RESEARCH REPORT

VTT-R-05255-13

CORE Project Final Report

Authors: Marja Matinmikko

Confidentiality: Public

Report's title CORE Project Final Report	
Customer, contact person, address Tekes, Elektrobit, EXFO, Finnish Defence forces, Nokia Siemens Networks, PehuTec, PPO Yhtiöt, and Renesas Mobile Europe.	**Order reference**
Project name Cognitive Radio Trial Environment	**Project number/Short name** 74854/CORE
Author(s) Marja Matinmikko	**Pages** 10/
Keywords Cognitive radio system, trial environment, spectrum regulation, mobile communication network	**Report identification code** VTT-R-05255-13

Summary

Cognitive Radio Trial Environment (CORE) project was a joint research project between VTT, University of Oulu and Centria University of Applied Sciences, funded by Tekes, Elektrobit, EXFO, Finnish Defence Forces, Nokia Siemens Networks, PehuTec, PPO Yhtiöt, and Renesas Mobile Europe. This report summarised VTT's research in the CORE project.

The future mobile telecommunication market is expected to experience strong growth in the next decade leading to increasing spectrum demand for mobile communication systems. As the availability of new spectrum for mobile communications is challenged by the unavailability of unallocated feasible spectrum bands, efficient spectrum sharing techniques and network resource usage optimisation techniques using cognitive radio system (CRS) capabilities are a promising approach to respond to the growing demand.

The CORE project has developed a trial environment for showcasing and development of CRS technologies for mobile communication systems to improve their resource use. The project has developed cognitive decision making techniques to optimise the resource use of future networks and verified their performances. The project has analysed the status of the current spectrum occupancy in Industrial, Scientific, and Medical (ISM) band. Business aspects have been taken into account by developing scenarios and business models for the future CRS business ecosystem by arranging several business workshops. The project has contributed to the international spectrum regulatory framework to promote the introduction of CRS techniques by participating in International Telecommunication Union Radiocommunication (ITU-R) sector in their work on cognitive radio systems (CRS). The project has prepared several spectrum sharing related input contributions to ITU-R WP5A including chairmanship of CRS sub-working group. International cooperation has also been carried out in COST Action IC0905 TERRA forum, and by giving several invited talks and a research visit.

Confidentiality	Public

Oulu 9.8.2013

Written by	**Reviewed by**	**Accepted by**
Marja Matinmikko Senior Scientist	Kyösti Rautiola Technology Manager	Jussi Paakkari VicePresident, ICT

VTT's contact address

Kaitoväylä 1, P.O. Box 1100, FI-90571 Oulu, Finland

Distribution (customer and VTT)

VTT

Preface

The Cognitive Radio Trial Environment (CORE) project was conducted at VTT in Oulu, Finland, in 2011-2013. The project was a cooperation project between three research organizations: VTT, University of Oulu and Centria University of Applied Sciences. The project belonged to Tekes Trial Environment for Cognitive Radios and Networks program. The project was funded by Tekes, Elektrobit, EXFO, Finnish Defence forces, Nokia Siemens Networks, PehuTec, PPO Yhtiöt, and Renesas Mobile Europe. In addition, Finnish Communications Regulatory Authority (FICORA) participated in the project's steering group in advisory role.

The CORE project consortium was coordinated by Dr. Marja Matinmikko from VTT and she also acted as a project manager for VTT's part of the CORE project. The project participants at VTT were Jouni Hiltunen, Jyrki Huusko, Marko Höyhtyä, Miika Lahti, Marja Matinmikko, Miia Mustonen, Jukka Mäkelä, Aarne Mämmelä, Marko Palola, Esa Piri, Jarmo Prokkola, Tapio Rauma, Tapio Rautio, and Teemu Rautio. VTT steering group consisted of the following participants: Kyösti Rautiola, Jukka-Pekka Laulajainen and Marja Matinmikko as secretary. This report summarizes VTT's research in the project.

The contributions from the project participants from all organizations are gratefully acknowledged.

Oulu 9.8.2013

Marja Matinmikko

Contents

1. Introduction

The mobile telecommunication market is expected to experience strong growth towards the year 2020. The increasing data rate requirements will lead to increasing spectrum requirements for mobile communication systems. Future mobile communication systems will need to find new ways to access spectrum bands in addition to the current approaches to meet the growing data rate demand with predictable quality of service (QoS). A promising approach is to develop spectrum sharing techniques that could allow mobile communication systems to be deployed in new spectrum bands that are currently only lightly occupied by other systems.

A key building block for meeting the growing demand is to take advantage of the recently developed cognitive radio system (CRS) technology. CRS technology could help to optimize network resource usage and facilitate spectrum sharing between different wireless communications systems. A CRS includes capabilities to obtain knowledge of system internal and external state, dynamically and autonomously adjust its operations accordingly, and learn from the results. Future CRSs can enhance spectrum sharing by exploiting temporarily and locally available spectrum while guaranteeing that incumbent systems remain free from harmful interference.

The CORE project was established to develop a trial environment that allows the trialing of cognitive decision making techniques and quantify their benefits. The project was a cooperation project between VTT, University of Oulu and Centria University of Applied Sciences in 2011-2013. The project belonged to Tekes Trial Environment for Cognitive Radio and Networks program. This report summarized VTT's part of the CORE research project.

2. Goal

The focus in the CORE project was on trial environments for showcasing and developing CRS techniques to help the future mobile communication systems to meet the growing data rate demand. The overall goals of the CORE project were to:

1. Develop trial environments for cognitive technologies in wireless communication.

2. Define an interface between cognitive solutions and cognitive networks or devices. The goal is to enable co-optimization of the performance.

3. Research and develop cognitive solutions for selected use cases.

4. Verify the performance of the cognitive solutions, using the trial environments and the open interface.

5. Clarify the expected changes in the business environment, arising from cognitive technologies. Explore models for the successful regulation and commercialization of cognitive solutions and the promotion of new business.

VTT's research work was divided into five work packages (WPs):

WP 0: Project management

- Project consortium coordination and dissemination of results.

WP 1: Cognitive R&D trial environment

- Development of a trial environment for supporting development, testing and verification of CRS solutions.

WP 3: Cognitivity research

- Definition of use cases and specifications for the trial environment.
- Research and development of cognitive features for performance optimization of the selected use cases and verification of their performance.
- Measurements of the spectrum occupancy in Industrial, Scientific and Medical (ISM) band.

WP 4: Business environment

- Scenarios and business models for future mobile communications business ecosystem with the introduction of CRS technology.
- Joint contributions with industry to selected regulatory/standardization forums.

3. Description

CRS technology offers potential to improve the resource usage of wireless communication systems. This project has focused on applying CRS technology to mobile communication systems with the goal to optimize their network resource usage and facilitate spectrum sharing between the mobile communication systems and another wireless system. In particular, this project has been trial oriented aiming at practical trial demonstrations of the CRS technology. The results are discussed in more detail in Chapter 6.

4. Limitations

The CORE project has focused on the practical trialing of CRS technology by building a trial environment. It has not aimed at finding optimal solutions for the network resource usage optimization problems. Thus, the developed solutions arise from practical needs and do not present optimised solutions.

5. Methods

Research methods included development of trial environment, performance measurements, analysis of measurements, literature reviews, arrangement of workshops and active participation in international forums related to spectrum regulation.

6. Results

The achieved results to meet the project's goals are summarized in the following.

6.1 CORE trial environment

VTT's CORE cognitive radio trial environment has been built into VTT's Converging Networks Laboratory (CNL) in Oulu, Finland, where the trialling of different wireless networks and solutions is possible in a controlled environment. The trial environment is presented in e.g. [1]-[3]. VTT's CORE trial environment is a dynamic, generalized rule-based decision making environment for real-life external system using the CORE tools. The purpose of the trial environment is to allow researchers carry out experiments on cognitive decision making. This has been realized by developing a CORE trial environment with methods for data

collection, decision making, and data transport with a browser-based user interface that allows editing of the decision rules.

Demonstration of the cognitive trial environment have shown the optimisation of resource usage among different wireless networks by making decisions about handovers based on collected information from the network and users. Different factors have been taken into account in the cognitive decision making including e.g. QoS, current network location, and list of available networks of each user. Design aspects for cognitive decision making are summarized in [4].

VTT's CORE trial environment is extensible as new services, networks, and terminals can be integrated into the environment by using an event-based cognitive application programming interface (API) and specific client-side tools such as Core Clients and CORE Cognitive manager. A browser-based user interface is available for remote decision management, controlling of the trial environment and visualisation of the collected information from the target system.

The performance of the developed cognitive decision making methods for handover decisions has been measured using the trial environment. The results showed that the CORE system works as it is supposed to and leads to more efficient use of access network resources. In the decision making, real-time monitored QoS can be used as input, leading to QoS-based decision making for making handover decisions, which in turn has been shown to increase quality for the end user.

6.2 Analysis of ISM band spectrum occupancy

If CRSs were used in current ISM bands with unlicensed operations, they should find free spectrum channels in those bands. The project has analysed the results of a measurement campaign of the spectrum occupancy in the 2.4 GHz ISM band in Oulu area in several places, including the university, a hotel, offices and the airport environment, for long periods of time, i.e., a week in a spot. The results were analysed based on different criteria to see how much, if any, space is left for CRSs. Depending on the selected criteria, the results were promising; in the measurement locations there was a lot of free space in the ISM band. The analysis showed that the resolution of the data affects strongly to the availability results. The narrower frequency channels are analysed, the more there seems to be space for CRS. However, the bandwidth of the wireless local area networks (WLAN) operating in the ISM band as well as CRS channel width has to be taken into account in measurements to get realistic view on the situation.

6.3 Business studies

The underlying mobile telecommunication business ecosystem could be affected by the advent of the CRS technology as the new spectrum sharing techniques can revolutionise the way to access the radio spectrum. The CORE project has studied the business aspects of CRS in order to understand their potential effects from a business perspective. Key findings from the literature on the technological and business context of CRS have been summarized and a theoretical framework of business scenarios, business models, and business ecosystems has been developed. Preliminary scenarios, business models and business ecosystems for CRS have been developed based on workshops by first identifying the key actors within the CRS business ecosystem together with their needs and the benefits of CRS technology. Future scenarios were then created for the business ecosystem together with an analysis of the drivers, limitations and challenges of the different scenarios. Attempts to develop business models for selected scenarios were also shown. The results are summarized in [4].

In addition the CORE project has reviewed the spectrum sharing framework that consists of regulatory, technology, and business domains and reported the findings in [6]. The role of the mobile network operators (MNO) in the spectrum sharing business has been considered in more detail and a set of simple rules have been developed for both incumbent and challenger MNOs to develop their sharing-based business models as presented in [6].

6.4 Spectrum regulation

Spectrum regulation plays an important role in the development of CRS technology. The real-life deployment of CRS techniques to allow spectrum sharing among different wireless systems is a spectrum regulatory decision that requires evidence of the potential benefits of the developed technologies. The CRS concepts have been introduced into the international spectrum regulatory framework at the ITU-R but a lot of effort is needed to make them part of the operations. The CORE project has participated in the international spectrum regulatory activities on CRS at the ITU-R by preparing contributions and participating in the meetings of ITU-R Working Party 5A (ITU-R WP5A). The contributions have been incorporated into the recent ITU-R Report M.2225 [7] and the work continues in the development of a new report on CRS in the land mobile service. Active participation in international spectrum regulation has also included the chairman of CRS studies at the ITU-R WP5A.

The project has carried out international cooperation on the spectrum management related aspects in in COST Action IC0905 TERRA on techno-economical and regulatory aspects of cognitive radio systems by participating as Finnish Management Committee member and vice-chair of Working Group (WG 2) on CR/SDR coexistence studies.

7. Validation of results

The performance of the developed CORE trial environment and cognitive decision making methods was verified by conducting measurements using the trial environment.

8. Conclusions

The CORE project has developed a trial environment for cognitive radios and networks and investigated CRS technology from technical, business and regulatory points of view. The developed CORE trial environment forms a good basis for future studies and trials on spectrum sharing and network resource optimisation. Overall, the tests with the first CORE cognitive systems show very promising results: The cognition brings intelligence to the usage of the radio and network resources, and, at best, increase considerably end user's QoS compared to the standard systems.

In the future the developed CORE trial environment will be used to demonstrate new spectrum sharing concepts such as the newly developed industry driven Authorised Shared Access (ASA) concept. The ASA concept would allow mobile communication systems to share spectrum from other incumbent systems. The development of these new spectrum sharing concepts will deserve further attention in terms of technical, regulatory and business domains.

9. Summary

The CORE project has developed a trial environment for the showcasing and development of CRS technologies for mobile communication systems to improve their resource use. The project has developed cognitive decision making techniques to optimise the resource use of future networks and verified their performance using the CORE trial environment. The project

has analysed the status of the current spectrum occupancy in Industrial, Scientific, and Medical (ISM) band and identified spectrum opportunities. Business aspects have been taken into account by developing scenarios and business models for the future CRS business ecosystem by arranging several business workshops. The project has contributed to the international spectrum regulatory framework to promote the introduction of CRS techniques by participating in International Telecommunication Union Radiocommunication (ITU-R) sector in their work on cognitive radio systems (CRS). The project has prepared several spectrum sharing related input contributions to ITU-R WP5A in their CRS work including chairmanship of CRS group.

References

[1] M. Matinmikko, M. Palola, H. Saarnisaari, J. Känsäkoski, M. Höyhtyä, M. Katz, M. Mustonen, H. Tuomivaara & P. Ahokangas. Älyä verkkoon päätöksentekokoneella. Prosessori. 2011.

[2] M. Matinmikko, M. Palola, M. Höyhtyä, J. Prokkola, H. Saarnisaari, H. Tuomivaara, J. Känsäkoski, T. Kippola, M. Heikkilä & T. Kupiainen. CORE Project White Paper 29.6.2012.

[3] The CORE Project. http://core.willab.fi/

[4] M. Höyhtyä, M. Palola, M. Matinmikko & M. Katz. 2011. Cognitive engine: Design aspects of mobile clouds. Proceedings of 4th International Conference on Cognitive Radio and Advanced Spectrum Management (CogART 2011). Barcelona, Spain, 26-29 October 2011. Pp. 1-5.

[5] P. Ahokangas, M. Matinmikko, J. Myllykoski & H. Okkonen. 2012. Future scenarios, ecosystems and business models for cognitive radio systems. VTT Technology 55.

[6] P. Ahokangas, M. Matinmikko, S. Yrjölä, H. Okkonen & T. Casey. “Simple Rules” for mobile network operators’ strategic choices in future cognitive spectrum sharing networks. IEEE Wireless Communications Magazine, Vol. 20, No. 2, pp. 20-26, April 2013.

[7] ITU-R Report M.2225. 2011. Introduction to cognitive radio systems in the land mobile service. International Telecommunication Union Radiocommunication sector. 17 p.