikasi semasa perayauan MN. kelebihan skim ini telah dicapai dari segi kos penimpanlan berbanding dengan kerja rakan sejawat.

Eksperimen simulasi meluas dan model analisis analitik melalui Simulator Rangkaian (NS2) telah dibangunkan dan dilaksanakan dengan mengambilkira pelbagai persekitaran rangkaian PMIPv6 dan senario. Hasil simulasi menunjukkan bahawa skim yang dicadangkan dapat meningkatkan prestasi keseluruhan sistem. Peningkatan ini memenuhi pengguna mudah alih keperluan Kualiti Perkhidmatan (QoS) yang ketat dari segi latensi penyerahan, kos penampan, kos isyarat, kelewatan beratur dan pengimbangan beban.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy.

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CHAPTER 1

INTRODUCTION

1.1 Background

Internet of Thing (IoT) paradigm is indeed an interesting research which is set in order to enable the unconnected objects (e.g., devices, vehicles and fridges) to be connected with each other via the Internet with or without human interventions.IP-enabled Wireless Sensor Network (IP-WSN) is among the most essential elements in enabling the IoT (Jang et al., 2017; Kwon et al., 2012). This is achieved because the IoT devices requires a global address in order to be reachable. The IP-WSN can fulfill this requirement by enabling the sensor to get an address from IPv6. However, sensor mobility arises as among the serious issues, especially with regards power constraints and the low processing resources of sensors.

To address these issues various mobility management protocols for IP-WSN have been proposed with consideration of low cost communication with dedicated resources. The IP management protocols, which have been introduced to support mobility have evolved from host-based to network-based mobility management protocols (Jabir et al., 2012). In the host-based protocols, the Mobile Node (MN) is involved with the mobility-related signaling, while network-based protocols shield the MN from the responsibility by transferring the mobility-related signaling to the network entities. This is means that the mobility is performed by the layer 3 (network layer) in the proxy entities with slight cooperation from layer 2 (link layer). Thus, the mobility is performed generally by layer 3 regardless the under-layer interaction. IP-WSN nodes are capable of achieving mobility due to their shrinking size and enhanced portability. This goal is accomplished through coupling the WSN nodes with mobility entities such as phone, people or vehicles. Thus, in the wireless network mobility is an important feature. Consequently, designing an efficient and effective mobility management protocol becomes very essential in order to satisfy the mobile users (best possible delivered service).

1.1.1 Mobility Management Protocols

To provide IP mobility management, the Internet Engineering Task Force (IETF) has released several protocols such as the Mobile Internet Protocol version 4 (MIPv4) (Perkins, 2002), the Mobile Internet Protocol version 6 (MIPv6) (Johnson and Arkko, 2004), Network Mobility Basic Support (NEMO-BS) approach (Devarapalli and Thubert, 2005), Hierarchal MIPv6 Protocol (HMIPv6) (Soliman and Bellier, 2005), -Fast Handoff scheme in Proxy Mobile IPv6 Networks (FH-MIPv6) (Chuang and Lee, 2011) and Fast MIPv6 Protocol (FMIPv6) (Koodli, 2009). However, all these protocols demand the MN to be involved in the mobility signaling, which is not an efficient option for the IoT domain applications.

To address the issue related the host-based protocols, a protocol was been released by IETF, named Proxy MIPv6 (PMIPv6) (Gundavelli and Patil, 2008). Two new entities are added in this solution, which are the Local Mobility Anchor (LMA) and the Mobile Access Gateway (MAG) to enable the MN mobility during the MN handoff. The LMA takes the responsibility of maintaining the MN reachability while it moves between sub-networks in the local PMIPv6 domain. The MAG takes the responsibility of the mobility management instead of MN having to manage it.

An significant feature of the PMIPv6 is the detecting the MN movement and the initiation of required mobility-related messages by using the network entities instead of MN during the handoff process. Researchers have been motivated to use the PMIPv6 instead of the host-based protocols. An example is the Sensor PMIPv6 protocol (SPMIPv6) (Islam and Huh, 2011), cluster based PMIPv6 for wireless mesh networks (Nguyen and Bonnet, 2008) and the Cluster Sensor PMIPv6 protocol (CSPMIPv6) (Jabir et al., 2012), which employ clustering techniques to reduce the handover latency. Their architectures suffer from existing problems in PMIPv6 due to the ignorance towards the load balancing issues and the MNs movement manner in a group. Thus, methods to decrease the queuing delay and the signaling cost by considering an efficient load balancing, fast handoff and buffering utilization is necessary and essential for IoT, which addressed by this research. The next discused the detail of the cluster based Proxy Mobile IPv6.

1.1.2 Cluster-based Proxy Mobile IPv6

The research work in Jabir et al. (2012) has addressed the issues related to the architecture of the SPMIPv6 protocol (Islam and Huh, 2011) by introducing an enhanced architecture, named CSPMIPv6 protocol. This is done by strategically dividing the PMIPv6 domain into sub-local networks, as shown in Figure 1.1. The main objective of this work is to reduce the LMA load. This is achieved by clustering the MAGs into several clusters and each cluster is managed by the cluster head MAG within the CSPMIPv6 domain. In addition to the existing PMIPv6 entities, a new entity is added by the CSPMIPv6, named the Head MAG (HMAG), which is responsible for performing the intra-domain mobility without the LMA interventions. Furthermore, the Authentication Authentication Authorization and Accounting (AAA) server functions are integrated with HMAGs functions in order to reduce the signaling cost for the MN registration. The HMAGs also reduces the handoff latency and provides a route-optimized path for the handoff MN during the intra-communication mobility. However, in this research, several limitations in this protocol. This protocol constraints in terms of load balancing, handoff latency and resource buffering. This is caused by the features of this protocol that does not take into account the load balancing between the MAGs within its new structure, the MNs grouping during its handover process and the insufficient buffer resource utilization which is created by the Binding Cache Entry (BCE) for each connected MN.

In Chapter 2, several studies, which have improved the performance of the PMIPv6 in terms of load balancing (Koodli, 2009; Mun-Suk and SuKyoung, 2010; Kim and Lee, 2010, 2009; Kong et al., 2010a; Dimple and Kailash, 2013) handover latency (Nguyen and Bonnet, 2008; Jabir et al., 2012; Islam and Huh,

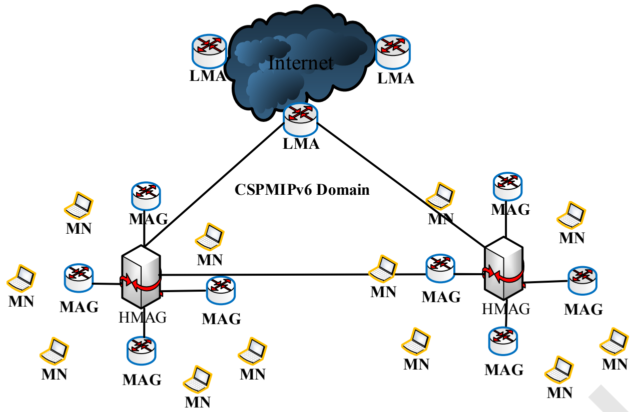

Figure 1.1: CSPMIPv6 System Architecture Jabir et al. (2012)

2011; Chiang et al., 2015) and resource utilization (Bi et al., 2016), have been extensively analyzed. However, these research either suffer from the same issues related to the CSPMIPv6 protocol or have limitations with regards to the efficiency of the algorithm.

1.2 Research Motivation

The main purpose of this research is to provide a seamless handover process within the clustered PMIPv6 domain. The handover process is the movement of MN from an old network to a new network within the PMIPv6 domain. The PMIPv6 and its derivation protocols provide an insufficient seamless mobility management. This is due to the extensive signaling messages, insufficient buffering and high queuing delay which effects the IoT devices' requirements. These research have motivated this study on the effect of load balancing in the clustered PMIPv6, clustering MNs as well as grouping the MNs binding information in order to reduce the signaling cost and handover delay. Previous works have either not considered the multi-domain during their load balancing, which increases the queuing delay or have not considered the MNs travel in a group that leads to the extensive singling messages(Kim and Lee, 2010; Chiang et al., 2015). Moreover, the LMA buffering has also not been utilized efficiently, which may cause serious issues(Bi et al., 2016).

1.3 Problem Statements

The usage of the Internet video and real time applications continues to grow at a rapid pace especially in mobile environment. The performance of the wireless connectivity is affected by the emergence of such services. Thus, providing seamless handover in order to increase the MN performance becomes a very challenging issue. The standard PMIPv6 protocol is originally designed to maintain the connectivity of MN continue even when the MN moves to another network without much disruption. However, this protocol still experiences long handover latency, high signaling cost, high queuing delay, end-to-end delay and insufficient buffer utilization. Therefore, reducing these metrics will definitely lead to provide efficient handover management during change the MN point of its attachment without noticeable service disruption.

The problem statements of this research are as follow:

- In the clustered PMIPv6 protocol, the MAG acts as a gateway between the MNs and the cluster head HMAG inside the PMIPv6 domain. Therefore, the MAG performs mobility-related signaling instead of the MNs. Hence, all the MNs connect to a particular MAG within the PMIPv6 domain which leads to an overload of the MAG. The previous load balancing solutions have been designed without considering the new hierarchal structure of the clustered PMIPv6 protocol. Thus, the MNs may move to the MAG that has the least load but which belongs to another cluster. This causes serious issues. This includes, when moving the MN to another cluster an increase in the number of messages needed to update the MN's location and requires the LMA to be involved extensively. Subsequently, leading to add an additional bottleneck on the LMA.
- Existing mobility management protocols are not efficient in terms of handoff for each MN in an independent and a separate manner. This is due to the requirement of the mobility-related signaling to be performed for every MN that enters the PMIPv6 domain. Performing mobility for each MN separately in this solution when they when they arrive simultaneously or moved in a group increases the signaling, consumes high bandwidth as well as increases the handoff delay. That means, when the MNs change their point of attachment to another MAG, the MAG, upon receiving the Router solicitation messages sent by the MNs, must exchange a Proxy Binding Update (PBU) message with the related LMA for every MN. Then, the LMA updates its BCE and sends a Proxy Binding Acknowledgment (PBA) for every MN. This process consumes time and effort which defiantly degrades the overall system performance
- The LMA in PMIPv6 maintains a BCE for every MN to track the MN movement. Although most of the current group mobility management performs a handoff process for the entire network. However, these solutions still have to create a record for every attached MN in the network. Hence, consuming the buffer resources at the MAG and LMA, which subsequently degrades the overall system performance. This degradation happens especially when the LMA serves tens of thousands of MNs, which requires the LMA to manage their information, location and their respective communication. Therefor, consuming full buffer which will not serve more MNs or at the least will cause a delay to their connection during the search for the MNs information or during serving the incoming packets .

1.4 Research Objectives

The main objective of this research is to develop a network-based mobility management protocol that provides the key requirements of an efficient mobility support. This research aims to achieve balance of loads, minimize the handoff latency and ensure efficiently utilization of the resource buffering. Below are the details of the research objectives:

- To propose and develop a load balancing scheme, named Load balancing of Clustered PMIPv6 (LB-CSPMIPv6) scheme, to mitigate the loads among the MAGs for cluster-based PMIPv6 protocols. The proposed scheme selects the optimal network for the MN handoff through detail consideration of the load balancing status, the domain number an in specialization to the clustered PMIPv6.
- To improve the performance of the clustered PMIPv6 protocol by proposing and developing an enhanced scheme to provide a seamless and fast handoff for the MNs that move in a group, which shall be known an Enhanced CSPMIPv6 (E-CSPMIPv6) scheme. The proposed scheme clusters the MNs that move closely to each other or the MNs that trigger their handover process at the same time within the same network to register them simultaneously.
- To develop and propose an enhance mobility management scheme focusing on the reduction of buffering cost. This is performed by developing a low cost buffering scheme by applying a virtual addresses mechanism and is named an Efficient PMIPv6 (AE-PMIPv6) scheme. The scheme is aimed at reducing the buffer cost at MAG and LMA. The proposed scheme is built on an efficient proxy mobile IPv6 (E-PMIPv6) scheme to take the advantage of group mobility based on the PMIPv6 principles to provide low buffering cost and handover latency. To ensure low buffering cost even when there is no Mobile Router (MR) in the network, the proposed scheme is designated to be able to group the binding information of MNs handoff by using a virtual addresses mechanism. In order to eliminate the IP acquisition time, pool addressing is used in the proposed scheme to reduce the handover latency and the signaling cost.

1.5 Research Scope

This research focuses on providing substantial support for load balancing within the clustered PMIPv6 protocol to evenly distribute the loads among the MAGs. Grouping the MNs to reduce the handover latency during the handoff process in the clustered PMIPv6 protocol is the second element within the scope and the utilization of the buffering resource in an efficient way within the PMIPv6 domain to enhance the mobility management.

1.6 Thesis Organization

This thesis consists of seven chapters. **Chapter** 2 discusses in detail the IP integration with WSN empowering the IoT. Moreover, a detailed review is made on the mobility management protocols (i.e. host-based and network-based). In addition, detail discussion on the load balancing and the fast handoff mechanisms used in the existing mobility management solutions, and their respective advantages and disadvantages. Finally, the chapter concludes with an in depth discussion on the open issues. **Chapter** 3 discusses the methodology of the research, which encompasses the performance analysis, simulation model, the overall system framework and the network topology. In addition, the parameters setting and the metrics used for evaluating the system performance are deliberated in detail. **Chapter** 4 introduces and explains in detail the proposed Load Balancing Mechanism for Clustered PMIPv6 Domain (LB-CPMIPv6). Discussion on the previous works limitation with reference to load balancing is done and subsequently present the ability of the proposed scheme to solve these issues to increase the overall system performance is done. **Chapter** 5 deliberates in detail the proposed Enhanced CSPMIPv6 (E-CSPMIPv6) scheme. The chapter begins by presenting the issues related to the handoff procedure and concludes with the analysis and simulation results. **Chapter** 6 presents the proposed scheme: (AE-PMIPv6). Detail explanation on the incapability of the E-PMIPv6 scheme to utilize the buffering efficiently and next the ability of the AE-PMIPv6 scheme to reduce the buffering cost when the mobile routers are not a part of the network. **Chapter** 7 concludes the thesis and suggests some promising directions for the future work.

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