UNIVERSITI PUTRA MALAYSIA

PREDICTION AND MULTI-CRITERIA-BASED SCHEMES FOR SEAMLESS HANDOVER MECHANISM IN MOBILE WIMAX NETWORK

MOHAMMED AWADH AHMED BEN MUBARAK

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By

MOHAMMED AWADH AHMED BEN MUBARAK

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

July 2013

DEDICATION

قال تعالى:

((وَوَصَّيْنَا الإِنسَانَ بِوَالِدَيْهِ حَمَلَتْهُ أُمُّهُ وَهْناً عَلَى وَهْنٍ وَفِصَالُهُ فِي عَامَيْنِ أَنْ اشْكُرْ لِي وَلِوَالِدَيْكَ إِلَيَّ الْمَصِيرُ))

لقمان 14

This thesis dedicated to

To the most Merciful Allah S.W.T

To my dearest parents, whom I got the power form their Doa'a.

To my wife for her love, loyalty, and support

To my lovely daughters (Amaal, Maram and Basma), whom eased the alienation's pains.

To my brothers and sisters for their extraordinary love, support, endless care and encouragement

To Mr. Abdurrahman Ahmed Taha, who supported me to achieve my first academic step (B.Sc degree) and I am now in this level because of him after Allah S.W.T.

Thank you All

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

PREDICTION AND MULTI-CRITERIA-BASED SCHEMES FOR SEAMLESS HANDOVER MECHANISM IN MOBILE WIMAX NETWORK

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July 2013

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Mobile WiMAX introduces several interesting advantages including last mile wireless access, variable and high data rate, point to multi-point communication, large frequency range and QoS (Quality of Service) for various types of applications. However, mobility in WiMAX system is still an issue when a mobile station (MS) moves and its connection is handed over between base stations (BSs). This thesis focuses on three main stages of the handover procedure in Mobile WiMAX; scanning, cell selection and handover initiation and decision. It introduces four main schemes to optimize the handover mechanism. The first scheme is Mobile Station Movement Direction Prediction (MMDP) based handover scanning that reduces the redundant scanning activities, scanning delay and signalling overhead. Simulation results show that the proposed MMDP scheme reduces handover scanning delay and scanning interval duration by 50% and 25% respectively and reduces the signalling

overhead. The second scheme is Hybrid AHP (Analytic Hierarchy Process) and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)-based Cell Selection (HATCS) scheme based on a set of multiple criteria. Cell selection is a key element that insures that the QoS and user requirements during and after handover process is met. In the proposed HATSC scheme, the AHP method is uese for criteria weighting, while the TOPSIS method uses for the selection technique based on a multi-criteria decision-making algorithm is proposed. This enables it to meet the MS application requirements based on some criteria such as CINR, BW, and delay. The third scheme is a fuzzy logic-based self-adaptive handover (called FuzSAHO) for handover decision to provide an intelligent self-adaptive handover parameters technique based on received signal strength indicator (RSSI) and MS velocity. Finally, the FuzSAHO decision algorithim is optimized for real-time application, by using a new handover criteria, namely queue length besides RSSI and MS velocity. This new self-adaptive handover scheme for real-time application called RFuzSAHO. Simulation results show that FuzSAHO reduces the ping-pong handover, and handover delay. It reduces the number of handovers by 29.7% and 26.9%, respectively, compared to the conventional RSSI based handover algorithm and the previous worked, mobility improved handover (MIHO) algorithm. In terms of handover delay, FuzSAHO reduce handover delay by 40% and 15% compared to RSSI based-HO and MIHO respectively. Also, it is shown that FuzSAHO enhances the overall handover operation in term of reduced overhead signalling, average E2E packet delay and satisfactory CINR which satisfies network end user requirements. For real-time applications, simulation results show that RFuzSAHO decision algorithm enhances the VoIP quality (Mean Opinion Score, MOS) up to 5.4% compared to FuzSAHO algorithm when the MS velocity is 20m/s.

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

SKIM BERASASKAN RAMALAN DAN KRITERIA BERGANDA UNTUK MEKANISME PENYERAHAN LANCAR DALAM RANGKAIAN WIMAX MUDAH ALIH

Oleh

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Mobile WiMAX memperkenalkan beberapa kelebihan yang menarik termasuk lepas akses sambungan tanpa wayar, kadar data berubah dan tinggi, mata untuk komunikasi pelbagai titik, julat frekuensi yang besar dan QoS (Kualiti Perkhidmatan) untuk pelbagai jenis aplikasi. Walau bagaimanapun, pergerakan dalam sistem WiMAX masih satu isu apabila stesen mudah alih (MS) bergerak dan sambungan yang diserahkan antara stesen pangkalan (BSS). Tesis ini memberi tumpuan kepada tiga peringkat utama prosedur penyerahan dalam Mobile WiMAX pengimbasan, pemilihan sel dan penyerahan permulaan dan keputusan. Ia memperkenalkan empat skim utama untuk mengoptimumkan mekanisme penyerahan. Skim pertama adalah Mobile Station Pergerakan Arah Ramalan (MMDP) berdasarkan penyerahan imbasan yang mengurangkan aktiviti pengimbasan berlebihan, imbasan kelewatan dan isyarat atas. Keputusan simulasi menunjukkan bahawa skim MMDP cadangan mengurangkan penyerahan imbasan

kelewatan dan masing-masing mengimbas tempoh selang sebanyak 50% dan 25% dan mengurangkan overhed isyarat.

Skim kedua adalah hibrid AHP (Proses Hierarki Analisis) dan TOPSIS (Teknik Perintah Keutamaan oleh Persamaan untuk Penyelesaian Ideal) Pemilihan your-berasaskan (HATCS) Skim berdasarkan satu set kriteria berganda. Pemilihan sel adalah elemen utama yang akan memastikan bahawa QoS dan keperluan pengguna semasa dan selepas proses penyerahan dipenuhi. Dalam skim HATSC cadangan, kaedah AHP adalah uese untuk kriteria pemberat, manakala kaedah TOPSIS menggunakan untuk teknik pemilihan berdasarkan pelbagai kriteria algoritma membuat keputusan dicadangkan. Ini membolehkan ia untuk memenuhi keperluan permohonan MS berdasarkan beberapa kriteria seperti CINR, BW, dan kelewatan. Skim ketiga adalah kabur berasaskan logik sendiri penyesuaian penyerahan (dipanggil FuzSAHO) untuk penyerahan keputusan untuk menyediakan diri penyesuaian parameter penyerahan teknik pintar berdasarkan kepada kekuatan isyarat yang diterima penunjuk (RSSI) dan halaju MS. Akhirnya, keputusan FuzSAHO algorithim dioptimumkan untuk aplikasi masa nyata, dengan menggunakan baru penyerahan kriteria, iaitu panjang beratur selain RSSI dan halaju MS. Ini baru skim diri penyesuaian penyerahan bagi permohonan masa nyata dipanggil RFuzSAHO. Keputusan simulasi menunjukkan bahawa FuzSAHO mengurangkan ping-pong penyerahan, dan penyerahan kelewatan. Ia mengurangkan bilangan handovers sebanyak 29.7% dan 26.9%, masing-masing, berbanding dengan RSSI konvensional berdasarkan penyerahan algoritma dan sebelumnya bekerja, pergerakan penyerahan (Miho) bertambah baik algoritma. Dari segi penyerahan kelewatan, FuzSAHO mengurangkan kelewatan penyerahan sebanyak 40% dan 15%

berbanding dengan RSSI berasaskan HO dan Miho masing-masing. Selain itu, ia menunjukkan bahawa FuzSAHO meningkatkan penyerahan operasi keseluruhan dalam tempoh dikurangkan isyarat atas, purata kelewatan paket E2E dan CINR memuaskan yang memenuhi keperluan pengguna rangkaian akhir. Untuk aplikasi masa nyata, keputusan simulasi menunjukkan bahawa RFuzSAHO keputusan algoritma meningkatkan kualiti VoIP (Min Skor Pendapat, MOS) sehingga kepada 5.4% berbanding dengan FuzSAHO algoritma apabila halaju MS adalah 20m/s.

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I certify that a Thesis Examination Committee has met on **date of viva voce** to conduct the final examination of Mohammed Awadh Ahmed Ben Mubarak on his doctoral of philosophy thesis entitled "Prediction and Multi-criteria-based Schemes for Seamless Handover Mechanism in Mobile WiMAX Networks" 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 degree of Doctoral of Philosophy.

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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. The members of the Supervisory Committee were as follows:

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Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

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MOHAMMED AWADH AHMED BEN MUBARAK

Date: 19 July 2013

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LIST OF ABBREVIATIONS

AHOP	Actual Handover Phase
AHP	Analytic Hierarchy Process
ASN-GW	Access Service Network Gateway
BER	Bit Error Rate
BS	Base Station
CDMA	Code-Division Multiple Access
CINR	Carrier to Interference-plus-Noise Ratio
CSN	Connectivity Service Network
FBSS	Fast Base Station Switching
HHO	Hard Handover
HO	Handover
IP	Internet Protocol
L2	Layer 2 (MAC Layer)
L3	Layer 3 (Network Layer)
LBS	Location-based Service
MAC	Media Access Control
MAHO	Mobile Assisted Handover
MCHO	Mobile Controlled Handover
MDHO	Macro Diversity Handover
MIP	Mobile Internet Protocol
MIPv6	Mobile Internet Protocol version 6
MOS	Mean Opinion Score
MS	Mobile Station

nBS	Neighbour Base Station
NCHO	Network Controlled Handover
NLOS	Non-Line-of-Sight
NRM	Network Reference Model
NTAP	Network Topology Acquisition Phase
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Accesses
PHY	Physical
PMIP	Proxy Mobile Internet Protocol
QoS	Quality of Services
RS	Relay Station
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
RTD	Round Trip Delay
SBS	Serving Base Station
SNR	Signal-to-Noise Ratio
TBS	Target Base Station
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over Internet Protocol
WiMAX	Worldwide Interoperability for Microwave Access
WSM	Weighted Sum Model

CHAPTER 1

INTRODUCTION

1.1 Background

Over the past two decades, the Internet has played very important role in the way we work and play. The proliferation of mobile devices, laptops, tablets and smart phones significantly drives the demand for ubiquitous wireless Internet access for diverse sets of applications ranging from simple email, social networking, to real time and bandwidth intensive applications such as VoIP, streaming, and gaming.

To respond to this demand, the IEEE 802.16 set of standards has been developed for Metropolitan Wireless Access. It has developed over several versions and the latest version (802.16m) has been defined to satisfy 4G network specifications. It defines a new MAC layer protocol based on orthogonal frequency division multiplexing (OFDM) which is robust against severe channel conditions. IEEE 802.16e adds the support of mobility and uses orthogonal frequency division multiplexing access (OFDMA) as its air interface technique [1].

The IEEE 802.16 known as Worldwide Interoperability for Microwave Access (WiMAX) introduces several interesting advantages including support of high data rate, covering large areas, corporate-grade security, dynamic quality-of-service (QoS), and good spectral efficiency. It also provides better support for non line-of-sight (NLOS) technologies, multiple services with different QoS policies, fast and inexpensive deployment of “last mile access” to public networking, and being a cost-effective alternative to WiFi and 3G/4G cellular networks [2].

Full mobility management feature has been introduced in IEEE 802.16e called Mobile WiMAX. Although the basic handover procedure was introduced for IEEE 802.16e to support full mobility, the emerging standards of IEEE 802.16j and IEEE 802.16m also exploit the same handover principles of IEEE 802.16e with other amendments on the requirements of these new standards [1], [3]. Mobile WiMAX supports small cell size and high mobility in which MS will experience frequent handover between base stations (BSs) of WiMAX system. Therefore, handover mechanism is one of the critical operations in mobile WiMAX, when it handles mobile station (MS) for switching from one serving BS (SBS) to a target BS (TBS).

IEEE 802.16j introduces a relay station (RS) entity to provide larger coverage and better performance especially around blind alleys [4]. In contrast, the most recent standard of IEEE 802.16m promises to meet the IMT-Advance requirements to provide high data rates of at least 1 Gbps for fixed subscribers and 100 Mbps for mobile stations (MSs) at a vehicular speed of up to 350 km/h [5]. In addition, IEEE 802.16m supports the MAC and PHY features with the location based service (LBS) solution, where the BS can track the MS movement.

There are two components in mobility management feature: location and handover management [6]. Location management is used by the network to monitor and get updated information on the location of MS while moving into a new cell. Handover management is a mechanism that maintains uninterrupted mobile user communication session when a user moves from one location to another between the coverage areas of BSs, this is called handover.

Generally, handover can be categorised as either horizontal handover or vertical handover [7], [8]. Horizontal handover is handover that occurs between two BSs of the same network system, for example, handover between two cells of a WiMAX system. Vertical handover on the other hand, is defined as a handover that occurs between two BSs of different wireless access technologies, for example, between WLAN and WiMAX networks.

The horizontal handover in mobile WiMAX system can be further categorized into three types -- hard handover (HHO), macro diversity handover (MDHO), and fast base station switching (FBSS) [9], [10]. In HHO, the MS communicates with only one BS at a time. It means all connections with the serving BS (SBS) will be broken before the connection with a target BS (TBS) is established, this is break-before-make handover type. The other two types of handovers, MDHO and FBSS, are known as soft handover or make-before-break, where a connection to the TBS is established before MS leaves the connection from SBS [11]. Although the IEEE 802.16e standard has defined these three types of handover, the WiMAX Forum in

[2] only considers the HHO as a mandatory handover, whereas both MDHO and FBSS are taken as optional.

Further, handover process comprises of two main phases; the network topology acquisition phase (NTAP) also known as pre-handover phase, and the actual handover phase (AHOP). The first phase includes the network topology advertisement, the neighbouring BS scanning and association and cell selection. The second phase consists of handover decision and initiation, and network re-entry including ranging, authorization and re-registration [11]. These phases of handover procedure can be summarized as shown in Figure 1.1.

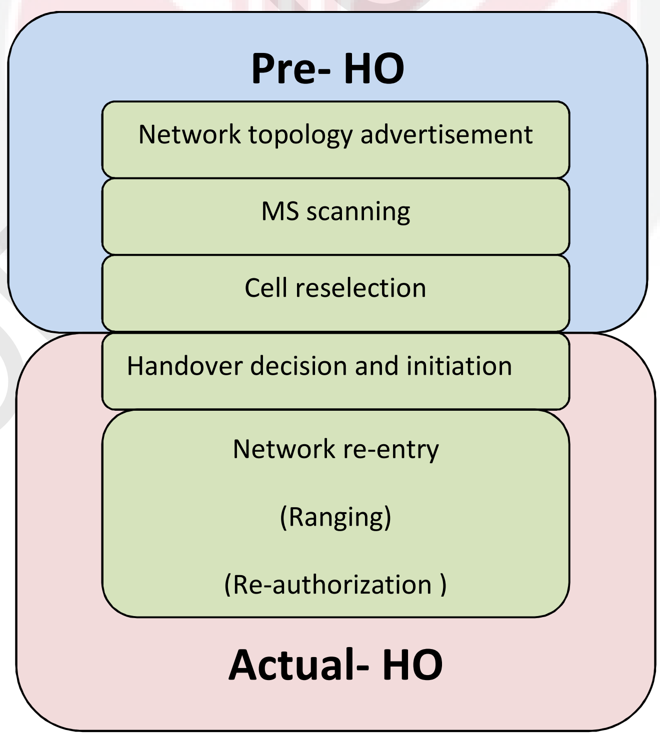

Figure 1.1 Handover phases

As mentioned earlier, Mobile WiMAX supports small cell size and high mobility which means that the MS will experience frequent handover between BSs. Thus, handover mechanism is considered as one of the critical operations in mobile WiMAX, when it handles MS for switching from one SBS to a TBS. Thus, the mobility management in WiMAX system should seamlessly perform the handover without affecting real-time sessions such as video conferencing, media streaming, and multiplayer interactive gaming. For this, they require suitable link quality from the underlying wireless networks in order to meet the specific QoS requirement.

This thesis focuses on handover management especially at the MAC layer or layer 2 handover. This is because layer 2 handover is more frequent than network layer (layer 3 handover); whereas the network layer handover happens only when the handover happens between two cells from different network subnets. Usually, a subnet covers a large area that consists of many of BSs.

The following parts of the chapter is organized as follows. First, the problem statement of the thesis is discussed. This is followed by a listing of the objectives of the thesis, and its scope. Finally, the organization of the thesis is presented.

1.2 Problem Statement

As highlighted earlier, the handover procedure can be divided into several phases; network topology advertisement, cell reselection via scanning, handover decision and initiation, and network entry including ranging, re-authorization and re-registration. This thesis focuses on the problems explained below through scanning, cell reselection, and handover decision and initiation phases:

1. In the handover scanning process, the MS must synchronize with all the advertised neighbour BSs (nBSs) to select the best BS candidate for the incoming handover action. Without terminating the connection between the SBS and MS, the SBS will schedule the scanning intervals and sleep-intervals (called interleaving interval) to MS for the handover scanning. Due to the multiple stages in this phase causing redundant scanning, all data transmissions will be paused, and this may cause handover delay and throughput degradation. This issue will affect the real-time continuity of multimedia application sessions.

2. Cell selection scheme on Mobile WiMAX is based on a single criterion, normally, signal quality only. Due to the inefficient handover procedure of this scheme, single criteria based selection is not enough to choose the best BS for different application requirements. Suppose the MS is in an overlapping area of two or more BSs that have similar signal quality, which one will be chosen for different user application requirements? Putting a cell

selection criterion on signal quality entirely may make an MS to choose a TBS with good signal quality but with one high delay or less bandwidth; this may affect some applications. Choosing a TBS has to be smart to meet the end-user application requirements. There are many parameters that can be considered for cell selection criteria to meet the required QoS; some examples are signal quality, bandwidth, and delay.

3. For the handover initiation and decision, the WiMAX is based on a single criterion, which usually uses RSSI with fixed handover parameters of handover threshold and margin. Since handover criteria and handover decisions are key factors that determine a handover system efficiency, limited intelligence handover schemes may cause unnecessary handover (referred to as "ping pong" handover), handover failure, and handover delay which can affect real-time sessions

1.3 Aim and Objectives

Thus, the main aim of this thesis is to design and develop efficient and seamless handover schemes with the following objectives:

1. To enhance scanning scheme and reduce the number of redundant scanning, scanning delay and signalling overhead.

2. To optimize the selection of the best target Base Station (TBS) to meet the QoS requirements by way of reduced the delay and increased the BW after handover process.

3. To develop an adaptive handover parameters technique, to reduce the handover delay, number of unnecessary/ping-pong handover and signalling overhead.

1.4 Brief Methodology

To achieve a seamless handover mechanism in Mobile WiMAX, four schemes MS Movement Direction Prediction (MMDP), Hybrid AHP and TOPSIS Methods-based Cell Selection (HATCS), and Fuzzy logic based Self-Adaptive Handover (FuzSAHO) and Real-time Fuzzy logic based Self-Adaptive Handover (RFuzSAHO), each scheme being performed at a different handover phase. The MMDP scheme for the scanning phase, is proposed in Chapter 3. The scheme for the cell selection phase is proposed in Chapter 4. The FuzSAHO and RFuzSAHO schemes for the decision phase are proposed in Chapter 5. As highlighted earlier this thesis focuses on issues such as delay and signalling overhead. This is done through some handover phases, scanning, cell reselection, and handover decision and initiation phases.

In the conventional WiMAX handover scanning scheme the MS performs redundant scanning activities in this phase, and all the data transmissions will be paused, and this may cause handover delay and throughput. These problems of handover scanning are addressed in the proposed MMDP scheme as shown in Chapter 3. MMDP predicts the MS movement direction and based on that, it only scans the BSs that the MS is heading towards.

The HATCS scheme on the other hand is proposed to help in choosing the most optimum TBS. It does TBS selection based on multiple criteria to meet application QoS requirements during and after the handover procedure, this is described in Chapter 4.

An adaptive handover decision and initiation problems based on fuzzy logic is proposed in Chapters 5. Chapter 5 describes FuzSAHO a method which adapts to the handover parameters based on a set of criteria viz. the received signal strength indicator (RSSI), and MS velocity to reduce the unnecessary handover, delay, and signalling overhead. The next version designed for real time application called RFuzSAHO is also proposed in Chapter 5. In this method, queue length is being considered as an additional handover criterion besides RSSI, and MS velocity is considered for handover decision algorithm to enhance the VoIP quality during the handover procedure.

All the proposed schemes evaluate using Qualnet 5.0 simulation tools. T All the results generates by Qualnet and plot using MATLAB. The proposed schemes makes up solutions for different handover phases, and every optimization in each phase will optimize the following phase. For example, when the MMDP scheme reduces the number of the most likely TBS to visit next in the scanning phase, this will also optimize the HATCS scheme, because it will reduce the number of candidate TBS which will in turn speed up the HATCS scheme. In addition, choosing the right TBS that meets the user requirements in the cell selection phase, the FuzSAHO will take the handover decision to the right TBS, which will reduce the number of handovers. A brief description of the methodology is shown in Figure 1.2.

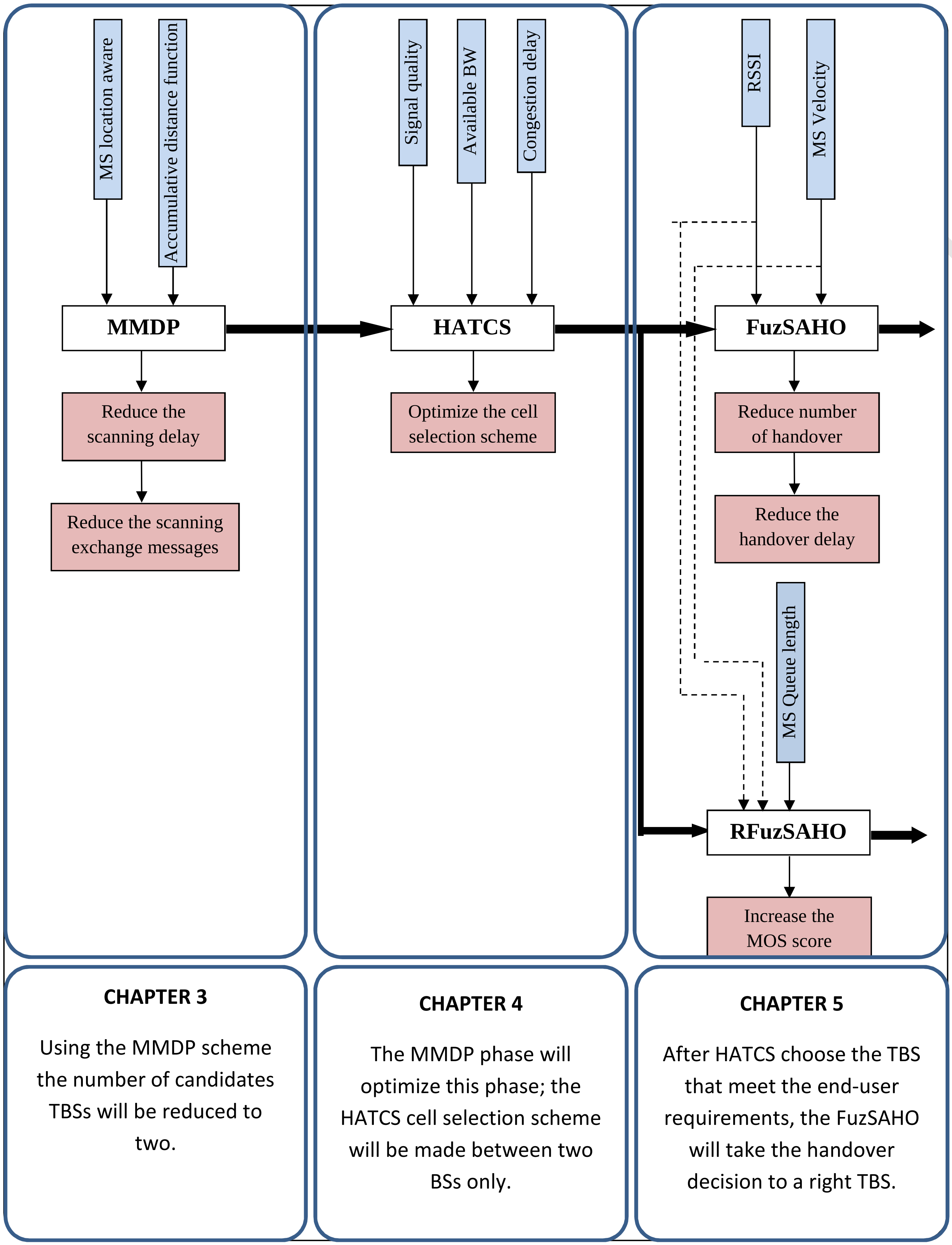

Figure 1.2 The value chain of handover schemes showing the input parameters and their benefits respectively

1.5 Thesis Scope

The flow of this thesis is illustrated in Figure 1.3. The solid lines represent the direction followed in this thesis to achieve our goal and objectives while the dotted lines refer to other related research areas that are out of the scope of this work. The figure shows that mobility can be handled in several layers. In this thesis, the focus of study will be on L2 mobility management for Mobile WiMAX networks. We further propose handover schemes that support handover management for different handover procedure phases.

1.6 Contributions

The main contributions in this thesis are as follows:

- Developing a MS Movement Direction prediction (MMDP)-based handover scanning scheme. This method reduces redundant scanning and hence scanning delay.
- Improving cell selection based on Multi Criteria Decision Making (MCDM) methods using Analytic Hierarchy Process (AHP) for multi criteria weighting with Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for the candidate BSs ranking.
- Introducing a fuzzy logic based handover initiation and decision called FuzSAHO to provide an intelligent self-adaptive HO parameters technique based on RSSI and MS velocity.

- Optimizing the fuzzy initiation and decision for real-time applications using RFuzSAHO with queue length consideration.

1.7 Thesis Organization

This thesis addresses an efficient handover mechanism for mobile WiMAX. The thesis is organized as follows. Chapter 1 introduces the research background on the issue of mobility and handover, and defines the objectives and scope of the research topic. In Chapter 2, the WiMAX technology is briefly reviewed, followed by the mobility management architectures for WiMAX. Handover schemes relevant for different handover procedure phases are also discussed. Chapter 3 describes the architecture and procedure for handover scanning in mobile WiMAX using MMDP. Chapter 4 described the proposed HATCS scheme using hybrid AHP/TOPSIS methods to improve cell selection phase in mobile WiMAX.

Chapter 5 introduces the proposed the FuzSAHO. It will self-adapt to the handover parameters based on received signal strength indicator (RSSI) and MS velocity, to reduce unnecessary handover, delay, and signalling overhead. For real-time applications such as VoIP, a real time extension called RFuzzSAHO is also proposed as in Chapter 5. In this scheme, queue length is considered as an additional handover criteria besides RSSI and MS velocity for handover decision algorithm. In Chapter 6, the thesis is summarized, followed by a discussion of the key contributions of the work. Several directions for future research are also suggested for further investigation.

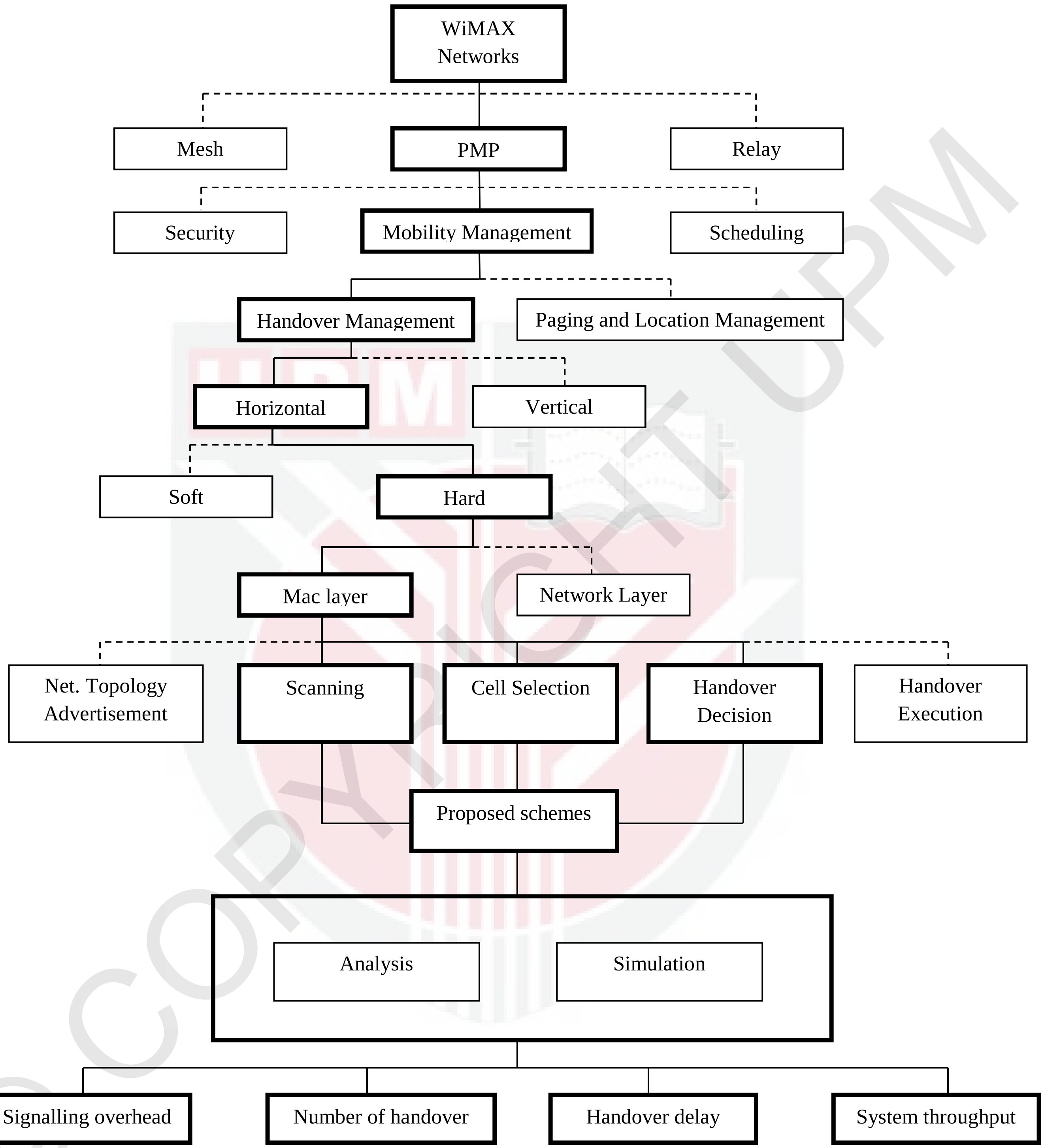

Figure 1.3 Study Model

REFERENCES

1. Bacioccola A., Cicconetti C., Eklund C., Lenzini L., Li Z., and E. Mingozzi, *IEEE 802.16: History, status and future trends.* Elsevier: Computer Communications, 2010. **33**(2): p. 113-123.

2. *Mobile WiMAX - Part I: A Technical Overview and Performance Evaluation*, 2006, WiMAX Forum. p. 9-24.

3. Teo, K.H., Z. Tao, and J. Zhang, *The mobile broadband WiMAX standard.* Signal Processing Magazine, IEEE, 2007. **24**(5): p. 144-148.

4. Genc V., Murphy S., Yang Y., and Murphy J., *IEEE 802.16J relay-based wireless access networks: an overview*. Wireless Communications, IEEE, 2008. **15**(5): p. 56-63.

5. Srinivasan R., Zhuang J., Jalloul L., Novak R., and Park J., *IEEE 802.16 m evaluation methodology document (EMD).* IEEE 802.16 Broadband Wireless Access Working Group, 2008.

6. Akyildiz, I.F., X. Jiang, and S. Mohanty, *A survey of mobility management in next-generation all-IP-based wireless systems.* Wireless Communications, IEEE, 2004. **11**(4): p. 16-28.

7. Kassar, M., B. Kervella, and G. Pujolle, *An overview of vertical handover decision strategies in heterogeneous wireless networks.* Computer Communications, 2008. **31**(10): p. 2607-2620.

8. Dai Z., Fracchia R., Gosteau J., Pellati P., and Vivier G., *Vertical Handover Criteria and Algorithm in IEEE802.11 and 802.16 Hybrid Networks*. in *Communications, 2008. ICC '08. IEEE International Conference on*. 2008.

9. Becvar, Z. and J. Zelenka, *Handovers in the Mobile WiMAX*. Research in Telecommunication technology, 2006. **1**: p. 147-150.

10. *IEEE Standard for local and metropolitan area networks Part 16: Air interface for fixed and mobile broadband wireless access systems amendment 2: Physical and medium access control layers for combined fixed and mobile operation in licensed bands and corrigendum 1.* IEEE std, 2006.

11. Ray, S.K., K. Pawlikowski, and H. Sirisena, *Handover in Mobile WiMAX Networks: The State of Art and Research Issues.* Communications Surveys & Tutorials, IEEE, 2010. **12**(3): p. 376-399.

12. *WiMAX Forum*, www.wimaxforum.org

13. Cicconetti C., Erta A., Lenzini L., and Mingozzi E., *Performance evaluation of the IEEE 802.16 MAC for QoS support.* Mobile Computing, IEEE Transactions on, 2007. **6**(1): p. 26-38.

14. Ahmadi, S., *An overview of next-generation mobile WiMAX technology*. Communications Magazine, IEEE, 2009. **47**(6): p. 84-98.

15. Papapanagiotou I., Toumpakaris D., Lee J., and Devetsikiotis M., *A survey on next generation mobile WiMAX networks: objectives, features and technical challenges.* Communications Surveys & Tutorials, IEEE, 2009. **11**(4): p. 3-18.

16. So-In, C., R. Jain, and A.K. Tamimi, *Scheduling in IEEE 802.16 e mobile WiMAX networks: key issues and a survey*. Selected Areas in Communications, IEEE Journal on, 2009. **27**(2): p. 156-171.

17. Pollini, G.P., *Trends in handover design.* Communications Magazine, IEEE, 1996. **34**(3): p. 82-90.

18. Ekiz N., Salih T., Kucukoner S., and Fidanboylu K., *An overview of handoff techniques in cellular networks.* International Journal of Information Technology, 2005. **2**(3): p. 132-136.

19. Tripathi, N.D., J.H. Reed, and H.F. VanLandinoham, *Handoff in cellular systems.* Personal Communications, IEEE, 1998. **5**(6): p. 26-37.

20. Barooah M., Chakraborty S., Nandi S., and Kotwal D., *An architectural framework for seamless handoff between IEEE 802.11 and UMTS networks.* Wireless Networks, 2012. **19**(4): p. 411-429.

21. Bashar H., Chee N., Noordin N., Rasid M., and Ismail A., *Review of Minimizing a Vertical Handover in a Heterogeneous Wireless Network.* IETE Technical Review, 2010. **27**(2): p. 97-106.

22. Lin, Y.B. and A.C. Pang, *Comparing soft and hard handoffs.* Vehicular Technology, IEEE Transactions on, 2000. **49**(3): p. 792-798.

23. Zeng, Q.A. and D.P. Agrawal, *Handoff in wireless mobile networks.* Handbook of wireless networks and mobile computing, 2002: p. 1-25.

24. Bertin, P., K. Guillouard, and J.C. Rault. *IP based network controlled handover management in WLAN access networks*. in *Communications, 2004 IEEE International Conference on*. 2004.

25. Melia T., Boscolo L., Vidal A., and Oliva A., *IEEE 802.21 Reliable Event Service Support for Network Controlled Handover Scenarios*. in *Global Telecommunications Conference, 2007. GLOBECOM '07. IEEE*. 2007.

26. Zhang, W., J. Jaehnert, and K. Dolzer. *Design and evaluation of a handover decision strategy for 4th generation mobile networks*. 2003. IEEE.

27. Linlin, Y., H. Zhenan, and W. Wenbo. *Fuzzy logic based handover in MC-CDMA system*. in *Circuits and Systems, 2005. ISCAS 2005. IEEE International Symposium on*. 2005.

28. Alatise, M., M. Mzyece, and A. Kurien. *A Handover Scheme for Mobile WiMAX Using Signal Strength and Distance*. in *The Southern Africa Telecommunication Networks and Applications Conference (SATNAC)*. 2011.

29. Singh, B., *An improved handover algorithm based on signal strength plus distance for interoperability in mobile cellular networks.* Wireless Personal Communications, 2007. **43**(3): p. 879-887.

30. Chia, S.T.S. and R.J. Warburton. *Handover criteria for city microcellular radio systems*. in *Vehicular Technology Conference, 1990 IEEE 40th*. 1990.

31. Qureshi, S.U.R., Nawaz S., Patwary M., Abdel-Maguid M., and Kamar A., *The impact of propagation environment and velocity on the handover performance of LTE systems*. in *Wireless Communications and Signal Processing (WCSP), 2010 International Conference on*. 2010.

32. Jaheon G., Sueng Jae B., Min Young C., Kyung-yul C., and Ae-Soon P., *Mobility-based handover decision mechanism to relieve ping-pong effect in cellular networks*. in *Communications (APCC), 2010 16th Asia-Pacific Conference on*. 2010.

33. Ching-Hung, L. and Y. Chun-Jie. *An intelligent handoff algorithm for wireless communication systems using grey prediction and fuzzy decision system*. in *Networking, Sensing and Control, 2004 IEEE International Conference on*. 2004.

34. Shin, S.-Y., J.-C. Lee, and Y.-W. Rhee, *An Improved Handover Method Using Mobile Tracking on Telematics*, in *Proceedings of the 2006 International Conference on Hybrid Information Technology - Volume 01*2006, IEEE Computer Society.

35. Lee, C.C., *Fuzzy logic in control systems: fuzzy logic controller. I.* Systems, Man and Cybernetics, IEEE Transactions on, 1990. **20**(2): p. 404-418.

36. Tripathi, N.D., *PhD thesis: Generic adaptive handoff algorithms using fuzzy logic and neural networks*, in *Electrical and Computer Engineering*1997, Virginia Polytechnic Institute and State University.

37. Chan P., Sheriff R., Hu Y., Conforto P., and Tocci C., *Mobility management incorporating fuzzy logic for heterogeneous a IP environment.* IEEE Communications magazine, 2001. **39**(12): p. 42-51.

38. Ahmed T., Kyamakya K., Ludwig M., Anne K., Schroeder J., Galler S., Jobmann K., Rass S., and Eder J., *A context-aware vertical handover decision algorithm for multimode mobile terminals and its performance*. 2006. The 13th International Conference on Neural Information Processing (ICONIP'06), October 3-6, 2006, Hong Kong.

39. Wei Q., Farkas K., Prehofer C., Mendes P., and Plattner B., *Context-aware handover using active network technology*. Comput. Netw., 2006. **50**(15): p. 2855-2872.

40. Gu, B. and I.R. Chen, *Performance analysis of location-aware mobile service proxies for reducing network cost in personal communication systems.* Mobile Networks and Applications, 2005. **10**(4): p. 453-463.

41. Qi, L. and M. Maode. *A Location-Aware fast handover scheme for mobile WiMax networks*. in *Information, Communications and Signal Processing, 2009. ICICS 2009. 7th International Conference on*. 2009.

42. Paolini, M. and S.F. Consulting, *White Paper: Building End-to-End WiMAX Networks*. Senza Fili Consulting, Apr, 2007.

43. Ergen, M., *The access service network in WiMAX: the role of ASN-GW.* WiChorus, Inc., Oct, 2007.

44. Semin S., Seung-jae H., Joon-sang P., and Seong-choon L., *Seamless IP mobility support for flat architecture mobile WiMAX networks.* Communications Magazine, IEEE, 2009. **47**(6): p. 142-148.

45. Min K., Jong-min K., Hwa-sung K., and Il-kyeun R., *A proxy mobile IP based layer-3 handover scheme for mobile WiMAX based wireless mesh networks*. in *Ubiquitous and Future Networks (ICUFN), 2010 Second International Conference on*.

46. Sousa, B., K. Pentikousis, and M. Curado. *Evaluation of multimedia services in mobile WiMAX*. in *MUM '08 Proceedings of the 7th International Conference on Mobile and Ubiquitous Multimedia*. 2008. ACM.

47. *Network Working Group, WiMAX Forum Network Architecture "Detailed Protocols and Procedures" Release 1, Version 1.2*. 2008.

48. Hu R. Q., Paranchych D., Mo-Han F., and Geng W., *On the evolution of handoff management and network architecture in WiMAX*. in *Mobile WiMAX Symposium, 2007. IEEE*. 2007.

49. Sultan J., Ismail M., Misran N., and Jumari K., *Spectral efficiency evaluation of downlink mobile multi-hop relay systems employing macro diversity handover technique.* IJCSNS, 2008. **8**(5): p. 122.

50. Fattah, H. and H. Alnuweiri. *A New Handover Mechanism for IEEE 802.16e Wireless Networks*. in *Wireless Communications and Mobile Computing Conference, 2008. IWCMC '08. International*. 2008.

51. Ulvan, A. and R. Bestak. *The Analysis of Scanning Time in IEEE802.16m's Handover Procedure*. in *Systems, Signals and Image Processing, 2009. IWSSIP 2009. 16th International Conference on*. 2009.

52. Rouil, R. and N. Golmie. *Adaptive Channel Scanning for IEEE 802.16e*. in *Military Communications Conference, 2006. MILCOM 2006. IEEE*. 2006.

53. Boone, P., M. Barbeau, and E. Kranakis, *Strategies for fast scanning, ranging and handovers in WiMAX/802.16.* International Journal of Communication Networks and Distributed Systems, 2008. **1**(4): p. 414-432

54. Winston, P.P.E. and K. Shaji, *Optimizing Channel Scanning during IEEE 802.16 e Handover*, in *4th International Conference on Computer Research and Development*2012, IACSIT Press.

55. Al-Khateeb, M.K. and A.H.A. Hashim, *A Fuzzy-based Mobility Prediction in the IEEE 802.16 e.* International Journal of Communication Networks and Information Security (IJCNIS), 2011. **1**(1): p. 14-19.

56. Wang, L., F. Liu, and Y. Ji, *Performance Analysis of Fast Handover Schemes in IEEE 802.16 e Broadband Wireless Networks.* Asia Pacific Advanced Network, 2007.

57. Lee, D.H., K. Kyamakya, and J.P. Umondi. *Fast handover algorithm for IEEE 802.16e broadband wireless access system*. in *Wireless Pervasive Computing, 2006 1st International Symposium on*. 2006.

58. Hoon-gyu, C., J. Jongpil, and C. Hyunseung. *CTBS: Cost-effective target bs selection scheme in IEEE 802.16e networks*. in *Telecommunication Networks and Applications Conference, 2007. ATNAC 2007. Australasian*. 2007.

59. Ray S. K., Mandal A., Pawlikowski K., and Sirisena H., *Hybrid predictive base station (HPBS) selection procedure in IEEE 802.16e-based WMAN*. in *Telecommunication Networks and Applications Conference, 2007. ATNAC 2007. Australasian*. 2007.

60. Priya, K. and G. Raja. *QoS enhancement in future generation network by handoff delay minimization*. in *Recent Trends In Information Technology (ICRTIT), 2012 International Conference on*. 2012.

61. Zhang Z., Pazzi R. W., Boukerche A., and Landfeldt B., *Reducing Handoff Latency for WiMAX Networks Using Mobility Patterns*. in *Wireless Communications and Networking Conference (WCNC), 2010 IEEE*. 2010.

62. Ray S. K., Pawlikowski K., McInnes A., Sirisena H., Szabó R., Zhu H., Imre S., and Chaparadza R., *A Fast and Simple Scheme for Mobile Station-Controlled Handover in Mobile WiMAX Access Networks*, 2011, Springer Berlin Heidelberg. p. 32-44.

63. Ray S. K., Pawlikowski K., McInnes A., and Sirisena H., *Self-Tracking Mobile Station Controls Its Fast Handover in Mobile WiMAX*. in *Wireless Communications and Networking Conference (WCNC), 2010 IEEE*. 2010.

64. Lu, Q. and M. Ma, *Achieving Faster Handovers in Mobile WiMAX Networks.* Wireless Personal Communications, 2011. **65**(1): p. 165-187.

65. Shen, G. and W. Jiajing. *An enhanced handover target cell selection algorithm for WiMAX network*. in *Communications, 2009. APCC 2009. 15th Asia-Pacific Conference on*. 2009.

66. Shinde, P., *Optimization of Handover Performance in Mobile WMax 802.16 E.* International Journal of Emerging Technology and Advanced Engineering, 2012. **2**(8): p. 251-252.

67. Shinde, P., *Algorithm for the Selection of Target Base Station during Handover in Mobile Wimax 802.16 e.* International Journal of Emerging Technology and Advanced Engineering, 2012. **2**(9): p. 218-221.

68. Hao, C., H. Liu, and J. ZHAN, *A Velocity-Adaptive Handover Scheme for Mobile WiMAX.* Int. J. Communications, Network and System Sciences, 2009. **2**: p. 874-878.

69. Anwar, M.I., A. Khosla, and N. Sood, *A Mobility Improvement Handover Scheme for Mobile-WiMAX.* International Journal of Computer Applications 2010. **11**(3): p. 28--31.

70. Nguyen Hoang, A. and M. Kawai. *An adaptive mobility handoff scheme for Mobile Wimax Networks*. in *Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology, 2009. Wireless VITAE 2009. 1st International Conference on*. 2009.

71. Kozlowska, E., R. Bestak, and B. Simak, *Optimization of Handover Mechanism in 802.16e using Fuzzy Logic Personal Wireless Communications*, 2007, Springer Boston. p. 115-122.

72. Sunghyun C., Jonghyung K., Chihyun P., Jung-Hoon C., Ok-Seon L., and Kiho K., *Hard Handoff Scheme Exploiting Uplink and Downlink Signals in IEEE 802.16e Systems*. in *Vehicular Technology Conference, 2006. VTC 2006-Spring. IEEE 63rd*. 2006.

73. Ji-Su, K. and K. Jae-Hyun. *Handover Scheme Using Uplink and Downlink Channel Information in IEEE 802.16e Systems*. in *Vehicular Technology Conference (VTC 2010-Spring), 2010 IEEE 71st*. 2010.

74. Niswar M., Kashihara S., Taenaka Y., Tsukamoto K., Kadobayashi Y., and Yamaguchi S., *MS-initiated handover decision criteria for VoIP over IEEE 802.16e*. in *Communications, Computers and Signal Processing, 2009. PacRim 2009. IEEE Pacific Rim Conference on*. 2009.

75. Sik C., Gyung-Ho H., Taesoo K., Ae-Ri L., and Dong-Ho C., *Fast handover scheme for real-time downlink services in IEEE 802.16e BWA system*. in *Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005 IEEE 61st*. 2005.

76. Wenhua, J., J. Pin, and M. Yuanyuan. *Fast Handover Scheme for Real-Time Applications in Mobile WiMAX*. in *Communications, 2007. ICC '07. IEEE International Conference on*. 2007.

77. Ling C., Xuejun C., Sofia R., and Zhen H., *A Cross-Layer Fast Handover Scheme For Mobile WiMAX*. in *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*. 2007.

78. Jui-Hung, Y., C. Jyh-Cheng, and P. Agrawal, *Fast Intra-Network and Cross-Layer Handover (FINCH) for WiMAX and Mobile Internet.* Mobile Computing, IEEE Transactions on, 2009. **8**(4): p. 558-574.

79. *IEEE Standard for local and metropolitan area networks Part 16: Air interface for fixed and mobile broadband wireless access systems amendment 3: Management plane procedure and services" 802.16g-2007*. IEEE std, 2007.

80. Roxin A., Gaber J., Wack M., and Nait-Sidi-Moh A., *Survey of Wireless Geolocation Techniques*. in *Globecom Workshops, 2007 IEEE*. 2007.

81. Lee J., Kim H., Kim K., Sloot P., Abramson D., Bogdanov A., Gorbachev Y., Dongarra J., and Zomaya A., *Resource Reservation and Allocation Based on Direction Prediction for Handoff in Mobile Multimedia Networks*, in *Computational Science*2003, Springer Berlin / Heidelberg. p. 719-720.

82. Wang C., Ray S., Pawlikowski K., and Sirisena H., *A Fast MAC-Layer Handover for an IEEE 802.16e-Based WMAN*, in *AccessNets*2009, Springer Berlin Heidelberg. p. 102-117.

83. Jain, R. *WiMAX system evaluation methodology v2. 1*. in *WiMAX Forum*. 2008.

84. Ramanathan, R., *A note on the use of the analytic hierarchy process for environmental impact assessment.* Journal of Environmental Management, 2001. **63**(1): p. 27-35.

85. Triantaphyllou E., Shu B., Sanchez S. N., and Ray T., *Multi-criteria decision making: an operations research approach.* Encyclopedia of electrical and electronics engineering, 1998. **15**: p. 175-186.

86. Mohamed, M.A., F.W. Zaki, and R.H. Mosbah, *Improving Quality of VoIP over WiMAX.* IJCSI International Journal of Computer Science Issues, 2012. **9**(3): p. 85-91.

87. Shun-Fang, Y., W. Jung-Shyr, and H. Hsu-Hung. *A vertical Media-Independent Handover decision algorithm across Wi-Fi and WiMAX networks*. in *Wireless and Optical Communications Networks, 2008. WOCN '08. 5th IFIP International Conference on*. 2008.

88. Wu, J.S., S.F. Yang, and B.J. Hwang, *A terminal controlled vertical handover decision scheme in IEEE 802.21 enabled heterogeneous wireless networks.* International Journal of Communication Systems, 2009. **22**(7): p. 819-834.

89. Kumar, R. and B. Singh, *Comparison of vertical Handover Mechanisms Using Generic QoS Trigger for Next Generation Network.* the International Journal of Next-Generation Networks (IJNGN) Vol, 2010. **2**: p. 80-97.

90. Balasubramaniam, S. and J. Indulska, *Vertical handover supporting pervasive computing in future wireless networks.* Computer Communications, 2004. **27**(8): p. 708-719.

91. SuKyoung L., Sriram K., Kyungsoo K., Yoon K. Hyuk, and Golmie N., *Vertical Handoff Decision Algorithms for Providing Optimized Performance in Heterogeneous Wireless Networks.* Vehicular Technology, IEEE Transactions on, 2009. **58**(2): p. 865-881.

92. Quoc-Thinh N.-V., Agoulmine N., Cherkaoui E. H., and Toni L., *Multicriteria Optimization of Access Selection to Improve the Quality of Experience in Heterogeneous Wireless Access Networks.* Vehicular Technology, IEEE Transactions on, 2013. **62**(4): p. 1785-1800.

93. K. Yap, S. Katti, G. Parulkar, and N. McKeown, *Deciphering a Commercial WiMAX Deployment using COTS Equipments*, 2010, Technical report, Stanford University.

94. Velásquez J. D., Ríos S. A., Howlett R. J., and Jain L. C., *Multi Criteria Decision Making in Fuzzy Description Logics: A First Step*, in *Knowledge-Based and Intelligent Information and Engineering Systems*2009, Springer Berlin Heidelberg. p. 78-86.

95. Yang, Z., A. Mohammed, and T. Hult. *Uplink Performance Evaluation of WiMAX Broadband Services via High Altitude Platforms (HAPs)*. in *Antennas and Propagation, 2007. EuCAP 2007. The Second European Conference on*. 2007.

96. Dong, M. and M. Maode. *A QoS-Based Vertical Handoff Scheme for Interworking of WLAN and WiMAX*. in *Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*. 2009.

97. Andrews, J.G., A. Ghosh, and R. Muhamed, *Fundamentals of WiMAX: understanding broadband wireless networking*2007: Prentice Hall PTR.

98. Saffer, Z. and S. Andreev. *Delay analysis of IEEE 802.16 wireless metropolitan area network*. in *Telecommunications, 2008. ICT 2008. International Conference on*. 2008.

99. Andreev, S., Z. Saffer, and A. Anisimov. *Overall Delay Analysis of IEEE 802.16 Network*. in *Communications Workshops, 2009. ICC Workshops 2009. IEEE International Conference on*. 2009.

100. Iyengar, R., P. Iyer, and B. Sikdar. *Analysis of 802.16 based last mile wireless networks*. in *Global Telecommunications Conference, 2005. GLOBECOM '05. IEEE*. 2005.

101. Aguado M., Jacob E., Saiz P., Matias J., Higuero M., Toledo N., and Berbineau M., *Scanning on handover enhancement issues in video application deployments on WiMAX mobile networks*. in *Broadband Multimedia Systems and Broadcasting, 2008 IEEE International Symposium on*. 2008.

102. Po-Hsuan, T. and F. Kai-Ten. *A Predictive Movement Based Handover Algorithm for Broadband Wireless Networks*. in *Wireless Communications and Networking Conference, 2008. WCNC 2008. IEEE*. 2008.

103. Po-Hsuan, T. and F. Kai-Ten. *Location tracking assisted handover algorithms for broadband wireless networks*. in *Personal, Indoor and Mobile Radio Communications, 2008. PIMRC 2008. IEEE 19th International Symposium on*. 2008.

104. Ulvan, A., M. Ulvan, and R. Bestak. *The enhancement of handover strategy by mobility prediction in broadband wireless access*. in *Proceedings of the International Conference on Networking and, Electronic Commerce Research*. 2009.

105. Yap, K.-K., *All-IP 4G Mobile Networks and Beyond*, 2010, Rutgers University: North Brunswick.

106. Hole, D.P. and F.A. Tobagi. *Capacity of an IEEE 802.11 b wireless LAN supporting VoIP*. in *Proceedings of IEEE International Conference on Communications*. 2004. Paris, France.

107. Pedrycz, W., *Why triangular membership functions?* Fuzzy sets and Systems, 1994. **64**(1): p. 21-30.

108. Patel, A.V. and B.M. Mohan, *Some numerical aspects of center of area defuzzification method.* Fuzzy sets and Systems, 2002. **132**(3): p. 401-409.

109. Velo F. J. M., Baturone L., Solano S. S., and Barriga A., *Rapid design of fuzzy systems with Xfuzzy*. in *Fuzzy Systems, 2003. FUZZ'03. The 12th IEEE International Conference on*. 2003. IEEE.

110. QualNet5.0, *Advanced Wireless Model Library*, 2009, Scalable Network Technologies, Inc.