# A NEW STANDARD RECOGNITION SENSOR FOR COGNITIVE RADIO TERMINALS

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## ABSTRACT

We present in this paper a new Blind Standard Recognition Sensor (BSRS). It is one of the most important sensor of our new concept called the "Sensorial Cognitive Radio Bubble". This concept aims at giving more sensorial information to the cognitive terminal for safety utilization. The BSRS is composed of the combination of several signal processing elements from our own and from the literature. It is decomposed on three steps: band adaptation step, analysis step and fusion step. In the analysis step, the extraction of different features from the received signal is processed with different sensors to extract the information about the bandwidth, channel filter shape, single/multiplcarrier signal, frequency hopping or Direct sequence access, and telecom signal detection. Then, using all these features, with an adequate fusion process it is possible to recognize any standard in use in the vicinity of the terminal within a large number of current commercial wireless standards.

## 1. INTRODUCTION

In this paper, we propose to improve an existing sensor published in 2003 in IEEE communications Magazine, in a paper entitled "A new concept for wireless reconfigurable receiver" [4], which consists in finding blindly the standards in use among a predetermined list of standards.

The term blind here refers to the use of the measured characteristics of the transmitted signal: these characteristics are known in general because we address standardized signals in a cooperative environment, but the adaptation is blind as the parameters are inferred from the environment, not dictated by the network. All these characteristics are indirectly given through the spectrum features, particularly the channel bandwidth and the spectrum shape. Consequently, whatever the standard, nothing has to be known before starting the recognition process in a given place and time.

The main assumption of the previous work of [4] was that the channel bandwidth of all the considered standards was fully discriminant. This was true in 2003, but is no more in 2007. It is the reason why we propose in this paper to improve this Blind Standard Recognition Sensor (BSRS). This improvement is performed through the detection of other parameters of the standards. Then with all this information, a fusion is performed in order to decide which standard is recognized. Another assumption of [4], which limits the applicability of the method, was that the standards to be detected should not coexist in the same frequency band. Nevertheless this situation may occur and is addressed in subsection 3.2.4.

| 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 Layers

The rest of the paper is organized as follows. The Cognitive Radio (CR) concept is described in section 2. We particularly present our vision with a simplified model in three layers. We also highlight in this section the need of standard recognition. In section 3, the new proposed BSRS is described, with a focus on the new signal processing techniques needed for detecting standards which were not detected with the previous work. Conclusions will be stated in section 4.

## 2. COGNITIVE RADIO SENSORS

A cognitive radio system is able to adapt its behavior to its environment through: capabilities of analysis of its situation, smartness to make adequate decisions in function of established criteria, and capabilities of self-reconfiguration to adapt its functionality. Cognitive radio often focuses on spectrum issues and how to efficiently use the frequency resource [1], [2]. But, based on the previous definition, cognitive radio may be extended at a larger scale as in Figure 1. In this figure, we model the communication system in three main layers:

- the upper layer comprising the classical application layer of the OSI model and the human interface,
- an intermediate layer in which we consider the classical network and link layers.
- a lower layer for the physical and medium layers.

At each level are associated examples of sensors which are able to give information related to the layer (left side of the figure). In addition, at the right side, we identify areas of current research which are more or less connected to Cognitive Radio. As the idea is to optimize the overall system, this is obviously also connected to the cross layer adaptation and optimization topics. 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.

High-level sensors has to be understood here in the sense that the sensing information comes from the higher layers of the system. It consists basically in using application layer information to take decisions of modification of the radio configuration. The possible applications proposed here consists in taking advantage of sensing characteristics based on video analysis in order to manage the system behavior. The use-cases that are foreseen may concern the old persons kept at home under medical surveillance, the service proposal in a public area (airport, train station, museums, public building, *etc.*), as well as at work. Emergency situation are of particular interest, as well as access control and context-dependent applications. In this context, the video sensor addresses people detection, tracking and identification. We particularly address in the following the intermediate level sensors. The sensing information comes from the intermediate layers of the system. The sensors could be the presence of a particular standard in the vicinity, the load of a particular radio link, *etc.* It consists basically in using network layer information to take decisions of modification of the radio configuration. Following this idea, the work described uses pertinent sensing characteristics based on standard analysis and shows how they could be used to manage the system behavior.

## 3. GENERAL DESCRIPTION OF THE NEW BLIND STANDARD RECOGNITION SENSOR

The aim of the Blind Standard Recognition Sensor (BSRS) is to identify all the different systems in the vicinity of the received area. A reasonable assumption, is that the detector identifies one (or several) Radio Access Technologies (RAT) among a predefined set of RAT. To perform this identification, a classification should be done using the physical parameters of the received signal. These parameters could be the bandwidth, the carrier frequency, the symbol frequency, the chip rate, the number of carriers, the code length,the presence of a Guard Interval, *etc.* It exists a huge literature on this topic both in the military and civil telecommunications domains. Typically, system identification studies try to determine the type of modulation or other characteristics of the signal with, for example, Second Order Statistics methods (with or without cyclostationarity information) [6], [7], [8] or Neural Networks or Monte Carlo Markov Chain methods, in order to determine the mapping of the modulation [4], [9], [10], [11], [12].

In 2003, "A new concept for wireless reconfigurable receiver" [4] has been proposed. The main idea of this work was to identify blindly the standards in use in the vicinity of the terminal so that it can adapt itself to this new standard. That is why it was called a Self Adaptive Universal Receiver (SAUR). The main assumption of this work was that the channel bandwidth of all the considered standards was fully discriminant, as it is presented in table 1. This approach was validated with real signal experimentations [4].

This was true in 2003, but is no more in 2007 (see table 3) mainly due to the huge number of new IEEE standards. Some of these new IEEE standards of table 2 indeed could be recognized by the same principle. Nevertheless there are several standards that can not be distinguished that way, as they exactly have the same bandwidth and filtering shape. So we extend the previous work by adding the detection of other parameters of the physical layer of the standards. We had voluntarily limited our study to the physical layer of the standards. Then, as it can be seen in Figure 2, a fusion on these detected parameters is performed. In fact, the parameters of this layer are directly responsible for the shape of the transmitted signal; furthermore, they are easier to access than the upper layer parameters as no demodulation is required.

The top box of this figure at STEP 2 is the previous SRS which is briefly described in subsection 3.2.2. The extension is the bottom of the figure and is presented in the other following subsections.

Table 1: The bandwidth parameter to discriminate the standards below

| standards | channel bandwidth | shape filter |
|---|---|---|
| PDC | 25 kHz | SRC($\alpha = 0.5$) |
| ADC (D-AMPS) | 30 kHz | SRC($\alpha = 0.5$) |
| CT2 | 100 kHz | Gaussian 0.5 |
| GSM | 200 kHz | Gaussian 0.3 |
| PHS | 300 kHz | SRC($\alpha = 0.5$) |
| Bluetooth | 1 MHz | Gaussian 0.5 |
| IS95, Globalstar | 1.25 MHz | RIF 48 taps |
| DAB | 1.712 MHz | Window |
| DECT | 1.728 MHz | Gaussian 0.5 |
| UMTS (FDD) | 5 MHz | SRC($\alpha = 0.2$) |
| DVB-T, LMDS | 7-8 MHz | Window |
| Hiperlan I | 20 MHz | Gaussian 0.5 |
| DVB-S | 32-36 MHz | SRC($\alpha = 0.3$) |
| LMDS | 32-36 MHz | SRC($\alpha = 0.2$) |
| Hiperlan II | 50 MHz | Window |

Table 2: The new recognized standards with the bandwidth recognition

| standards | channel bandwidth | shape filter |
|---|---|---|
| IEEE 802.11g | 20 MHz | Window |
| IEEE 802.15.4 | 2 MHz | Gaussian 0.5 |

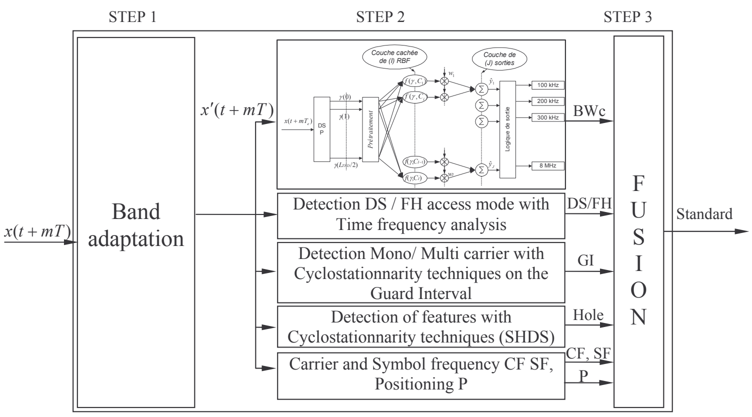


Figure 2: The new Blind Standard Recognition Sensor.

This sensor analyzes the received signal in three steps. STEP 1 is an iterative process that decreases the signal bandwidth to be analyzed further, so that the band of analysis is reduced to the only non zero regions as it is described in subsection 3.1. STEP 2 performs an analysis thanks to several sensors which are fully presented in subsection 3.2. As it could be noticed, these sensors belong to the lower level of our model of Figure 1. Then during STEP 3, a fusion of all the information given by the analysis phase is performed in order to decide which standard is present.

During STEP 2, different sensors analyze the bands selected in step one. Six sensors have been chosen for the recognition of the standard in use :

- positioning of the terminal,
- presence of the telecom signal,
- detection of the carrier frequency,
- recognition of the bandwidth of telecom signals,
- identification of the FH/DS signal,
- discrimination of Single/Multi-carrier.

These sensors will be described in subsection 3.2.

### 3.1 STEP 1: Bandwidth adaptation

The difficulty here relies in the fact that the ratio between the global bandwidth to be analyzed and the smallest bandwidth parameter to be recognized may be very high. Therefore an iterative adaptation of the bandwidth to be analyzed is performed to solve it. At each iteration, the process analyzes energy in the band with a conventional periodogram, then filters and decimates the samples around the detected peak of energy.

### 3.2 STEP 2: Analysis with sensors

#### *3.2.1 The received Signal*

Before analyzing the signal we should give its expression at the receiver side. The model of the composite signals, at the input of the receiver, is given by equation 1:

$$x(t) = \sum_{s=1}^{S} S_s(t) \tag{1}$$

where $S_s(t)$ is the standard $s$. With the expression of the modulated carrier, equation 1 becomes equation 2:

$$x(t) = \sum_{s=1}^{S}\sum_{p=1}^{P_s}\sum_{l=1}^{L_p}(fem_s(t) * m_{s,p,l}(c(t)))\exp(2\pi j f_{s,p,l}t) \tag{2}$$

Where $L_p$ is the carriers number of the multicarriers modulation inside one channel of the standard, $fem_s(t)$ is the expression of the shape filter and $m_{s,p}(c(t))$ the modulation of the carrier p.

At the receiver side we add to equation (2) the channel impulse response $h_p(t)$ at frequency $f_p$, and the noise $b(t)$. This received signal is then sampled at the frequency $f_e$, which gives equation (3) considering single-carrier modulation for each channel of the standards:

$$x(kT_e) = \sum_{s=1}^{S}\sum_{p=1}^{P_s} h_{s,p}(kT_e) * (fem_s(kT_e) * m_{s,p}(c(kT_e))) \cdot \exp(2\pi j f_{s,p} k \frac{f_p}{f_e}) + b(kT_e) \tag{3}$$

#### *3.2.2 Bandwidth recognition*

In [4] it was claimed that, in the frequency domain, the channel bandwidth (BWc) was a fully discriminant parameter, as presented in table 1. This means that to recognize the standard, the receiver should analyze all the non-empty bands.

The question now is how to find the bandwidth shape on the received signal. The choice has been made to perform a power spectrum density (PSD) on this signal in order to obtain its BWc shape. This shape is compared with reference spectrum shapes given by equation 4. This comparison is performed using Radial Basis Functional Neural Networks (RBF NN). Several NN classes are described in the literature [5] in which the reader can find all the basic information. Among them, the better known are the multilayer perceptron, Kohonen network, Sigma-Pi network, and RBF network. Each is adapted for a particular application. For example, the multilayer perceptron is well adapted to equalization, and the RBF is well suited to pattern recognition. Since the problem looks like pattern recognition, the authors decided to use the RBF NN. On the received signal, a Power Spectrum Density (PSD) is performed , and using the RBF NN presented in Figure 3, this PSD is compared with the reference signals PSD. Then a neuron will be active. To each neuron number i corresponds the bandwidth of the standard number i.

$$\gamma_{ref}(k) = C_s(k) = |Fem_s(\frac{f_p}{f_e} - k)|^2 \gamma_{mod}(\frac{f_p}{f_e} - k) \tag{4}$$

Were $C_s$ is spectrum of reference and $\gamma_{mod}(\frac{f_p}{f_e} - k)$ is the PSD of modulation.

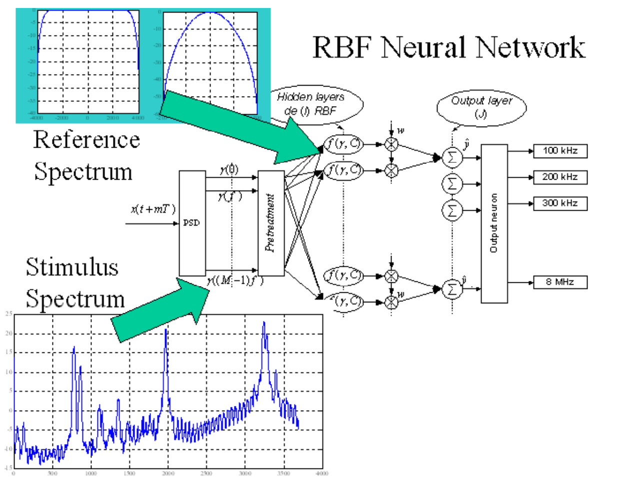


Figure 3: The bandwidth recognition sensor.

Table 3 lists the new standards that should be discriminated. Note that several of these new standards have a similarity in terms of both bandwidth and the channel filter shape.

In the case of UWB (IEEE 802.15.3a), the level of the power of the UWB signal is situated under the level of the noise. This situation gives a new challenge for the detection of the UWB signal, and will not be addressed in this paper.

Table 3: Unrecognized standards with bandwidth recognition

| Standards | channel bandwidth | feature |
|---|---|---|
| IEEE 802.11b | 1 or 25 MHz | DS |
| IEEE 802.15.1 | 1 MHz | FH |
| IEEE 802.11a | 20 MHz | 5 GHz |
| IEEE 802.11n | 20 MHz | 2,4;5 GHz |
| IEEE 802.11h | 20 MHz | 5,15-5,25 GHz |
| IEEE 802.11j | 20 MHz | 4,9-5 GHz |
| IEEE 802.16d | 20 MHz | 2-11 GHz |
| IEEE 802.16e | 20 MHz | 2-6 GHz |

The two standards IEEE 802.11h and IEEE 802.11j will be discriminated thanks to the positioning sensor (11j in Japan), whereas the IEEE 802.11a and IEEE 802.11n standards will be discriminated thanks to the carrier frequency sensor. The main difficult situation remains for IEEE 802.11b and IEEE 802.15.1 standards. This will be solved with the Frequency Hopping (FH)/Direct Sequence (DS) sensor as explained in subsection 3.2.4. In order to have upper limits for the thresholds of the RBF NN, the error obtained between one reference signal for the neuron and the other reference signals as stimuli of this neuron are computed in table 4. Therefore, an error confusion matrix is obtained. We use the best error from [4]. It is called "combined error" and is given by equation 5. A column of table 4 gives, for this error function, the errors of one neuron excited by all the others signals. In the same way, a line gives the errors of different neurons excited by the same signal. The spectrum being classified in the table by ascending order of the BWc, both in line and column, the smallest error values are located around the diagonal. These values give a good indication of the threshold level so as to obtain the desired discrimination. In fact, this smallest value corresponds to the upper limit of the threshold of the considered neuron.

$$MSE_{Comb} = \frac{1}{L_i}\sum_{l=1}^{L_i}((\gamma_l - C_{i,l})^2 \times |\log(\frac{\gamma_l}{C_{i,l}})|) \qquad (5)$$

As it could be seen on the two last lines of the table there is a confusion between the two standards IEEE 802.11.b and IEEE802.15.1. This fact is illustrated by the same errors and by the two cells equal to 0 on each line. To discriminate these two standards, we will use time frequeny analisys in order to detect FH from DS as it is explained in sub-section 3.2.4.

#### 3.2.3 *Single/Multicarrier detection*

The overall results presented in [4] shown that the recognition rate between DVB-T and LMDS on the one hand, DAB and DECT on the other hand, was not good enough. We propose to improve this recognition adding a new sensor that discriminates between single and multi-carriers systems based on Guard Interval (GI) detection. It is well known that a GI is inserted in multi-carriers systems in order to avoid intersymbol interference (ISI). There are several possibilities for creating this GI. The simplest and the most usual way is to copy the end of the symbol in the GI.

After the computation of the autocorrelation function, the cyclic frequency corresponding to the GI is derived. An example of this detection is presented in Figure 4.

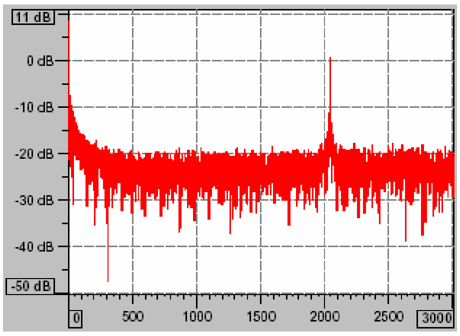


Figure 4: Guard Interval detection for $IG/Tu = 1/4$

#### 3.2.4 *Recognition of FH/DS signal*

The results previously presented with the fusion of the two previous sensors are not sufficient yet. It fails in the discrimination of Bluetooth and IEEE 802.11b at 2.4 Ghz in FH mode. In this situation, the two standards coexist at the same time in the same frequency band, so the resulting spectrum is the product of the original spectrums and consequently the previous sensor does not run correctly. Therefore,we need to find another parameter. The detection between FH and DS modes should solve this difficulty.

Recently, M. Gandetto addressed this particular problem. In [14], he proposed to use Wigner-Ville Transform in order to discriminate between Bluetooth and IEEE802.11b. His results are well adapted to our needs. He uses an underlying time frequency analysis method [13] for extracting features of signal which allow to discriminate between DS and FH signals.

#### 3.2.5 *Detection of the telecom signal*

The spectrum-hole sensor functionality is to find vacant frequency bands over the radio spectrum by detecting cyclostationary features in the received signal. A frequency band is said to be vacant if the received radio signal within this band is constituted only of the thermal noise. In the opposite case, the band will be occupied by at least one telecommunication signal. Since a telecommunication signal is well modelled as a cyclostationary random process [16] and the noise is rather stationary, the presence of cyclostasionarity in the received signal asserts whether the tested frequency band is vacant or not. In [15], a test for presence of cyclostationarity is proposed. But this test requires the knowledge of the cyclic frequency of the signal. To take into account the situation where the cognitive radio has little or no information about the structure of the received signal, we apply the test over an interval of frequencies. If none of them is detected as a cyclic frequency, then the considered band is declared vacant. Else, we decide the band is occupied.

### 3.3 STEP 3: Fusion

Then during the third step, a fusion of all the information given by the analysis phase is performed in order to decide which standard is present. At the end of the analysis step, six indicators are obtained (see Figure 2 between step 2 and fusion boxes). The simplest way to make the fusion is to apply some logical rules on these indicators. This method

Table 4: Error confusion matrix with combined error function

| | CT2 | GSM | PHS | DECT | IS95 | DAB | UMTS | DVB | LMDS | 802.11.g | 802.15.4 | 802.11b | 802.15.1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CT2 | 0.000 | 0.021 | 0.533 | 2.001 | 12.698 | 18.159 | 47.85 | 138.01 | 93.467 | 440.131 | 60.22 | 2.311 | 2.311 |
| GSM | 0.013 | 0.000 | 0.126 | 0.902 | 6.869 | 9.853 | 25.154 | 73.011 | 49.264 | 232.094 | 31.53 | 2.311 | 2.311 |
| PHS | 0.084 | 0.039 | 0.000 | 0.086 | 1.768 | 3.121 | 8.68 | 25.168 | 16.880 | 77.786 | 10.44 | 0.134 | 0.134 |
| DECT | 0.109 | 0.099 | 0.033 | 0.000 | 0.136 | 0.497 | 3.224 | 10.110 | 6.680 | 28.874 | 3.821 | 0.0003 | 0.0003 |
| IS95 | 0.117 | 0.127 | 0.115 | 0.030 | 0.000 | 0.398 | 2.934 | 7.092 | 4.864 | 17.862 | 2.505 | 0.016 | 0.016 |
| DAB | 0.117 | 0.127 | 0.115 | 0.082 | 0.185 | 0.000 | 1.352 | 3.800 | 2.502 | 10.126 | 1.346 | 0.052 | 0.052 |
| UMTS | 0.117 | 0.127 | 0.115 | 0.115 | 0.185 | 0.249 | 0.000 | 2.334 | 1.161 | 4.238 | 0.519 | 0.121 | 0.121 |
| DVB | 0.117 | 0.127 | 0.115 | 0.115 | 0.185 | 0.249 | 0.352 | 0.000 | 0.078 | 0.642 | 0.051 | 0.121 | 0.121 |
| LMDS | 0.117 | 0.127 | 0.115 | 0.115 | 0.185 | 0.249 | 0.352 | 0.111 | 0.000 | 1.408 | 0.106 | 0.121 | 0.121 |
| 802.11g | 0.117 | 0.127 | 0.115 | 0.112 | 0.181 | 0.242 | 0.272 | 0.060 | 0.112 | 0.000 | 0.002 | 0.117 | 0.117 |
| 802.15.4 | 0.117 | 0.114 | 0.114 | 0.110 | 0.177 | 0.236 | 0.218 | 0.039 | 0.060 | 0.027 | 0.000 | 0.114 | 0.114 |
| 802.15.1 | 0.111 | 0.105 | 0.045 | 0.0002 | 0.068 | 0.288 | 2.526 | 8.631 | 5.641 | 24.221 | 3.177 | 0.000 | 0.000 |
| 802.11b | 0.111 | 0.105 | 0.045 | 0.0002 | 0.068 | 0.288 | 2.526 | 8.631 | 5.641 | 24.221 | 3.177 | 0.000 | 0.000 |

could be improved by the use of a neural network (like a perceptron). Moreover as these indicators give an information which could be weighted by a reliability factor, a future work will further explore solutions based on Bayesian network.

## 4. CONCLUSION

In the context of Cognitive Radio, we have presented in this paper a new Blind Standard Recognition Sensor. It realizes the fusion of information given by several sensors in order to recognize the standard in use. The preliminary results we obtain are very promising and we will describe in a further paper the final complete results combining all the sensors.
Note that there is some paradox in CR, as CR currently uses standard recognition to make adequate decisions. But 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 context would definitely prevent CR from making standard recognition judicious. But is the idea of a world free of standard viable? Probably not. At least some basic rules are necessary, some kind of light standards which will be a fraction of current standards, but giving degrees of freedom to match the communication context and optimize radio resource use (spectrum, battery, carrier frequency, *etc.*). Blind recognition will only be possible on the remaining fixed rules indeed.

## 5. 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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