COOPERATIVE SPECTRUM SENSING USING ADAPTIVE QUANTISATION MAPPING FOR MOBILE COGNITIVE RADIO NETWORKS

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To my beloved family

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ABSTRACT

Sparsity in spectrum is the result of spectrum underutilization. Cognitive radio (CR) technology has been proposed to address inefficiency of spectrum utilisation through dynamic spectrum access technique. CR in general allows secondary node (SN) users to access the licensed or primary users' (PU) band without disrupting their activities. In CR cooperative spectrum sensing (CSS), a group of SNs share their spectrum sensing information to provide a better picture of the spectrum usage over the area where the SNs are located. In centralised CCS approach, all the SNs report their sensing information to a master node (MN) through a control reporting channel before the MN decides the spectrum bands that can be used by the SNs. To reduce unnecessary reporting information by the cooperating nodes, orthogonal frequency division multiplexing (OFDM) Subcarrier Mapping (SCM) spectrum exchange information was proposed. In this technique, the detection power level from each secondary SN user is quantized and mapped into a single OFDM subcarrier number before delivering it to the MN. Most researches in cooperative spectrum sensing often stated that the SNs are absolutely in stationary condition. So far, the mobility effect on OFDM based SCM spectrum exchange information has not been addressed before. In this thesis, the benchmarking of SCM in mobility environment is carried out. The results showed that during mobility, the performance of OFDM-based SCM spectrum exchange information degraded significantly. To alleviate the degradation, OFDM-based spectrum exchange information using adaptive quantization is proposed, which is known as Dynamic Subcarrier Mapping (DSM). The method is proposed to adapt to changes in detected power level during mobility. This new non-uniform subcarrier mapping considers the range of received power, threshold level and dynamic subcarrier width. The range of received power is first compressed or expanded depending on the intensity of the received power against a pre-determined threshold level before the OFDM subcarrier number is computed. The results showed that OFDM-based DSM spectrum exchange information is able to enhance the probability of detection for cooperative sensing by up to 43% and reduce false alarm by up to 28%. The DSM spectrum exchange information method has the potential to improve cooperative spectrum sensing for future CR mobile wireless networks.

ABSTRAK

Kekurangan dalam spektrum adalah hasil dari spektrum yang kurang digunakan sepenuhnya. Teknologi radio kognitif (CR) telah dicadangkan untuk menangani ketidakcekapan penggunaan spectrum melalui Teknik akses spectrum dinamik. CR secara umum membolehkan pengguna nod sekunder (SN) untuk mengakses jalur berlesen atau pengguna utama (PU) tanpa mengganggu aktiviti-aktiviti mereka. Dalam pengesanan spektrum korporatif (CSS) CR, sekumpulan SN berkongsi maklumat pengesanan spektrum mereka untuk member gambaran penggunaan spectrum yang lebih baik pada kawasan di mana SN-SN itu berada. Dalam pendekatan CCS berpusat, semua SN-SN melaporkan maklumat pengesanan mereka kepada nod induk (MN) melalui saluran pelaporan terkawal sebelum MN memutuskan jalur spektrum yang boleh digunakan oleh SN-SN tersebut. Untuk mengurangkan maklumat laporan yang tidak diperlukan oleh nod-nod yang bekerjasama, maklumat pertukaran spektrum Pemetaan Subpembawa (SCM) berasaskan pemultipleksan bahagian frekuensi ortogon (OFDM) telah dicadangkan. Dalam teknik ini, tahap kuasa pengesanan dari setiap SN pengguna sekunder adalah terkuantum dan dipetakan kedalam bentuk nombor subpembawa OFDM tunggal sebelum menyampaikannya kepada MN tersebut. Sebahagian besar penyelidikan dalam penderiaan spektrum korporatif sering menyatakan bahawa SN-SN adalah benar-benar dalam keadaan tak bergerak. Setakat ini, kesan pergerakan pada pertukaran maklumat SCM spektrum berasaskan OFDM tidak ditangani. Dalam tesis ini, penanda aras SCM dalam persekitaran mudah alih telah dilaksanakan. Hasil kajian menunjukkan bahawa semasa pergerakan, prestasi pertukaran maklumat spektrum SCM berasaskan OFDM turun dengan ketara. Untuk mengurangkan degradasi, pertukaran maklumat spectrum berasaskan OFDM menggunakan pengkuantuman mudah-suai dicadangkan yang juga dikenali sebagai Pemetaan Subpembawa Dinamik (DSM). Kaedah ini adalah dicadangkan bagi penyesuaian kendiri dengan perubahan dalam tahap kuasa yang dikesan semasa pergerakan. Pemetaan subpembawa tidak seragam baharu mengambil kira lingkungan kuasa yang diterima, tahap ambang dan pemetaan lebar subpembawa dinamik. Julat kuasa yang diterima pada mulanya dimampatkan atau dikembangkan bergantung kepada keamatan kuasa yang diterima terhadap tahap ambang yang telah ditentukan sebelum nombor subpembawa berasaskan OFDM dikira. Hasil kajian menunjukkan bahawa maklumat pertukaran spektrum DSM berasaskan OFDM boleh menambahkan kebarangkalian pengesanan untuk pengesan korporatif sehingga 43% dan mengurangkan penggeraan palsu sehingga 28%. Kaedah pertukaran maklumat spektrum DSM mempunyai potensi untuk meningkatkan pengesanan spektrum korporatif untuk rangkaian tanpa wayar CR mudah alih di masa hadapan.

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LIST OF ABBREVIATIONS

AoA	-	Angle of Arrival
APD	-	Amplitude probability distribution
ASK	-	Amplitude shift keying
AWGN	-	Additive White Gaussian Noise
BEP	-	Bit Error Rate Probability
BPF	-	Band pass filter
CCI	-	Co-Channel Interference
CCC	-	Common Control Channel
CDF	-	Cumulative Density Function
CR	-	Cognitive radio
CRN	-	Cognitive radio networks
CSMA	-	Carrier sense multiple access
CSI	-	Channel State Identification
D-OFDM	-	Differential OFDM
DSM	-	Dynamic Subcarrier Mapping
FC	-	Fusion Center
FFT	-	Fast Fourier Transform
FMCW	-	Frequency Modulated Continuous Wave
GLA	-	Generalized Lloyds-type algorithm
ICI	-	Inter-carrier Interference
ISI	-	Inter-symbol Interference
ITU	-	International Telecommunication Union
LOS	-	Line of Sight

LLR	-	Log-likelihood Ratio
MN	-	Master Node
MIMO	-	Multi input multi output
MSN	-	Mobile sensing node
NLOS	-	Non Line of Sight
N-SCM	-	New Subcarrier Mapping
OFDM	-	Orthogonal frequency division multiplexing
OFDMA	-	Orthogonal frequency division multiplexing Access
PD	-	Probability of Detection
PFA	-	Probability of False Alarm
Pr	-	Power Received
PU	-	Primary User
RSS	-	Received Signal Strength
RoC	-	Region of Convergence
RoI	-	Region of Interference
Rx	-	Receiver
SecWN	-	secondary wireless network
SDT	-	Subcarrier Detection Threshold
SINR	-	Signal to interference noise ratio
SN	-	Sensing Node
SNR	-	Signal to noise ratio
PDF	-	Probability Density function
TDoA	-	Time Difference of Arrival
ToA	-	Time of Arrival
TV	-	Television
Tx	-	Transmitter
UWB	-	Ultra wide band

LIST OF SYMBOLS

γ_m	-	Threshold
P_k	-	Subcarrier Power
$\widehat{x_J}$	-	Normalize power
N_c	-	Number of Subcarrier
α	-	Mapping Parameter
k	-	Subcarrier index number
$k'_{mobile}(i)$	-	Subcarrier mapping for mobile node
$x_{map}\ (i)$	-	Quantize Power level of mobile node
$P_T(SN_i)(i)$	-	Power transmit each sensing node
$P_{PU}(power)$	-	Primary user power
$d_0(i)$	-	References distance
d_{PU}	-	PU distance
d_{SN}	-	SN distance
N_i	-	Noise power (AWGN)
σ	-	Noise Variance
P_{FA}	-	False alarm probability
H_0	-	Decision for un-occupied channels
H_1	-	Decision for occupied channels
t_x	-	Energy Detection Signal
$\|\|Yx_n\|\|^2$	-	Energy Signal
$Y_x(t)$	-	Observed Signal
n_x	-	Noise (AWGN)
h_x	-	Complex Channel Gain (Rayleigh Fading)

s_x	-	Transmitted Signal
I	-	Number of Users
$\lvert w_i[n]\rvert^2$	-	the noise of the n^{th} sample
$A_i[n]$	-	Amplitude of the received signal
N	-	Number of samples
$s_i[n]$	-	Channel gain
ρ	-	Amplitude of a subcarrier signal
σ^2	-	Noise variance
P_{fse}	-	False Detection estimation probability
γ_{mean}	-	Average Threshold
ρ_{mean}^2	-	Average amplitude of signal
$log(e)$	-	Logarithmic normal 0.4343
P_{cse}	-	Correct detection probability
Q	-	Q function
$\widehat{x_j}$	-	the soft combined information retrieved
$G_t G_r$	-	Gains of transmitter & receiver antennas
P_t	-	Power at which the signal was transmitted
f_s	-	Spatial sampling frequency of the wavelength
d_{SN} (m)	-	Distance SN in meter
Δf_R	-	The function of frequency in Doppler Effect
M	-	Signal sampled
f_T	-	Frequency transmission (carrier frequency)
V_r	-	Velocity of the SN,
$cos\,\theta$	-	SN's target angle
$V_r(i)$	-	Velocity of SN in meter per seconds (m/s)
Δt	-	Time travel which is needed to moving from source place to current position, d'_{SN} in second
$cos\,\theta$	-	Angle of arrival position
$P_r(d)$	-	Detected signal power in Watts
$r(t)(i)$	-	Rayleigh fading based on summing sinusoids with Jakes model
f_d	-	Doppler shift
a_m and b_m	-	Amplitude of the signal

N	-	Multipath components with angle of arrival α_m of the nodes
$P_{R-Mobile}(i)$	-	Received power at i^{th} mobile sensing nodes
$P_{Tx}dBm$	-	PU transmit power
P_{Txgain}	-	PU transmit gain at the i^{th} nodes
$SN_{gain}(i)$	-	The SN node gain
$k_{conv}(i)$	-	Conventional quantisation mapping the spectrum exchange information at i^{th} SN given by [54] without Doppler Effect
$P_{R-conv}(i)$	-	The received detection power at i^{th} conventional SN's
$N_o[k]$	-	The noise of the n^{th} sample,.
M_s	-	The number of all signal samples during the sensing periods T_s(e.g., 1 ms)
B_iC_i	-	The amplitude of the detected signal when the signal $C_i[k]$ transmitted.
$erfc^{-1}$	-	Error function
$\widehat{S_m}(dB)$	-	The value of the soft information converted from the detected subcarrier number of OFDM signal,
$k_{dynamic}$	-	Dynamic Subcarrier Mapping
m	-	The detected sensing node index
$\widehat{R_n}(dB)$	-	De-normalized power for the mobile spectrum exchange information that utilized dynamic subcarrier mapping

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Rapid proliferation of wireless services to support a variety of applications ranging from a voice call to high speed Internet connection has virtually exhausted the available radio spectrum. To mitigate this problem, Cognitive Radio (CR) has been identified to be a viable solution. According to the ITU definition, CR technology is a radio system that could dynamically adopt and adjust its operational parameters and protocol to achieve pre-defined objectives and to learn from the results obtained. In CR systems, there is a primary user network (PU) and a secondary user or SN network. Generally, CR allows SN to access the licensed band without disrupting its primary users' activity. The most significant part of CR mechanism is spectrum sensing where the secondary users are required to detect the primary users' activity precisely. In order to satisfy the sensing requirements such as high degree of detection and low degree of false alarm, cooperative spectrum sensing is introduced. By fusing sensing information from multiple secondary users, the sensing result is statistically more reliable and has a higher accuracy. Thus, the process of exchanging the sensing information among the secondary users is crucial.

This is particularly important when the secondary users are mobile where the channel condition is more susceptible to wireless radio propagation impairments.

In this study, a sensing information exchange mechanism for cooperative spectrum sensing is applied in mobile wireless channel. Traditionally, sensing information exchange for cooperative spectrum sensing in Cognitive Radio Network (CRN) assumes a stationary node. Here, the velocity, distance, phase angle and Signal to Noise Ratio (SNR) of the reporting nodes are heavily influenced by the nodes' mobility. These mobility parameters are measured, analysed and benchmarked to validate the proposed sensing information exchange mechanism.

1.2 Problem Statement

In spectrum sensing scenario, the objective of the local spectrum sensing is to detect the PU's signal detection. The performance of SN ability to sense the PU's signal is crucial. How the PUs signal are sensed, sampled and processed in relation to how SN cooperates with each other is the fundamental elements of cooperative spectrum sensing. However, in most of the SN in CRN is assumed stationary. This model is insufficient for wireless nodes that are mobile. Moreover, algorithm that manages wireless nodes mobility in traditional wireless networks has a high cost in terms of communication overhead.

Incidentally, to reduce the overhead and overcoming the problem with an unreliable SN reporting channel, exchanging and sharing observed information between SNs within cooperative sensing areas are needed. To achieve this, every sensing result representing the PU's activity gathered by SNs must be collected. However, traditional cooperative spectrum sensing networks does not consider the methods for spectrum information exchange. In practice, the spectrum information would be exchanged among nodes by using some information exchange protocol. A packet based communication protocol could be utilized as a method to exchange the information among nodes which then can be shared between SN or can be collected at the fusion centre.

This thesis describes the spectrum information exchange technique development for a mobile SN cooperative spectrum sensing. Cooperative spectrum sensing in general could improve the detection performance against the channel impairments conditions such as fading, shadowing and multipath propagation. Another advantage of cooperative spectrum sensing is a shorter sensing time for each SN due to the decision fusion effectiveness which in turn would increase the amount of time for SN to transmit its payload. This increase in throughput would naturally increase the spectrum utilization satisfying CRN objective. The spectrum information exchange scheme based on the concept of underlay approach in cognitive radio systems is employed. This concept allows the SN to utilize the PU's signal detection and sensing results reporting simultaneously without interfering PU's activity.

Sensing information exchange mechanism has been explored in several studies. The previous work done by [1, 2] proposed a cooperative spectrum sensing scheme using a single orthogonal subcarrier that could combat bandwidth limitation on reporting channel by quantizing the detected power level into an OFDM tone signal structure to transmit the sensing SN data to the MN. This stage is called local spectrum sensing process by SN. Channel access, calculation complexity, delay and synchronization problems rise during the contention period in the reporting channel. In [3] proposed the cooperative networking without common control channel, this method aimed to reduce the complexity function using M orthogonal sub-channel that being equally divided from the licensed band. However, the dwelling time between the pair is increased the delay and idle time makes sensing process inefficient.

From the previous works, it was shown that, as the detected power is quantized into information bit. However, the studies assumed that the SN station is stationary. Mobile environment in spectrum information exchange is an interesting topic for further investigation. Most of the CR research does not consider the mobility of SN. However, the mobility of the PUs and SNs heavily influence the detection performance on local observation. The movement of the SNs create spatial diversity in the observation of the PU’s signal. Due to the movement, spatial distance, velocity, Doppler Effect and geo-location information, the signals condition would fluctuate during the sensing process. Mobility’s speed also reduces the average received signal strength and must be compensated by spatial diversity. On the other hand, mobile SN can improve the detection performance with its local observation’s samples and minimal cooperation from others to reduce the cooperation overhead, depending on the speed and the direction of the movement.

1.3 Thesis Objectives

This thesis explores the OFDM spectrum information exchange under mobility model for CR Network (CRN).This could be achieved only by establishing several objectives as follows:

1. To analyse OFDM spectrum information exchange mechanism for cooperative spectrum sensing in CRN.
2. To investigate mobility effect on OFDM-based spectrum information exchange cooperative spectrum sensing.
3. To propose dynamic subcarrier mapping for OFDM-based spectrum information exchange for mobile CRN.

1.4 Scope of Works

In this thesis, it is assumed that each SN performs local spectrum sensing independently. The noise is white, additive and Gaussian, with zero mean and known variance. And it is assumed that the noise variance is precisely known to the receiver. Initially the SN, are statically located and the velocity is set to be normal distribution. A centralized network topology is assumed for the CR networks and the directions of the SNs movements are random within the boundary of the centralized CR networks. In cooperative spectrum sensing, the exchange information (soft) is perfectly collected by MN from each SN. It is also assumed that energy detection technique for sensing method is used. Timing synchronization among the signals from multiple SNs is not needed due to the use of a tone signal as a narrowband signal. It is considered that timing offset only occur in the MN. Therefore, large timing information for request signal from the surrounding SNs is not required. It is also assumed that timing synchronization among the signals from multiple SNs is perfect and delivery delay due to the transmission through the channel is negligible.

1.5 Thesis Contributions

This thesis presents the contributions in the research area of wireless digital communication under cooperative spectrum sensing transmission exchange model in CR communication where two important contributions had been identified as follows:

The preliminary implementation of CRNs with OFDM signal structure as the main backhaul for spectrum information exchange is developed. In this thesis the mobility model of cooperative spectrum information exchange in cognitive radio networks is developed and investigated. The design of adaptive information quantization for mobile SNs in cooperative spectrum exchange information cognitive radio environment is proposed and evaluated.

The result of this study is used to support the design of an underlay communication model within the context of spectrum information exchange in mobile environment. In addition, this study also supplement the similarity and universality aspects of mobile parameters' behaviour of wireless communication, as already known is the narrow gap, so that a practical characterization of the gap is completely possible.

1.6 Outline Thesis Organization

Chapter 1 of this thesis describes the introduction of this thesis, the background of the problem, problem statement, objectives, scope of works, as well as the research contributions.

In Chapter 2, a brief introduction to cognitive radio wireless transceivers, motivation using the multi carrier frequency modulation techniques and the basic principles of cooperative spectrum sensing communication system are presented. This chapter also presents an overview of several spectrum information exchange techniques for improving the spectrum utilization in mitigating spectrum scarcity problems. The chapter went on further to elaborate OFDM based techniques and cooperative sensing terms to overcome the shortcomings of spectrum information exchange, and analyses several research topics associated with the development of OFDM based cognitive radio networks.

In Chapter 3, the demonstrations of OFDM based cooperative spectrum sensing in CR networks are presented. A research methodology of the study is presented. It comprises the general methodology of spectrum information exchange, mobility model of the spectrum information exchange and adaptive quantization of spectrum information exchange. The numerical analysis by using mobility parameters was reviewed and then validated. Subsequently, the proposed adaptive quantization method is analyzed to conduct the performance analysis in CR.

Chapter 4 presents the detailed overview of mobility platform for OFDM-based signal structure in CR networks. The chapters outline the motivation for the conventional exchange spectrum sensing results with stationary nodes. Moreover, the benchmark for the mobility environment in spectrum sensing information exchange is presented. Thus, this chapter give brief information about the performance of spectrum information exchange’s quantization for OFDM-based cooperative spectrum sensing using mobility model.

Chapter 5 gives an analysis of the adaptive quantization’s spectrum information exchange within the mobility environment. In this chapter the description of the cognitive radio task is explained. In order to improve cooperative spectrum sensing decision in MN, the detection power level is quantized according to the amount of power that is within an acceptable range. The detection power is adjusted according to the quantization width and the quantization level that has been determined to control the detection power.

Chapter 6 describes the achievements of this works as well as the research future direction.

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