CHANNEL ASSIGNMENT AND OPTIMAL PATH SELECTION FOR COGNITIVE RADIO WIRELESS MESH NETWORKS

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ABSTRACT

In Cognitive Radio (CR) technology, secondary or CR users are allowed to occupy primary licensed spectrum in an opportunistic manner subsequently improving spectrum utilisation in telecommunication networks. Cognitive Radio Wireless Mesh Networks (CR-WMNs) have gained in popularity in recent years as a vivid and promising solution for efficient resource utilisation. Since the channels in CR-WMNs are dynamic and exhibit diverse characteristics, the channel assignment and path selection are two essential methods needed for the optimal network performance. These caused complexities for the CR-WMN secondary users, such as spectrum heterogeneity, unpredictable primary user activity, and interference constraints. If spectrum heterogeneity and primary user activity are considered while assigning the channel and selecting end to end path, then the network performance improvement can be achieved. The objective of this thesis is to develop a channel assignment algorithm and end to end path selection scheme to enhance the CR-WMN user channel and path reliability. For the optimal channel assignment, the Link Capacity based Channel Assignment (LCCA) algorithm is developed in which primary user activity, secondary user activity and link interference parameters are considered in decision-making. The proposed LCCA algorithm provides a 63% more reliable channel among the available channels in the network. Next, this thesis focuses on optimal end to end path selection analytical modelling. The results show that the developed analytical model has achieved about 18.9% improvement compared to the conventional Gateway Discovery method. The last objective of this thesis is to develop fuzzy logic based end to end path selection technique. The relation of path route with users, bandwidth, and mobility are considered in this intelligent algorithm. The proposed fuzzy based system delivers up to 62.1% improvement in providing optimal path in comparison to the analytical model and the Gateway Discovery method. Lastly, the intelligent end to end path selection has the potential to improve spectrum utilisation in multi-hop wireless networks such as 5G network and Internet of Things (IoT) applications.

ABSTRAK

Dalam teknologi Radio Kognitif (CR), pengguna sekunder atau CR dibenarkan untuk menggunakan spektrum berlesen primer secara oportunis yang secara langsung dapat meningkatkan penggunaan spektrum dalam rangkaian telekomunikasi. Sejak beberapa tahun kebelakangan ini, Rangkaian Jejaring Tanpa Wayar Radio Kognitif (CR-WMNs) telah menarik perhatian sebagai suatu kaedah penyelesaian yang jelas serta menjanjikan penggunaan sumber yang cekap. Oleh kerana saluran dalam CR-WMNs adalah dinamik dan mempamerkan pelbagai ciri, tugasan saluran dan pemilihan laluan adalah dua kaedah penting yang diperlukan untuk menghasilkan prestasi rangkaian yang optimum. Ini menimbulkan kerumitan bagi pengguna sekunder CR-WMN seperti keheterogenan spektrum, aktiviti pengguna primer yang tidak dapat diramalkan, dan kekangan gangguan. Sekiranya keheterogenan spektrum dan aktiviti pengguna utama dipertimbangkan semasa tugasan saluran dan pemilihan laluan hujung ke hujung, maka peningkatan prestasi rangkaian dapat dicapai. Objektif tesis ini adalah untuk membangunkan algoritma tugasan saluran dan skim pemilihan laluan hujung ke hujung bagi meningkatkan kebolehpercayaan saluran dan laluan pengguna CR-WMN. Untuk penugasan saluran yang optimum, algoritma Tugasan Saluran berdasarkan Keupayaan Pautan (LCCA) dibangunkan di mana aktiviti pengguna primer, aktiviti pengguna sekunder dan parameter gangguan pautan dipertimbangkan dalam membuat keputusan. Algoritma LCCA yang dicadangkan dapat menyediakan lebih 63% lebih saluran boleh percaya di antara saluran-saluran yang terdapat dalam rangkaian. Seterusnya, tesis ini memfokuskan pada pemodelan beranalisis pemilihan laluan hujung ke hujung yang optimum. Perbandingan hasil menunjukkan bahawa model analisis yang dibangunkan telah mencapai peningkatan 18.9% berbanding kaedah Penemuan Get Laluan yang konvensional. Objektif terakhir tesis ini adalah pembangunan teknik pemilihan jalan hujung ke hujung berdasarkan logik kabur. Hubungan laluan dengan pengguna, lebar jalur, dan kebolehgerakan dipertimbangkan dalam algoritma cerdik ini. Sistem berasaskan kabur yang dicadangkan memberikan peningkatan penyediaan saluran laluan optimal sehingga 62.1% berbanding dengan model beranalisis dan kaedah Penemuan Get Laluan. Akhir sekali, pemilihan laluan hujung ke hujung yang cerdik ini berpotensi untuk meningkatkan penggunaan spektrum bagi rangkaian wayerles berbilang hop seperti aplikasi rangkaian 5G dan Internet Benda (IoT).

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LIST OF ABBREVIATIONS

CR	-	Cognitive Radio
WMN	-	Wireless Mesh Network
CR-WMN	-	Cognitive Radio Wireless Mesh Network
SA	-	Spectrum Assignment
MC	-	Mesh Client
MR	-	Mesh Router
MG	-	Mesh Gateway
CA	-	Channel Assignment
SUs	-	Secondary Users
PUs	-	Primary Users
ITL	-	Interference Temperature Limit
AODV	-	Ad-hoc On-demand Distance Vector
FCC	-	Federal Communications Commission
SNR	-	Signal to Noise Ratio
SINR	-	Signal-to-Interference-Plus-Noise Ratio
BER	-	Bit Error Rate
LCCA	-	Link Capacity Based Channel Assignment
CCC	-	Common Control Channel
QoS	-	Quality of Service
MISD	-	Minimum Cumulative Interference and Channel Switching Delay
TPRA	-	Two-Phase Resource Allocation
IACA	-	Interference Aware Channel Assignment
SAMER	-	Spectrum-Aware Mesh Routing
SPEAR	-	Spectrum Aware Routing Protocol
ADCA	-	Adaptive Dynamic Channel Allocation
ICAR	-	Interference and Congestion Aware Routing
MISD	-	Minimum cumulative Interference and channel Switching Delay
RREQ	-	Route Request

LIST OF SYMBOLS

S	-	Source Node
D	-	Destination Node
PU_{ac}	-	Primary User Active
PU_{ua}	-	Primary User Un-active
SU_{scal}	-	Secondary User using the same channel but another link
SU_{scl}	-	Secondary User sharing the channel on the link
R_T	-	Node Transmission Range
A	-	Set of nodes in the system
L	-	Set of all available channels in the system
m	-	Represents node conflicting link availability
R_i	-	Node interference range
L_i	-	Set of available channels
$Link_{ij}$	-	Link between node *i* and node *j*
k	-	Binary variable
C_j^k	-	Binary variable that is set to 1 if channel *k* is assigned to node *j*, and 0 otherwise
R_i	-	Interference range
G	-	Represent (*Vi*, *E*)
V	-	Vertices and represent a set of nodes
E	-	Edges and represents a set of wireless links
V_c	-	Corresponding to the communication links
l_{ij}	-	Node *i* and Node *j* have the same channel in their channel list
$P_i(j)$	-	Packet that is on the *Linkij* from node *j* to node *i* is if received without error
N	-	Background noise
M	-	Set of neighbouring SUs
m_j	-	Set of nodes from which node *j* can receive the packet
$\tau(m)$	-	Fraction of time node m occupies the channel
$T(m)$	-	Weight the signal strength from an interfering node *m*

CHAPTER 1

INTRODUCTION

1.1 Overview

In the past decade, economic and scientific dynamic services have been developed and in the upcoming years, they are anticipated to totally redesign the future of wireless networks. It has been said without doubt that the daily usage of wireless networks has increased to a great extent that users are not able to imagine a life without the use of wireless gadgets including mobile phones, PDAs, tablets, laptops, etc. The radio spectrum is the only available natural resource provided to the service providers that have license holders on a long-term basis using a fixed spectrum assignment policy [1]. This has a great effect on the spectrum usage because recent literatures [2-4] have depicted that its utilization is very less compared to the large slices of the spectrum, this results in the underutilization of the only available frequency resources. In order to use the underutilized slices of the spectrum, the concept of Cognitive Radio (CR) technology has been introduced by J. Mitola in [5, 6].

The main breakthrough of the cognitive radio technology is that it can allow a reuse of the spectrum resources, thus enabling a greater number of users to access it at a given time. In CR networks, there is a noteworthy interference that enables users to connect to any portion of the spectrum. The interference can be caused not just by users of CR technology, but also by the licensed users who are accessing the licensed spectrum bands. Thus, in order to solve this problem, an efficient Spectrum Assignment (SA) and end to end optimal path selection for CR networks is foreseen as a vital focus of research.

One of the most widely used networks of CR technology is Wireless Mesh Networks (WMNs), also known as CR-WMN. CR-WMN uses the spectrum sensing for mesh client denoted by MC and mesh router denoted by MR [11]. This technology is being foreseen as a promising development in the wireless communication era with the potential gains it will bring for both CR and WMN technologies [12-17]. In order to enable the cognitive radio technology in the mesh client node, it should sense the underutilized spectrum chunk in the primary user and then access these chunks dynamically. Nevertheless, the dynamic usage of the licensed spectrum bands must not ignore the multiple spectrum allocation confronted by the time-varying radio frequency environment. Therefore, it is very important to consider not only the efficiency, but also the general fairness and complexity of communication systems. The use of multi-radio devices in multi hop CR-WMNs can raise the capacity of the network. However, the interference between the links can be a major cause of performance degradation [7, 8].

1.2 Statement of Problem

Interference is a crucial factor that can lead to a loss in maximum achievable capacity and performance. The presence of interferences in CR-WMNs decreases the achievable transmission rate of wireless interfaces, increases the frame loss ratio, and moderates the utilization resources. Additionally, interference can either be produced by links belonging to the same network or it can be instigated from external sources. The literature referred to so far has established that there is a sheer need for restricting interference, in order to achieve maximum performance in wireless networks since the interference can directly cause problems in the reception of the mesh clients [18], [19]. Channel assignment (CA) as defined in the previous section, is one of the most promising technique that can be used to mitigate the instances of interference in the CR-WMN. The purpose of CA in CR networks is to assign the channels to radio interfaces of wireless devices for attaining efficient spectrum utilization and minimization of the interference that is triggered by the users that connect on the same channel. However, the cognitive wireless mesh networks are constraint. The constraint is that that the Secondary Users (SUs) must create zero or very little interference to the licensed users of the same spectrum. Furthermore, to maximize the CR technology performance, the amount of interference between secondary users must also be retained at a minimum value. Therefore, the design of a channel assignment algorithm for wireless mesh networks is important as it affects the interference factors of CR-WMN [20-22].

Numerous channel assignment methods are grounded on imposing an Interference Temperature Limit (ITL) at the primary user interfaces and assign channels to SU interfaces for retaining the value of ITL below the predefined threshold [1], [23– 31]. The ITL shows the quantity of interference detected by the receiver which can be computed as the power received by an antenna divided by the associated radio frequency bandwidth with Boltzmann's constant as defined by FCC [32]. Regulating the ITL under the given threshold is typically attained using power control. This is done to keep the transmission power of secondary user terminals and subsequently, lowering interference at primary user terminals. This methodology has a disadvantage of reducing the transmission power that also reduces the interference at a primary user, but at that instant, it also drops the SINR at the receiving secondary user. Therefore, it is very important to select the correct transmission power considering that the received the SINR for secondary users must be above the nodes' sensitivity for successful receptions.

A Dynamic Interference Graph model is proposed in [33], [34] for capturing the interference between a pair of transmissions. In [35] a method to calculate interference based on the path loss model is given. Many approaches [21] [36], and [37] considered the SINR based interference model at each CR node to perform an efficient channel assignment. A binary interference model based on the protocol model is applied in [38]. Few studies evaluated the hierarchy interference model [22], [39].

Most of the channel assignment work done in previous research only considered a single type of interference, i.e. interference caused by the secondary and primary user terminals. Researches did not take into account of the activities done by primary users and only relied on models where the interference is solely caused by secondary users in the vicinity. Hence, it is important to develop an end to end interference model, in which all possible kinds of interference can be regarded. The interference in CR-WMN may lead to serious performance degradation. This requires a suitable channel assignment technique and route selection mechanism to be developed, to be able to assign the channel and select optimal route for the CR-WMN users.

1.3 Aim and Objectives

The main goal of this research is to enhance the spectrum utilization in the CR-WMN. To achieve the said goal in this research the CR-WMN are analysed to develop the channel assignment and end to end path selection mechanism. The main objectives of the research are stated below:

i. To develop channel assignment algorithm for CR-WMN.
ii. To develop end to end analytical model for CR-WMN.
iii. To develop end to end path selection mechanism for CR-WMN based on fuzzy logic system.

1.4 Scope of the Research

In the CR-WMN, the channel availability and path selection depends on the behaviour of PUs and other SUs in the system, which are using the same channels. This research mainly focuses on the channel selection and end to end optimal path selection in CR-WMN.

First, the CR-WMN model is proposed and the parameters are defined. The link capacity-based channel assignment (LCCA) algorithm is developed for the proposed model to select a channel among the available channels. The proposed algorithm considers interference, PU, and SU activity to determine the best available channel for SU.

Next, the end to end analytical model is developed for CR-WMN to provide the characterization of each node and each link in the network. This is to determine the best node and link towards the destination node in the network. In order to overcome the complexity issue explained in the analytical model, the fuzzy logic system is developed to find the optimal path to destination. The MATLAB is used for the simulation and evaluation.

1.5 Research Contributions

The contribution of this research is to develop the optimal model for channel assignment and route selection for cognitive radio wireless mesh networks (CR-WMNs). Implementation of the resulting algorithm is to increase the performance of resource utilization of CR-WMNs.

The contributions of this research are listed as follows:

- Channel Assignment Algorithm for CR-WMNs

When the WMN is equipped with CR technology, it becomes a more complex wireless network by adding additional parameters to be considered while making the channel assignment decision. In the proposed Link Capacity Based Channel Assignment Algorithm (LCCA), it is considering and calculating that additional factors like Primary Users (PUs), Secondary Users (SUs) and Link interference ratio for selecting channel. Eventually, every secondary user will be able to evaluate and compare cognitive radio parameters to find a reliable channel.

- End to end analytical model for CR-WMNs

Secondly, a robust analytical model for end to end path selection in CR-WMNs is developed. Graph theory has been used to model the nodes and edges, hence modeling the path which can be optimally selected using proposed analytical model. Link existence in vicinity of primary user is modeled using overlapping disks. The effect of varying probability of path existence in region has been evaluated and node characteristics are analyzed. The proposed analytical model is able to achieve 44 probabilities for the optimal route selection which is a 0.07% greater probability as compared to the Gateway discovery method [113].

- End to end path selection mechanism for CR-WMNs based on fuzzy logic system

The third major contribution of this work is development of fuzzy logic-based route selection system for CR-WMNs using artificial intelligence algorithm. After analyzing the results of the abovementioned contributions, it was noticed that the linear algorithms match less to the real behaviors of users, which is quite random and suits more to the artificial intelligence algorithms. Thus, an algorithm using fuzzy system was developed for routing and path selection. The result shows that the proposed fuzzy system for route selection provides a better/more optimal route selection compared to the gateway discovery method [113]. Moreover, the fuzzy system also outperforms the fixed routing model proposed in chapter 4.

1.6 Organization of the Thesis

This thesis provides the gap in channel assignment and route selection faced by the cognitive radio wireless mesh systems. In order to fill the gap, an in-depth literature review has been performed, and channel assignment and path selection algorithms have been developed. This thesis consists of six chapters. Chapter 1 acts as a thesis introduction and it cover topics such as problem statement, objectives, scope and significance of the research.

Chapter 2 presents the related research work background of CR-WMN and also elaborates the CR-WMN challenges. The applicable channel and path selection approaches have been studied.

Chapter 3 provides the development and results on the channel assignment algorithm for Link Capacity in CR-WMN.

Chapter 4 elaborates the detailed study and terminologies of link creation using graph theory. It develops link existence and channel conditions which are used to finally develop path selection model. The results of different paths have also been depicted in chapter 4.

Chapter 5 describes the details on the methodologies adopted in order to carry out artificial intelligence algorithm of fuzzy system that was developed for joint routing and channel allocation. The problem of channel assignment and joint route selection has been mapped to the steps of fuzzy system. The results are finally presented at the end of chapter

Finally, Chapter 6 concludes the thesis providing the importance of channel allocation and path selection, and also highlights the contributions of this work and the results achieved.

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