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Methods and technologies for wideband spectrum sensing

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ABSTRACT

The paper presents a review of the measurement methods and the technologies for wideband spectrum sensing. Wideband spectrum sensing is a relevant task in RF measurement instruments and telecommunications equipments. The first part of the paper is dedicated to the discussion of methods. They have been classified into five main approaches: (i) signal detection with known sub-band width; (ii) joint sub-band boundaries and level estimation; (iii) spectrum segmentation; (iv) compressed sensing; and (v) cooperative sensing. Methods following approaches (ii) and (iii) are the most suitable for the implementation in measuring instruments, since they allow separation of the signals, sharing the observed band. Therefore, greater attention has been paid to these approaches throughout the paper. A second part of the paper is dedicated to the analysis of main technologies enabling wideband spectrum sensing, dealing with the (i) RF frontend, (ii) A/D conversion, and (iii) waveform processing section of a potential instrument.

1. Introduction

The scenario of radio communications is highly changing in last years, since the overcrowding of some spectrum bands is pushing regulatory institutions to introduce new policies, aiming at increasing opportunities and competitiveness. One of the practical solutions to achieve such target, first proposed in the academic community and then accepted by the regulatory institutions, is the usage of *white spaces* for an opportunistic spectrum access. A white space or a spectrum hole is a sub-band of the radio spectrum, unused at a particular time and a specific geographic location [1]. The opportunistic spectrum access introduces the possibility for a *secondary user*, not having the license for the same band, to transmit when the licensee, called *primary user*, does not use that band. Therefore, the secondary user can transmit by searching for *white spaces* left unused by several primary users, and moving over such spaces, as shown in Fig. 1.

In particular, in the United States of America, the Spectrum Policy Task Force, established by the Federal Communication Commission in 2002, recently published its opinion about the usage of unused spectrum in the UHF TV bands available for unlicensed broadband wireless devices [2] and in December 2011 approved the first devices operating on TV white spaces [3]. In Europe, the European Communication Commission (ECC) is evaluating the use of the white spaces in the 470–790 MHz frequency band [4] and it is working on the identification of possible candidate bands for services based on the opportunistic access model.

The scenario, resulting from the application of the new regulations, is very complex and susceptible to harmful interferences, both vs. adjacent frequency channels and successive time slots. Such interferences depend not only on the position and width of the transmission in the time–frequency plane, but also on the signal parameters, such as modulation type and order, symbol rate, pulse shape and roll-off factor. Therefore, appropriate monitoring instruments and test equipment are needed, which can verify the appropriate behavior of the radios, with the aim of avoiding harmful interferences [5]. Such instruments should be capable of (i) observing a very wide

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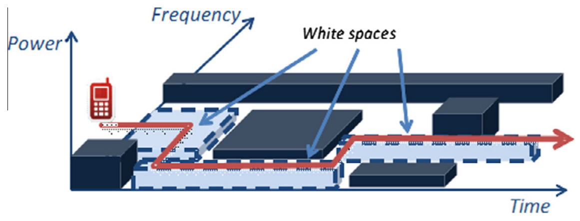

Fig. 1. Spectrum holes are frequency bands left unused by a primary used for a certain amount of time. In order to exploit the spectrum holes, the cognitive radio can adjust its transmission parameters.

frequency band, covering the whole spectrum subjected to dynamic access, (ii) identifying the portions of the observed band where signals are present, (iii) separating the signals, (iv) identifying the modulation scheme and order, and (v) measuring the physical layer parameters of each signal [6]. The scheme of an instrument for radio spectrum monitoring is shown in Fig. 2. In this scheme, a key role is played by the *spectrum sensing* module, which is in charge of measuring the Power Spectral Density (PSD) of the signal and detecting the presence of signals in the observed band and determine the sub-bands where they are located [7].

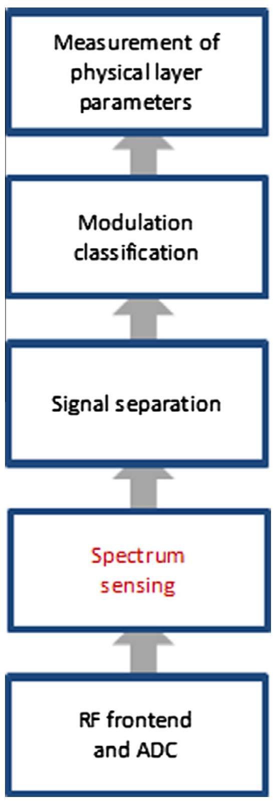

Fig. 2. Block scheme of an instrument for radio spectrum monitoring. A spectrum sensing module is needed to identify the presence of a signal to be measured in a certain frequency band.

Spectrum sensing represents a key task even in the communication equipment working in a dynamic spectrum access scenario and for the future implementations of such equipments, the candidate platform is the Cognitive Radio (CR), thanks to its ability of dynamically reconfiguring its internal states with the two primary objectives of optimizing the transmission performance and the radio spectrum usage [8].

From an architectural point of view, CR is built on a Software Defined Radio (SDR), which realizes the data acquisition and generation and the frequency up/down conversion functions. The SDR provides the samples of the acquired signal to two measurement blocks. The former executes the spectrum sensing task, in order to identify the occupied sub-band, where it is not possible to transmit; the latter measures the quality of the current communication, in order to guarantee a given performance level. On the basis of such information, an intelligent block, called *cognitive engine* takes decisions about the dynamic change of the communication parameters. A scheme of the CR architecture is shown in Fig. 3 [9].

Several papers can be found in the scientific literature, dealing with spectrum sensing in a narrow band. Narrowband spectrum sensing consists of observing a radio spectrum band and deciding whether there is a signal or there is noise. In [10–12], some reviews about the most promising algorithms for signal detection in a narrow band are presented. However, they do not present solutions to the wideband detection problem. In [13], some papers dealing with wideband spectrum sensing are cited, but a complete review of such research is missing. A first review of wideband spectrum sensing method is given in [14]; however, it is oriented to the design of communication equipment and does not provide comments about the applicability of wideband spectrum sensing methods to measurement instruments.

In [15], a preliminary survey of wideband spectrum sensing methods has been presented, focusing the attention even to the instrumentation design. This paper is an extended version of such work, providing a more complete presentation about the spectrum sensing methods, focusing on measurement instrumentation and adding a survey of the technologies enabling wideband spectrum sensing. In particular, the applicability of the wideband spectrum sensing methods to the spectrum monitoring instruments will be discussed.

The paper does not intend to cover the whole literature in this field, but aims to select representative contributions, in order to give the general reader an understanding of main concepts, approaches and research trends.

The paper is organized as follows: in Section 2, the spectrum sensing requirements for RF measuring instruments are sketched. In Section 3, the wideband spectrum sensing problem is presented and compared to the narrowband spectrum sensing. Then, in Section 4 the main approaches to narrowband spectrum sensing are briefly presented, as they are often used as building blocks for wideband spectrum sensing methods. In Section 5, a review of wideband spectrum sensing methods is reported. Finally, in Section 6 a survey of the technologies enabling wideband spectrum sensing is presented.