UNIVERSITI PUTRA MALAYSIA

CHANNEL ASSIGNMENT AND CONGESTION CONTROL IN MULTI-RADIO MULTI-CHANNEL WIRELESS MESH NETWORKS

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By

ARSLAN MUSADDIQ

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

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DEDICATION

In the name of Allah, Most Gracious, Most Merciful

This thesis is dedicated to:

My dearest parents for their unconditional love and support

And

My dearest siblings and sibling-in-law, for their whole-hearted and substantial support

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

CHANNEL ASSIGNMENT AND CONGESTION CONTROL IN MULTI-RADIO MULTI-CHANNEL WIRELESS MESH NETWORKS

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Wireless Mesh Network (WMN) has been growing rapidly due to its low cost and self-organizing feature. Capacity is one of the most important design goals for WMN. Overall network capacity can be improved by using the Multi-Radios with Multi-Channels (MR-MC). IEEE 8021.11a protocol provides 12 non-overlapping channels. In an MR-MC system, the fundamental research problem is the assignment of limited number of frequency channels to the respective radio interfaces. The ultimate objective of this channel assignment (CA) strategy is to reduce the overall network interference and link congestion. If nearby nodes operate on the same frequency channel, they can interfere with each other and produce congestion in the logical links. The MR-MC can provide more coverage area due to multi-hop forwarding and can offer more capacity by simultaneously operating on multiple radios. In this study, a Joint Channel Assignment and Congestion Control (JCACC) scheme for MR-MC WMN has been proposed.

The proposed method is based on node queue length information which as-signs the frequency channels based on queue threshold level that indicates the congestion status of the link. OMNET++ simulation tool and graph theory concept have been used to model the network. The algorithm does not allow the node to switch to the channels in which non-intended nodes are operating. JCACC schedules the channel selection mechanism and keeps record of previously congested channel to avoid assigning the same channel again. The simulation based experiment shows the CA for WMN in a quick, efficient and effective manner. The proposed JCACC mechanism provides a more sophisticated solution with 25.16% reduction in round-trip time (RTT) and 24.1% improvement in throughput as compared to previously proposed Distributed Congestion Aware Channel Assignment (DCACA) algorithm.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

UMPUKAN SALURAN DAN KAWALAN KESESAKAN DALAM RANGKAIAN JARINGAN WAYARLES BERBILANG RADIO BERBILANG SALURAN

Oleh

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Rangk aian Jaringan Wayarles (WMN) telah berkembang pe-sat kerana kosnya yang rendah dan ciri pengelolaan tersendiri. Kapasiti adalah salah satu matlamat reka bentuk yang paling penting untuk WMN. Kapasiti rangkaian keseluruhan boleh diperbaiki dengan menggunakan berbilang radio dengan berbil-ang saluran (MR-MC). Protokol IEEE 802.11a menyediakan 12 saluran tidak bertindih. Dalam sistem MR-MC, masalah asas penyelidikan adalah umpukan bilangan saluran frekuensi yang terhad kepada pengantara muka radio tertentu. Mat-lamat utama baqi strategi umpukan saluran (CA) ini adalah untuk mengurangkan gangguan rangkaian secara keseluruhan dan kesesakan pautan. Jika nod berdekatan beroperasi pada saluran frekuensi yang sama, ia boleh mengganggu satu sama lain dan menghasilkan kesesakan dalam pautan logik. MR MC boleh menyediakan kawasan liputan yang lebih disebabkan lon-catan berbilang penghantaran dan menawarkan lebih banyak kapasiti dengan beroperasi serentak pada beberapa radio. Dala-m kajian ini, skim umpukan saluran dan kawalan kesesakan bersa- ma (JCACC) untuk WMN berbilang radio berbilang saluran telah dicadangkan.

Kaedah yang dicadangkan adalah berdasarkan maklumat panjang baris giliran nod yang mene-tapkan saluran frekuensi berdasarkan tahap ambang giliran yang menunjukkan status kesesakan pautan. Alat simulasi OMNET ++ dan konsep teori graf telah digunakan untuk model rangkaian. Algoritma tersebut tidak membenarkan per-tukaran nod kepada saluran di mana nod yang tidak diingini sedang beroperasi. JCACC menjadualkan mekanisme pemili-han saluran dan menyimpan rekod sebelum kesesakan saluran untuk mengelakkan pengsunaan saluran yang sama. Eksperi-men berasaskan simulasi menunjukkan CA untuk WMN adalah cepat, efisyen dan efektif. Mekanisme JCACC yang dicadan-gkan memperuntukkan penyelesaian yang lebih canggih den-gan pengurangan sebanyak 25.16% dalam masa pulang-pergi dan peningkatan sebanyak 24.1% dalam pemprosesan berband-ing dengan algoritma umpukan saluran kesesakan sedar beredar yang dicadangkan sebelum ini.

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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 Master of Science

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LIST OF ABBREVIATIONS

WMN	Wireless Mesh Network
MR-MC	Multi-Radio Multi-Channel
JCACC	Joint Channel Assignment and Congestion
CA	Channel Assignment
PHY	Physical Layer
Wi-Fi	Wireless Fidelity
GW	Gateway Node
MANETS	Mobile adhoc Network
ESS	Extended Service Set
WDS	Wireless Distribution Set
MAC	Media Access Control
SR-MC	Single-Radio Multi-Channel
CST	Channel Switching Delay
MAC	Media Access Control
~Real	Real Delay
~Phy	Physical Channel Switching Time
~HDWR	Hardware Register Reconfiguration Time
~MAC	MAC Layer Packets Processing Time
MIMO	Multiple-Input Multiple=Output
NP-HARD	Non-deterministic Polynomial Hard
BFS−CA	Breadth First Search Channel Assignment
MCG	Multi Radio Conflict Graph
MCCA	Maxflow-based Centralized Channel
CTA	Centralized Tabu-based Algorithm
DGA	Distributed Greedy Algorithm
CLICA	Connected Low Interference Channel
CCA	Cluster Channel Assignment
CH	Cluster Head
FNI	Fractional Network Interference
CCAS	Cluster-Based Channel Assignment
INSTC	Interference Survivable Topology Control
LPI	Link Potential Interference
LPImin	Link Potential Interference Minimum
CoCAG	Partially Overlapped Channel Assignment
NE	Nash Equilibrium
PoA	Price of Anarchy
UNET	Network Utility
ADCA	Adaptive Dynamic Channel Allocation
UDP	User Datagram Protocol
NIC	Network Interface Controller
LA−CA	Load Aware Channel Assignment
BSCA	Balanced Static Channel Assignment
PDCA	Packing Dynamic Channel Assignment
GA	Genetic Algorithm
MCR	Multi-Channel Routing
DCACA	Distributed Congestion-Aware Channel
MCI−CA	Matroid Cardinality Intersection Channel

RCL	Joint Routing, Channel Assignment
WLAN	Wireless Local Area Network
AP	Access Point
BSS	Base Service Set
DS	Distribution System
GPS	Global Positioning System
IP	Internet Protocol
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
AODV	Ad hoc On-Demand Distance Vector
DSR	Dynamic Source Routing
OLSR	Optimized Link State Routing
TCP	Transmission Control Protocol
DYMO	Dynamic MANET On-demand Routing
OFDM	Orthogonal Frequency-division Multiplexing
AQM	Active Queuing Management
ACK	Acknowledgment
DLL	Data Link Layer
RTT	Round Trip Time
SINR	Signal to Interference Plus Noise Ratio

CHAPTER 1

INTRODUCTION

1.1 Introduction

IEEE 802.11s is an evolving standard for Wireless Mesh Net-work (WMN) (Hiertz, 2010). It exhibits the characteristics of IEEE 802.11 (Wi-Fi) based wireless local area network and can be used for several applications, e.g., last mile connectivity of ISPs, broad-band home networking, building automation and metropolitan area networking (Yarali, 2008; MeshDynamics, 2006). WMN has been growing rapidly be-cause of its low cost and self-organizing feature. It is a next generation wireless network that is made up of a number of stationary mesh routers and mesh clients (Akyildiz, 2004). The mesh routers function as the backbone of the network, which collect and relay the tra ¥c generated by the mesh clients. Mesh routers are usually static and have no power constraint as opposed to mesh clients. Apart from routing, the mesh routers are also responsible for bridging to the Internet. The router that is connected to the internet is called Gateway node (GW) which utilizes a high speed wired connection. Mesh clients also act as a router that propagates packets on behalf of the other nodes that are not within the direct communication range of their destination. Message is transmitted to and from the client in a multi-hop fashion that avoids blocked and broken path by forming a mobile ad hoc network (MANET) that is capable of self-forming, self-healing and self-organizing. The nodes in the backbone network adhere to the IEEE 802.11 standard wireless technology to establish radio links and maintain net-work connectivity despite link failures (Akyildiz, 2004; Pathak, 2011; Benyamina, 2012; Riggio, 2008).

Packets are propagated to the internet through multiple radios in a multi-hop fashion. Capacity is one of the most important design goals for WMN. The overall network capacity can be improved using the Multi-Radios with Multi-Channels (MR-MC) (Adya, 2004). In MR-MC a node is equipped with multiple radios that can operate on distinct frequency channels. The neigh-boring nodes can communicate only if one of the radios is operating on same frequency channel.

In WMN, assigning a multiple channels to the multiple radios interfaces in such a way that they produce less congestion and interference is a key factor in optimizing the network throughput.

7KH SK\VLFDO OD\HU 3+< VSHFL¿FDWLRQ LQ ,(((SU -foro allows the use of multiple non-overlapping channels simultaneously (IEEEWorkingGroup, 1999). Neighbouring radios operating on overlap-ping channels interfere with each other, a ¡ecting the capacity of WMN. Hence, by using MR-MC such that the operating frequencies do not interfere with each other can result in improved capacity network. When the packet arrival rate exceeds; the queue management system in a wireless router manages the queue length by inserting and dropping the packets in the queue. The queue management technique can be classi ¿ed into two categories. (1) Reactive

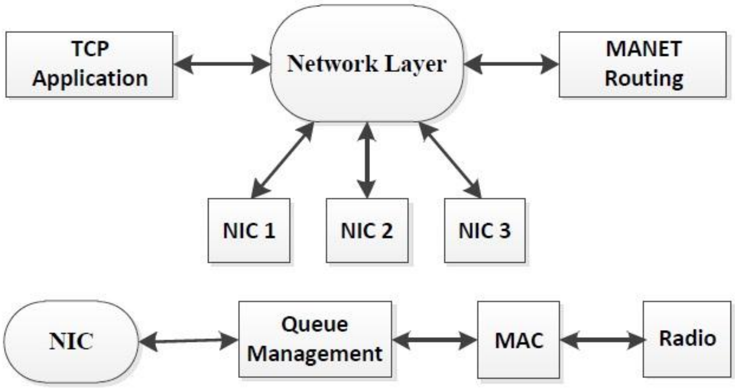

Figure 1.1: Building Blocks of Wireless Node

(passive) queue management. (2) Proactive (active) queue management (AMQ). The ¿rst method does not prevent packet drop before bu ¡er is full whereas AMQ detects the congestion before the limit of the bu ¡er have been reached. Drop tail and Random Early Detection (RED) are two widely used congestion control mechanism employed in a wireless router (Pibiri, 2009). The Transmission Control Protocol (TCP) and queue management algorithms are related to each other. TCP is layer-4 protocol that works along with the Internet Protocol (IP) which enables the server and client to establish a FRQQHFWLRQ EHWZHHQ WKHP 7&3 GLYLGHV WKH SDFNHWV data by sending acknowledgement (ACK) of all the packets that is sent.

Figure 1.1 illustrates the building blocks of wireless node. In general, a wireless node consist of a number of Network Inter-face Controllers (NICs), connected with network layer. Inside NIC, there is a queue management system, Media Access Con-trol (MAC) and radio. The number of orthogonal frequency channels in IEEE 802.11 frequency band is limited. For ex-ample, The IEEE 802.11 b/g protocol provides three non-overlapping channels (1, 6, and 11). Similarly, IEEE 802.11a has 12 non-overlapping channels (Hiertz, 2010). Due to the limited number of channels, some NICs may operate on same frequency band. If these NICs are operating closer to each other, they will produce considerable amount of interference which causes the congestion in the network (Rangwala, 2008). Hence, capacity and over all data rate of the network gets e ¡ected. Therefore, congestion aware CA is essentially to increase the network throughput.

1.2 Problem Statement and Motivation

Wireless Mesh Network (WMN) has been growing rapidly be-cause of its low cost and self-organizing feature. Deployment of MR-MC is considered a simpler option for WMN, mainly because it can provide a multiple paths for data transmission. Hence, increases the overall capacity and throughput with low cost. However, IEEE 802.11 protocol provides limited number of orthogonal frequency channels therefore some nearby radios may operate on same frequency band. In MR-MC system, the fundamental research problem is the assignment of channels to the respective radio interfaces. The ultimate objective of this channel assignment (CA) strategy is to reduce co-channel interference and link congestion. The reduction in conges-tion and co-channel interference on a logical link in WMN can be achieved by e ¥ciently assigning these limited numbers of Allocating a multi-access channels to a multiple users with-out causing co-channel interference and congestion is a key challenge in WMN. This motivates us to highlight the importance of CA approach for enhancing the network performance by utilizing limited channel resources. In light of this issue, this research will focus on assigning the channels based on queue mechanism and link congestion information. The pro-posed CA mechanism will provides a more sophisticated solution with much better results in terms of Round-Trip Time (RTT), throughput and number of overheads, but in practice it can be very complex for the overall network connectivity.

1.3 Aims and Objectives

Deployment of MR-MC is considered a simpler option for WMN, mainly because it can provide a multiple paths for data transmission. Hence, it increases the overall capacity and throughput with low cost. However, IEEE 802.11 protocol provides limited number of orthogonal frequency channels therefore some nearby radios may operate on same frequency band. The aim of this research is to present an e ¡ective solution to assign a limited number of orthogonal frequency channels to the wireless nodes to reduce congestion and co-channel interference on logical link in WMN equipped with multiple radios while producing minimum control tra ¥c. To achieve this goal, a distributed, Joint Channel Assignment and Congestion Control (JCACC) scheme is introduced. The proposed method assigns frequency channels based on queue threshold level which indicates the congestion status of the link. The algorithm features a congestion table mechanism which keeps record of previously congested channel to avoid assigning them again.

With the assistance of simulation modeling, the performance metrics in Multi-Radio Multi-Channel WMN of the proposed architecture are evaluated and acquired results are compared with the well-known CA algorithm, namely Distributed Congestion-Aware Channel Assignment (DCACA). Thus, this validates the e ¡ectiveness of the proposed architecture. Moreover, through simulation the e ¥ciency of the proposed CA algorithm is demonstrated. Therefore, the objectives of this research can be summarized as follows:

- To propose, design and simulate a dynamic distributed CA algorithm to improve the performance of WMN by improving queue mechanism and reducing link congestion.
- To test and analyze the performance of proposed JCACC method, which is based on queue mechanism and link congestion information.

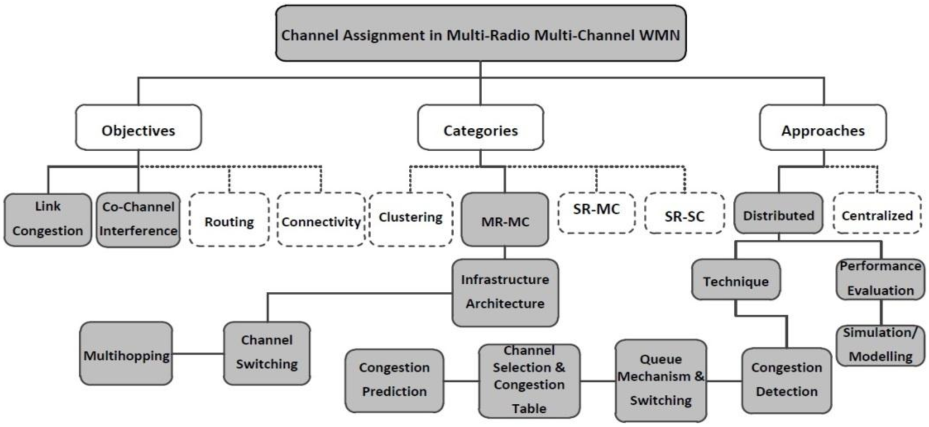

Figure 1.2: Study module

1.4 Thesis Scope

To reduce congestion and increase the capacity of WMN, many researchers introduced techniques such as the use of directional antenna, smart antenna, Multiple-Input Multiple-Output techniques and MR-MC method and a limited number of papers focus on CA techniques. However, the MR-MC method is a more practical solution in increasing capacity and minimizing link congestion as each node has simultaneous communication via different radios. Approximately, all current research trends on improving the capacity of WMN are towards MR-MC deployment. However, a concerted effort should be taken in assigning the multiple channels to multiple radios that maintain the performance by reducing co-channel interference and congestion in the logical l inks. Hence, the focus of this dissertation is on examining the CA mechanism in MR-MC WMN. An efficient CA technique is proposed which is based on queue length mechanism. .Moreover, special emphasis is placed on the channel selection technique which is based on congestion table information. Also, special emphasis is placed on pro-visioning appropriate algorithm for alleviating overhead and performance degradation resulting from continues switching and computational complexity.

1.5 Study Module

The summary of chosen approach in this dissertation is illustrated in Figure 1.2, where the solid lines along with the colored boxes denote the followed direction to achieve determined objectives and the dashed lines shows the other research directions of CA technique which have not been covered in this thesis.

1.6 Thesis Organization

The thesis structure proceeds as follows: Chapter 1 provides a brief introduction of WMN and its issues of reducing co-channel interference and link congestion using MR-MC systems, especially through CA procedure, which is the main focus of this thesis. Problem statement, R E M H F W L Y H V D Q G V F R S H R I W K H W K H V L V D U H F O D U

Chapter 2 highlights the importance of CA technique as a promising network improvement solution for MR-MC WMN. Moreover, it provides a detailed analysis of the need of MR-MC, interference model and constraints of CA. The di ¡erences between di ¡erent constraints of CA along with classical CA mechanisms (both distributed and centralized) are deliberated. The most commonly used CA techniques are presented and a comparison is made between existing techniques. This chapter places an emphasis on the need for an e ¥cient channel switching procedure and in depth analysis of interference models be adopted in WMN. The chapter also discussed the advantages and limitations of the proposed mechanisms. Fi-nall y, by focusing on the CA as a good technique for network improvement, this chapter provides a review on the CA in MR-MC WMN.

Chapter 3 is divided into four main sections. A brief overview is followed by a section discussing a modeling of multi-hop W MN. Then, the selected research methodology approach which is based on simulation is presented in detail in third section. Proposed approach, mathematical formulas, assumptions and desired metrics for CA performance T X D Q W L ¿ F D W L R Q D U H S U R vided in third section as well. Simulation environment related assumptions, performance measures and simulation scenarios are described thoroughly in the fourth section. The last section summarizes this chapter.

In Chapter 4, the acquired results from the simulation model over the proposed solution and algorithms are delineated. The outcomes have been utilized to evaluate the e ¡ectiveness of the o ¡ered CA algorithms to enhance the performance of the network by comparing results with benchmark method.

Finally, in Chapter 5, the conclusion is drawn followed by the thesis contributions and recommended future research directions.

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