Signal Processing: *Image Communication* 27 (2012) 893–899

Contents lists available at SciVerse ScienceDirect

Signal Processing: *Image Communication*

journal homepage: www.elsevier.com/locate/image

TV white spaces exploitation for multimedia signal distribution

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ARTICLE INFO

Available online 2 February 2012

Keywords:
Signal processing for transmission
Dynamic spectrum access
TV white spaces
Spectrum sensing

ABSTRACT

The new spectrum regulation policies for dynamic spectrum access, especially those concerning the use of the white spaces in the Digital Terrestrial Television (DTT) bands, arise the need for fast and reliable signal identification and classification methods. In this paper we present a two-stage identification method for signals in the white spaces, using combined energy detection and feature detection. The band of interest is divided by means of the Discrete Wavelet Packet Transformation (DWPT) in sub-bands where the signal power is calculated. Modulation classifiers taking into account the statistical parameters of the signal in the wavelet domain are used as features for identifying the modulation schemes, in this case specifically for the DVB-T broadcast standard. Finally, a signal transmission architecture based on Motion JPEG XR has been implemented in order to explore and evaluate a practical application of indoor signal distribution over white-spaces.

1. Introduction

Within the cognitive radio paradigm, as a highly praised alternative for overcoming the inherent limitations of the RF spectrum, the current worldwide situation of the VHF and UHF TV channels is an excellent application scenario. In the US, the complete switchover to digital television in 2009 opened an entire new topic of the usability of the TV white spaces (TVWS) for short-range wireless consumer devices. Moreover, the gradual global passage to digital television poses new specific challenges to the white spaces detection.

Within this framework, spectrum sensing for DTT broadcasting signals plays a crucial role, along with geolocation databases [1] (GL-DBs). In the US, the Federal Communications Commission (FCC) has already commissioned the creation of GL-DBs, free to access any cognitive radio (CR) [2] device. The database entries provide, for a certain location (geographical coordinates), the list of available channels and the allowable maximum effective isotropic radiated power (EIRP) useful to transmit without providing harmful interference [3]. Even if the GL-DBs are up-to date, the values provided for a specific geographical point are still the results of applying signal propagation models and estimated power levels. Due to this static approach, the provided data might be inaccurate for different reasons such as variable atmospheric conditions or multipath and fading phenomena [4,5]. Therefore, there is still the need of a validation in terms of frequency occupancy and maximum EIRP of the free frequency channels provided by the GL-DBs, using specific spectrum sensing methods.

As it is known, spectrum sensing techniques mainly focus on primary transmitter detection and can be classified into three categories: matched filter, energy detection and signal feature detection [3]. Combinations of these methods are used for achieving good results in terms of sensitivity, computational time and signal classification, in the so-called two-stage spectrum sensing schemes proposed initially in [4] and then refined in [5] and especially in [6]. The mentioned two-stage schemes

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doi:10.1016/j.image.2012.01.014

perform coarse sensing based on energy detection, followed by a feature detection performed on the signals in the sub-bands declared free by the previous stage.

This work presents a different spectrum sensing approach in a two-stage scheme using the Discrete Wavelet Packet Transformation (DWPT) for dividing the analyzed frequency band and calculating the signal power in the resulting sub-bands (channels). The sub-bands identified as free can be directly used for transmission. The remaining sub-bands with a signal power higher than a pre-defined threshold are subsequently analyzed by the feature detector, for distinguishing between primary users (PU) and possible secondary users (SU). The feature detection method used in the second stage of the spectrum sensing exploits the statistical properties of the DWPT's coefficients.

The performance of the proposed system for distributing high-definition video content is tested and evaluated. In order to satisfy requirements of high-quality image compression and low computational complexity a recent standard by ISO/IEC named Motion JPEG XR has been chosen over other standard video coding tools. The remainder of the paper is organized as follows: in Section 2, we first present the use of the DWPT for sub-band division and energy detection and then we analyze the proposed feature detection method. Section 3 presents the initial software simulation, while Section 4 shows the hardware set-up and the test results using real recorded signals. Section 5 presents a signal transmission architecture based on Motion JPEG XR, its hardware implementation and the experimental results. Finally, in Section 6 we draw the conclusions and present the future work.

2. Energy detection and signal classification

This two-stage approach is based on the work proposed initially in [7]. We are performing an energy detection based on DWPT sub-bands analysis, considering an initial band centered on the region occupied by the TV channels. The band is divided by means of a wavelet decomposition tree into sub-bands with a bandwidth specific to the various DTT standards (from 6.5 to 8 MHz). We are calculating the power level of the received signal in the wavelet domain by summing the corresponding squared wavelet coefficients for each sub-band. The resulting values are compared to opportune threshold values [8] to mark the channels for the frequencies corresponding to the TV channels of interest as free ("white") or occupied.

As it is known [3], the drawback of the energy detection method is the reliability of the power level thresholds. Therefore, in the second stage of the spectrum sensing, for all the channels that previously were identified as not "white", implicitly having a signal power surpassing the noise threshold mentioned in [8], we estimate whether they are occupied by PUs or SUs using a modulation classifier.

The modulation types used by the DTT broadcasting systems are standard, so a feature-based classifier for the modulation schemes typical for terrestrial communications can be used to classify a possible modulated signal. The proposed scheme supports the classification of QPSK, 16QAM and 64QAM modulations, specific for the European DVB-T standard. Similar to the methods proposed in [9], we are starting from the normalized histogram generation of the wavelet-transformed coefficients with N samples in the particular process.

The first-order moment of the statistical process is the mean, given by

$$\mu_1(x) = \sum_{i=0}^{N-1} x_i p(x_i) \tag{1}$$

The second-order moment of the DWPT represents the variance, given by

$$\mu_2 = \frac{1}{N}\sum_{i=0}^{N-1} |c_i|^2 - \left[\frac{1}{N}\sum_{i=0}^{N-1} |c_i|\right]^2 \tag{2}$$

where c_i are the wavelet coefficients in each single sub-band.

The constellation type, circular (M-ary PSK) or in quadrature (M-ary QAM), can be detected by comparing the mean with the first threshold T_1, computed using known, pre-calculated mean and variance values for M-ary QAM and M-ary PSK signals:

$$T_1 = \frac{\mu_{1,M-QAM} C\mu_{2,M-PSK} + \mu_{1,M-PSK} C\mu_{2,M-QAM}}{\mu_{2,M-QAM} + \mu_{2,M-PSK}} \tag{3}$$

Subsequently, based on the same principle, if the modulation is a M-ary PSK we can compare the variance with a second threshold T_{P2} to find if it is a QPSK or a different PSK order modulation.

$$T_{P2} = \frac{\mu_{1,QPSK} C\mu_{2,PSK} + \mu_{1,PSK} C\mu_{2,QPSK}}{\mu_{2,QPSK} + \mu_{2,PSK}} \tag{4}$$

If the modulation is an M-ary QAM, we can detect if it is a 16QAM or a 64QAM comparing the variance of the signal with a third threshold T_{Q4}:

$$T_{Q4} = \frac{\mu_{1,16QAM} C\mu_{2,64QAM} + \mu_{1,64QAM} C\mu_{2,16QAM}}{\mu_{2,16QAM} + \mu_{2,64QAM}} \tag{5}$$

Opposed to the work presented in [9] we are considering the coefficients in each of the S sub-bands for calculating and using N/S coefficients from the original N signal samples.

Fig. 1 presents the flowchart of the proposed feature detection method. If the channel is identified as being occupied by a PU, the corresponding channel is definitively marked as "black", meaning it is undoubtedly used by PUs and therefore not suitable for transmission. If the statistical analysis fails to identify a known type of modulation (QPSK, 16QAM, 64QAM), we categorize the channel as being "gray", which means that there is no broadcaster transmitting, but still the channel is occupied, most probably by another SU. Therefore, the channel is not completely discarded, being a potential candidate to be analyzed again after a certain amount of time in order to be re-evaluated and eventually included in the white list.

The channels marked as "black" are not suitable for transmission and therefore, after the first energy and