



# Flexible and Spectrum Aware Radio Access through Measurements and Modelling in Cognitive Radio Systems

## FARAMIR

## Document Number D7.5

## Awareness and Wider Societal Implications

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| Contractual date of delivery to the CEC: | 30.09.2012 |
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| Project Number and Acronym: | 248351 - FARAMIR |
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| Participants: | RWTH, IMEC, HWSE, TREL, UKIM, FT |
| Workpackage: | WP7 |
| Security: | PU |
| Nature: | R |
| Version: | 1.0 |
| Total number of pages: | 19 |

Abstract:

This document describes the different events and activities that the FARAMIR consortium partners have been involved in, in order to disseminate the results of the project and hence raise the public awareness and possibly participation to the adoption and further refinement of the radio environment map technologies.

Keywords: Radio environment maps, Public participation, Industrial exhibitions, Scientific conferences, Spreading awareness, Collaboration with other projects.

Document Revision History

| *Version* | *Date* | *Author* | *Summary of main changes* |
|---|---|---|---|
| 0.5 | 05.09.2012 | Janne Riihijärvi (RWTH) | Initial structure and first inputs |
| 0.8 | 23.09.2012 | Janne Riihijärvi (RWTH) | Second round of inputs integrated |
| 1.0 | 30.09.2012 | Janne Riihijärvi (RWTH) | Integrated version for delivery to EC |
| 1.0f | 30.09.2012 | Petri Mähönen (RWTH) | Coordinator review and approval |

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# 1 Introduction

The goal of the FARAMIR project is to research and develop techniques for increasing the radio environmental and spectral awareness of future wireless systems. The main approach in the project to accomplish this was by developing a reference architecture and implementation for Radio Environment Maps (REMs), which are essentially knowledge bases in which cognitive radios and store and access information on the environment and other wireless systems.

During the whole duration of the 33 months of the project, partner members have been committed to disseminate the results of the project both internally inside their respective companies, as well as externally, to raise public awareness of the research carried out. The consortium partners have identified several ways to disseminate the results and knowledge produced by the project. Notably, the participation to events such as conferences and fairs, the usage of the REM technologies in other collaborative projects has been found as key approaches to spread awareness to this work. This document presents a description of the main events and activities that have been taken place to present the radio environment map technology to the community and promote its broader usage.

# 2 Major Events for Spreading Awareness

During the FARAMIR project, several events have allowed the consortium partners to demonstrate the technology they have developed. This section presents the major events and the outcome of each of these events in term of public awareness.

## 2.1 IEEE DySPAN 2011

### 2.1.1 Event Description

The IEEE Dynamic Spectrum Access Networks (DySPAN) symposium is the leading scientific conference for presenting research on technical and policy aspects of cognitive radio, cognitive wireless networks and dynamic spectrum access. IEEE DySPAN was founded in 2005 to further the discussion of radically new spectrum access technologies, and the conference typically includes a full roster of system demonstrations, panels, tutorials and keynotes tailored to the advancement of spectrum engineering and sharing methods, regulations and systems oriented research. The 2011 conference was organized on 3rd – 6th of May, 2011, in Aachen, Germany, by RWTH, and attracted over 300 participants, including many of the leading researchers, technologists and policy makers in the field.

### 2.1.2 What was Presented?

The FARAMIR project made several technical contributions towards the conference, including two full technical papers, two posters, and one major integrated demonstration by UKIM, HWSE, FT and RWTH. The technical papers presented studies on available white space spectrum in Europe, as well as general methodology for evaluating performance of cognitive wireless networks. The two posters further presented indoor propagation and spectrum use measurements, as well as a study on the interconnections between population structures compared to deployment of different wireless networking technologies. Finally, the joint demonstration (see Figure 1) focused on dynamic construction of radio environment maps from measurements originating from heterogeneous spectrum sensors, including coverage estimation and localization of transmitters.

Figure 1: The joint FARAMIR demonstration in IEEE DySPAN 2011.

### 2.1.3 Main Outcomes

All the FARAMIR contributions were very well received in the conference. One of the technical papers was chosen for plenary presentation and was subsequently fast-tracked towards IEEE Transactions on Mobile Computing, a leading IEEE journal, as one of the three papers with highest marks from the review process. The joint demonstrator received major audiences throughout the conference, and was finally voted by a highly experience jury together with the audience as the best demonstration in the conference. As an overall outcome, the project received significant visibility both in the research community, as well as amongst policy makers and industry.

## 2.2 Orange Labs Research Exhibition

### 2.2.1 Event Description

The Orange Labs research exhibition took place from 6th to 8th of December, 2011, in the major research center of the company at Issy-les-Moulineaux, France. The aim of the exhibition is to have a dedicated time for sharing, enrichment and social interaction. The research exhibition offers to the group employees and its partners a condensed view of its innovative strength and a look at the future service and technology trends. The 50 demonstrations and 12 conferences illustrating the major research domains allow the visitors to understand better the keys and issues of the research within the group and to discover the latest innovations from the group's researchers. The employees and partners, in France and abroad can see the recent innovations and the most formative projects on technological breakthroughs likely to change the landscape of telecommunications over the next ten years.

### 2.2.2 What was Presented?

FARAMIR's REM-based intra-operator femtocell optimization prototype has been demonstrated in this exhibition (Figure 2). With the combined efforts of FARAMIR partners FT, TREL, RWTH, UKIM, it has been demonstrated that neighboring REM-enabled indoor access points avoid inter-cell interference through: 1-adaptive power control, 2-resource (channel) selection/allocation. The first part has been carried out by TREL. It uses programmable femtocell hardware (picoChip PC9608 LTE FDD as the base station and Aeroflex TM500 Test UE as the user terminal) as indoor access points on the LTE over-the-air interface. The REM backend is implemented on a laptop connected to SunSPOT sensors. The second part has been implemented by RWTH and UKIM. The indoor access points have been implemented using programmable WARP boards operating on the 2.4 GHz and 5GHz ISM bands (the same concept can be easily extended to the cellular domain). The REM backend has been implemented on a laptop computer and connected to programmable USRP2 cards and SunSPOT devices that act as sensors. The details of the demonstration scenario and setup can be found in deliverable D6.2, Section 4.


Figure 2. FARAMIR demonstration to Orange Labs
Research Director N. Demassieux at Orange Labs Research Exhibition

### 2.2.3 Main Outcomes

The FARAMIR demonstrator was one of the largest and most attractive setups of the exhibition, with a dozen screens, laptops and twice as much hardware devices (software programmable cards and devices). More than 75 visitor groups, both internal to Orange group and external entities such as equipment vendors, government agents and European Commission representatives, visited the demonstrator. Visitors included the research, development and operational directors of Orange group, as well as those of the external bodies. The feedback from all the visitors was extremely positive, receiving interest and collaboration requests from other internal research and development projects. Discussions with VIPs have been one of the main highlights (cf. the above photo depicts the FARAMIR demonstrator to the Research Director of Orange Labs).

## 2.3 ECC/COST-TERRA Workshop on Cognitive Radio and SDR

### 2.3.1 Event Description

The European Electronic Communications Committee organized the workshop jointly with the Cost-action COST-TERRA. The workshop took place on the 2nd and 3rd of May, 2012, in Mainz, Germany, and was intended as a place where academics, industry members, and policy makers could meet industrial exploitation, research developments, and regulatory progress in diverse topics related to cognitive wireless networks and software defined radio, including standardization activities. The workshop attracted more than 130 participants from all of the sectors mentioned

above. Also BNetzA, one of the FARAMIR partners, also provided logistical support for the workshop organization.

### 2.3.2 What was Presented?

For the workshop RWTH and UKIM collaborated to set up a demonstration of the FARAMIR REM construction technology, especially focusing on spatial estimation of coverage areas as well as localization of signal sources. This was specifically requested by some of the co-organizers of the event, especially coming from standardization organizations such as ETC, based on the earlier version of the demonstrator shown in IEEE DySPAN 2011. Figure 3 shows an overview of the demonstration setup.

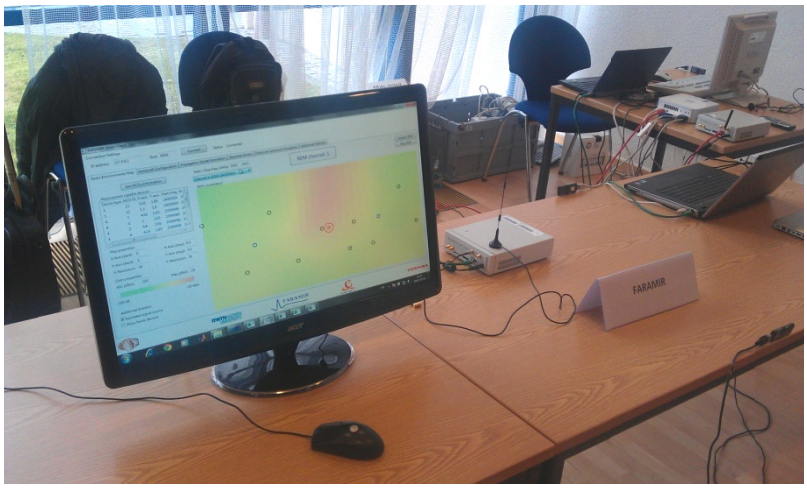


Figure 3: The FARAMIR demonstrator at the ECC/COST-TERRA workshop.

### 2.3.3 Main Outcomes

The FARAMIR demonstration was enthusiastically received, and attracted significant amount of audience throughout the workshop. Many of the attendees commented on the novelty of using spectrum measurements in a dynamic fashion to enhance dynamic spectrum access and cognitive radio operation, as opposed to traditional static geolocation databases.

## 2.4 2nd International Regulatory Conference (IRC)

### 2.4.1 Event Description

The Agency of Electronic Communications (AEC) of the Republic of Macedonia organized the 2nd International Regulatory Conference (IRC) in May 2012. The conference gathered more than 300 representatives from European regulators, prominent national and international operators (e.g. T-Mobile, Telekom Slovenia, Telekom Austria etc.) and major telecommunications vendors (e.g.

Huawei, Ericsson etc.). There were intensive discussions on the current regulatory status and the vision for ICT developments in the nearby future. The Minister of Information Society of the Republic of Macedonia as well as the Director of AEC emphasized the importance of the event giving keynote speeches at the conference opening.

### 2.4.2 What was Presented?

Prof. Liljana Gavrilovska from UKIM gave a presentation (see Figure 4) on future spectrum management concepts describing in details the development and the application of the FARAMIR's REM architecture. Additionally, representatives from UKIM involved in FARAMIR were demonstrating in practice the REM concept setting up a demo with several spectrum sensors that was providing real-time REM information from the conference venue and was showcasing the potentials for using this information for femtocell management. The demonstration booth is shown in Figure 5 below.

Figure 4: Presentation at IRC 2012

Figure 5: Demo booth at IRC 2012

### 2.4.3 Main Outcomes

The presentation and the demonstration triggered high interest among the conference participants initiating many fruitful discussions and invitations for further collaboration. Specifically, UKIM's group involved in FARAMIR was contacted by Huawei Macedonia, T-Mobile Macedonia, Telekom Slovenia and AEC for possible consultancy in their future operation.

## 2.5 7th International Symposium on Turbo Codes and Iterative Information Processing

HWSE has demonstrated a proof-of-concept prototype system at the 7th International Symposium on Turbo Codes & Iterative Information Processing. The following describes this demonstration event.

### 2.5.1 Event Description

The 7th International Symposium on Turbo Codes & Iterative Information Processing was held from Monday August 27 to Friday August 31 in Gothenburg, Sweden and attracted between 100

and 150 international, mostly academic experts on Information Theory and Coding. The Symposium was a major international event covering and reflecting the current status of advanced research in iterative information processing and its application to information theory and digital communications. HWSE was also a gold sponsor of this event.

### 2.5.2 What was Presented?

Within FARAMIR, HWSE has developed a hardware prototype of a TDD-LTE system operating in the white spaces of the TV band. During the first 3 days of the event (Monday to Wednesday) HWSE had a booth in the coffee/lunch area. In this booth HWSE showed how a REM-architecture can be useful in the operation of a future opportunistic use of the TV spectrum by LTE systems. The demo included a TDD-LTE base station (hardware prototype modules), an instance of the REM architecture (PC software module), and an LTE controller (PC software module), see Figure 6.

The proof-of-concept prototype showed

A) that LTE, when properly designed for spectrum agility, can be deployed in the TV bands, and
B) that a REM architecture can be of significant use when operating such an opportunistic network.

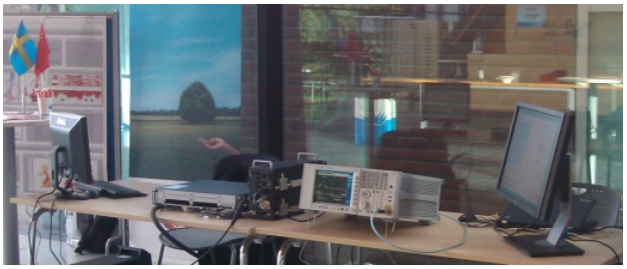

Figure 6: The LTE base band and radio modules along with a spectrum analyzer.

Concretely, based on a changing radio interference reality, reflected through the radio-environment map (REM), an LTE controller module takes control over the spectral behaviour of an LTE base station. When interference regulations require, the LTE controller instructs the LTE bases station to evacuate the TV channel it occupies and move its operation to another TV channel. The REM-content, and the evacuation process could be monitored by the audience through a rich GUI and on a spectrum analyzer.

### 2.5.3 Main Outcomes

The demo, being the only one at the conference, and with a prominent location (see Figure 7), was well received. There was a great interest of the audience and roughly one third of all the people took the opportunity to learn about the concepts being shown in detailed discussions with us. Roughly another third of the audience, browsed by our both and was more briefly introduced to the motivation and purposes of the demo.

Figure 7: Coffee/lunch area with HWSE demo booth.

In short, this event targeted a part of the academic research community where cognitive radio and dynamic spectrum access, if known at all, are typically treated from a theoretical angle. Hence, this event has contributed to spread awareness among researchers *beyond* the regular circle of people who typically would learn about this material through other means of scientific dissemination, researchers who typically could adopt these use cases and scenarios in their future research focus.

## 2.6 3rd COST IC0902 workshop

### 2.6.1 Event Description

The COST IC0902 action organized its 3rd workshop in Ohrid, Macedonia, in September 2012. Most of the action members were present giving keynotes and talks on their latest research efforts in the field of cognitive radio and networking for cooperative coexistence of heterogeneous wireless networks.

### 2.6.2 What was Presented?

Prof. Liljana Gavrilovska from UKIM gave a presentation on MAC protocols for cognitive radio networks while assist. prof. Vladimir Atanasovski gave a talk on the construction aspects and the reliability of REMs. Additionally, representatives from UKIM involved in FARAMIR were demonstrating in practice the REM concept with a demo comprising several spectrum sensors providing real-time REM information from the conference venue. These are illustrated in Figures 8 and 9 below.

Figure 8: Discussions at the demo booth

Figure 9: Demonstration of the FARAMIR's REM prototype

### 2.6.3 Main Outcomes

The presentation and the demonstration triggered high interest among the conference participants initiating many fruitful discussions and invitations for further collaboration. The workshop served as a good basis for widespread of the FARAMIR ideas within the COST IC0902 action.

## 2.7 IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2012)

HWSE, UKIM, IMEC and RWTH have submitted a joint demonstrator proposal to DySPAN 2012, which was accepted for presentation at the symposium. The following describes the consortium's preparation of this planned prototype demonstrator. In addition to the joint demonstrator further technical contributions from the project are also presented, including latest work on spectrum measurements (again chosen for plenary presentation), as well as additional individual demonstrations on specific technologies by project partners.

### 2.7.1 Event Description

The 6th IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2012) will take place 16–19 October 2012 in Bellevue, Washington. IEEE DySPAN 2012 is the premier global forum that focuses solely on the development and deployment of advanced spectrum engineering and smart radio systems.

Figure 10: Bellevue, Washington, location of the upcoming DySPAN 2012.

This year's IEEE DySPAN event will include four full days of technical, business and policy symposia consisting of nearly 60 paper presentations and more than 15 new technology demonstrations and posters.

### 2.7.2 What will be Presented?

In the joint demonstration we will show how a REM-architecture can be useful in the operation of a future opportunistic use of the TV spectrum by LTE systems. The demo will include a TDD-LTE base station (hardware prototype modules), a REM architecture (PC software module), an LTE controller (PC software module) and a sensing engine (hardware prototype), along with appropriate graphical user interfaces and spectrum analyzing hardware.

The proof-of-concept prototype will show aspects of the entire cognitive chain of events, in particular

A) that sensing can contribute to significant increased awareness of the radio environment through REMs,
B) that a REM architecture can be of significant use when operating such an opportunistic network, and
C) that LTE, when properly designed for spectrum agility, can be deployed in the TV bands

Concretely, based on a changing radio interference reality, reflected through the radio-environment map (REM) (fed with measurements of the sensing engine), an LTE controller module takes control over the spectral behaviour of an LTE base station. When interference regulations require, the LTE controller instructs the LTE bases station to evacuate the TV channel it occupies and move its operation to another TV channel. The REM-content, and the evacuation process could be monitored by the audience through a rich GUI and on a spectrum analyzer.

# 3 Collaboration with Other Projects

Most of the members of the FARAMIR consortium also actively participate to other European Projects. An efficient approach to raising awareness of the radio environment map technologies, and promote their usage is to exploit them and disseminate the work in other projects.

## 3.1 FP7 ICT 257626 ACROPOLIS

### 3.1.1 PROJECT DESCRIPTION

ACROPOLIS is a Network-of-Excellence aimed at integrating the European research in the fields of cooperation and coexistence in cognitive radio, cognitive networking and flexible networking. It is an interdisciplinary project aiming to foster rapid innovation and bridging the gaps in the European research in the corresponding areas.

### 3.1.2 Collaboration Activities

UKIM and RWTH have collaborated with several partners from ACROPOLIS Network of Excellence on topics highly relevant to and originating from FARAMIR. These collaborations are also means to continue the technical work initiated in FARAMIR beyond the project lifetime, as ACROPOLIS continues well after the end of FARAMIR. Specifically, the collaborations are:

- Collaboration on learning and knowledge management aspects in cognitive radio networks with UKIM from FARAMIR with UPRC and UoS from ACROPOLIS.
- Collaboration on security aspects for policy controlled cognitive radio between UKIM and JRC
- Collaboration on rendezvous protocols for cognitive radio networks and reliability of REMs with RWTH
- Collaboration between RWTH and KCL on spectrum measurements.
- Collaboration on transmitter(s)' localization in indoor environments between UKIM and IASA
- Collaboration by UKIM on network selection and classification using a combination of spectrum sensing and machine learning with KCL

So far, the collaborations resulted in six joint papers:

[1] V. Stavroulaki, A. Bantouna, Y. Kritikou, K. Tsagkaris, P. Demestichas, P. Blasco, F. Bader, M. Dohler, D. Denkovski, V. Atanasovski, L. Gavrilovska, K. Moessner, "Learning and Knoweldge Management Toolbox for Cognitive Radio Network Applications," *IEEE Vehicular Technology Magazine: Special Issue on Applications of Cognitive Radio Networks*, 2012.

[2] G. Baldini, V. Rakovic, V. Atanasovski and L. Gavrilovska, "Security aspects of policy controlled cognitive radio," *5th IFIP International Conference on New Technologies, Mobility and Security (NTMS)*, Istanbul, Turkey, May 2012.

[3] D. Denkovski, V. Atanasovski, L. Gavrilovska, J. Riihijarvi and P. Mahonen, "Reliability of a Radio Environment Map: Case of Spatial Interpolation Techniques," *7th International Conference on Cognitive Radio Oriented Wireless Networks (CROWNCOM)*, Stockholm, Sweden, June 2012.

[4] S. Romaszko, D. Denkovski, V. Pavlovska and L. Gavrilovska, "Asynchronous Rendezvous Protocol for Cognitive Radio Ad Hoc Networks," *the 4th International Conference on Ad Hoc Networks (AdHocNets) 2012*, Paris, France, October 16–17, 2012.

[5] I. Dagres, A. Polydoros, D. Denkovski, M. Angjelicinoski, V. Atanasovski and L. Gavrilovska, "Algorithms and Bounds for Energy-based Multi-source Localization in Log-normal Fading," *IEEE GLOBECOM 2012 Workshop: Green Internet of Things*, Anaheim, California, USA, December 2012.

[6] A. Palaios, J. Riihijärvi, O. Holland, A. Achtzehn, P. Mähönen, "Measurements of Spectrum Use in London: Exploratory Data Analysis and Study of Temporal, Spatial and Frequency-Domain Dynamics", Proc. of IEEE DySPAN 2012, Bellevue, Washington, October 2012.

## 3.2 FP7 ICT 248303 QUASAR

### 3.2.1 PROJECT DESCRIPTION

QUASAR was a STREP project aiming to quantify the available spectrum for secondary usage and propose appropriate business models and scenarios for its subsequent usage.

### 3.2.2 Collaboration Activities

FARAMIR and QUASAR were complementary during their life-time with the former providing the technology for the latter project. Therefore, there were many opportunities for mutual collaborations among the partners involved in both projects. Specifically, UKIM used its spectrum sensing and REM creation backend technology from FARAMIR to provide practical assessment tools for the QUASAR objectives. Further, RWTH has fostered collaboration between the projects in areas related to spectrum measurements and coverage and service area estimation from these. The FARAMIR was also able to provide some technical advice and opinions on the development of various spectrum assessment tools for QUASAR team. Similarly the spectrum assessment work of QUASAR has helped to focus FARAMIR work so that it can contribute towards possibly interesting application domains.

## 3.3 COST IC0902

### 3.3.1 PROJECT DESCRIPTION

The COST IC0902 action gathers the European researchers in the fields of cognitive radio and networking for cooperative coexistence of heterogeneous wireless networks.

### 3.3.2 Collaboration Activities

UKIM representatives involved in both FARAMIR and COST IC0902 disseminate the knowledge on spectrum sensing and REMs within the COST IC0902 action. Collaboration was initiated with Trinity College Dublin by writing an overview paper on the topic of learning and reasoning for cognitive radio networks.

# 4 Conclusions

During the lifetime of the FARAMIR project, the consortium partners have tried to make sure that the concepts and ideas developed within the projects are consistently made public and largely disseminated. This has mostly been implemented by participations to major conference such as IEEE DySPAN, as well as various dedicated workshops and other outreach opportunities. The FARAMIR consortium partners have also worked to spread awareness of their research results into other European funded collaborative projects, with already successful continuation work and collaboration arising from these activities.

So far, it has been striking to see that the feedback, received in the research community, regarding the radio environment map technologies, has been very positive. Researchers usually recognize that there is definitely a need for a common platform that will simplify the access to information about the radio environment. Also members of the industry have been highly intrigued by the work, as increasing heterogeneity of cellular networks is calling for new and innovative operations and management solutions, in which radio environment maps can play a major role.