

平成 27 年度修士論文

Radio Environment Database considering  
Primary User Activity in Time Domain

プライマリユーザの時間的变化を考慮した  
電波環境データベース構築

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## 修士論文の和文要旨

研究科・専攻	大学院 情報理工学研究科 情報・通信工学専攻 博士前期課程		
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### 要 旨

コグニティブ無線を用いた周波数共用において、周波数の二次利用者 (SU: Secondary User) は既存の周波数割り当てユーザ (PU: Primary User) への干渉を回避する必要がある。その中で自身の通信品質を確保するためには、正確な電波環境推定技術が重要である。筆者らは、これまで車載無線機やスマートフォンといった移動端末が観測した膨大な電波環境情報から構築される電波環境データベースを提案してきた。テレビ帯域を対象とした実証実験により、従来の距離減衰モデルに基づく手法と比較して PU の平均受信電力値の空間的な分布を精度良く推定できることを明らかにしている。しかし、これまでは PU の通信状態の ON/OFF 遷移を考慮せずに観測値を一意に平均化していた。そのため、無線 LAN のように観測期間内に状態遷移する可能性のあるシステムについては、最終的な平均結果と ON 状態の平均受信電力値に差が生じる恐れがあった。そこで本稿では、PU の通信状態の遷移を検出するセンシング手法を提案する。提案手法では、電波環境データベースに蓄積された統計情報と連携し、協調センシングによって電波環境を観測することで状態遷移を検出する。本手法により、通信を行なっている状態での受信電力値の取り出しが可能となり、結果として PU が通信を行なっている状態での平均受信信号電力値を精度良く推定できる。本稿では特に、状態遷移時間の検出に焦点を当てたシミュレーション評価を行ない、その有効性を示す。

# 和文概要

コグニティブ無線を用いた周波数共用において、周波数の二次利用者 (SU: Secondary User) は既存の周波数割り当てユーザ (PU: Primary User) への干渉を回避する必要がある。その中で自身の通信品質を確保するためには、正確な電波環境推定技術が重要である。筆者らは、これまで車載無線機やスマートフォンといった移動端末が観測した膨大な電波環境情報から構築される電波環境データベースを提案してきた。テレビ帯域を対象とした実証実験により、従来の距離減衰モデルに基づく手法と比較して PU の平均受信電力値の空間的な分布を精度良く推定できることを明らかにしている。しかし、これまでは PU の通信状態の ON/OFF 遷移を考慮せずに観測値を一意に平均化していた。そのため、無線 LAN のように観測期間内に状態遷移する可能性のあるシステムについては、最終的な平均結果と ON 状態の平均受信電力値に差が生じる恐れがあった。そこで本稿では、PU の通信状態の遷移を検出するセンシング手法を提案する。提案手法では、電波環境データベースに蓄積された統計情報と連携し、協調センシングによって電波環境を観測することで状態遷移を検出する。本手法により、通信を行なっている状態での受信電力値の取り出しが可能となり、結果として PU が通信を行なっている状態での平均受信信号電力値を精度良く推定できる。本稿では特に、状態遷移時間の検出に焦点を当てたシミュレーション評価を行ない、その有効性を示す。

# Abstract

Recently, with the fast development of wireless communication technology, cognitive radio (CR) has been recognized as a promising solution to address the problem of impending spectrum scarcity for improving the utilization of spectrum for various wireless applications [1], [2]. In a CR system, it allows the Secondary Users (SUs) to opportunistically utilize the temporal and/or spatial unused spectrum holes without harmful interference to Primary Users (PUs). While SUs can occupy available spectrum holes as long as the corresponding PU is in active, they must immediately evacuate the band as soon as the corresponding PU appears. One of the main challenges is to intelligently determine ongoing PU activity to avoid interference toward PU. SUs can evacuate the band without affecting PU's activity and opportunistically access the spectrum to maximize the spectrum usage if the information about PU can be obtained in advance. Hence, more information about PU leads to more effective spectrum usage for SUs, and an external device for providing information of PU is necessary. One of the main challenges is to intelligently determine ongoing PU activity to avoid interference toward PU. SUs can evacuate the band without affecting PU's activity and opportunistically access the spectrum to maximize the spectrum usage if the information about PU can be obtained in advance. Hence, more information about PU leads to more effective spectrum usage for SUs, and an external device for providing information of PU is necessary.

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# Chapter 1

## Introduction

In chapter 1, present spectrum scarcity problem as the background of this thesis and technology proposed for solution is described. Also, the overview of this thesis and purpose is described.

### 1.1 Background

Due to the rapid development of wireless communication systems, a demand on spectrum resource for communication has increased explosively. Because the data rate and performance of the wireless communication system, such as mobile phone, are improved, it leads to a serious spectrum scarcity problem.

From Fig. 1.1, reference [1] predicts that Global mobile data traffic will increase nearly tenfold between 2014 and 2019 and mobile data traffic will grow at a compound annual growth rate (CAGR) of 57 percent from 2014 to 2019, reaching 24.3 exabytes per month by 2019. In addition to the increase of the data traffic, a fixed resource allocation method as the



Figure 1.1: Cisco Forecasts 24.3 Exabytes per Month of Mobile Data Traffic by 2019

current spectrum allocation policy, which is utilized for avoiding harmful interference toward licensed systems with each other, is also considered as a major reason for the scarcity of the



spectrum resource. As a reason, almost linear increasing demand on necessary bandwidth for communication leads to a difficult allocation for new systems. From Fig. 1.2 reported from Ministry of Internal Affairs and Communications(MIC) in Japan government, it is shown that most of the spectrum resources has already been allocated. Thus, the lack of spectrum resources has become a serious problem.

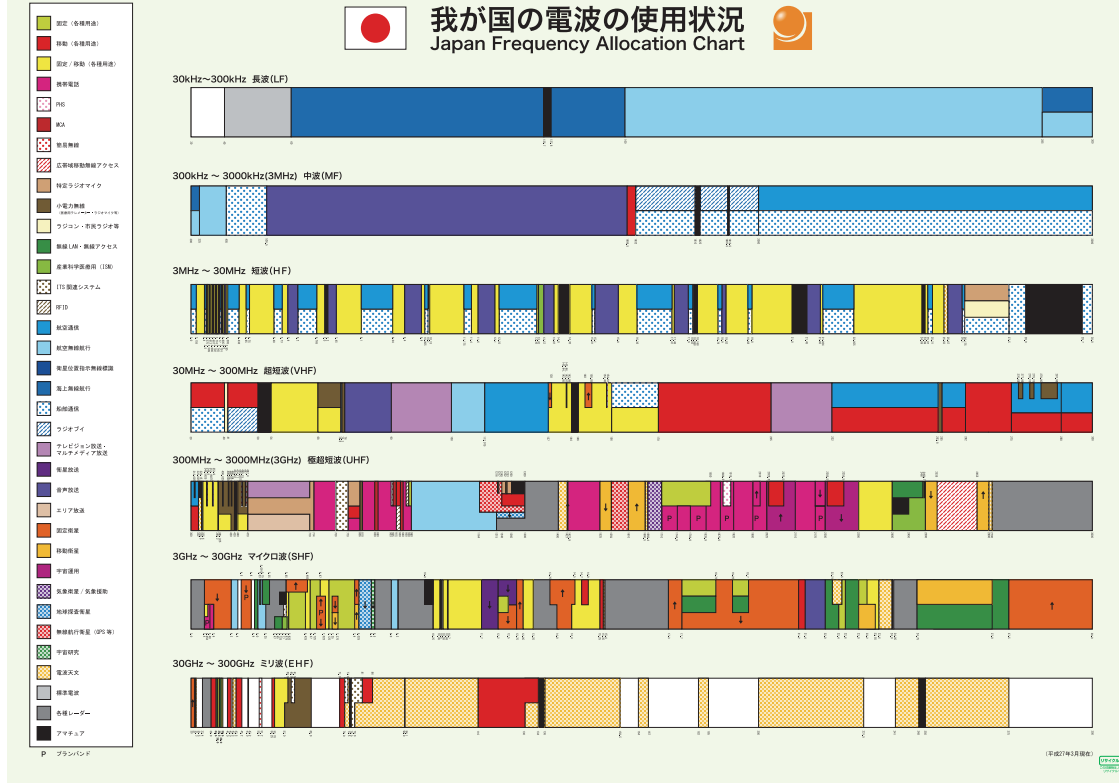


Figure 1.2: Japanese Frequency Allocation Chart.

Since the finite spectrum resources are not able to fulfill the exponential growth of demand on traffic, it is necessary to review the present spectrum policy with fixed resource allocation for the next generation wireless communication systems and a efficient spectrum utilization turns to be a key problem.

There are 2 main methods to ensure the bandwidth for new systems. Firstly, a spectrum arrangement on the whole wireless communication systems is utilized to extend available bandwidth. In 2011, an arrangement on television broadcasting is executed with switching to digital television broadcasting. However, it is not available for supporting the exponential growth of the data traffic and the number of systems. Second, an efficient and dynamic utilization method of bandwidth is considered to extend the probability for the future wireless communication systems, which is attracted attention as effective solution to the shortage of spectrum resources.

According to the report [2] from Federal Communications Commission(FCC), actual spectrum usage on the licensed band is lack of balance in both temporal and spatial domain and instantaneous usage efficiency remains at 15% ~ 80% even under crowd environment, such as

urban areas, which means that an unused White Space(WS) exists even under temporal and spatial varying environment. However, it is not allowed to utilize White Space by other licensed or unlicensed systems based on current radio regulations.

## 1.2 Spectrum Sharing Trend and Problem

Cognitive Radio(CR)[3] has been recognized as a promising solution to address the problem for improving the utilization of spectrum for various wireless applications. In a CR system from Fig.1.3 and 1.4, it allows the Secondary Users (SUs) to opportunistically utilize the temporal and/or spatial unused spectrum holes without causing interference to Primary Users (PUs). While SUs can occupy available spectrum holes as long as the corresponding PU is inactive, they must immediately evacuate the band as soon as the corresponding PU appears.

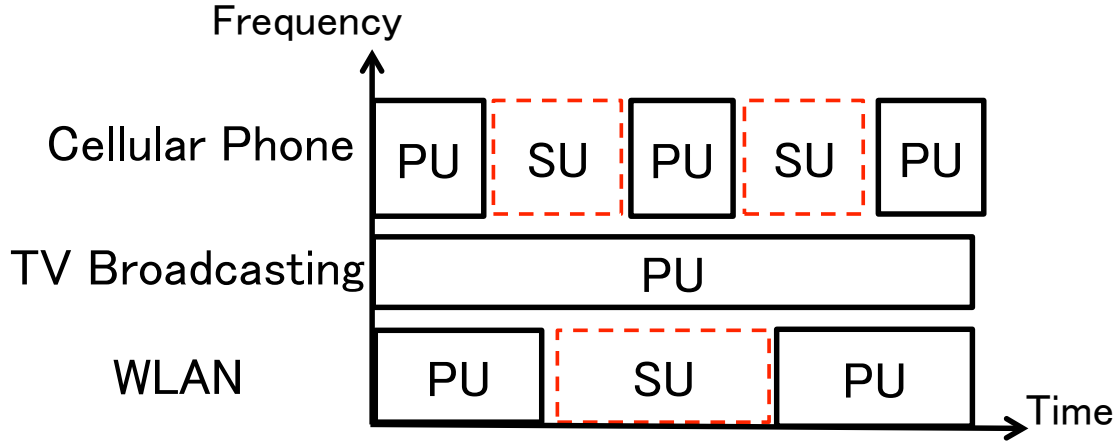


Figure 1.3: Coexistence between PU and SU in time domain.

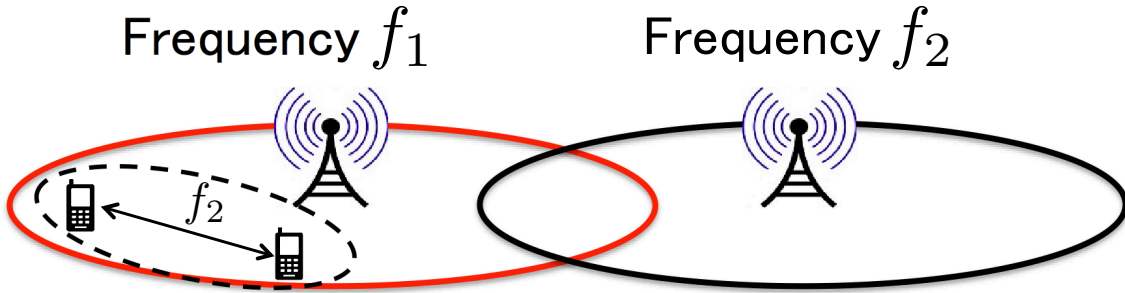


Figure 1.4: Coexistence between PU and SU in space domain.

One of the main challenges is to intelligently determine ongoing PU activity to avoid interference toward PU. SUs can evacuate the band without affecting PU's activity and opportunistically access the spectrum to maximize the spectrum usage if the information about PU can be obtained in advance. Hence, more information about PU leads to more effective spectrum usage for SUs, and an external device for providing information of PU is necessary. One of the

main challenges is to intelligently determine ongoing PU activity to avoid interference toward PU. SUs can evacuate the band without affecting activity of PU and opportunistically access the spectrum to maximize the spectrum usage if the information about PU can be obtained in advance. Hence, more information about PU leads to more effective spectrum usage for SUs, and an external device for providing information of PU is necessary. However, it is difficult for SU to obtain the information about activity of PU individually according to the position of SU and it may leads a performance degradation on PU protection.

The idea of Spectrum Database has been studied for assisting SUs to effectively reuse the spectrum. SUs can access the database to obtain the surrounding radio environment information and optimize their own parameters, such as modulation, transmitting power and so on. Federal Communication Committee (FCC) has been considered a propagation model-based spectrum database to provide the spectrum available information whether the spectrum locating SU can be used or not [3]. The model-based database has to set a large margin to avoid interference to PU because the realistic radio environment with considering the effect of surrounding obstacles cannot be considered. Therefore, there is a limit to improve the spectrum utilization efficiency.

Authors in [4, 5, 6] proposed a measurement-based spectrum database as a realistic method. The measurement-based database generates the database information by gathering the measuring received power at SUs, which are inactive for communication. Then the real radio propagation situation can be known and more accurate information at SU location can be provided. Then, SUs access to the database with their own location information and download the responding average received signal power at the SU location as shown in Fig.1.5.

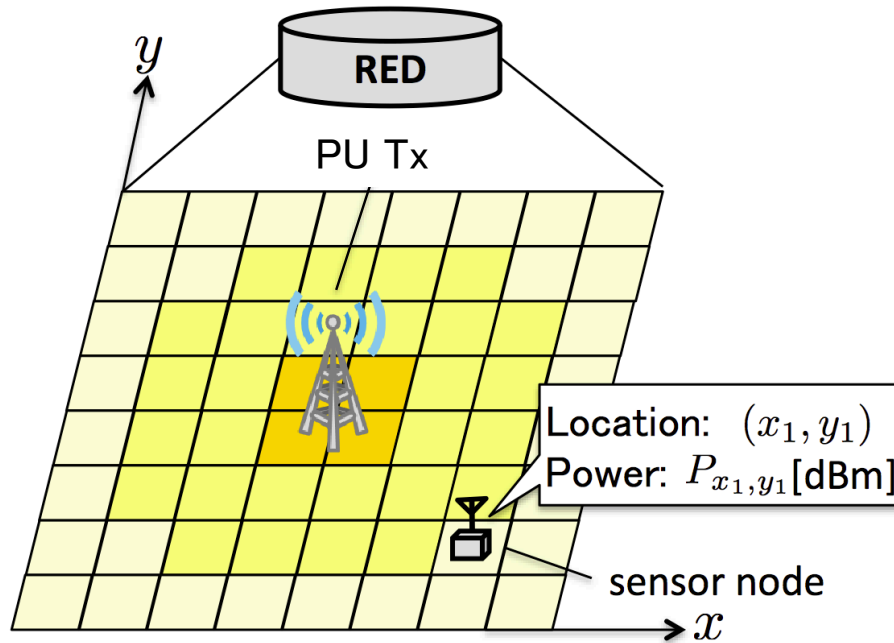


Figure 1.5: Measurement-based Spectrum Database.

The database is constructed by using reported measurement results of averaged sampling

value in each sensor node like energy detection spectrum sensing algorithm to calculate the average received signal power at each location. However, it is only appropriate under the assumption that the PU status is always ON. For example, in [7][8], the channel scenario is not considering primary user traffic during the sensing period. If there is a state transition from ON to OFF, sensor node will report the wrong received signal power to the database, which leads to low reliability and performance. Thus, it is necessary to detect PU 's state transition and extract the ON part only to the database to improve the reliability of database. In [9], single status change of primary user is focused.

### 1.3 Purpose

In this thesis, we focus on a distribution transition between the ON status and OFF status, CUSUM (cumulative sum) algorithm [10] and GLR (Generalized Likelihood Ratio) algorithm [11] are used to detect the rise up point and rise down point, which is status change point from OFF to ON and ON to OFF. Finally, only ON power can be extracted with using the detected transition point and the sensing error reduction is possible.

The remainder of this thesis is organized as follows. The overview of Cognitive Radio and Spectrum Sharing with Spectrum Database is introduced in Chapter 2. In Chapter 3 the basic sensing method for calculating the reported information is presented as a measurement-based spectrum database construction metrics and the problem of Spectrum database construction is described in detail. Chapter 4 proposes the active period detection method of primary signal for spectrum database in detail and the simulation results and performance evaluation are discussed in Chapter 5 . Finally, Chapter 6 concludes the thesis.

## Chapter 2

# Cognitive Radio

### 2.1 Overview of Cognitive Radio

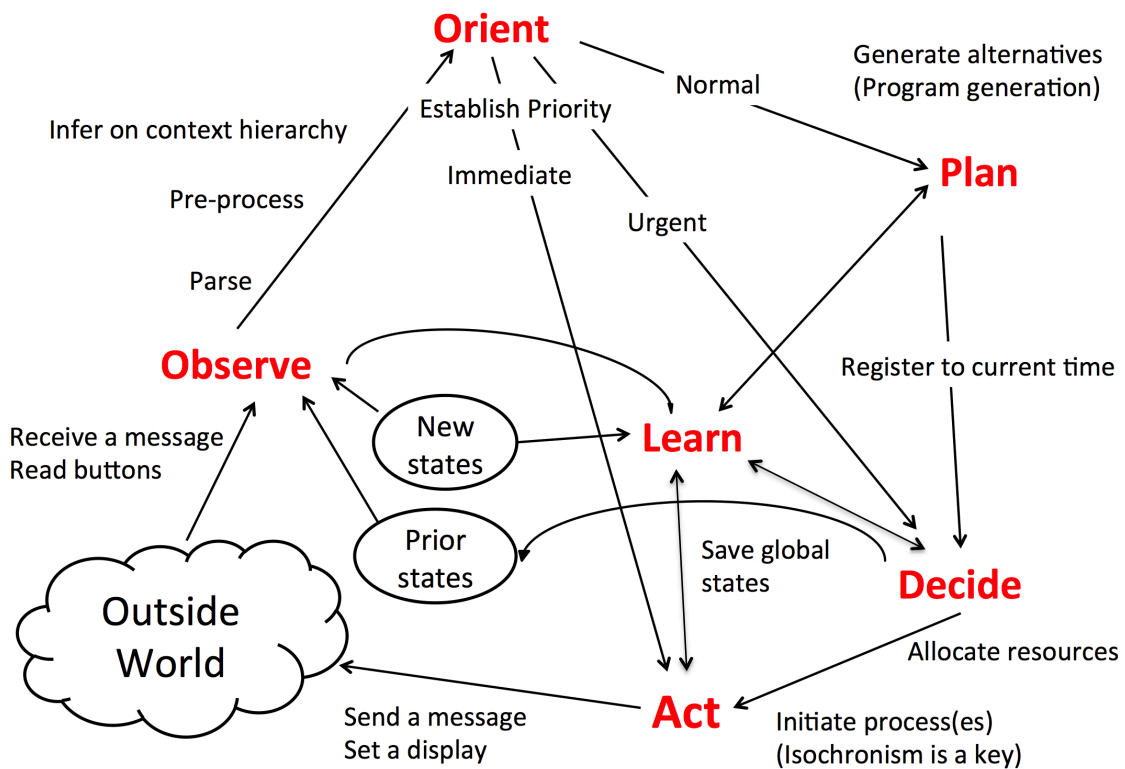


Figure 2.1: Cognitive Cycle.

## **2.2 Dynamic Spectrum Access for Spectrum Sharing**

### **2.2.1 Overlay Spectrum Sharing**

### **2.2.2 Underlay Spectrum Sharing**

## **2.3 Overview of Spectrum Sharing with Spectrum Database**

## Chapter 3

# Spectrum Database

### 3.1 Spectrum Sharing with Spectrum Database

### 3.2 Measurement-based Spectrum Database

#### 3.2.1 Spectrum Database Construction based on Energy Detection

### 3.3 Problem of Spectrum Database Construction

## Chapter 4

# Proposed Method

### 4.1 System Model

### 4.2 Transition Point Detection Method under Multiple ON/OFF Environment

#### 4.2.1 CUSUM

#### 4.2.2 GLR



## Chapter 5

# Simulation

### 5.1 System Model

### 5.2 Simulation Results

## Chapter 6

# Conclusion

In this paper, as a solution to the sensing error under multiple ON/OFF environment for Spectrum Database, a transition point detection algorithm is applied for the received power detection. Based on the detected transition point of the primary user status by using CUSUM algorithm and GLR algorithm. an active period of the primary user can be extracted. Transition point is well-detected and an improvement of sensing error can be confirmed through simulation results.

# Acknowledgments

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## International Conference Papers

- i. Hao Wang, Takeo Fujii, "Transition detection with Spectrum Database using Weighted Cooperative Sensing," Proc IEEE ICUFN, July. 2014.
- ii. Hao Wang, Takeo Fujii, "Active Period Detection Method of Primary Signal for Radio Environment Database," SmartCom2015, SR2015-50, pp. 21-22 , Oct. 2015.
- iii. Hao Wang, Koya Sato, Takeo Fujii, "Received Power Detection under Multiple ON/OFF Environment for Registering Radio Environment Database," Proc IEEE ICTC, Oct. 2015.
- iv. Koji Ichikawa, Hao Wang, Koya Sato, Takeo Fujii, "Height Power Estimation with Radio Environment Database in Urban Area," Proc IEEE IFUCN, July. 2015.

## Domestic Conference Papers

- i. 王昊, 中川洸佑, 北村優行, 藤井威生, "重み付け協調センシングを用いた無線環境データベースによる状態遷移検出法," 信学総大, B-17-19, March 2016.
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- v. 長谷川嶺, 王昊, 藤井威生, "電波環境データベース精度向上のための観測データクラスタリング法," 信学総大, B-17-19, March 2016.

# Appendix

From the next page, the program source is attached.