A SMART SPECTRUM ACCESS TECHNIQUE FOR DYNAMIC MULTI-HOP ROUTING IN COGNITIVE RADIO-BASED DISASTER RESPONSE NETWORKS

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A thesis submitted
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DECLARATION

I declare that this thesis entitled " A Smart Spectrum Access Technique for Dynamic Multi-Hop Routing in Cognitive Radio Based Disaster Response Networks" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : ....

Name : ....Khaled F. I. Alaqad......................

Date : ....15/07/2022............................

APPROVAL

I declare that I have read this thesis and, in my opinion, this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature : ....

Name : Prof. Ts. Dr. Burhanuddin Bin Mohd Aboobaider

Date : ....15/07/2022...............................

DEDICATION

This dissertation is dedicated to my late father, whose inspiration paved the way to pursue my doctoral studies. Although he is not around to bless my success, his soul is always with me. I also dedicate this achievement to my beloved mother whose supplications and prayers involved me all the time, this journey would not have been made without encouragement and support given by my dear brothers and sisters. My gratitude to my beloved wife and sons whose struggle and support always gave me the power to move ahead, to all my nephews, nieces, friends, and colleagues, for them, I dedicate this research.

ABSTRACT

Disasters frequently occur across both developed and developing countries, the existing communication systems are highly prone to malfunction and damage, these systems are necessary to coordinate disaster relief efforts, therefore, it is extremely important to autonomously deploy a network that can provide communication services for both victims and first responders in the first 48 critical hours, these consequences along with other distinct routing requirements imposed by disaster occurrence necessitate the availability of a Cognitive Radio based Disaster Response Network CR-DRN operated with a routing protocol that is designed considering the emerging routing requirements and variations imposed by disaster, In Cognitive Radio Network, the allocation of spectrum is a crucial process which affects the communication. The allocation of the spectrum during emergencies is a challenging task, which is not yet solved. In this research, a novel Smart Agent Aided Scalable Spectrum Access (SASSA) technique for Cognitive Radio networks CRN-based disaster networks is proposed in which the overall network is considered as hexagonal cells to achieve better coverage. The disaster-based cluster formation is carried out to locate the disaster region in the cell. The efficient spectrum sensing is performed by deploying Smart Spectrum Agents (SSAs) and the sensing is carried out using Enhanced Bayesian Compressive Sensing (EBayesCS). The cognitive base station implements the Combined Quality of Service Score (CoQS) to rank the available channels. A novel Dual–Environment Deep Deterministic Policy Gradient (DE-D2PG) is proposed to decide the QoS switching based on spectrum availability and data emergency. The multi-hop route selection is executed using the Hybrid Spiral Penguin Optimization (HSPO) algorithm based on the decision made by the DE-D2PG. The allocation of spectrum is carried out by performing one-to-K matching which enables multiple channels to the Secondary Users (SUs) for effective transmission. Further, the deployment of Mobile Cognitive Base Stations (McBS) using the Dynamic Rule-Based Movement (DRUM) algorithm facilitates the effective transmission of data with low latency. The proposed SASSA model was evaluated using NS-3.26 through a comparative analysis with existing most recent approaches, the results of this analysis proved that SASSA empowered CR-DRNs with higher data ratios as network size and sensing time increase with minimum standard deviation and Min-Max variations of 1.02-1.2 Mbps. The proposed technique was also proved to be scalable, reliable and spectrum-efficient by achieving minimum delay, maximum probability of detection, maximum spectrum utilization and maximum throughput compared to other approaches concerning both network size and sensing time.

TEKNIK CAPAIAN SPEKTRUM PINTAR UNTUK PENGHALAAN DINAMIK HOP PELBAGAI DALAM RANGKAIAN MAKLUMBALAS BERASASKAN BENCANA RADIO KOGNITIF

ABSTRAK

Bencana sering berlaku di semua tempat, tanpa mengira negara maju atau negara yang sedang membangun. Sistem komunikasi yang sedia ada digunakan untuk penyelarasan bantuan bencana adalah sangat terdedah kepada kerosakan dan kepincangan. Oleh itu, adalah sangat penting untuk menggunakan rangkaian yang mampu menyediakan perkhidmatan komunikasi untuk kedua-dua pihak mangsa dan responden terutamanya dalam tempoh kritikal 48 jam pertama. Hal yang demikian itu menyebabkan keperluan penghalaan yang berbeza yang dikenakan oleh kejadian bencana memerlukan persiapan Rangkaian Bencana Respons CR-DRN berdasarkan Radio Kognitif yang dikendalikan dengan protokol penghalaan yang dirancang dengan mempertimbangkan keperluan dan variasi penghalaan yang muncul disebabkan oleh bencana. Dalam Rangkaian Radio Kognitif, peruntukan spektrum adalah proses penting yang mempengaruhi komunikasi khususnya peruntukan spektrum semasa situasi kecemasan yang merupakan cabaran yang masih belum dapat diselesaikan. Dalam penyelidikan ini, teknik baru Smart Agent Aided Scalable Spectrum Access (SASSA) untuk rangkaian bencana berdasarkan CRN dicadangkan di mana keseluruhan rangkaian dianggap sebagai sel heksagon untuk mencapai liputan yang lebih baik. Pembentukan kelompok berdasarkan bencana dilakukan untuk mencari kawasan bencana di dalam sel. Sensing spektrum yang cekap dilakukan dengan menggunakan Smart Spectrum Agents (SSA) dan disebarkan dengan menggunakan Sensing compressive bayesian (EBayesCS). Stesen pangkalan kognitif menerapkan Combined QoS Score (CoQS) untuk memeringkatkan saluran yang telah tersedia. Dual – Environment Deep Deterministic Policy Gradient (DE-D2PG) adalah kaedah novel yang akan memutuskan pertukaran QoS berdasarkan spektrum dan data kecemasan. Pemilihan saluran hop pelbagai pula dilaksanakan dengan menggunakan algoritma Hybrid Spiral Penguin Optimization (HSPO) berdasarkan keputusan yang dibuat oleh DE-D2PG di dalam penyelidikan ini. Peruntukan spektrum dilakukan dengan melakukan pemadanan one-to-K yang memungkinkan banyak saluran ke pengguna sekunder untuk pemindahan yang berkesan. Selanjutnya, penyebaran Mobile Cognitive Base Stations (McBS) menggunakan algoritma Dynamic Rule Based Movement (DRUM) memudahkan penghantaran data dengan kependaman yang rendah. Model SASSA yang dicadangkan dinilai menggunakan NS-3.26 melalui analisis perbandingan dengan pendekatan terkini yang sedia ada, hasil analisis ini membuktikan bahawa SASSA memperkasakan CR-DRN dengan nisbah data yang lebih tinggi apabila saiz rangkaian dan peningkatan masa penderiaan dengan sisihan piawai minimum dan Min- Variasi maksimum 1.02-1.2 Mbps. Teknik yang dicadangkan juga terbukti boleh diskalakan, dipercayai dengan spektrum cekap bagi mencapai kelewatan minimum, kebarangkalian pengesanan, penggunaan spektrum dan daya pemprosesan maksimum berbanding pendekatan lain berkaitan kedua-dua saiz rangkaian dan masa pengesanan.

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LIST OF SYMBOLS

Cn	-	Number of network clusters
γ_x	-	Bayesian model unknown variable
w’	-	Available alternate solution
$\widetilde{w}$	-	Underdetermined system
Z	-	Scalar positive
$s(n)$	-	Spectrum sensing
R_p	-	Channel rank
ζ	-	Agent state
$\zeta\,'$	-	Future time step agent state
α	-	Agent action
α'	-	Future time step agent action
γ	-	Agent reward
φ	-	Agent penalty
r	-	Discount factor
Q^{Π}	-	Expected reward
Q^{*}	-	Optimal
Ω	-	Approximator parameters
L	-	Loss function
c_i	-	Multi-point spiral model

c^*	-	Center set
N_{max}	-	Maximum iteration
AF	-	Attractiveness factor
ω	-	Search space area
$\mathfrak{I}$	-	Spiral model search parameter 1
θ	-	Spiral model search parameter 2
∂	-	Velocity of McBS
σ	-	Heading angle of McBS
$\ddot{K}$	-	UAV computed kinematics
η	-	Traffic density
ϑ	-	Damage level

LIST OF ABBREVIATIONS

2LR5G	-	2-Layer Routing for Wireless 5G Networks
ADC	-	Analogue to Digital Conversion
ANNs	-	Artificial Neural Network/ Networks
AODV	-	Ad Hoc On-Demand Distance Vector
Bi-PUF	-	Binate Physically Unclonable Function
cBS	-	Cognitive Base Station
CCC	-	Common Control Channel
CCSS	-	Centralized Cooperative Spectrum Sensing
CEEA	-	Cognitive Energy-Efficient Algorithm
COBRA	-	Cost-Based Routing Assist System
C-OLSR	-	Cognitive Radio Assisted Optimized Link State Routing Protocol
CoQS	-	Combined Quality of Service Score
CR	-	Cognitive Radio
CRAHNs	-	Cognitive Radio Based Ad Hoc Networks
CR-DRNs	-	Cognitive Radio Based Disaster Response Networks
CR-IoT		Cognitive Radio Based Internet of Things
CRNs	-	Cognitive Radio Network/ Networks
CR-WRAN	-	Cognitive Radio Wireless Regional Area Network
C-TRP	-	Tree Routing Protocol for Cognitive Radio Network
CUs	-	Cognitive User/ Users
CWN	-	Cognitive Wireless Networks

DANs	-	Disaster Area Networks
DE-D2PG	-	Dual Environment Deep Deterministic Policy Gradient
DRC	-	Disaster Region Based Clustering
DRNs	-	Disaster Response Network/ Networks
DRUM	-	Dynamic Rule Based Movement Algorithm
DSA	-	Dynamic Spectrum Access
DSL	-	Digital Subscriber Line
DTNs	-	Delay Tolerant Networks
DWPT	-	Discrete Wavelet Packet Transform
EAQR	-	Exploring Actions Multi-Agent Q Learning Ratios
EBayesCS	-	Enhanced Bayesian Compressive Sensing
EKKT	-	Karush-Kuhn-Tucker
EMCA	-	Extended Modular Clock Check Algorithm
EMM-TRP	-	Enhanced Multi-Hop Multichannel Tree Routing Protocol
ETED	-	Enhanced Threshold Detection
FBM	-	Fully Blind Multi-Hop
FC	-	Fusion Center
FCC	-	Federal Communications Commission
GEAR	-	Geographic And Energy-Aware Routing
GHAR	-	Graph-Based Hybrid Adaptive Routing
GMAC	-	Group Media Access Control
GPS	-	Global Positioning System
HC	-	Home Channel
HSPO	-	Hybrid Spiral Penguin Optimization
IEEE	-	Institute of Electrical and Electronics Engineers
ISM	-	Industrial, Scientific and Medical
ITU-R	-	International Telecommunication Union-Radio Communication Sector

LBT	-	Listen Before Talk
LinGo	-	Link Quality & Geographical Beaconless OR Protocol
M2M	-	Machine-To-Machine
MAC	-	Media Access Control
MAEB	-	Movement-Aided Energy-Balance
MANETs	-	Mobile Ad Hoc Networks
McBS	-	Mobile Cognitive Base Station
MINLP	-	Mixed Integer Non-Linear Problem
Multi-RATs	-	Multiple Radio Access Technologies
NS	-	Network Simulator
OCA	-	Optimal Channel Assignment
OCR	-	Opportunistic Cognitive Routing
OFDM	-	Orthogonal Frequency Division Multiplexing
ORC	-	Optimal Routing Criterion
OSI	-	Open Systems Interconnection
PBS	-	Primary-User Base Station
PCA	-	Principal Component Analysis
PCs	-	Personal Computers
PDPS	-	Probabilistic and Deterministic Path Detection
PHY	-	Physical Layer
PLC	-	Powerline Communications
PU	-	Primary User
PUkR	-	Primary User Aware K-Hop Routing
PRISMA		Preferred reporting items for systematic review and meta-analysis
QESAR	-	QoS-Enabled Spectrum Aware Routing Protocol
QoS	-	Quality of Service
QSTOD	-	QoS Spectrum-Tree Based On-Demand Routing Protocol

QPSK	- Quadrature Phase Shift Keying
ReInForM	- Reliable Information Forwarding Using Multiple Paths
RSRA	- Reduced Search Space Routing for Large-Scale CR Networks
SAAR	- Spectrum-Aware Any-Path Routing
SA-MOICR	- Spectrum-Aware Minimum Outage Intelligent Cooperative Routing
SARFD	- Spectrum Aware Routing in Full-Duplex Cognitive Radio Networks
SARPPSA	- Spectrum Aware Routing Protocol for Public Safety Applications
SASSA	- Smart Agent-Aided Scalable Spectrum Access
SDR	- Software Defined Radio
SINR	- Signal-to-Interference-to-Noise Ratio
SMART	- Spectrum-Aware Cluster-Based Routing
SMCA	- Successive Multi-Step Convex Approximation Scheme
SMQRP	- Stability Based Multipath QoS Routing Protocol
SNR	- Signal to Noise Ratio
SS	- Spectrum Sensing
SSA	- Smart Spectrum Agents
SUs	- Secondary User/ Users
TAG	- Trajectory Aware Geographical Routing
TVWS	- TV White Space
UAVs	- Unmanned Aerial Vehicle/ Vehicles
VANETS	- Vehicular Ad Hoc Networks
WiFi	- Wireless Fidelity
WiMAX	- World Interoperability for Microwave Access
WLAN	- Wireless Local Area Network
WRANs	- Wireless Regional Area Network
WSNs	- Wireless Sensor Networks