SENSORIAL ANTENNAS FOR RADIO-FEATURES EXTRACTION IN VEHICULAR COGNITIVE APPLICATIONS

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ABSTRACT

In the last years *wireless communication systems* attracted commercial interest because of the possibility of developing innovative mobile networks. Cognitive Radios and Smart Antennas are technologies that could allow substantial improvement both for user and system sides.
In particular in this paper the attention is focused on the antenna equipment for a *Cognitive Base Transceiver Station (CBTS)*, with high degree of reconfigurability, for an highway vehicular framework.

1. INTRODUCTION

In the last years *wireless communication systems* [1] attracted commercial interest because of the possibility of developing innovative mobile networks. Prime goal of these systems is to provide multimedia contents and safety and security information to the users in every condition and also to solve problems of spectrum sensing and monitoring for spatially and temporally distributed phenomena.
About spectrum usage and monitoring, the new emerging standards are reducing the amount of unlicensed frequencies. Unlikely a wide part of licensed frequencies are not simultaneously used in every time instant and in every place. In fact, a study, developed by the *U.S. Federal Communication Commission (FCC)* [2], has pointed out that the variation of use of licensed spectrum ranges from 15% to 85%, whereas the *Defense Advance Research Projects Agency (DARPA)*, estimated that, at any given moment, only the 2% of the spectrum is in use in *U.S.*.
For these reasons, it's clear that nowadays a flexible approach to bandwidth allocation is required. Dynamic observation of the spectrum and adaptive reactions to wireless channel conditions represent hence main methods for improving the spectrum efficiency.
In order to overcome previously cited difficulties, a possible solution consist in a joint approach based both on improving the hardware used in wireless techniques and on adding to this hardware a software intelligence able to analyze and manage communication problems.
A viable approach of representing and designing just mentioned intelligence could be looking at the natural evolution of the species and their internal mechanism, as proposed by *Cognitive Radio (C.R.)* [3],[4] *paradigm*, in order to develop a smart space system. This paradigm allows to create an artificial cognitive entity able to learn, as a biological cognitive process, from the past experiences and to react to external environment.
On the other side, a possible way for improving wireless hardware technologies is based on *Smart Antennas (S.A.)* [5],[6],[7] concept. In fact a *smart antenna* device, otherwise traditional antennas, may be able to adapt its own characteristics dynamically, "following" the desired user while minimizing the interference among nearby systems.
Hence in order to built up an adaptive and aware network, with high performances overcoming the inefficient use of the radio resources, it's possible to equip itself with highly flexible capabilities, as the ones provided by *cognitive radios* [3],[4] and *smart antennas* [5],[6],[7] paradigms.
In particular in this paper the attention is focused on the antenna equipment for a *Cognitive Base Transceiver Station (CBTS)*, with high degree of reconfigurability, for an highway vehicular framework.
The capability of extracting features on the basis of actual simulation data coming from electromagnetic full-wave design of the antenna equipment is explored.
The tight cooperation between the actual sensor and the feature extraction algorithm design processes allows a significant improvement of the algorithm performances and tuning with respect to the exploitation of idealized models for the antenna equipment. This cooperation represents one of the key features of the *cross-layer* design optimization necessary to fully exploit cognitive capabilities of *CBTSs*.

2. SMART ANTENNAS AND COGNITIVE RADIOS

2.1. Smart Antennas

Smart antennas are flexible devices able to dynamically adapt themselves respect to the environment evolution [5],[8]. In general, a smart antenna is composed by an array of radiators connected with *Radio-Frequency (R.F.)* down-converters and receivers. After *RF* stage, data stream is processed by several DSPs, in order to reconfigure the radiation pattern of antenna gear.
A conventional antenna device is said to be *smart* only if suitable and adaptive algorithms are exploited. As a matter of fact, the only radiating structure would not be, by itself, "*intelligent*", as pointed out in [5],[8].
Research on smart antenna systems has grown in the last few years, as they are considered one the most important incoming evolution of cellular systems, for

they capability to provide *"space diversity"* (and then to increase significantly the overall network capacity) to such systems [5],[8]. In particular, the so-called *"adaptive-arrays"* are the most advanced smart antenna systems proposed [5],[8]. Adaptive-arrays are in principle characterized by their capability of adapting their characteristics to channel and users evolution; this flexibility could provide lots of advantages over existing antenna arrays, such as minimized interference, reduced power consumption, enhanced security, better localization and increased range of operation [5],[8].

For these reasons, reconfigurable smart antennas characteristics could be exploited also for cellular systems in order to allow an high frequency reuse while preserving low handover rates. In fact a smart antenna device may be able to generate a dynamic cell coverage which should "follow" the considered target, i.e. a mobile user, while minimizing the other interferences.

Such as this solution may allow a significant boost in the wide-band service availability in wireless networks, as greatly supported by recent research efforts spent in this high-tech field [5],[8].

While the concept of adaptive-array is quite well established, the actual techniques and antenna systems which should be exploited to obtain the desired overall performances are subject of research. In fact, smart antenna systems are much more complex than traditional arrays, as a consequence of the required flexibility at both the physical and processing levels.

As an example, it is only in the last few years that the availability of DSPs with adequate processing capabilities has allowed the realization of the first prototypes of smart antennas at reasonable costs [5],[8].

The difficulties of managing such complex systems have often lead to the design of simplified structures, such as the so-called "switched-beam" systems, which exploit only a part of smart antenna concept capabilities [5],[8].

Nevertheless, also the most modern smart antenna systems are based on a countable set of a-priori defined strategies, so an antenna system could not operate in a optimal way in many practical situations. Therefore in order to overcome this lack of flexibility, cognitive radio paradigm is could be exploited as possible solution.

2.1. Cognitive Radios

The so-called cognitive radios were defined for the first time by Mitola [3]. This paradigm foresees devices able to adapt themselves to radio environment and, in general, to external environment [4]; they are also able to learn, as a biological cognitive entity, from the past experiences how to carry out the reactions towards the external environment.

The cognitive behavior can be described through the so-called *cognitive cycle* in Figure 1: it is composed by four main stages, or processes: *Sensing*, *Analysis*, *Decision* and *Action*.

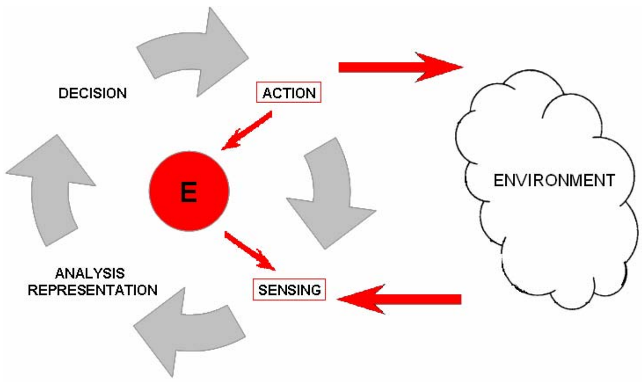

Figure 1 Cognitive cycle representation

The first one provides to the system an awareness of own internal status and a representation of the external world: in cognitive radio systems this representation is mostly based on an analysis of the electro-magnetic frequencies: the spectrum *sensing* process. The *analysis* process translates the synthetic representation of the external world into a context label which describes the current channel condition from a semantic point of view.

Both these stages require signal processing procedures in order, firstly, to express the information about the spectrum in a synthetic form, and then to analyze it for the extraction of the context label.

The *decision* stage, by considering also the position and the internal status of the terminal, chooses the best reaction to the conditions of the external environment while the *action* stage carries out the decided action conditioning both external environment and internal status.

3. FRAMEWORK AND PROPOSED SYSTEM

A possible operative framework is the one considered in the *PRIN-SMART project*, financed by the Italian *Ministry of the University and Research (M.I.U.R.)*. The project foresees the hardware/software integrated design of a mobile/fixed info-mobility network.

In Figure 2 a possible operative situation for a generic CBTS is shown: it generates radiation pattern lobes in each direction of interest, i.e. where there is a transmitting user.

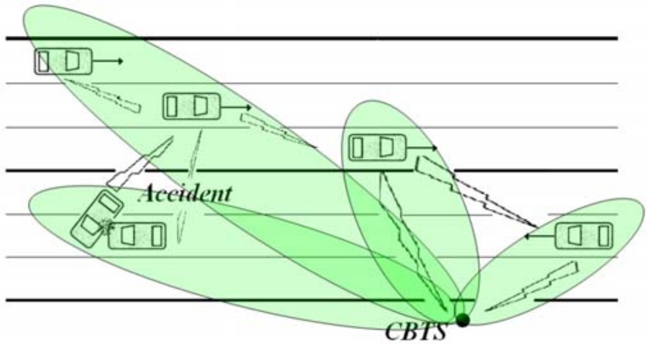

Figure 2 CBTS operative framework

In the paper, a simple CBTS layout is considered: goal of the CTBS is only to detect in which directions transmitting users reside and to configure itself in order to steer the antenna only in those directions. Even if it could be assimilated to an adaptive radio, because no learning method hasn't been developed and tested yet, it could be a good starting point for developing a Cognitive intelligence through successive evolutive (in Darwinian sense) strategies.
CBTS perceives the radio environment with different *Angles of View (AoVs)* and with different modalities. In this manner is possible to localize in which *AoV* one or more transmitting users reside and decide which will be the most useful strategy to adopt, i.e. scanning plan and driving sensing antenna beam-former. A possible logical CBTS architecture is pointed out in Figure 3.

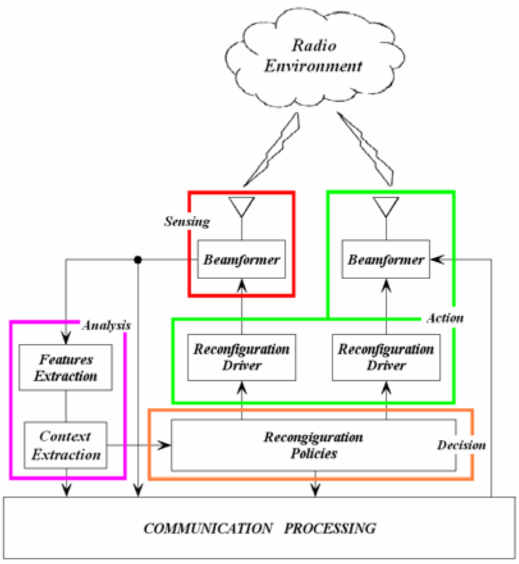

Figure 3 Logical CBTS architecture

CBTS antenna equipment is able to perform a spatial-temporal scanning of the spectral environment oriented to extract contextual environmental information about frequencies in use, i.e. to provide *Space-Time-Frequency (S.T.F.) Sensing Maps*. These maps will be used for a partial features extraction embedded in the antenna equipment.
It's hence clear that it's possible to extract and process context information directly on the antenna gear, decreasing the load of the central processor and exploiting a cheaper DSP hardware.

3.1. Sensing Antenna

Sensing antenna equipment is here considered "the body" of the cognitive system; through this body the Cognitive device is able to sense the external world.
The sensing antenna is based on a uniform linear array of thin dipoles which can perform a two-dimensional scanning. In order to steer the array in a desired direction, the signal coming from each dipole is delayed of a time quantity depending on the dipole position and the steering direction itself. In particular, if the direction of interest is represented by the angle $\theta *$, and the spacing between adiacent dipoles is equal to *d*, the signal on the *i*-th dipole is delayed by:

$$\Delta t = -\frac{id}{c}\cos(\theta *)$$

This steering technique, known as "time scanning", is preferred for broadband operation because the direction of the main beam does not change with frequency (this characteristic does not hold true if "phase scanning" is considered). We point out that, as it is well known, the width of the main lobe depends on frequency for the considered uniform array. Starting from this body it's possible to build a simple self-reconfigurant system.
In the considered antenna architecture, in order to provide an accurate wide-band representation of the radio environment, the antenna gear should be linked to a processing structure like the one showed in Figure 4.

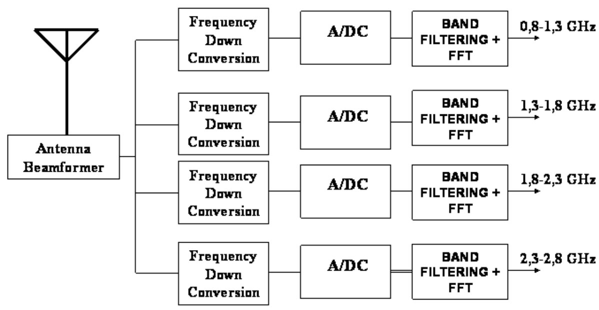

Figure 4 Ideal Processing Architecture

After a first analog frequency downconversion stage, the signal coming from the antenna beamformer should be splitted into four processing lines, each one representing a limited 500 MHz bandwidth. This sub-band division is useful to obtain a uniform and more accurate spectral resolution through FFT transform. In fact the sub-bands have the same lenght (500 MHz) and they are downconverted to the same Intermediate Frequency (IF). In the entire considered bandwidth, a wide part of the most common wireless transmission modes reside: in fact between 800 MHz and 2,8 GHz, standards like GSM/GPRS, T-UMTS, Wi-Fi and the satellite S-UMTS and GPS/Galileo are present.
In a certain time instant *t** output of the antenna devices is a Fast Fourier Transform of the radio signal acquired in a certain direction by the main antenna lobe. By considering a time interval *T* that correspond

to the completion of the desired scanning strategy, after *T* it's possible to obtain a view of the occupied frequencies in all the directions of interest (DoIs). These views contain information both on acquisition direction and bandwidth occupation: it's hence possible to define them as Space-Frequency Maps of the Environment.The frequency occupation is represented by the FFT module. At each time *T* it's possible to obtain a new map: a time evolution of the maps allows to observe how the context vary during time: the time dimension is now added to the maps in order to obtain a 4D space that can be represented as time evolutions of 3D curves.

4. SIMULATIONS END RESULTS

Since main focus of this paper is about sensing antenna equipment and its own numeric and electromagnetic test, in **Figure 5** the functional simulator scheme considered is represented.

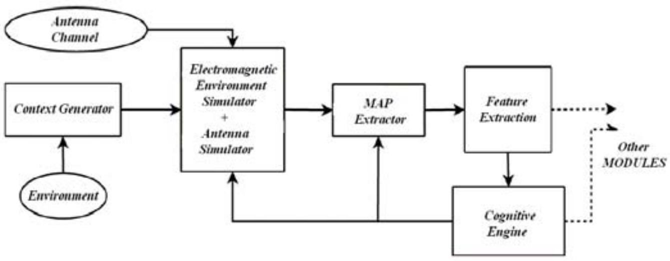

Figure 5 Functional scheme of developed software for sensing stage of cognitive cycle

The simulator is formed as follow:

- A context generator able to create the most realistic and reasonable physical context on the basis of predefined environment settings;
- An electromagnetic simulator able to provide a faithful numeric simulation of the physical environment supplied by context generator and to manage the antenna gear in the exploited simplified hypotheses;
- A map extractor able to build up, for each time interval, a 3D radio image from the signal received by the sensing antenna, in order to detect the regions of interest in the contextual image;
- A cognitive engine able to take decisions about reconfiguration policies on the basis of the available and apprehended knowledge.

In particular the designed system has self reconfiguration capabilities. In fact, the cognitive engine is able to optimize the sensing process by exploiting a-priori knowledge of the physical environment. It's hence possible to affirm that in this case the Cognitive Cycle closes its loop directly on itself, in fact the Action stage influences in a direct way the Sensing stage.

Cognitive engine strategies exploited in this paper are directly driven by the detection stage, in the sense that it alters both the number and values of the direction of interest. This means that when a user is detected in a certain region, the cognitive system tries to improve its detection by considering more directions around the observed zone. On the other hand, when a zone is free of users it is observed in a quite rough way in order to minimize the overall processing load.

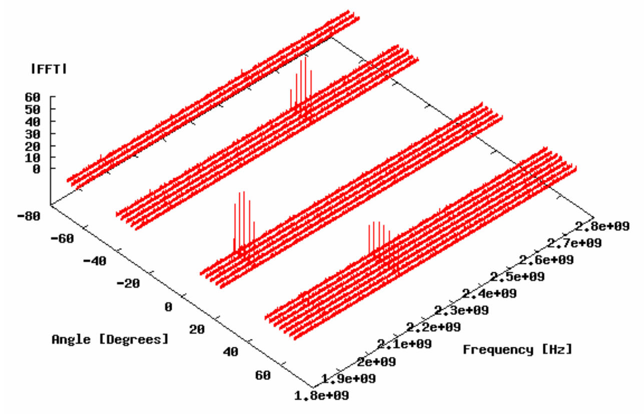

Figure 6 Output sensing maps

Output of the sensing module is represented by a space-frequency map, described in the previous section and shown in Figure 6. It's evident that outside the direction of interest (red lines) there are no gathered data. a fine scanning around detected users is performed together with a rough scanning of empty zone.

Moreover, a-priori knowledge of the environment helps the system to choose the direction of interest from where new users will probably appear (red lines on the left side of map).

This is only one of the possible sensing strategies; other strategies can be or embedded into the device or they can be learned by the Cognitive entity during its "life".

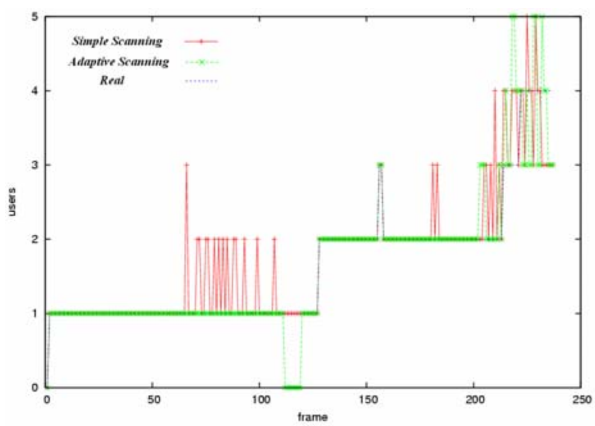

Figure 7 Comparison between simple and adaptive scanning respect to users detection

Given a DoI extraction method, in Figure 7 it is possible to observe the detection performances between two different considered strategies.

Red line represents the number of detected DoIs by using a continuous scanning strategy that explores all the environment in every time interval *T*, here called "frame". The green line represent the performances obtained by using the adaptive scanning strategy. It's clear that the adaptive behavior allows to obtain a reduced number of "false alarms", i.e. a detected direction where no users are present. With the implemented methods, it's possible to obtain this improvement when the number of users in the context is less than 4. On-going researches are focused both in simulating a more efficent hardware antenna equipment and more "intelligent" scanning strategies.

5. CONCLUSIONS

In the paper, after a brief introduction on actual and interesting technologies like smart antennas and Cognitive Radios, a design process for developing intelligent CBTSs was presented. The paper focused the attention on the antenna gear used to perform the observation of the real world through a spectrum sensing process. Results, obtained in a completley simulated framework, for a simplified CBTS, were presented. Results proof that an emerging intelligent behavior can help CBTS to perform its tasks: improvement, respect to a continuous scanning strategy, were obtained in the detection of DoIs.

Future works will follow different directions: first of all it's possible to simulate dipole arrays with more particular characteristics; another path will lead to the improvement of the signal processing and pattern recognition process in order to allow CBTS to perform also Mode Identification processes. Last but not less important, researches about evolutionary strategies for the CBTS intelligence are trying to implement learning on-line processes.

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