

HANDOVER MANAGEMENT TECHNIQUES FOR WiMAX BASED WIRELESS MESH NETWORKS

L. RAJYA LAKSHMI



DEPARTMENT OF COMPUTER SCIENCE AND
ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
MAY 2014

© Indian Institute of Technology Delhi (IITD), New Delhi, 2014.

HANDOVER MANAGEMENT TECHNIQUES FOR WiMAX BASED WIRELESS MESH NETWORKS

by

L. RAJYA LAKSHMI

Department of Computer Science and Engineering

Submitted in fulfillment of the requirements
of the degree of Doctor of Philosophy

to the



Indian Institute of Technology Delhi
May 2014

Certificate

This is to certify that the thesis entitled **Handover Management Techniques for WiMAX Based Wireless Mesh Networks** submitted by **Ms. L. Rajya Lakshmi** to the Indian Institute of Technology Delhi, for the award of the Degree of Doctor of Philosophy, is a record of the original bonafide research work carried out by her under our supervision. The thesis has reached the standards fulfilling the requirements of the regulations relating to the degree. The results contained in this thesis have not been submitted in part or full to any other university or institute for the award of any degree or diploma.

New Delhi
May 2014

Dr. Vinay J. Ribeiro
Assistant Professor

Prof. Bijendra N. Jain
Professor

Department of Computer Science and Engineering
Indian Institute of Technology Delhi
New Delhi-110 016

Acknowledgements

The journey of completing a PhD thesis is a culmination of never-ending efforts and in pursuit of the same, one requires the involvement of multiple individuals. I take this opportunity to express my thanks to all those who have guided, encouraged, remained patient and showed faith in me to conclude my academic pilgrimage.

First and foremost, I express my deepest sense of gratitude to my thesis supervisors Dr. Vinay J. Ribeiro and Prof. B. N. Jain for their constant support, encouragement and constructive suggestions throughout my thesis work. I am extremely fortunate to have supervisors who gave me the freedom to explore on my own, and at the same time the guidance to recover whenever my steps faltered. Their enthusiasm, knowledge, support and patience throughout the program kept me on track and encouraged me when the going got tougher.

I am also deeply grateful to Prof. Subiman Kundu, Prof. Subhashis Banerjee and Prof. Anshul Kumar, for their suggestions during the initial stage of my thesis work. I would like to give my special thanks to my SRC (Student Research Committee) members Prof. Huzur Saran, Prof. Sanjiva Prasad and Dr. Swades De, for their valuable time and suggestions. I am greatly indebted to all faculty members of Department of Computer Science and Engineering, IIT Delhi, for their co-operation and support in particular, Prof. S. N. Maheswari, Prof. Naveen Garg and Prof. S. K. Gupta.

Many thanks to IIT Delhi authorities for providing me the research fellowship and necessary facilities all through the PhD program.

I am immeasurably grateful to my family who gently offered counseling and gave unconditional support at each and every point of my academic journey. I thank my husband Prof. S. Chandra Sekhara Rao for his support, guidance and encouragement which led me to complete this sojourn. It was the patience and support of my children, Bhavyesh and Bhaagyesh, which led me to complete this long journey. It is the blessings of my parents and in-laws that made me reach this milestone.

I like to express a heartfelt thank to all my lab mates and friends Swati Sharma, Nish Jain, Mona Jain, Dr. Rudra Mohan Tripathy, Chinmay Narayan, Shibashis Guha, Syamantak Das, Anuj Gupta, Yamuna Prasad, Manoj Gupta and Ankit Kapoor. I also thank my senior colleagues Dr. Smruti Padhy and Dr. Ayesha Choudhary.

Most importantly, I thank almighty God for his blessings in helping me reach this landmark.

New Delhi

L. Rajya Lakshmi

Abstract

This thesis is concerned with the design and analysis of handover management methods for WiMAX (Worldwide Interoperability for Microwave Access) based wireless mesh networks (WMNs). Even though many mobility management methods are developed for other wireless networks, the special characteristics of WMNs and the radio access technology used by WiMAX make it necessary to develop new methods for WiMAX WMNs. Based on the architectures of WMNs, they can be categorized into three classes: *Infrastructure* WMNs, *Client* WMNs and *Hybrid* WMNs.

In these networks flows are established between the nodes along multihop paths. Since WiMAX WMNs are Time Division Multiple Access (TDMA) based networks, to establish Quality of Service (QoS) constrained flows, routing and scheduling issues need to be addressed together. Whenever either the end nodes or some nodes on the path of a flow perform handover, to support the QoS requirements of the flow, a new path with the required bandwidth needs to be established as quickly as possible or it should be available instantaneously.

For WiMAX Infrastructure WMNs in which the mesh among the static Base Stations (BSs) act as a backbone, we propose a novel handover management technique called PaRtIal path establishment based handover Management tEchnique (PRIME). PRIME handles re-routing and scheduling issues of a handing over Mobile Node (MN) together through a concept called crossover node. In addition, to analyze the performance of PRIME, we propose a multi-dimensional Markov model

and give the theoretical upper and lower bounds on the call dropping probabilities of handoff calls.

In WiMAX Client WMNs, in which only MNs establish wireless meshes, any node on the path of a flow can perform handover. We propose a backup path management method for WiMAX Client WMNs. Each node along the current path between a source and a destination finds out backup paths with the required bandwidth in order to handle failure of the link to its downstream node and its own failure or handover. Also, we prove an important property of our proposed method.

For WiMAX Hybrid WMNs, in which both the static BSs and mobile MNs together establish wireless meshes, we propose a backup parent based handover management method. In these networks, to allocate bandwidth for inter-mesh flows, the BS maintains a routing tree of the mesh network. In our proposed method, to support the QoS requirements of inter-mesh flows in the mobile environments, nodes maintain alternate paths to the BS through a concept called *secondary parent*. Also, we prove two important properties of the proposed method.

In addition to developing handover management techniques for WiMAX WMNs, we also develop a distributed Base Station Cooperation (BSC) based handover management method for WiMAX Point-to-MultiPoint (PMP) networks to provide QoS to handover nodes at the last hop. In this method, the two BSs involved in the handover of an MN coordinate among themselves over the backbone (without any central controller) to continue QoS constrained service flows to the MN. A call admission control (CAC) algorithm is proposed to handle handover calls of various service classes according to their priorities. A bandwidth borrowing scheme which does not starve the lower priority calls is also proposed. A Markov model is developed to analyze the proposed CAC method and to obtain the approximated handover call dropping probabilities of various service classes.

The performance advantages of the proposed methods are established through simulation experiments.

Contents

Certificate	i
Acknowledgements	iii
Abstract	v
List of Acronyms	xiii
List of Tables	xvii
List of Figures	xix
List of Algorithms	xxiii
1 Introduction	1
1.1 Mobility Management: An Important Issue of WMNs	6
1.2 Types of Handovers	7
1.3 Handover Management in Infrastructure WMNs	8
1.4 Handover Management in Client WMNs	9
1.5 Handover Management in Hybrid WMNs	10
1.6 Handover Management in WiMAX Networks Deployed in Point-to-MultiPoint Mode	11

1.7	Contributions	13
1.8	Organization of the Thesis	15
2	Literature Survey	19
2.1	Fundamentals of WiMAX Networks	20
2.1.1	Centralized Scheduling	24
2.1.2	Distributed Scheduling	25
2.2	Handoff in Multihop Networks	26
2.2.1	Rerouting in Wired Backbone of Point-to-Multipoint Networks	27
2.2.2	Handoff in WiMAX WMNs	28
2.2.3	Handoff in Wi-Fi WMNs	29
2.2.4	Performance Analysis of Wireless Networks Using Markov Chains	30
2.3	Backup Path Management Methods for Ad Hoc Networks	30
2.4	Handover Management in WiMAX PMP Networks	35
2.5	CAC in WiMAX PMP Networks	37
3	Partial Path Establishment Based Handover Management Method for TDM Infrastructure WMNs	41
3.1	Introduction	42
3.2	Contributions	44
3.3	System Architecture	45
3.3.1	Routing and Scheduling Algorithm	45
3.3.2	Data Structures	47
3.3.3	Slot Allocation Rules	48
3.4	Partial Path Establishment Based Handover Management Technique for WiMAX Infrastructure WMNs	48
3.4.1	Partial Path Establishment Algorithm	49
3.4.2	Handover Protocol	55
3.5	RFP Based Handover Management Method (RFPHMT)	56

3.6	Probabilistic Analysis	57
3.7	Simulations and Results	65
3.7.1	Experimental Setup and Assumptions	66
3.7.2	Performance Comparison of PRIME and RFPHMT	67
3.7.3	Number of Control Slots vs. Handover Delay	73
3.7.4	Time vs. Packet Delivery Delay	74
3.7.5	Comparison of Simulation and Analytical Results	76
3.8	Conclusions	76
4	Backup Path Based Handover Management Method for TDM Client WMNs	79
4.1	Introduction	80
4.2	Contributions	81
4.3	Initial Path Establishment	82
4.4	Dynamic Backup Path Management with QoS Guarantees	83
4.4.1	Backup Path Establishment and Maintenance	84
4.4.2	Backup Path Extension Method	89
4.5	Local Maintenance of Link/Node Failure and Node Handover	91
4.5.1	Handling of Link Failure	91
4.5.2	Handling of Node Failure or Handover	91
4.6	Analysis	92
4.7	Simulation Results and Discussion	94
4.7.1	Speed vs. Average Packet Delivery Delay	95
4.7.2	Speed vs. Average Packet Delivery Ratio	96
4.7.3	Speed vs. Control Overhead	97
4.8	Conclusions	98
5	Backup Parent Based Handover Management Method for TDM Hybrid WMNs	101

5.1	Introduction	102
5.2	Contributions	106
5.3	Motivation for the Proposed Method	106
5.4	Handover Management in WiMAX Mesh Networks	108
5.4.1	Secondary Parent Selection	109
5.4.2	Finding Crossover Nodes	114
5.4.3	Preparation to Preserve QoS Requirements During Handovers	115
5.4.4	Handover of a Node	117
5.4.5	Prevention of Centralized Bandwidth Wastage	120
5.5	Analysis	122
5.6	Simulation	125
5.6.1	Speed vs. Average End-to-End Delay	126
5.6.2	Speed vs. Average End-to-End Throughput	126
5.6.3	Speed vs. Average Bandwidth Available for Distributed Flows	127
5.6.4	Speed vs. Average End-to-End Delay of Distributed Flows . .	129
5.7	Conclusions	130
6	Distributed Base Station Cooperation Based Handover Manage-	
	ment Framework for WiMAX PMP Networks	133
6.1	Introduction	134
6.2	Contributions	138
6.3	QoS Provisioning at the Last Hop in WiMAX PMP Networks During	
	Handover	139
6.3.1	Handover Process	140
6.3.2	Admission of Handover Calls	141
6.3.3	Cooperative Data Transmission	145
6.3.4	Delay Reduction (DR) Algorithm	148
6.4	Probabilistic Analysis of Call Admission Control Method	149
6.4.1	State transitions	150

6.4.2	Analytical Handoff Call Dropping Probability	151
6.4.3	Upper Bounds	158
6.4.4	Lower Bounds	158
6.5	Implementation	159
6.5.1	Performance of The Proposed Handover Method	160
6.5.2	Speed vs. Packet Drop Rate	162
6.5.3	Speed vs. Packet Delivery Delay	164
6.5.4	Performance of the Proposed CAC Method	164
6.5.5	Simulation vs. Analysis	168
6.6	Conclusions	168
7	Conclusions	171
	References	175
	Bio-Data	187