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MOBILITY SCHEMES IN CLUSTERED PROXY MOBILE IPV6

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By

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MOBILITY SCHEMES IN CLUSTERED PROXY MOBILE IPV6

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IP-based Wireless Sensor Networks (IP-WSNs) provide a tremendous potential to improve the capabilities of many systems, for instance, healthcare, home automation, environmental monitoring, industrial control, agricultural monitoring, and motivating the rise of the Internet of Things (IoT) paradigm where different devices are connected to the Internet with no or minimal human involvement.

Mobility management protocols are very essential in the new research area of IoT. This is mainly due to the static attributes of nodes are no longer dominant in the current and emerging applications. It should provide users with full access to information irrespective to their locations while preserving the sensor nodes energy and system reliability.

Sensor Proxy Mobile IPv6 (SPMIPv6), which is an adaptation of the network based basic PMIPv6 protocol, was designed for IP-WSNs mobility management to save sensors energy consumption by relying the mobility process on the network entities, named Local Mobility Anchor (LMA) and Mobility Access Gateways (MAGs), to relieve the sensor nodes from participating in the handoff process. However, SPMIPv6 inherited most of the problems observed in PMIPv6 protocol, including long handoff latency because all the binding update messages are processed by LMA, non-optimized communication path because all data packets are obligated to pass through LMA, the lack of buffering scheme that is important to reduce the packet loss during handoff, and bottleneck issues in the LMA. Previous work enhanced the PMIPv6 performance in many directions by applying fast handoff and route optimization mechanisms. However, previous schemes are either proposed multiple LMA domains, built on the host based principles which involves the MNs in the mobility process, or it incurs a high signaling cost due to the requirement for exchanging extra control messages and rely the mobility process on the far LMA.

The goals of this thesis are: firstly, to develop an enhanced architecture for SPMIPv6 called Clustered PMIPv6 (CPMIPv6) to overcome the problems in the

existing solutions. In the proposed architecture, the MAGs are grouped into clusters, each with a distinguished cluster head MAG (HMAG). The HMAG is mainly introduced to reduce the load on LMA by performing intra-cluster handoff signaling and providing an optimized path for data communications. Secondly, to develop a new fast handoff scheme based on the CPMIPv6, in which, the HMAGs carry out the intra-cluster handoff to reduce both the handoff signaling, packet loss ratio and the buffered packets delay. Thirdly, to develop a new route optimization scheme for the CPMIPv6, in which, the HMAGs are utilized to reduce the handoff latency while achieving a fast recovery of the optimized path after handoff.

Thorough analytical models and simulations using the Network Simulator (NS2) are developed and used for evaluating the performance of the proposed schemes compared with standard PMIPv6, SPMIPv6, state-of-the-art fast handoff and route optimization schemes. The numerical and simulation results show that the proposed model and schemes enhanced the overall performance by reducing of the load on LMA through relying the intra-cluster operations on the HMAGs, shortening the transmission path by excluding the LMA from participating in the intra-domain transmission process, reducing the handoff latency, and hence reducing the buffered packets delay. However, in some circumstances when MNs generate a high inter-cluster mobility or inter-domain communications, the protocol performance is degraded and the PMIPv6 problems are emerged again.

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

PENETAPAN SKIM MOBILITI DALAM KELOMPOK PROKSI MUDAH ALIH IPV6

Oleh

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Rangkaian Sensor Tanpa Wayar berasaskan IP (IP-WSNs) mempunyai potensi yang besar dalam peningkatan keupayaan pelbagai sistem, misalnya, penjagaan kesihatan, automasi rumah, pemantauan alam sekitar, kawalan industri, pemantauan pertanian, serta mendorong paradigma Internet Perkara (IoT) yang mana pelbagai peranti akan disambungkan ke Internet, secara minimalnya atau tanpa penglibatan manusia.

Protokol pengurusan mobiliti amat penting dalam bidang penyelidikan IoT. Ini disebabkan oleh sifat-sifat statik nod tidak lagi menjadi dominan dalam aplikasi semasa. Ia harus menyediakan akses penuh kepada maklumat tanpa mengira lokasi pengguna, di samping itu, mengekalkan tenaga nod sensor dan kebolehpercayaan sistem.

Sensor Proksi Mudah Alih IPv6 (SPMIPv6), yang merupakan pelarasan rangkaian berasaskan protokol asas PMIPv6, direka untuk pengurusan mobiliti IP-WSNs bagi menjimatkan penggunaan tenaga sensor, dan bergantung kepada proses mobiliti entiti rangkaian yang bernama Mobiliti Sauh Tempatan (LMA) dan Gerbang Laluan Mobiliti (MAGs), untuk melegakan nod sensor daripada proses pemindahan data itu. Walau bagaimanapun, SPMIPv6 mewarisi kebanyakan masalah yang terdapat dalam protokol PMIPv6, termasuk masa pemindahan data yang lama kerana semua pengemaskinian mesej diproses oleh LMA, laluan komunikasi tidak optimum kerana semua paket data wajib melalui LMA, kekurangan skim penampan bagi mengurangkan kehilangan paket semasa pemindahan data, dan isu-isu leher botol dalam LMA. Kerja dahulu meningkatkan prestasi PMIPv6 dalam pelbagai bidang dengan menggunakan mekanisme pemindahan data laju dan laluan optimum. Walau bagaimanapun, skim-skim dahulu sama ada mencadangkan beberapa bidang utama LMA berkaitan dengan prinsip-prinsip utama berasaskan MN dalam proses mobiliti, ataupun memerlukan kos isyarat yang

tinggi kerana perlu menukar mesej kawalan tambahan dan bergantung pada proses mobiliti LMA yang lama.
Matlamat projek ini adalah: Pertamanya, bagi membentuk kemajuan seni bina dalam SPMIPv6 yang bernama Kelompok PMIPv6 (CPMIPv6) untuk mengatasi masalah yang terdapat dalam mekanisme yang sedia ada. Dalam cadangan seni bina tersebut, MAGs dibahagikan ke dalam kelompok-kelompok, semuanya mempunyai Ketua MAG kelompok cemerlang (HMAG). HMAG direka bagi mengurangkan beban LMA melalui pemindahan isyarat intra-kelompok dan menyediakan laluan optimum komunikasi data. Keduanya, bagi membentuk satu skim baru pemindahan data laju berdasarkan CPMIPv6, di mana, HMAGs melakukan pemindahan data intra-kelompok supaya mengurangkan isyarat pemindahan, nisbah kehilangan paket dan kelambatan paket penampan. Ketiganya, bagi membangunkan satu skim laluan optimum baru untuk CPMIPv6, di mana, proses pengoptimuman laluan bergantung kepada HMAGs supaya mengurangkan kelewatan pemindahan data sambil mencapai pemulihan yang laju daripada laluan yang dioptimumkan selepas pemindahan data.

Model analisis dan simulasi yang menggunakan Penyalinan Rangkaian (Ns2) dibentuk dan digunakan dalam penilaian prestasi skim yang dicadangkan, telah dibandingkan dengan piawai PMIPv6, SPMIPv6, skim pemindahan data laju dan laluan optimum. Keputusan menunjukkan bahawa model dan skim yang dicadangkan menunjukkan peningkatan prestasi LMA dengan bergantung kepada intra-kelompok HMAGs, pemendekan laluan pemindahan data tanpa melibatkan LMA dalam proses antara domain, pengurangan kelewatan pemindahan data, dan pengurangan kelambatan paket penampan. Walau bagaimanapun, dalam keadaan tertentu, apabila MN menjana mobiliti antara kelompok atau antara domain komunikasi yang tinggi, prestasinya akan menurun dan masalah PMIPv6 timbul sekali lagi.

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I certify that a Thesis Examination Committee has met on 23-4-2015 to conduct the final examination of Adnan Jumaa Jabir on his thesis entitled “Mobility Schemes in Clustered Proxy Mobile IPv6” in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

AAA	Authentication, Authorization and Accounting
AP	Access Point
AR	Access Router
BCE	Binding Cache Entry
BLT	Buffer Life Time
BU	Binding Update
BULE	Binding Update List Entry
CBA	Correspondent Binding Acknowledgement
CBU	Correspondent Binding Update
CH	Cluster Head
CN	Corresponding Node
CoA	Care of Address
CPMIPv6	Clustered PMIPv6
DAD	Duplicate Address Detection
FBA	Fast Binding Acknowledgment
FBU	Fast Binding Update
FFD	Fully Function Device
FMIPv6	Fast MIPv6
RF	Forwarding Request
GW	Gateway
HA	Home Agent
HM	Handoff Imminent
HMAG	Head MAG
HMIPv6	Hierarchical MIPv6
HNP	Home Network Prefix
HoA	Home of Address
IA	Intermediate Anchors
IETF	Internet Engineering Task Force
IoT	Internet of Things
IP	Internet Protocol
IPv6	Internet Protocol version 6
LGD	Link Going Down
LMA	Local Mobility Anchor
LMAA	LMA Address
LoWPAN	Low Power over Personal Area Network
LPBA	Local PBA
LPBU	Local PBU
LRA	Localized Routing Acknowledgment
LRI	Localized Routing Initiation
MAG	Mobile Access Gateway
MAP	Mobile Anchor Point
MIH	Media Independent Handover
MIPv6	Mobile IPv6
MN	Mobile Node
MN-ID	MN Identifier
MNN	Mobile Network Node
MNP	Mobile Network Prefix
MR	Mobile Router

NAM	Network Animation
ND	Neighbor Discovery
NEMO	Network Mobility
NIST	National Institute of Standards and Technology
NS2	Network Simulator 2
PAN	Personal Area Network
PBA	Proxy Binding Acknowledgment
PBQ	Proxy Binding Query
PBU	Proxy Binding Update
PCoA	Proxy CoA
PMIPv6	Proxy MIPv6
PQA	Proxy Query Acknowledgment
RA	Router Advertizing
RFD	Reduced Function Device
RO	Route Optimization
ROT	RO Trigger
RS	Router Solicitation
RSS	Received Signal Strength
SLMA	Sensor LMA
SMAG	Sensor MAG
SNEMO	Sensor NEMO
SPMIPv6	Sensor PMIPv6
SMR	Session-to-Mobility Ratio
TCL	Tool Command Language
WSN	Wireless Sensor Network

CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, the Internet of Things (IoT) is getting much attention by industry and academia due to its new trend of connecting different types of devices to the Internet without human intervention (Jamali et al., 2014). Wireless Sensor Network (WSN) is considered as the core of IoT which uses sensing technologies for communication and nodes cooperate together to achieve their objectives (Jamali et al., 2014). IoT will provide a wide range of smart applications and services like remote healthcare monitoring, intelligent transportation, smart environment, home automation, military and agriculture domains (Bojkovic et al., 2013, Li et al., 2013, Zhou and Zhang, 2013, Jamali et al., 2014). WSNs consist of a large number of tiny devices which are characterized by low bandwidth, power, cost, processing, and memory. WSNs nodes sense and collect information from their immediate environment and transmit the collected data hop-by-hop through the network to the sink node, the point where these data are analyzed (Akyildiz et al., 2002).

With the advent of IoT and ubiquitous computing, the need has emerged to design protocols for connecting WSN to Internet. Such a mapping or correlation posses the power to create a paradigm shift in the way networks operates. Tailoring these to the low capabilities sensor nodes has given a great advance in WSNs applications. Since Internet is the most widespread network, connecting WSN to it in order to disseminate the sensed data is essential for making the IoT into a reality (Rodrigues and Neves, 2010). Integrating Internet Protocol (IP) with WSN would indeed facilitate WSN to interconnect with other IP networks and to capitalize the existing Internet infrastructure and IP-applications to sensor networks (Zinonos and Vassiliou, 2010, Chen et al., 2013). In addition, mobility has also an important role in realizing IoT by achieving “anywhere, anytime” communication. However, the IP protocol does not natively support mobility because it is used as locators and identifiers at the same time. IP addresses locator role means how to reach a node using a specific address, while the identifier role means that IP addresses are used by upper layers to identify the end point of communication channels (Soto et al., 2010). Since mobility is an important feature in any wireless network, designing efficient mobility management protocols becomes very crucial to ensure best service for mobile users.

1.1.1 Mobility Management Protocols

Mobility management protocols are very essential in the new research area of IoT as the static attributes of nodes are no longer dominant in the current environment. It aims to track and locate Mobile Nodes (MNs) efficiently to provide the user with full access to information irrespective of their locations. The function of mobility management protocols is to separate the IP address identifier role from the locator one, such that, IP address must never change when it is used as an identifier, but it should be changed every time the MN moves to a new network when it is used as a locator (Soto et al., 2010).

Several mobility management protocols were presented by the standardization bodies like Internet Engineering Task Force (IETF). For example, Mobile IPv6 (MIPv6) (Johnson et al., 2004) protocol was standardized by the IETF to address the global mobility of MNs. MIPv6 enables communication session continuity for hosts while they are moving. However, it suffers from critical performance aspects such as handoff latency, packet loss, binding update latency, and signaling overhead (Kong et al., 2008). As a result, Hierarchical Mobile IPv6 (HMIPv6) (Soliman et al., 2005) and Fast Mobile IPv6 (FMIPv6) (Koodli, 2005) protocols are derived from MIPv6 in a hope to enhance its performance.

Host based mobility management protocols including MIPv6, FMIPv6, and HMIPv6, involve the MNs in the mobility process and generally introduce significant overhead on the MNs which should install complicated mobility protocols. In addition, in case where an MN has no capability to transmit the mobility related signaling, host-centric mobility management protocols will be no longer functional (Zhang, 2008). Therefore, methods for relieving MNs from participating in mobility process and reducing handoff latency, packet loss, and communication path are indeed essential for IoT (Bojkovic et al., 2013).

1.1.2 Proxy MIPv6 Protocol

Proxy Mobile IPv6 (PMIPv6) (Gundavelli et al., 2008) was standardized by IETF NETLMM working group as a network-based mobility management protocol to solve these problems associated to the host based protocols by relocating the mobility functions from MNs to the network components. As shown in Figure 1.1, PMIPv6 adds two functional entities which are the Mobile Access Gateway (MAG) and the Local Mobility Anchor (LMA). The LMA is responsible for maintaining the reachability to the MN address while it moves in the local PMIPv6 domain.

The MAG is responsible for detecting the MN movements and initiating the required authentication signals with the Authentication, Authorization and Accounting (AAA) server in order to register the MN with LMA. For the registration to be performed by MAG, it needs to know the MN's LMA address, MN's network prefix and the allowed address configuration modes. All these information are stored into AAA server in a centralized or distributed manner (Korhonen and Muhanna, 2008).

The salient feature of PMIPv6 is its network-based attribute, in which, the network detects the node mobility and initiates the required mobility signals, so that, it relieves the MN from participating in the handoff process. This feature allows MNs, which installed only the conventional IP protocol, to roam freely between wireless networks without any need for the installation of complicated mobility management protocols.

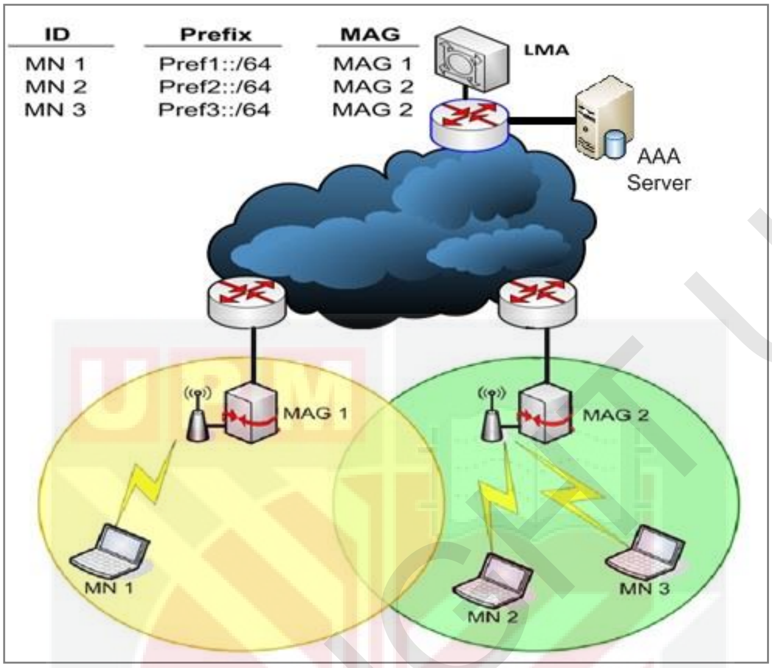

Figure 1.1: PMIPv6 Architecture

Considering both the network based feature of PMIPv6 and the low capabilities of WSN which makes the use of host based mobility protocols like MIPv6 insufficient; researchers are motivated to use PMIPv6 for managing the WSN mobility. For example, the SPMIPv6 (Islam and Huh, 2011) was proposed as an adaptation of PMIPv6 protocol, which fits with the WSN needs as it reduced signaling cost, mobility cost, and level of energy consumption. However, SPMIPv6 inherits most of the PMIPv6 downsides which are: in PMIPv6, the LMA is involved in all registration and handoff operations which leads to increase the handoff latency time. Also, PMIPv6 incurs a long data packet transmission time because all communication messages must pass through an LMA even though the communicating entities are located at the same network domain (Hwang et al., 2010a). In addition, this single central entity architecture leads to a single point of failure and the system becomes vulnerable to bottleneck problem. Moreover, an efficient buffering scheme during MN's handoff has not been considered, so that all packets that are sent during this handoff period are definitely lost (Heijenk et al., 2008).

In the literature, several research works were presented to enhance the PMIPv6 performance in terms of LMA load (Nguyen and Bonnet, 2008, Hwang et al., 2010a), handoff latency and packet loss (Hwang et al., 2010b, Yokota et al., 2010, Kwon et al., 2011, Mphatsi and Falowo, 2012, Berguiga and Youssef, 2013), and Route Optimization (RO) problem (Choi et al., 2009a, Boc et al., 2011, Liebsch et al., 2011, Guan et al., 2012). However, previous works are either proposed multiple LMA domains, built on the host based principles which involves the MN in the mobility process, or it incurs a high signaling cost due to the requirement for exchanging extra control messages and rely the mobility process on the far LMA.

1.1.3 Clustering

In computer network field, a cluster can be defined as a group of nodes located within close physical proximity and within range of each other. Each cluster encompasses one leader node called Cluster Head (CH) which is elected, either dynamically or statically, during the cluster formation. The CH has complete information about the cluster membership and is responsible for accomplishing all the data communication inside cluster. The idea behind network clustering is to perform all local data communication within the cluster, which is called intra-cluster communication. CHs can cooperate with each other to achieve the communication between clusters, which is called inter-cluster communication. Heading this way, the network top level base station is required only when the communication should go outside the network domain, which called inter-domain communication (Nguyen and Bonnet, 2008).

The cluster formation process normally leads to multi-level hierarchy architecture. As shown in Figure 1.2, base station forms the higher level and cluster nodes form the lower level, while CHs act as intermediate gateways between cluster members and the network base station. The CH election and cluster size can be determined either statically during the system installation or dynamically based on some factors like network size and load (Maimour et al., 2010). In this thesis, clusters are formed statically to make fixed and equal size clusters.

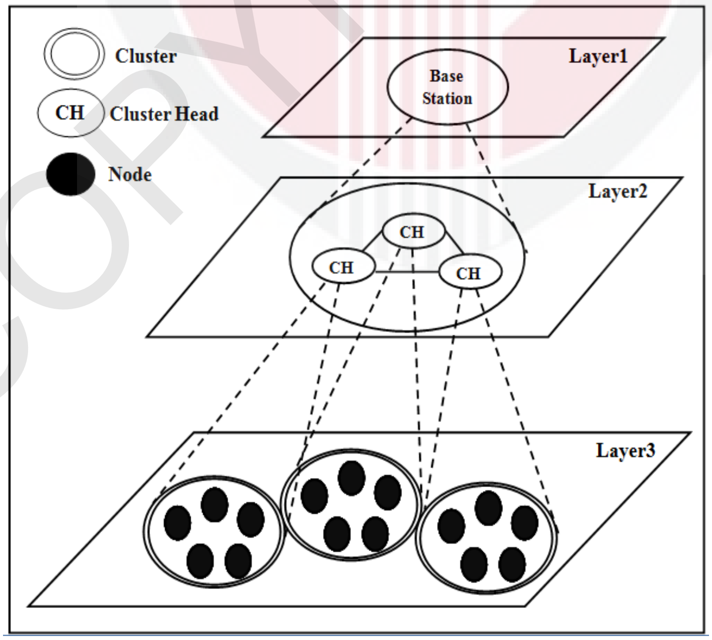

Figure 1.2: Network Clustering (Maimour et al., 2010)

1.2 Problem Statement

According to the discussion presented in the previous section, the following points show the shortcoming of PMIPv6 and its extensions which represent the thesis problem statement.

- In PMIPv6, the LMA maintains a Binding Cache Entry (BCE) for each MN to keep its binding information. Each MN is identified by its MN Identifier (MN-ID), Home of Address (HoA), and Care of Address (CoA). When the MN enters PMIPv6 domain, all these information are added to the BCE by exchanging the proxy binding messages between LMA and MAG. The HoA should not be changed while the MN moves inside PMIPv6 domain. On the other hand, the CoA should be changed when MN moves from one MAG to another. That means, LMA should update the BCE of MN each time it changes its point of attachment. In addition, involving LMA in both control and data packets transmissions, cause the LMA to be extensively accessed to update the BCE as MNs keep moving and to forward the incoming packets which eventually leads to a bottleneck in LMA.

- The current fast handoff schemes are not efficient as most of them were built on the host mobility principles which involve MNs in the mobility process. Hence, this requires the MN to install a complicated protocol stack (like MIPv6) and this contradicts with the PMIPv6 principles of relieving the MN from any participation in the mobility process. Also, fast handoff schemes are still incur a long handoff signaling cost due to the involvement of LMA in the handoff process. This long handoff leads to buffering overhead as the incoming packets should be buffered until the end of handoff process and this also leads to increase the end-to-end delay for the buffered packets because it cannot be forwarded before completing the handoff process. Moreover, fast handoff schemes may overload the network by multicasting the incoming packets to the old and new MAGs. The fast handoff schemes which are based on predicting the target MAG may fail due to the wrong prediction.

- The current route optimization schemes have either added extra signaling cost or they have not considered the case of recovering optimal route after MNs handoff. In addition, most of the proposed works involve the LMA in the handoff process which results in a long handoff latency leading to increase the time required for route optimization status recovery after handoff.

1.3 Research Motivation

Dividing network into a number of clusters can enhance the overall system scalability and reduce the load on upper network layer entities. This is attributed to the low number of control messages and data packets transmitted to upper layers as communications inside the cluster is controlled by CHs. In addition, clustering reduces the topology maintenance overhead as nodes are not affected by the change in the upper layers (Mamalis et al., 2009).

Considering both the advantages of clustering and the PMIPv6 limitation, redesigning PMIPv6 in a hierarchical fashion would indeed enhance the overall protocol performance. To avoid the bottleneck problem, the binding update messages required for MNs registration are to be exchanged locally within same cluster. If all handoff signaling go through LMA, a large number of hops will be required because the distance between MAGs and their cluster head is shorter than the path to LMA. In addition, cluster heads can reduce the handoff latency for MNs which are moving inside the same cluster and a buffering scheme can be implemented in the cluster head to reduce the buffered packets delay. Moreover, clustering can contribute in shortening the path between the communicating MNs by rely the local communications to cluster heads rather than to the far LMA. Implementing a route optimization scheme in the cluster heads contributes to reduce the time required for recovering the optimized path after handoff.

1.4 Research Objectives

This thesis is prepared to solve the problems related to the basic PMIPv6 protocol and its extensions by presenting schemes to reduce LMA load, handoff latency, buffered packets delay, and End-to-End delay. The detailed objectives are:

- To propose a new architecture named Clustered PMIPv6 (CPMIPv6) to overcome the PMIPv6 problems in terms of reducing LMA load, handoff latency and data packet transmission cost. The proposed architecture divides the LMA domain into a number sub-domains, each encompasses a group of MAGs formed as a cluster and controlled by a single Head MAG (HMAG).

- To enhance the performance of PMIPv6 by presenting a scheme to provide a fast and seamless handoff for the moving MNs, named Clustered Fast PMIPv6 (CFPMIPv6). The proposed scheme is to be built on the basis of CPMIPv6 to satisfy relieving MNs from handoff participation, low handoff latency, low network overload, low buffering overhead, and low end-to-end delay.

- To further enhance the performance of the PMIPv6 in terms of packet transmission cost by presenting a low cost route optimization scheme named Cluster Based RO (CBRO) to shorten the transmission path between the communicating MNs. The proposed scheme is to be build on the basis of CPMIPv6 to provide a low signaling cost RO for bidirectional sides of communication. To ensure the optimized path even when the communicating nodes are changing their point of attachment, it should be able to preserve the RO status for the communicating MNs after their handoff.

Figure 1.3 shows the linkage between the research objectives, where the proposed CPMIPv6 architecture adopts the basic PMIPv6 by applying the clustering principles. The proposed CFPMIPv6 is built on the bases of

CPMIPv6 to provide a buffering and fast handoff schemes. Similarly, the proposed CBRO is also built on the bases of CPMIPv6 to provide an RO scheme to shorten the communication path while quickly recovering the RO status after handoff.

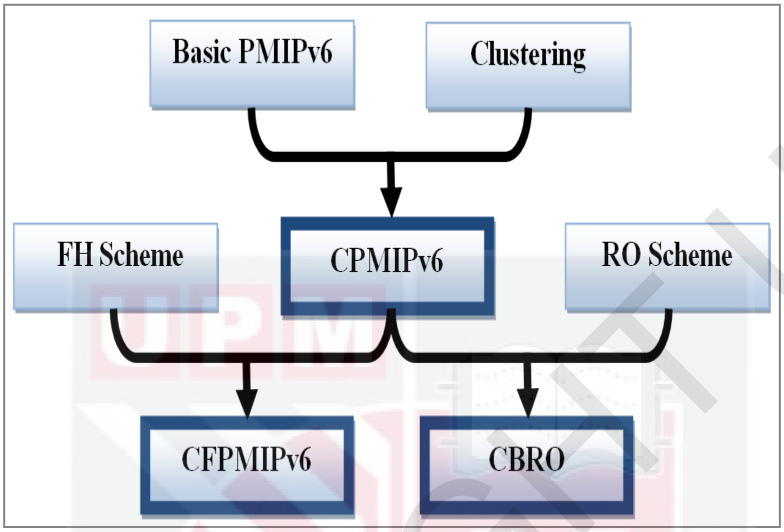

Figure 1.3: Research Objectives Linkage

1.5 Research Scope

This research concentrates on mitigating the load on LMA, which is the central entity of the basic PMIPv6 standard RFC 5231 (Gundavelli et al., 2008), that all the control signaling and communications are relied on, and to reduce the mobility and transmission costs. More focus is given on the problem of packet loss during handoff due to the absence of an efficient buffering scheme discussed by Yakota et al. (2010) in FPMIPv6 RFC 5949. The buffering scheme is required to save the incoming packets until the end of MN's handoff. Since the buffer size and buffered packets delay are proportional to handoff latency, attention is given to reduce the handoff latency. The communication path is another key enhancement in the PMIPv6 presented by Liebsch et al. (2011) as RFC 6279. This research focuses on reducing the communication path by excluding LMA from such path and to keep the optimized path active after handoff using a low signaling cost.

1.6 Organization of the Thesis

This thesis is organized into seven chapters. **Chapter 2** presents a detailed review on the mobility management protocols, namely, the host based and network based protocols. The methods currently used for connecting WSN to the Internet are then analyzed along with the research works devoted to manage the IP-WSN mobility. In addition, the demerits of the PMIPv6 are presented along with the current researches that attempt to solve the bottleneck problem, long handoff latency, the high packet loss ratio, and the long communication path problems. **Chapter 3** provides the methodology of the research with the required mathematical and simulation models. **Chapter 4** presents the proposed clustered PMIPv6. It starts by deliberating the PMIPv6 problems, analyzing the related clustered and hierarchical schemes, and shows the mathematical and simulation evaluations to prove the efficiency of the proposed architecture in comparison with the PMIPv6 and SPMIPv6 in terms of LMA load, communication path, and the handoff latency. **Chapter 5** presents the proposed fast handoff scheme. The chapter starts by presenting the problems of long handoff latency and packet loss. Then it gives the required analysis of the existing fast handoff schemes. After that, it presents the proposed fast handoff scheme which is based on the proposed CPMIPv6. Finally, the performance of the proposed handoff scheme is compared against the state-of-the-art handoff schemes, by using both mathematical and simulation approaches, in terms of handoff latency, packet loss size, and buffered packet delay. **Chapter 6** presents the proposed route optimization scheme. The chapter starts by identifying the route optimization problem in PMIPv6. Then it states the analysis of existing route optimization schemes. After that, the proposed route optimization scheme is presented which relies on the proposed CPMIPv6. The mathematical and simulation approaches are used to evaluate and compare the proposed route optimization against the latest existing schemes in terms of handoff signaling cost, total cost, and handoff latency. Lastly, **Chapter 7** concludes the work and recommends some promising directions for future research.

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