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変化を考慮した電波環境データベース構築

学生番号	1431019
氏名	王 昊
情報・通信工学専攻	情報通信システムコース
主指導教員	藤井 威生 教授
指導教員	山尾 泰 教授
提出日	平成28年1月29日

専攻主任印	主指導教員印	指導教員印

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		
氏　　名	王 昊	学籍番号	1431019
論文題目	Radio Environment Database considering Primary User Activity in Time Domain		

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 scarity 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 avaliable 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 chanllenges is to intelligently determine ongoing PU activity to avoid interferece 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 provding information of PU is necessary. One of the main chanllenges is to intelligently determine ongoing PU activity to avoid interferece 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.

Contents

Chapter 1

Introduction

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

1.1 Background

Due to the rapid development of wireless communication systems, a demand on sprectrum resource for communication has increased explosively. Because the data rate and perfomance of the wireless communication system, such as mobile phone, are improved, it leads to a serious sprectrum 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 increasement of the data traffic, a fixed resource allocation method as the

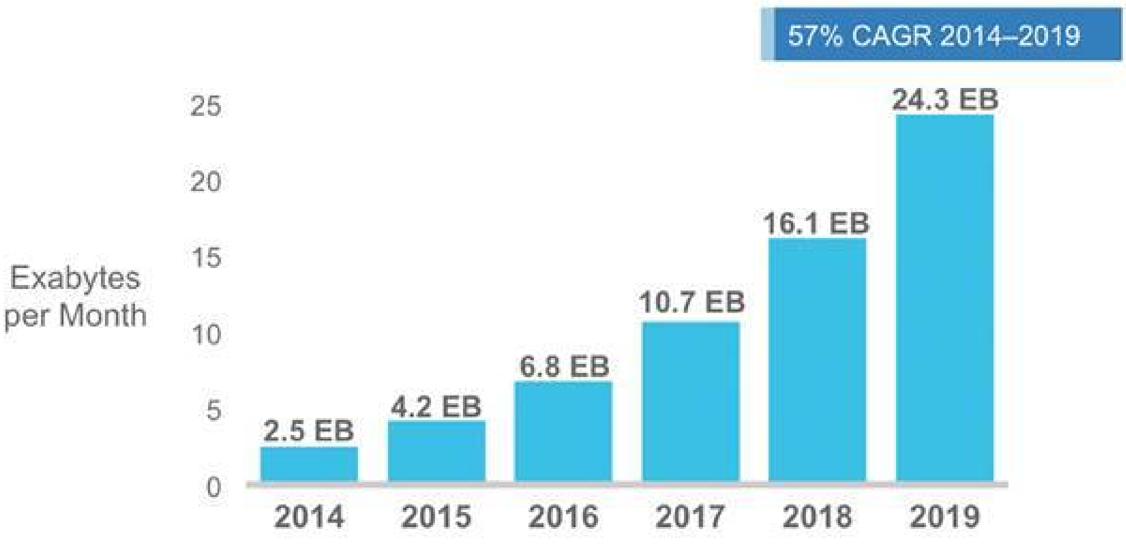

Figure 1.1: Cisco Forecasts 24.3 Exabytes per Month of Mobile Data Traffic by 2019

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.

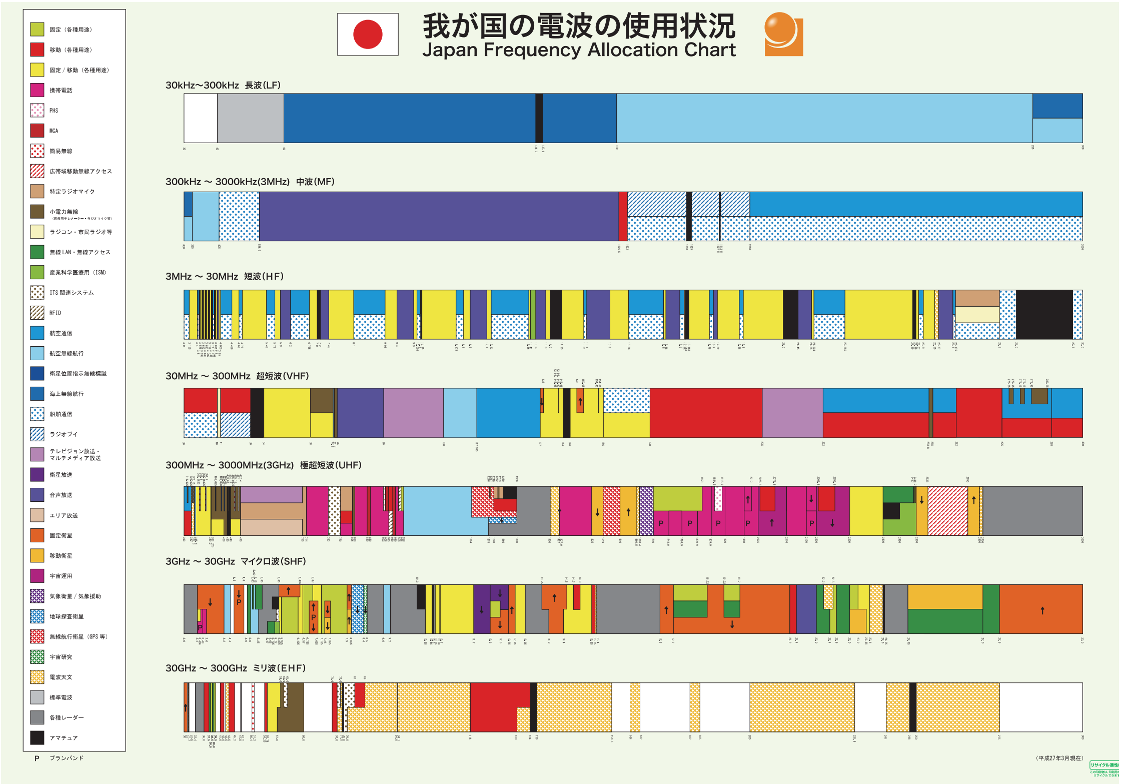

Figure 1.2: Japanese Frequency Allocation Chart.

Since the finite spectrum resources are not able to fulfill the expoential growth of demand on traffic, it is necessary to review the present spectrum policy with fixed resource allocation for the next generation wireless communication sysytems and a effecient 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 broadcasing. However, it is not available for supporting the expoential 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 envrionment. 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 utilizetion 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 avaliable spectrum holes as long as the corresponding PU is inactive, they must immediately evacuate the band as soon as the corresponding PU appears.

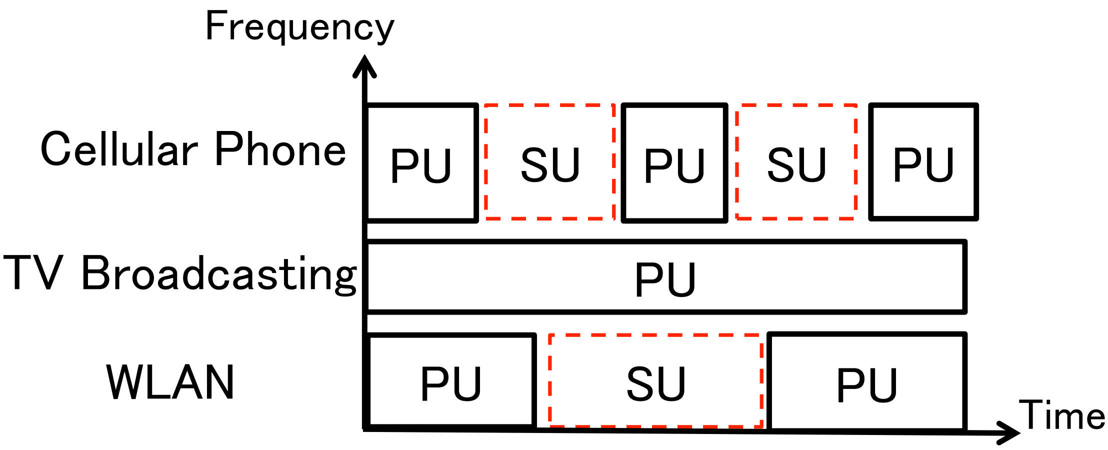

Figure 1.3: Coexsitance between PU and SU in time domain.

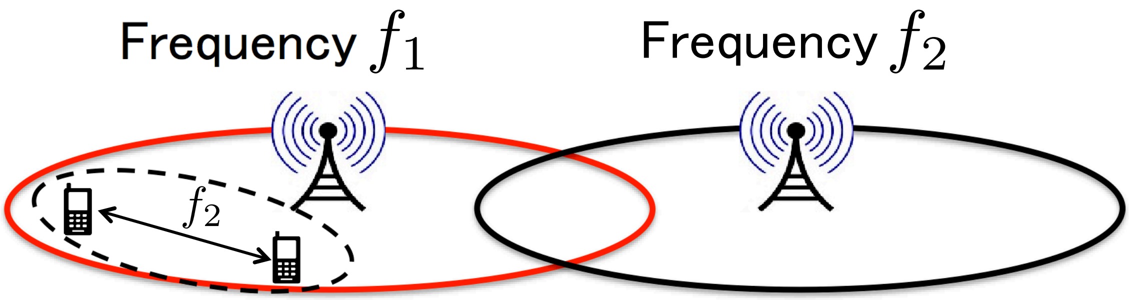

Figure 1.4: Coexsitance between PU and SU in space domain.

One of the main chanllenges is to intelligently determine ongoing PU activity to avoid interferece 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 provding information of PU is necessary. One of the main chanllenges is to intelligently determine ongoing PU activity to avoid interferece 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 performation 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 Comminication 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.

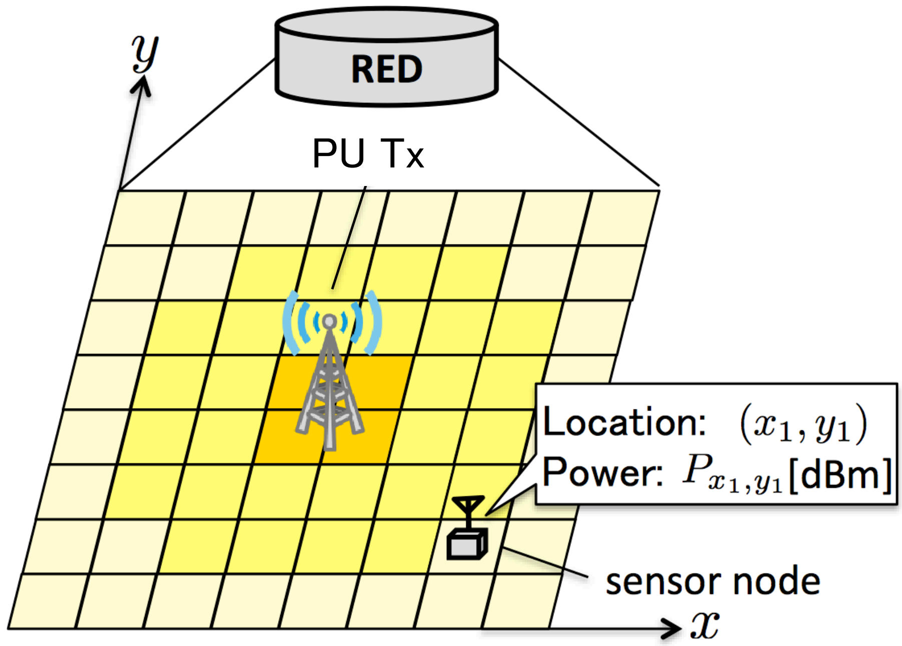

Figure 1.5: Measurement-based Spectrum Database.

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 method, 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 paper is organized as follows: In section II, the basic sensing method for calculating the reported information is presented as a database construction metrics. Section III introduces the proposed transition detection method in detail.The simulation results and performance evaluation are discussed in Section IV. Section V concludes the paper.

Chapter 2

Cognitive Radio

2.1 Overview of Cognitive Radio

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 Datbase 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

Acknowledgments

This paper is summarized the results of our research when the author is a student of master course in the University of Electro-Communications. I would like to express great thank to my supervisor, Prof. Fujii who always gives me great opportunities and provide me kindly feedbacks. Also, I have been helped and encouraged by Prof. Yamao, associate Prof. Ishibashi, and all the members of their laboratories.

References

[1] Cisco,"Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 20142019",Cisco White Paper.

[2] Federal Communications Commission, "Spectrum policy task force report,fcc 02-155," Nov. 2002.

[3] S. Haykin, "Cognitive radio: Brain-empowered wireless communications," *IEEE J.Selected Areas Commun.*,vol. 23, no. 2, pp. 201 - 220, Feb. 2005.

[4] H. Rajib, K. Inage, M. Ohta, T. Fujii," Measurement based radio environment database using spectrum sensing in cognitive radio, "Proc. iCOST 2011, Shanghai, Oct. 2011.

[5] T. Fujii, K. Inage, M. Kitamura, O. Altintas, H. Kremo, H.Tanaka, "Probing the spectrum with vehicles: towards an advanced spectrum database", IEEE VNC 2013, Dec. 2013.

[6] M. Kitamura, K. Inage, Y. Ohue, T. Fujii, "Development of measurement based spectrum database for efficient spectrum sharing, "SDR-WInncomm2014, Illinois, USA, Mar. 2014.

[7] G. Zhou, J. Wu, K. Sohraby, "Cooperative Spectrum Sensing with a Progressive MAP Detection Algorithm, " Proc. GLOBECOM, pp.1-5, Dec. 2011.

[8] Y. Pei; Y. Liang, K.C.Teh, K. H. Li, "Sensing-throughput tradeoff for cognitive radio networks: A multiple-channel sceario, " Proc. IEEE PIMRC, pp.1257-1261, 13-16 Sept. 2009.

[9] L.Lai, Y.Fan, and H.V.Poor," Quickest Detection in Cognitive Radio: A Sequential Change Detection Framework, " Proc. IEEE Globecom, Dec. 2008.

[10] E. Page, "Continuous inspection schemes," *Biometrika*, vol. 41, pp. 100-115, 1954.

[11] G. Lorden, "Procedures for reacting to a change in distribution," *Annals of Mathematical Statistics*, vol. 42, no. 6, pp. 1897-1908, 1971.

[12] G. Lorden, "ON excess over the boundary," *Annals of Mathematical Statistics*, vol. 41, pp.520-527, Apr. 1970.

[13] G. Lorden, "Open-ended tests for Koopman-Darmois families," *Annals of Statistics*, vol. 1, no. 4, pp. 520-527, Apr. 1970.

Publications

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.

ii. 王昊, 藤井威生, ”重み付け協調センシング及び電波環境データベースを用いたプライマリユーザの状態遷移検出法の一検討,” 信学技報 SR2015-1, pp. 1-6, May 2015.

iii. 市川浩次, 王昊, 佐藤光哉, 藤井威生, ”市街地環境における電波環境データベース連携による高さ方向の信号電力推定,” 信学技報 SR2015-2, pp. 7-12, May 2015.

iv. 王昊, 佐藤光哉, 藤井威生, ”フェージング環境におけるプライマリユーザ信号の時間的変化を考慮したデータベース精度向上法の検討,” 信学技報 SR2016-1, pp. 1-6, March 2016.

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.