TV White Spaces Exploitation for Signal Distribution

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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. As a possible application we are considering an indoor short-range distribution system for video signals.

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

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 so-called 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 topic, spectrum sensing for DTT broadcasting signals plays a crucial role, along with geolocation databases [1] (GL-DBs). In the US, the FCC has already commissioned the creation of geo-location databases, free to access for any CR 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 [2]. Even if the GL-DBs are up-to date, the values provided for a specific geographical point are

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still the results of applying a 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 [3, 4]. 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 known, spectrum sensing techniques mainly focus on primary transmitter detection and can be classified in three categories: matched filter, energy detection and signal feature detection [2]. Combinations of these methods are used for achieving good results in terms of sensitivity, computational time and signal classification, in so-called two-stage spectrum sensing schemes proposed initially in [3] and then refined in [4] and especially in [5]. The mentioned two-stage schemes 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 subbands identified as free can be used directly for transmission. The remaining subbands 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 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. Finally, in Section 5 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 [6]. 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 [7] to mark the channels for the frequencies corresponding to the TV channels of interest as free ("white") or occupied.

As known [2], 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 [7], 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 [8], we are starting from the normalized histogram generation of wavelet-transformed coefficient with N_i the 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 (MPSK) or in quadrature (MQAM), can be detected by comparing the mean with a first threshold T_1, defined as

$$T_1 = \frac{\mu_1 MQAM \cdot \mu_2 MPSK + \mu_1 MPSK \cdot \mu_2 MQAM}{\mu_2 MQAM + \mu_2 MPSK} . \tag{3}$$

If the modulation is a MPSK we can compare the variance with a second threshold T_{p2} to find if it is a QPSK or a different PSK order modulation. If the modulation is a QAM we can detect if it is a 16QAM or a 64QAM with the variance and a third threshold T_{q4}.

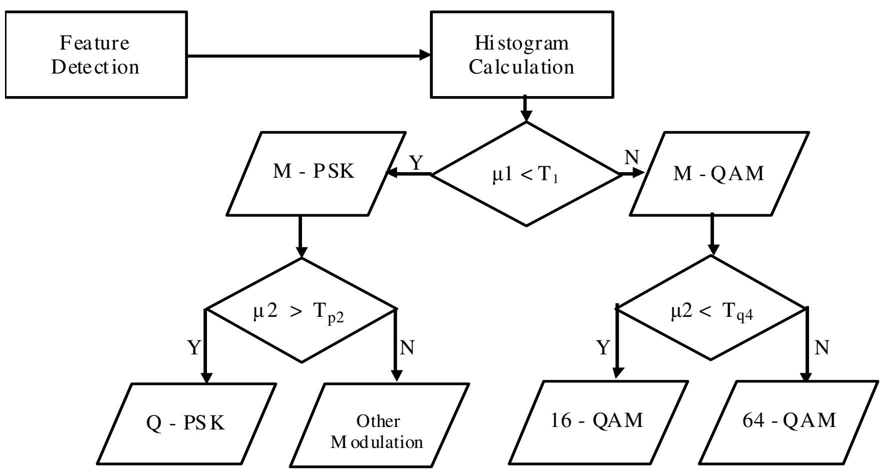

Fig. 1. Flowchart of the functionality of the proposed feature detection method

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.

Figure 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, 64 QAM), we categorize the channel as being "grey", 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 feature detection, we have to consider only the "grey" and "white" channels, thus reducing the number of operations and making the algorithm suitable for the use with real, live signals. Furthermore, the wavelet transformation has to be performed only once for both the two stages of the spectrum sensing scheme, the coefficients used for energy detection and signal classification being the same.

3 Software Simulations

The proposed spectrum sensing method is implemented using a two-stage algorithm. We perform an energy detection based on discrete wavelet packets sub-bands analysis followed by a feature detection stage as shown in section 2.

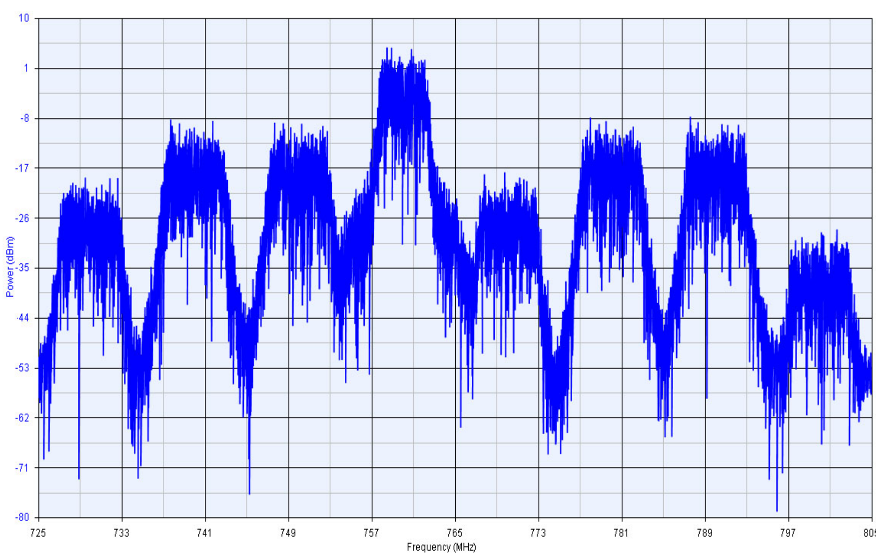

Fig. 2. Test signal composed by 8 DVB-T signals with different standard modulations

The algorithm was implemented in Simulink / Matlab using a 4-level DWPT block with 15th order Daubechies [9] wavelet filters.

The test signals for the system's functionality were generated using the Agilent SystemVue Software: 8 signals, spaced evenly at 8 MHz on 7.61 MHz - wide channels, with constant additive white Gaussian noise (AWGN), were modulated on carrier in the upper UHF band in order to simulate the behavior of a real terrestrial DVB-T system. Figure 2 depicts one of the test signals. Different modulation schemes were chosen even for adjacent signals in order to test the capacity of the system to correctly compute the thresholds values needed for the signal classification.

The first step consisted in the calculation of the threshold of the energy detection stage based also on the results from [7]. The next step implied calculating the reference thresholds for the modulation classifier based on the simulated input signals with known modulation type and signal-to-noise ratios.

Based on these thresholds, pre-set in the simulator, we tested the reliability of the proposed application scenario. A series of test consisting in changing the amplitude of the signals, their SNR and the modulation type has been performed. A total set of 200 different test signals has been fed to the simulator. For SNR values higher than 5 dB and specifically for the signals in the 700 MHz band, the proposed method equaled the best methods presented in the literature [8], [9]: for the typical DVB-T standard modulations the signal classifier had an identification percentage of 96.5 %.

4 Hardware Set-Up and Tests

After testing the functionality of the software implementation and calculating the appropriate threshold values for both the energy detector and the modulation classifier, we validated these results with real DVB-T signals acquired using RF hardware.

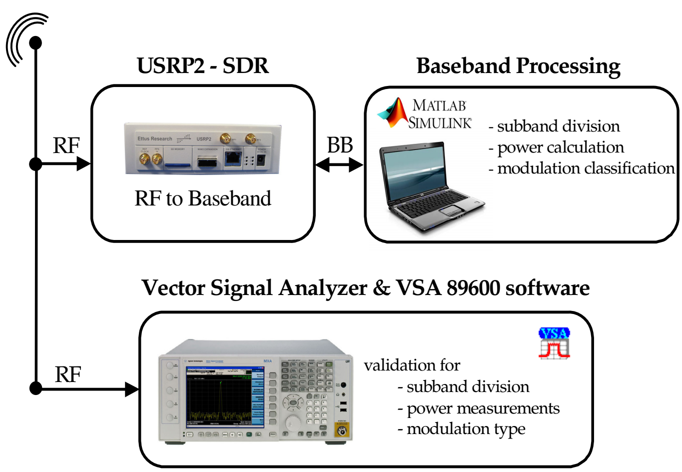

Fig. 3. Flowchart of the functionality of the proposed feature detection method

The hardware set-up consisted of USRP2 software radio boards equipped with WBX wideband daughterboards covering a spectrum range from 50 MHz to 2.2 GHz. The software radios were connected to a PC running a Simulink model that commands the RF hardware and implements the entire baseband processing. Appropriate antennas for the frequency band of interest were used during the tests. The measurements on the power of the DVB-T signals and on their modulation type were crosschecked using as reference the Agilent EXA9020A Vector Signal Analyzer, the 89600VSA software and the instrument's onboard software (figure 3).

A set of 50 real DVB-T signals, each one 30 seconds long, with different signal characteristics (modulation, symbol rate, FEC, SNR) were recorded to the Matlab environment using the RF hardware and an appropriate antenna. The signals were contemporary fed to the Agilent Vector Signal Analyzer for identifying their features.

The Simulink / Matlab set-up presented in the previous section was tested with the real recorded signals in terms of detection reliability. Figure 4 presents the receiver operating characteristics (ROCs) of our combined spectrum sensing approach, for both simulated and real DTT signals. While the system performed well for simulated signals with a SNR as low as 10 dB, we noticed a degradation of the detection curve for real signals. It can be seen that the ROC for a real signal with a 10 dB SNR is worse than the ROC curve for simulated signals with the same SNR. The discrepancy is due to the calculation of the initial thresholds values of the feature detection stage, done based on simulated signals.

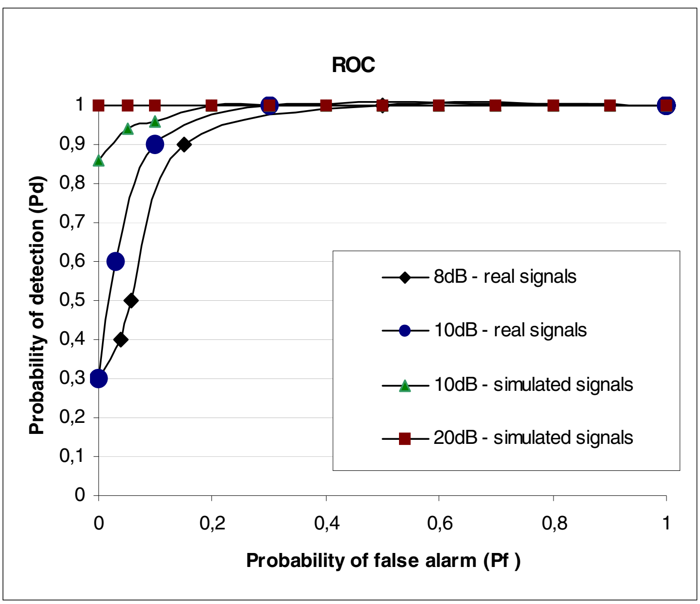

Fig. 4. Receiver operation characteristics for the proposed two-stage spectrum sensing method

5 Conclusions and Future Work

In this paper we propose a two-stage spectrum sensing approach for white spaces exploitation in the 470 - 790 MHz band, combining energy and feature detection methods in the wavelet domain, continuing the work initially presented in [6]. The current work is specifically adapted for PU signals compliant to the European DVB-T standard.

Different from other approaches we are looking at the energy detection and signal classification in a combined way, both at system level and at computational level. First we implemented the proposed sensing scheme in a fully software simulator and calculated with these simulated signals the thresholds for both energy detection and the signal classification stages. The simulations validated our design for the next step, i.e. the tests with real DVB-T signals. Consequently we tested our spectrum sensing approach in a functional system consisting of an RF hardware front-end (Ettus Research USRP2 Platform) connected to a computer running a Matlab / Simulink model. Real signals were acquired and fed offline to the computational model in order to test the system's behavior in real conditions. The receiver operation characteristics were slightly inferior to those obtained with the simulated signals.

The initial tests results and the obtained ROC curves showed us the need of improving the reliability of the sensing method for much lower SNR. A first step will be the calculation of new, more accurate threshold values using a large set of real DVB-T signals with various characteristics. Further steps will include also tests with different wavelet filters.

The hardware set-up presented in figure 3 will be extended to be used as an indoor short-range distribution system for video signals, with immediate implementations as home entertainment or infotainment systems. A central device (implemented by the USRP2 SDR platform), performing as server, can distribute video signals to clients in different areas of a building (e.g. apartment or hotel rooms). The aim is to implement a full cognitive transmission system to be deployed in the 470-790 MHz bands.

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References

[1] CEPT ECC Reprot 159 - Technical And Operational Requirements for the Possible Operation of Cognitive Radio Systems in the 'White Spaces' of the Frequency Band 470-790 Mhz (October 2010)

[2] Budiarjo, I., Lakshmanan, M.K., Nikookar, H.: Cognitive Radio Dynamic Access Techniques. Wireless Personal Communications 45(3) (May 2008)

[3] Benko, J., Cheong, Y.C., Cordeiro, C., et al.: A PHY/MAC Proposal for IEEE 802.22 WRAN Systems Part 1: The PHY. IEEE 802.22-06/0004r1 (February 2006)

[4] Yue, W., Zheng, B.: A Two-Stage Spectrum Sensing Technique in Cognitive Radio Systems Based on Combining Energy Detection and One-Order Cyclostationary Feature Detection. In: Proceedings of the 2009 International Symposium on Web Information Systems and Applications (WISA 2009), Nanchang, P. R. China, May 22-24, pp. 327–330 (2009)

[5] Maleki, S., Pandharipande, A., Leus, G.: Two-Stage Spectrum Sensing for Cognitive Radios. In: Proceedings of the ICASSP 2010 Conference, Dallas, USA (March 2010)

[6] Fadda, M., Murroni, M., Popescu, V.: Spectrum Sensing in the DVB-T Bands using Combined Energy Detection and Signal Classification in the Wavelet Domain. In: Proceedings of the 13th International Symposium on Wireless Personal Multimedia Communications (WPMC), Recife, Brazil (October 2010); ISBN: 978-85-60307-02-9

[7] Yoon, Y., Leon, H., Lung, H., Lee, H.: Discrete wavelet packet transform based energy detector for cognitive radios. In: IEEE Vehicular Technology 2007, Dublin, Ireland (2007)

[8] Prakasam, P., Madheswaran, M.: M-ary Shift Keying Modulation Scheme Identification Algorithm Using Wavelet Transform and Higher Order Statistical Moments. Journal of Applied Science 8(1), 112–119 (2008)

[9] Linfoot, S.: A Study of Different Wavelets in Orthogonal Wavelet Division Multiplex for DVB-T. IEEE Transactions on Consumer Electronics 54(3) (August 2008)