



AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electronics and Communications Engineering Department

**Enhancement Proposals of Routing Protocols
Performance in Cognitive Radio Networks**

A Thesis

Submitted in partial fulfillment of the requirements of the degree of
Doctor of Philosophy in Electrical Engineering
(Electronics and Electrical Communications Engineering)

Submitted By

Eng. Faisal Awad Mahgoub Mohamed

B.Sc. of Electrical Engineering Omdurman Islamic University, Sudan, 1998

M.Sc. of Electrical Engineering (Electronics and Communications Engineering)

Khartoum University, Sudan, 2006

Supervised By

Prof. Dr. Salwa Hussein EL-Ramly

Dr. Hussein Abd El Atty Elsayed

Cairo, 2017



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING

Examiners Committee

Name: Faisal Awad Mahgoub Mohamed

**Thesis: Enhancement Proposal of Routing Protocol Performance in
Cognitive Radio Networks**

Title, Name, and Affiliation	Signature
Prof. Dr. Hesham Mohamed Abd Elghaffar Elbadawy National Telecommunication Institute. NTI	
Prof. Dr. Hossam Mahmoud Fahamy Ain Shams University, Faculty of Engineering, Computer Engineering and System Dept.	
Prof. Dr. Salwa Hussein El-Ramly Ain Shams University, Faculty of Engineering, Electronics and Communications Engineering Dept.	
Dr. Hussein Abd Atty Elsayed Ain Shams University, Faculty of Engineering, Electronics and Communications Engineering Dept.	

Statement

This thesis is submitted to Ain Shams University for the degree of Doctor of Philosophy in Electrical Engineering (Electronics and Communications Engineering).

The work included in this thesis is carried out by the author at the Electronics and Communications Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis is submitted for a degree or a qualification at any other university or institution.

Name: Faisal Awad Mahgoub Mohamed

Signature:

Date: 11/10/2017

Researcher Data

Name of Researcher	Faisal Awad Mahgoub Mohamed
Date of Birth	27/4/1973
Place of Birth	Port Sudan, Sudan
First University Degree	B.Sc. in Electrical Engineering
Name of University	Omdurman Islamic, Sudan
Date of Degree	August , 1998
Second University Degree	M.Sc. in Electrical Engineering
Name of University	Khartoum University, Sudan
Date of Degree	May , 2006
Current Job	Lecturer in the Department of Electronics and communication, Faculty of Engineering, Red Sea university, Port Sudan-Sudan

Thesis Summary

The radio spectrum is one of the most heavily employed and costly natural resources due to the rapid growth of wireless technologies. The cognitive Radio (CR) has been proposed as a promising technology to solve the problem of radio spectrum scarcity and spectrum underutilization by allowing unlicensed users to opportunistically access the available licensed bands. In Cognitive Radio Ad-Hoc Networks (CRAHNs), which operate with absence of centralized management, data routing is one of the most important issues that needs intensive study and to be taken into account. Moreover, in CRAHNs the routing protocol is very challenging due to cognitive users (CUs) mobility, primary users (PUs) activity or mobility, link degradation or node fault. Also, the network performance is severely degraded due to a large number of path failures. In addition, with the unique characteristics of CRAHNs, another main issue is related with the establishment of appropriate path for data transmission which does not cause harmful interference to PUs' transmission and reflect accurate path characteristic in order to improve network performance.

In this thesis we study and analyze three of the most common CRAHN routing protocols, namely, Cognitive Ad-hoc On-demand Distance Vector (CAODV), SpEctrum Aware Routing protocol for Cognitive ad-Hoc networks (SEARCH), and Weighted Cumulative Estimation of Transmission Time (WCETT). The analysis is carried out using NS-2 simulator to evaluate and compare the network performance under the same environment conditions with varying number of nodes to study the effect of nodes density and traffic load.

Also, based on Cognitive Ad-hoc On-demand Distance Vector (CAODV) routing protocol, a new routing protocol named, Mobility and Activity Based Routing Protocol (MABRP) is proposed. In the proposed protocol we concentrate on reliability and expiration time of links. The proposed protocol performance is evaluated via NS-2 simulator. The used metrics for performance comparison between the MABRP and CAODV routing protocols are packet delivery ratio (PDR), end-to-end delay, hop count, and routing overhead under the same environment conditions with varying number of PUs in different CUs mobility scenarios. The results, observed that the MABRP provides better performance in terms of PDR and providing lower average end-to-end delay with a slight increase in overhead.

The performance of MABRP and Cognitive Ad-hoc On-demand Distance Vector (CAODV) are evaluated in two different scenarios: mobile PUs scenario, and static PUs scenario. The availability of a routing channel dynamically varies in time due to the changes of the PUs relative positions. The performance evaluation is carried out using NS2 simulator. Finally, we evaluate the performance of MABRP against three other protocol approaches CAODV, SpEctrum Aware Routing for Cognitive ad-Hoc networks (SEARCH), and Weighted Cumulative Estimation of Transmission Time (WCETT). Simulation results reveal that the proposed algorithm provides better performance in terms of higher PDR, with a slight increase in routing overhead, and delay especially in Low PUs activity.

Key words: Cognitive Radio Networks; CRAHNs; Routing Protocol; Mobility; Primary Users' Activity.

Thesis Supervisors:

Prof. Dr. Salwa Hussein EL-Ramly

Dr. Hussein Abd El Atty Elsayed

Acknowledgments

All gratitude to ALLAH

It is a pleasure to take this opportunity to convey thanks to those who made this thesis possible with their kindness and support.

I would like to express my deepest appreciation and thanks to my advisor, Prof. Dr. Salwa El-Ramly, and Dr. Hussein A. Elsayed, for encouraging my research and for guiding me all the way through my Ph.D studies. Without him, this thesis would not have been completed. Moreover, Prof. Dr. Salwa El-Ramly, and Dr. Hussein A. Elsayed, had a great influence on my scientific research life because of their scientific research attitude. Actually, it would have been difficult for me to complete this thesis without their assistance.

My deepest love and thanks to my mother and father for supporting my studies with enthusiasm and encouragement. Also, I would like to express my gratitude to my family for their never ending support, my lovely wife Dr. Nada and my kid Eyad and Ahmed for understanding, and encouragement during the preparation of this thesis.

Tables of Contents

	List of Figures.....	v
	List of Tables.....	viii
	List of Abbreviation.....	ix
	List of Symbols.....	xii
	 Chapter 1: Introduction.....	 1
1.1	Introduction.....	1
1.2	Motivation.....	3
1.3	Problem Statement.....	4
1.4	Thesis Contributions.....	5
1.5	Thesis Organization.....	6
1.6	Puplications Extracted from the Thesis.....	7
	 Chapter 2: Overview of Cognitive Radio Networks..	 8
2.1	Introduction.....	8
2.2	Cognitive Radio Technology.....	10
2.2.1	Cognition Capability of a Cognitive Radio.....	11
2.2.1.1	Spectrum Sensing.....	11
2.2.1.2	Spectrum Analysis.....	12
2.2.1.3	Spectrum Access Decisions.....	13
2.2.2	Reconfigurability of A Cognitive Radio.....	13
2.3	Cognitive Radio Networks.....	14

2.4	Cognitive Radio Ad-Hoc Networks.....	17
2.4.1	Classical Ad-hoc Networks vs. CRAHNs.....	18
2.4.2	Spectrum Management in CRAHNs.....	19
2.4.3	Challenges of CRAHNs.....	24
2.5	Summary.....	25

Chapter 3: Routing Techniques in Cognitive Radio

	Ad-Hoc Network.....	27
3.1	Introduction.....	27
3.2	Routing Challenges and Design Issues in CRAHNs....	27
3.3	Routing Protocols in CRAHNs.....	29
3.3.1	Proactive Approach.....	31
3.3.2	Reactive Approach.....	32
3.3.3	Hybrid Approach.....	33
3.3.4	Special Feature Routing.....	34
3.3.4.1	Link Quality.....	34
3.3.4.2	Geografic Forwarding.....	35
3.3.4.3	Spectrum Awarenesss.....	35
3.3.4.4	Primary Users Avoidance.....	36
3.3.4.5	Based on Clustering.....	36
3.4	Recent Routing Approach in CRAHNs.....	37
3.5	Metrics for Performance Evaluation.....	42
3.6	Summary.....	44

Chapter 4: Evaluation of Three Related Routing

	Protocols.....	45
4.1	Introduction.....	45
4.2	Conitive Ad-Hoc On-demand Distance Vector Routing..	46

4.3	Spectrum Aware Routing Protocol for Cognitive ad-Hoc Networks.....	51
4.3.1	Route Enhancement	56
4.4	Weighted Cumulative Estimation of Transmission Time.....	56
4.5	Simulation Model.....	58
4.5.1	Cognitive Radio Cognitive Network (CRCN) patch and NS2 Simulator.....	60
4.5.2	Simulation Setup.....	60
4.5.3	Mobility Model.....	61
4.5.4	Selected Performance Metrics for Evaluation.....	63
4.5.5	Results & Discussions.....	63
4.5.5.1	Results of Firest Scenario.....	65
4.5.5.2	Results of Second Scenario.....	68
4.5.5.3	Result of Third Scenario.....	71
4.6	Conclusion.....	74

Chapter 5: Proposal of the Mobility and Activity

	Based Routing Protocol.....	75
5.1	Introduction.....	75
5.2	Mobility and Activity Based Routing Protocol (MABRP).....	76
5.2.1	Principle of MABRP.....	77
5.2.2	Common Control (Coordinate) Channel (CCC) and MABRP.....	79
5.2.3	Link Expiration Time calculation in MABRP.....	80
5.3	Simulation Model Setup.....	84
5.3.1	Results & Discussions.....	86
5.4	Effect of PUs Mobility in CRAHNs using MABRP.....	90

5.4.1	Link Expire Time (LET) Calculations.....	90
5.4.2	Simulation Model Setup.....	93
5.4.3	Results & Discussions.....	96
5.4.3.1	Results of First Scenario.....	96
5.4.3.2	Results of Second Scenario.....	100
5.5	Performance Evaluation of MABRP against CAODV, SEACH, and WCETT.....	104
5.5.1	Simulation Setup.....	104
5.5.2	Results & Discussions.....	105
5.6	Conclusion.....	108
	Chapter 6: Conclusion & Future Work.....	109
6.1	Conclusion.....	109
6.2	Future Work.....	110
	References.....	112

List of Figures

Figure 2.1: Spectrum utilization.....	9
Figure 2.2: The Spectrum hole concept.....	10
Figure 2.3: Functional architecture of a cognitive radio.....	11
Figure 2.4: Cognitive radio network architecture.....	16
Figure 2.5: CRN architecture for: (a) infrastructure based CRNs, and (b) infrastructure less CRNs (CRAHNs).....	17
Figure 2.6: CRAHNs with its cognitive cycle.....	20
Figure 3.1: Routing protocol of CRAHNs.....	30
Figure 3.2: Classification of routing protocols for CRAHNs.....	34
Figure 4.1: RREQ packet flow chart.....	47
Figure 4.2: RREP packet flow chart.....	48
Figure 4.3: RERR packet flow chart	50
Figure 4.4: Greedy geographic forwarding mechanism.....	52
Figure 4.5: PU avoidance mechanism.....	52
Figure 4.6: Joint channel-path optimization mechanism.....	53
Figure 4.7: Three sub-fields of computer simulation.....	59
Figure 4.8: Sample simulation of CRAHNs environment with 14 PUs..	61
Figure 4.9: The PDR versus CUs number in the first scenario.....	66
Figure 4.10: The hop count versus CUs number in the first scenario.....	66
Figure 4.11: The routing overhead versus CUs number in the first scenario.....	67
Figure 4.12: The Delay versus CUs number in the first scenario.....	68
Figure 4.13: The PDR versus PUs number in the second scenario.....	69

Figure 4.14: The hop count versus PUs number in the second scenario.	70
Figure 4.15: The routing overhead versus PUs number in the second scenario.....	70
Figure 4.16: The delay versus PUs number in the second scenario.....	71
Figure 4.17: The PDR versus CUs number in the third scenario.....	72
Figure 4.18: The hop count versus CUs number in the third scenario.....	72
Figure 4.19: The routing overhead versus CUs number in the third scenario.....	73
Figure 4.20: The delay versus CUs number in the third scenario.....	73
Figure 5.1: LET1 between CUs and LET2 between CU and PU.....	77
Figure 5.2: Flow chart of MABRP operation.....	79
Figure 5.3: Two CUs movement diagram after t seconds.....	81
Figure 5.4: The PDR versus PUs number in the static PUs.....	87
Figure 5.5: The hop Count versus PUs number in the static PUs.....	88
Figure 5.6: The routing over-head versus PUs number in the static PUs..	89
Figure 5.7: The delay versus PUs number in the static PUs.....	89
Figure 5.8: The CUi and PUj movement diagram after t seconds.....	91
Figure 5.9: The PDR versus PUs number in dynamic PUs.....	97
Figure 5.10: The hop count versus PUs number in dynamic PUs.....	89
Figure 5.11: The routing over-head versus PUs number in dynamic PUs.	99
Figure 5.12: The delay versus PUs number in dynamic PUs.....	100
Figure 5.13: The PDR versus PUs number in static PUs.....	101
Figure 5.14: The hop count versus PUs number in static PUs.....	102
Figure 5.15: The routing over-head versus PUs number in static PUs.....	102
Figure 5.16: The delay versus PUs number in static PUs.....	103
Figure 5.17: The summarized PDR versus PUs number using MABRP...	104
Figure 5.18: The PDR versus PUs number in static PUs.....	105
Figure 5.19: The hop count versus PUs number in static PUs.....	106

Figure 5.20: The routing over-head versus PUs number in static PUs.....	107
Figure 5.21: The delay versus PUs number in static PUs.....	107

List of Tables

Table 3.1: Comparisons between routing protocols for CRAHNs.....	39
Table 4.1: Simulation parameters.....	64
Table 5.1: Simulation mobility ranges static PUs scenario.....	85
Table 5.2: Simulation parameters in static PUs scenario.....	85
Table 5.3: Simulation mobility ranges in dynamic PUs scenario.....	95
Table 5.4: Simulation parameters in dynamic PUs scenario.....	96