The "Sensorial Radio Bubble" for Cognitive Radio Terminals

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Abstract

We present in this paper the "Sensorial Radio Bubble" (SRB) for Cognitive Radio (CR) terminals. The bubble relies on a plurality of sensors based on several signal processing elements. It gives to communication systems the ability to explore the radio environment in order to provide knowledge of the spatial and spectrum environment, and some context awarereness. Such a CR system knows all about the signals coming inside and going outside its bubble, as well as the state of many parameters inside the bubble. This permits the terminal to securely transmit its communications with a guaranteed QoS, taking into account the state of all these parameters. That is why we also speak about the "security bubble". Two analogies, with the human bubble, are detailed to explain simply the concept. One of the contribution of the SRB is to manage spectrum resources with more efficiency. The context of a global hand-over is considered. A spectrum and a spatial map are generated to manage a double mobility, both in space and in frequency. This approach aims at providing prediction on the environment evolution, so that the CR terminal can anticipate with smartness the changes in order to take good decisions of reconfiguration at the appropriate time.

1 Introduction

In a cognitive behavior, the perception of the stimulus is the means to react to the environment and to learn the rules that permit to adapt to this environment. In the context of reconfigurable Cognitive Radio (CR) terminals, the environment is mostly the radio electromagnetic field. A CR system aims at using the radio resources with a good efficiency at the system level, and not only at a point to point optimization as usually done. This contributes to a global capacity increase and a better use of spectrum resources within all the standards in the area. One major impact expected with CR is to improve drastically frequency occupation in space and time (at the system level) while providing the appropriate QoS (not too low, but also not too high) for a given service transmission (at the level of one terminal). We propose to define a volume around the terminal, called the "sensorial radio bubble" or SRB, the diameter of which is at the scale of the sensing possibility of the terminal. It will be the responsibility of a CR terminal to be aware and interact with all the pertinent information available in the area that can help the terminal to match its functionality to the global state of its environment. A CR system as presented for the first time in [1], implies that a terminal is able to adapt its behaviour to its environment through capabilities of analysing its situation, smartness to take adequate decisions and capabilities of self-reconfiguration, as presented in [4], to adapt its functionality. The work presented here is a generalized approach of the work of [5], in which a terminal can recognize a set of standards and adapts its operation accordingly. CR often focuses on spectrum issues and how to efficiently use the frequency resource [1], [2], [3]. But the concept of CR may be extended at a larger scale as in Figure 1. In this figure (for our purpose), a communication system is modeled in three main layers:

- The upper layer corresponding to the classical application layer of the OSI model and the human interface,
- An intermediate layer in which we consider the classical transport and network layers,
- And a lower layer for the physical and link layers.

Any means that permits to analyze the environment, and that may be helpful for the adaptation of the communication system to the constraints imposed by the environment, is worth being taken into account. At each level, are associated examples of sensors which are able to give information related to this layer (left side of the Figure 1). In addition, at the right side, we identify areas of current research which are more or less connected to CR. As we would like to optimize the overall system, we are obviously also connected to the cross layer adaptation and optimization topics.

The paper is organized as follows. In section 2 a definition and a presentation of the concept of SRB are provided. The explanation for the understanding of the concept of the radio bubble is given in this section also with two analogies. The exchange of information between "bubbles" is discussed in section 2.4. Then the different sensors composing the radio bubble are presented and classified in section 3. A new map, called spectrum map, is built and defined in section 4. Section 5 addresses the conclusions and future evolution of SRB concept.

2 The radio bubble

2.1 Generalities and presentation

A CR is a radio whose behaviour respects the cognitive cycle of Figure 2. First step consists in sensing or observing the environment. Parameters measured from the environment of the terminal could be for instance: spectrum use, presence of other terminals in the area, multipath propagation conditions, standards available, etc. But the notion of environment of a terminal can be generalized. From a CR view point, the speed of the terminal, or its position are also addressed. Moreover internal conditions are also considered, such as battery level, hardware and software resources occupation for example. In a second step, an analysis

Sensors	Layer	Literature concepts
User profile (price, personal choices) Localization, sound, video, position, speed, security.	Application	Context Aware
Intra-network, and inter-network vertical handover , standards, load	Transport Network	Interoperability Ambiant networks
Access mode, power modulation, coding, Frequency, handover. Channel Estimation	Data link Physical	Link adaptation

"Middleware" and abstraction Layer

True Wide Band Software Radio

Figure 1 : Model in 3 layers of Cognitive Radio versus OSI Lavers.

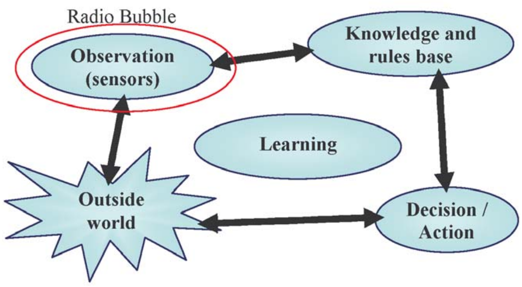


Figure 2 : Illustration of the cognitive circle with SRB.

of the acquired parameters can be used to synthesize high level information. This high level information gives a global vision of the terminal context. In the next step, decision step, the system selects the solution which optimizes the parameters of the radio terminal. In the last step, the terminal activates actions to adapt to its environment in order to reach its objective. The cognitive cycle operates in a continuous way so that the CR terminal dynamically adapts to the evolution of the parameters of its environment. The SRB uses all the 3 layers already defined (from PHY to application layer) to explore the environment of the terminal. Considering the cognitive circle, SRB is situated in the sensing function as illustrated in Figure 2. The SRB is a virtual sphere of several meters to several dozen of meters of diameter around a terminal. The diameter depends on the visibility of each sensing means. We can speak about a multi-dimensions space, with one dimension for each sensing capability. The spatial dimension is one of them, and is given through the information provided by the channel sounding sensor for its size and the positioning sensor for its center. The spectrum dimension is another dimension, and is given through, for example, carrier frequency sensor, bandwidth channel sensor, standards recognition sensor, etc. This paper addresses the context of a double mobility:

- A classical mobility associated with the horizontal handover, in space.
- A spectrum mobility associated with the vertical handover, in frequency.

We suggest hereafter to map these two mobilities on two different maps, in order to illustrate and validate our concept of the SRB:

- One is the classical spatial map, which already exists, and in which the terminal is moving.
- We propose to add a new one: the spectrum map. It contains all the environment information given by the corresponding sensors of the SRB. The way to build this map is described in [6].

In order to simply expose our concept, we use two analogies. The first and the most important one is the well known psychological and physiological human bubble. The second analogy addresses the human bubble within a car. A spectrum map is defined as a road map, therefore we can translate rules from the latter to the spectrum approach with the objective to secure transmissions the same way as motorists on the road. We already proposed in [6] a traffic code analogy. A close analogy was proposed also in [8]. We focus in this paper on the two maps representation of our concept and we highlight the necessity of information exchange between several SRB in order to assure a secure transmission (good QoS). It has to be stressed that this new spectrum map evolves as soon as the terminal is moving in the spatial map. So as to better explain this approach, we propose in the following to describe two analogies at the origin of the SRB concept.

2.2 The "human bubble" analogy

The well-known physiological and psychological "human bubble" is a virtual space, whose dimensions are given thanks to the human senses. A person knows all information inside his bubble and consequently has a feeling of safety and comfort. It is partly given by the five human senses. SRB in its side, collects information through sensors which analyze the received electromagnetic waves. For example one sensor detects spectrum holes, another one, the best (in respect to some criteria) standard for the communication. In addition, as the health condition of a human being may influence his behavior and mood, the internal state of a terminal should de considered (battery level, processor load, etc.). The radio bubble communicates this information to the higher layers of the CR terminal, which then may reconfigure itself to improve its global functionality [9]. To make maximum benefit, this behavior implies that the terminal is a fully Software Radio (SWR) one.

2.3 The "vehicle" analogy

The second analogy we took into account is the "vehicle bubble" analogy. This is clearly an extension to the car situation in the traffic of the "human bubble". Now the virtual sphere is around the car and moves with the car. The car driver should know everything within its bubble, and understand all the information inside the bubble. This bubble information is given thanks to the human driver senses with the help of:

- Signs of other cars and road infrastructure,
- Rules known and respected by everybody,
- Anticipation, prediction, thanks to previous experiences.

Let us continue our analogy with the following example:

- The aim of a car driver is to go from one point to a destination without accident with respect to some constraints (time, number of kilometers, price, etc.), thanks to its "bubble" all along the trip.
- The aim of a CR terminal is to send its information to the right recipient without accident (good QoS) with respect to some constraints (time, throughput, price, etc.), thanks to its "bubble" as well.

2.4 Information exchange between the "bubbles"

As already explained, the SRB perception will be limited by the sensor "visibility". The consequence is that, to better know the environment and to avoid problems as hidden nodes, the bubbles should exchange information and therefore communicate. The "Sunny Day" example explained in [7] in the context of human bubble could be simply transpose in our CR context. Because the bubbles are running on SWR technology, they should have all the technological means to establish a radio communication [10], with the adapted standard to the current situation (distance between them, state of their spectrum maps, etc.) This communication aspects between the bubbles will be described in a further paper.

3 The sensors of the radio bubble

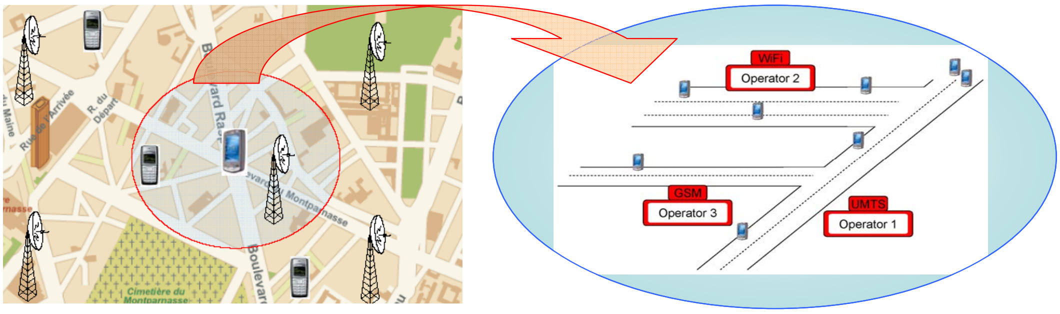
The word sensor here is used in its broad sense. It represents all means that can give information on the environment. It could be either a classical sensor (microphone, camera, etc.) or it could be a smart sensor based on advanced signal processing. The sensors are classified hereafter in two ways. The first way is related to the layer model (see [6]). The second way is a classification depending on the environment. Sensing means refer to all the possible methods a CR system has at its disposal for observing its environment, which can be categorized in four main families described in the Table 1 [10]. All the stimuli received by the sensors from the different layers (from physical to application) must be merged and analyzed jointly in order to reach the best possible decision. It can be noted that considering specific use cases, as the medical assistance situation of bottom Table 1, implies the use of specific sensors. The multiplication of use case studies would multiply the sensors list as well.

Table 1: Sensor classification versus the environment

Classes	Sensors
Electromagnetic environment	Signal to Noise Ratio (SNR), Spectrum occupancy, Multi-path Propagation sensors
Network environment	Number of HotSpot , Number of Users, Traffic Load, Standard Recognition sensors
Hardware environment	Battery Level, Power Consumption, Level memory, Computational Resources Load,Temperature sensors
User-related environment	Camera, audio, User Identification,User profile services available sensors
Medical specific case	Temperature of the User, Glycemia,Blood Pressure sensors

4 The spatial and the spectrum maps

Two maps were defined and completly described in [6]. The first one (classical map) describes the spatial environment. The second one describes the spectrum environment. Our objective is to build a spectrum map in which the terminal could move. The spatial map presents a set of pertinent information that is reported in a geographical map. These parameters can be, for example, the position of hotspots or access points, the position of others terminals, etc. To build the spectrum map, a different set of sensors contributes to analyse the spectrum using signal processing techniques. This map identifies and represents different spectrum parameters existing in the radio bubble that vary with the movement of the bubble, as for example, the carrier frequency, the free channels and the telecommunication systems inside the bubble. In the spectrum map, this information can be represented as roads. In Figure 3(a) we present the projection of the bubbles



(a) Spatial Map (b) Spectrum Map

Figure 3: Projection of the "Bubble" respect to a specific sensor on the corresponding map

in respect to a specific dimension (a sensor) on the different maps. Figure 3(a) presents the projection of for example the Direction Of Arrival sensor whereas Figure 3(b) presents the projection of the Standard Recognition Sensor.

5 Conclusion

In the context of Cognitive Radio, we have presented in this paper the "Sensorial Radio Bubble". It is an original approach for a CR terminal to get a vision of its environment. Several sensors constituting the bubble contribute to build this vision under the form of a spectrum and a spatial map. The sensors are based on advanced signal processing techniques that were not in the scope of this paper. Throught this SRB, the CR terminal observes its environment and reacts to the events. Our work is an anticipation of the evolution of CR terminal. It can be imagined that in the very long term, CR systems could reach the state of creating on-the-fly autonomously temporary communication systems with a PHY layer perfectly matched with the communication needs (depending on electro-magnetic context, speed of the terminal, the service nature, etc.). This paper proposes an original way to reach this target, taking into account the security and the prediction. In consequence, the terminal optimizes resources use (spectrum, battery, carrier frequency, etc.). We think the "SRB" concept and its associated tools (the maps and the projections on them) will be useful for comprehending the current limitations and for searching for ways to get beyond them.

Acknowledgment

This work was performed in project E2R II which has received research funding from the Community's Sixth Framework programme. This paper reflects only the authors' views and the Community is not liable for any use that may be made of the information contained therein. The contributions of colleagues from E2R II consortium are hereby acknowledged. The authors want to thank Region Bretagne, France, for its support of this work.

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