



# AAU PhD Degree

## *Tentative Detailed Plan of Research*

### Title

Spectrum Utilisation and Management in Cognitive  
Radio Network

### PhD Student

Kishor Puna Patil

### Supervisor

Prof. Ramjee Prasad  
CTiF, AAU, Denmark

### Co-Supervisor

Prof. Knud Erik Skouby  
CTiF, AAU, Denmark

### Co-Supervisor

Prof. U.B. Desai  
IIT, Hyderabad, India

**PhD Programme:** Wireless Communication  
**Project title:** Spectrum Utilisation and Management in Cognitive Radio Network  
**Name of PhD student:** Kishor Puna Patil ([kpp@es.aau.dk](mailto:kpp@es.aau.dk))  
**Education:** Master of Engineering  
**Institution:** PDA College of engineering, Gulbarga, Karnataka, India.  
**Academic supervisor:** Prof.Ramjee Prasad  
**Co-supervisor:** Prof. Knud Erik Skouby  
Prof.U.B.Desai, IIT, Hyderabad, India  
**Department:** Electronic Systems  
**Date of enrolment:** 15 November, 2009  
**Expected date of:** 14 November, 2012  
**Completion:**

**Signature**

Date                      PhD student

**Study plan approved**

Date                      Academic Supervisor                      Prof.Ramjee Prasad

Date                      Head of Department                      Prof. Børge Lindberg

Date                      Head of PhD program                      Prof. Bernard Fleury

# Table of Contents

<b>Section No</b>	<b>Description</b>	<b>Page Number</b>
1.	Research work Summary/Abstract	1
2.	The scientific content of the PhD project	1
a	Background for the project	1
b	State-of- the- Art	2
c	Project's Objectives	5
d	Key Methods	5
e	Significance and application of Projects expected outcome	5
f	Time Schedule	5
3.	Agreement on the relationship between supervisor and student	4
4.	Plan for PhD courses	5
5.	Plan for Dissemination of Knowledge and Findings from the project	6
6.	Agreements on Immaterial Rights to Patents	6
7.	Plans for external collaboration	6
8.	Financing Budget for the PhD Project	6
9.	Short References	7

# **Spectrum Utilisation and Management in Cognitive Radio Network**

## **Section 1 – Research work Summary/Abstract**

The radio frequency spectrum is the natural resource like acoustic spectrum. The available radio spectrum is divided into different frequency bands which are allotted for particular wireless service. Some frequency bands are regulated by the government through licensing agreements. Such bands are known as licensed bands. These bands are used by only the licensed users (primary users). When licensed user do not utilize the allotted spectrum then it creates white spaces (holes). Some frequency bands are left free for all. Such bands are known as unlicensed bands. The actual measurements clearly show the licensed spectrum is underutilized continuously across time and space [1]. There are many white spaces in the radio spectrum which are not utilised. The spectrum scarcity today perceived today due to bandwidth hungry emerging wireless technologies, inefficient fixed frequency allocation and underutilized licensed bands. Cognitive radio is a promising wireless technology in which a network is able to sense its spectral environment, and especially white spaces, and adapts its usage in opportunistic manner. Thus the cognitive radio improves radio spectrum utilization by sharing the licences band with unlicensed user (secondary users). This can be achieved through efficient spectrum management techniques. Before we exploit the licensed band, we need to understand the occupancy of the licensed band. The goal of the research work is to identify spectrum bands with low occupancy and how Cognitive Radio Network (CRN) could be applied in Indian scenario. Also study the existing works on spectrum management especially on spectrum assignment and scheduling problem in India. Further to study the implications of deploying Cognitive Radio on spectrum regulation.

## **Section 2 – Scientific content**

### **2.1 – Background**

The transition from voice communication to wireless multimedia and web type of applications results in increasing need of higher data rates. But the natural frequency spectrum is limited. The current fixed frequency band allocation scheme cannot accommodate these requirements of increasing number of high data rate devices. The challenges for managing the radio spectrums in India are mentioned in [2]. The spectrum utilisation in the frequency bands between 30 MHz to 3GHz averaged over six locations was studied by the Shared Spectrum Company [3]. The report shows that the maximum utilisation is approximately 25% in TV channel and the average usage is only about 5.2%. This finding suggests that spectrum scarcity as perceived today is mostly due to the inefficient fixed frequency allocation rather than

physical shortage of radio spectrum. As a result, innovative techniques that can offer efficient utilisation of available spectrum are needed. Cognitive radio [4] is a promising solution to spectral crowding problem by introducing the opportunistic usage of licensed frequency bands that are not heavily occupied by licensed users. The spectrum occupancy measurement is essential for understanding the current spectrum usage. Then the white spaces can be effectively exploited using cognitive radio technology. The spectrum utilisation is one of the essential tools of the spectrum management which provides the regulators with necessary information about the spectrum holes in the different bands. The efficient utilisation of available spectrum is essential requirement of the future with the use of cognitive radio technology. This necessitates the knowledge of the spectrum usage in Indian scenario before considering the deployment of the cognitive radio technology in future.

Spectrum management is an extremely important part of telecommunications policy and regulation. The cognitive radio technology provides new challenges for policy enforcement.

## **2.2 – State-of-the-Art**

Worldwide several spectrum occupancy measurement campaigns have been performed but mostly in America. Few studies have been carried out in other places. But the proposed spectrum occupancy measurement will be the first kind of campaign in India. The first spectrum occupancy measurement campaign was performed in USA by NTIA (National Telecommunication and Information and Administration) [5]. The spectrum occupancy was found to be higher in coastal cities due to presence of Radars. The next large scale spectrum occupancy measurement was done by Marc McHenry et.al. which was funded and ordered by NSF [6]. The high dynamic range measurement system, a data collection and processing system was used for spectrum occupancy measurement. The occupancy in many American cities was found always below 25% and it is mostly due to the higher threshold between -90 to -105 dBm. Robin Chiang et.al conducted the spectrum occupancy measurement in New Zealand [7]. Statistical analysis of the measurement results are presented in the form of noise distributions, signal amplitude probability distributions, and spectral occupancy rates as a percentage of time. They also found several bands are underutilized. Their approach was based on the thermal noise floor of the measurement system for fixing the decision threshold which is also applied in [8]. The spectrum measurement set up and the lessons learned from the measurement activities discussed in [9]. The average occupancy for the band 80 MHz and 5850MHz was found only 4.5% in the spectrum survey of Singapore [10]. The spectrum occupancy measurements conducted in the frequency range from 75 MHz to 3 GHz in an outdoor urban environment of Barcelona, Spain is presented in [11]. The measurements are

analyzed and compared to the official spectrum regulations. The obtained results demonstrate the existence of a significant amount of spectrum available for the deployment of future CR networks. An automated processing procedure and an adaptive threshold method based on the analysis of measurement data's statistic characteristic to calculate the spectrum occupancy is provided in [12]. A generic spectrum surveying framework has introduced standardisation and automation to spectrum surveying [13]. There are various signal detection techniques presented in literature [14]. But the energy detection is the optimal method when only power measurements are available [15]. It is the technique used in above mentioned spectrum occupancy measurement. The challenges in the spectrum occupancy measurement are manmade noise or ambient noise and large dynamic input signal.

In [16] author has discussed economic, legal and policy issues if Cognitive radio is deployed. Cognitive radio is a promising technology for the efficient use of spectrum but it requires solutions to at least three policy problems: shadowing, power mix and hit-and-run.

### **2.3 – Project Objectives**

The main goal of the research work is to conduct spectrum occupancy measurement in India at different locations and identify the low occupancy bands suitable for deploying cognitive radio technology. The RF spectrum measurement framework is to be developed for this work. The other goal of the research is to study the deployment of the cognitive radio technology in Indian scenario. The current research works also include the overview of the current spectrum management problems and study the implications of deploying Cognitive Radio on spectrum regulation in India.

### **2.4– Key Methods**

The proposed research work has spectrum occupancy measurement at different locations in the initial stage. The continuous/systematic measurement method for spectrum occupancy measurement will be used. The measurement set up includes a wideband antenna covering the spectrum band under measurement, spectrum analyser along with Laptop with proper RF shielding. Some spectrum utilisation parameters will be determined from appropriate modelling of spectrum measurement. It will be developed after studying the existing models. The mathematical analyses of the model will be done for determination of parameters. Key methods also include the best practices used in spectrum management.

### **2.5 – Significance and applications of the Project's outcome**

Cognitive Radio (CR) has been attracted much attention in both academic and industrial circles during the last years for its capability to solve the issues like spectrum demand growth and

spectrum underutilization. The basic principle of the CR paradigm is to allow unlicensed opportunistic access to temporarily unused licensed frequency bands provided that no harmful interference is caused to legal licensed users. This paradigm will result in improved spectrum utilization efficiency. Nevertheless, before investigating the technical issues of Cognitive Radio systems, it becomes essential to have a clear picture of how different frequency bands are used in particular environments. A proper study of the current spectrum usage in India will facilitate the characterization of temporarily unoccupied spectral resources in terms of frequency, time, and space, as well as the identification of the most suitable bands for Cognitive Radio Networks (CRNs). Therefore, the measurement of real network activities constitutes an important step towards a realistic understanding of dynamic spectrum utilization and hence towards the deployment of future CRNs in India. The most important use of the data from this campaign will be to regulatory body in taking action to improve the use of the currently under utilized RF spectrum bands and to make the research and development investments and policy changes needed to support the development of dynamic spectrum sharing technology i.e. cognitive Radio Technology.

## 2.6- Time Schedule for the PhD Project

Task		Year 1			Year 2			Year 3		
1	Literature Survey									
2	PhD courses to be taken*									
3	Background Study									
4	Concept Development									
5	Problem Specification and Project Delineation									
6	Preparation for the spectrum occupancy measurement									
7	Spectrum occupancy measurement at different locations in India									
8	Data processing and analysis, determination of parameters									
9	Overview of current spectrum management									
10	Study of deploying CRN in Indian scenario									
11	Study of implication of deploying CRN on spectrum Regulation									
12	Publication (Journal and conferences)									
13	Write of the Thesis									
14	Stay abroad									

\* I will attend courses organised by Aalborg University through video conferencing and courses related to my research area in well known institutes in India.

## Section 3 – Agreement between Student and Supervisor

The student-supervisors agreement can be summarized as follows:

- The student and supervisors are together responsible for time management in the project. Time plan for the PhD study should be reviewed every six months.
- At least two meetings per month while at SAE, Weekly while at AAU.
- Minutes will be made for video/telephone conferences.

- Feedback regarding the progress and quality of work will be given during the meeting/conferences.
- Most meetings are scheduled and arranged jointly by the student and the supervisors.  
In case of special needs, both can call for meeting.
- Agenda will be provided by the student one day prior to each meeting.
- The student is a staff member of both AAU and SAE and gets involved in group activities in both places.
- Cross collaboration in writing papers: Supervisor will contribute to the student's papers and the student will contribute to the supervisor's papers.
- E-mail and Skype contact is always welcome from both parts and often rapidly answered.
- Supervisor will read, correct and advise on the writing process of the thesis.

This agreement will be evaluated every six months.

#### Section 4 –Plan for PhD Courses\*

Courses	Place/ Organizer	ECTS	Joint or Project course	Status
Introduction of Internet of Things	Nilee Prasad, Albena Mihovska, Zheng Hua Tan, Ole Brun Madsen	1	Project	Completed
Intellectual Property Rights	Lisbeth Tved Linde	1	Joint	Completed
Management of Research and Development	Professor Frank Gertsen	2,5	Joint	Planned
PhD Entrepreneur	Professor Frank Gertsen	3	Joint	Planned
Writing and Reviewing Scientific Papers	Professor Jakob Stoustrup	3,75	Joint	Planned
Political Economy on Telecom Policy	Anders Henten	5	Joint	Planned
Information Theory	Christian Thommesen	3	Joint	Planned
Vehicle Communication	Tatiana Kozlova Madsen and Hans-Peter Schwefel	3	Project	Completed
Localization in Wireless Networks	Prof. Bernard H. Fleury, Henrik Schiøler & Jakob Gulddahl Rasmussen & Hans-Peter Schwefel	3	Project	Planned
Advanced Spectral Estimation and Array Signal Processing	Prof. Søren Holdt Jensen	3	Project	Planned
PBL in Engineering and Science – Development of Supervisor	Prof. Anette Kolmos	2	Joint	Planned
<b>Total (planned)</b>		<b>30,25</b>		

\*Based on the 2009 PhD Courses Catalog and this list may change according to course available in India.



## Section 5 - Plan for dissemination of knowledge and findings from the project

### Publication Plan

I will publish papers on my research work in the following Journals and conferences.

Sr. No	Name of the Conference and Journals	Conference Dates	Location	Conference Web Site
1	Wireless Vitae -2011	28 Feb-30 Feb 2011	Chennai, India	<a href="http://www.wirelessvitae2009.org">http://www.wirelessvitae2009.org</a>
2	2010 International Conference on Signal Processing and Communications (SPCOM)	18 Jul - 21 Jul 2010	Indian Institute of Science, Bangalore, India	<a href="http://www.ece.iisc.ernet.in/~spco/">http://www.ece.iisc.ernet.in/~spco/</a>
3	International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM)	23 Sep - 25Sep 2011	TBD Wuhan, China	<a href="http://www.wicom-meeting.org/2011/">http://www.wicom-meeting.org/2011/</a>
4	Wireless Personal Communications Journal	Journal Springer US		
5	IEEE Journal on Selected Areas in Communications	Journal		
6	IEEE Transactions on Wireless Communications	Transactions		

## Section 6 Agreements on immaterial rights to patents, etc. produced during the PhD project.

The outcome of the research work will be registered for IPR and all the rights will be shared between the Aalborg University and the PhD student, following the standard procedures at AAU.

## Section 7 Plans for external collaboration

I will work along with research groups from IIT, Hyderabad, India.

## Section 8 Financing budget for the PhD project

- CTIF, Aalborg University will provide the research facility.
- Expenses for tuition fee, lodging, boarding and travelling will be borne by STES, Pune

## Short References

- [1] FCC, "Spectrum Policy Task Force Report (ET Docket no. 02-135)," Nov. 2002
- [2] K. Sridhara, Ashok Chandra, P. S. M. Tripathi, "Spectrum Challenges and Solutions by Cognitive Radio: An Overview", *Springer Journal Wireless Personal communication*, vol.45, No.3, May 2008, pp.281-291.
- [3] M. A. McHenry, "NSF Spectrum Occupancy Measurements Project Summary", shared spectrum co. report, Aug. 2005
- [4] J. Mitola and G.Q. Maguire, "Cognitive radios: making software radios more personal", *IEEE Personal Communications*, vol. 6, no. 4, Aug.1999, pp. 13-18.
- [5] F. H. Sanders, "Broadband Spectrum Surveys in Denver, CO, San Diego, CA, and Los Angeles, CA: Methodology, Analysis, and Comparative Results," in *Proc. of IEEE Symposium on Electromagnetic Compatibility*, 1998.
- [6] M. A. McHenry, P. A. Tenhula, D. McCloskey, D. A. Roberson, and C. S. Hood, "Chicago Spectrum Occupancy Measurements & Analysis and a Long-term Studies Proposal", in *Proc. of Workshop on Technology and Policy for Accessing Spectrum (TAPAS)*, Boston, USA, August 2006.
- [7] R. I. C. Chiang, G. B. Rowe, and K. W. Sowerby, "A Quantitative Analysis of Spectral Occupancy Measurements for Cognitive Radio", in *Proc. of IEEE Vehicular Technology Conference (VTC)*, Dublin, Ireland, April 2007.
- [8] M. Wellens, J. Wu, and P. Mahonen, "Evaluation of spectrum occupancy in indoor and outdoor scenario in the context of cognitive radio", in *Proc. of International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM)*, Orlando, FL, USA, August 2007, pp. 420-427.
- [9] M. Wellens and P. Mahonen, "Lessons Learned from an Extensive Spectrum Occupancy Measurement Campaign and a Stochastic Duty Cycle Model", in *Proc. of International Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities (TridentCom)*, Washington D.C., USA, April 2009.
- [10] M. Islam, G. L. Tan, F. Chin, B. E. Toh, Y.-C. Liang, C. Wang, Y. Y. Lai, X. Qing, S. W. Oh, C. L. Koh, and W. Toh, "Spectrum Survey in Singapore: Occupancy Measurements and Analyses", in *Proc. of International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM)*, Singapore, May 2008, pp. 1-7.
- [11] Lopez-Benitez, M.; Umbert, A.; Casadevall, F.; "Evaluation of Spectrum Occupancy in Spain for Cognitive Radio Applications", in *Proc. of Vehicular Technology Conference, VTC Spring*, 26-29 April 2009, pp. 1-5.
- [12] Miao, Dan; Feng, Zhiyong; Cai, Huiyong; Yao, Yanjun; "An Adaptive Threshold Method for Data Processing in Spectrum Occupancy Measurements", in *Proc. of Vehicular Technology Conference*, 20-23 Sept. 2009, pp.1-5.
- [13] Dinesh Datla, Alexander M. Wyglinski, and Gary J. Minden, "A Spectrum Surveying Framework for Dynamic Spectrum Access Networks", in *IEEE Transactions on Vehicular Technology*, vol. 58, no. 8, October 2009.
- [14] D. Cabric, S. M. Mishra, and R. W. Brodersen, "Implementation Issues in Spectrum Sensing for Cognitive Radios", in *Proc. 38th Asilomar Conf. Signals, Systems, and Computers*, Pacific Grove, CA, Nov. 2004, pp. 772-76.
- [15] R. Tandra and A. Sahai, "Fundamental limits on detection in low SNR under noise uncertainty", in *Proc. of the WirelessCom 05 Symposium on Signal Processing*, Maui, HI 13-16 June 2005.
- [16] Gerald R. Faulhaber, "Deploying Cognitive Radio: Economic, Legal and Policy Issues", in *International Journal of Communication*, University of Southern California Law School, Vol.2, pp. 1114-1124,

