SPECTRUM SENSING FOR DYNAMIC SPECTRUM ACCESS NETWORKS IN THE 700-MHz UHF TV BAND USING WAVELETS

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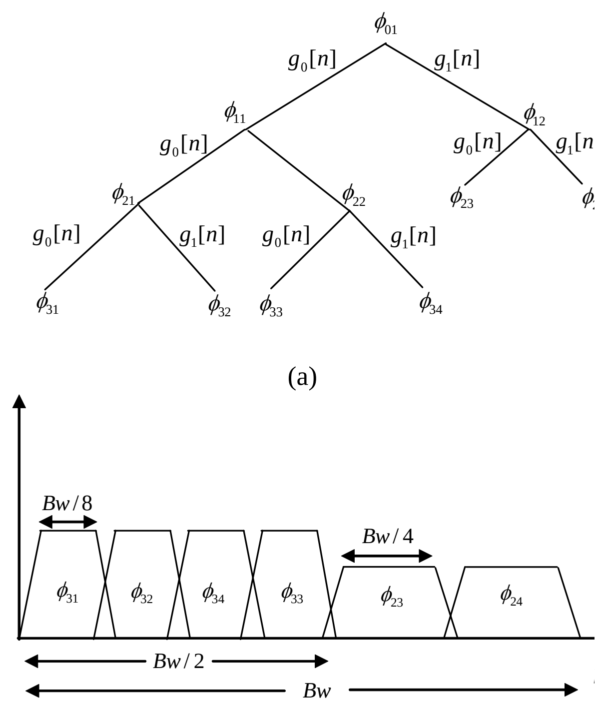
Abstract
Due to the transition to DTV, in early 2009 in the USA, the 700-MHz UHF band (channels 52 to 69) will be cleared of programming and set aside for bidding by wireless networks. In a framework of Dynamic Spectrum Access (DSA) networks, this paper presents a technique based on wavelet packet decomposition to locate "white spaces" in the 700-MHz band. The combined use of opportune energy detection techniques as well as polyphase IIR filter banks allows achieving fast and accurate results.

Keywords
UHF TV band, wavelet packets subband analysis, Dynamic spectrum access networks.

INTRODUCTION

The demand for ubiquitous wireless services has been on the rise in the past and is expected to remain the same in the future. Unfortunately, the vast majority of the available spectral resources have already been licensed. It thus appears that there is little or no room to add any new services, unless some of the existing licenses are discontinued. The enormous growth in the wireless industry has come from using only a small part of the wireless spectrum, nominally less than 10% under 3 GHz. There is growing evidence of scarcity and overcrowding in these bands reflected, for example, by the price paid for the 3G cellular spectrum (€ 90 billion in Europe). However, measurements have shown that other parts of the spectrum, although allocated, are virtually unused, and known widely as spectrum "white spaces". These white spaces vary from place to place and time to time. Emblematic is the case of the average TV market in the United States, which uses approximately 7 high-power channels of the 67 that it is allocated. This leaves an abundance of free channels that could be used for wireless access. With the US government having recently passed bills requiring television broadcasts to switch from analog to digital sometime in early 2009, the 700-MHz band (channels 52 to 69) will be cleared of programming and moved to lower frequencies (channels 2 to 51). The 700-MHz band will be set aside for public-safety emergency transponders and for bidding by wireless networks. In cases when the nature of the licensed signal is



(b)

Fig. 1. (a) Wavelet tree structure (b) Corresponding symbolic subband structure.

known, the white spaces can be identified through feature (e.g., pilot) detection. This is the case in IEEE 802.22 which is currently being designed to operate in the TV bands [1]. However, in the general case where such knowledge is unavailable, spectral analysis has to rely on energy detection, with likely higher requirements for sensitivity and frequency resolution. In this work we propose an energy detection techniques based on wavelet packets subband analysis [2] which can be used to identify white spaces in the UHF re-allocated TV band. The analysis is performed by deploying IIR filter banks polyphase which allow reducing the computational complexity [3] and makes the method feasible for dynamic spectrum access communications.

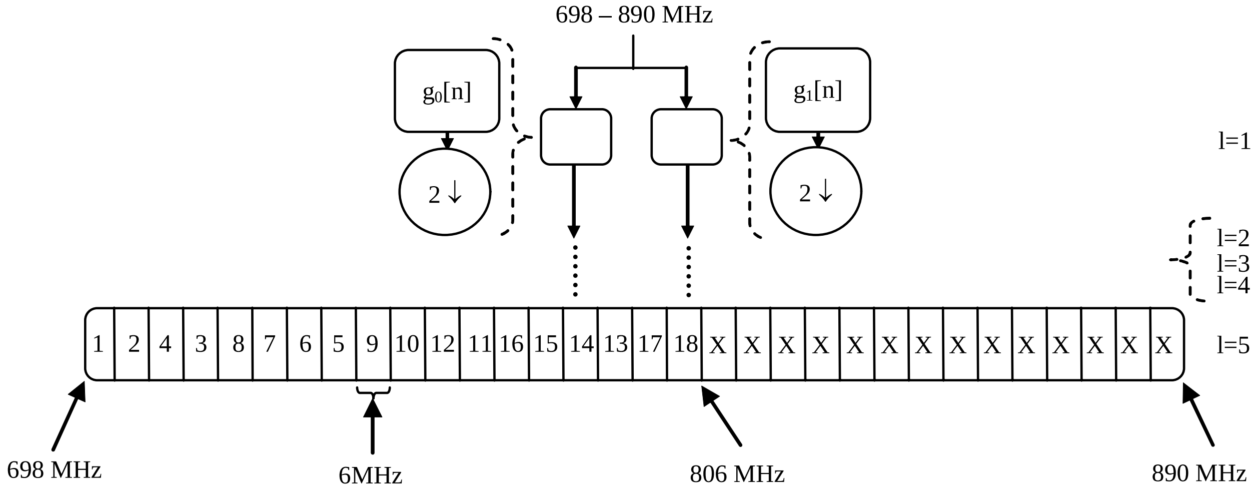


Fig. 2. Wavelet subband analysis for the 700-MHz band

WAVELET PACKET SUBBAND ANALYSIS

To define the wavelet packet basis functions we refer to wavelet multiresolution analysis (WMRA) [2]. Let $g_0[n]$ be a unit-energy real causal FIR filter of length N which is orthogonal to its even translates; i.e., $\sum_n g_0[n]g_0[n-2m]=\delta[m]$, where $\delta[m]$ is the Kroneker delta, and let $g_1[n]$ be the (conjugate) quadrature mirror filter (QMF), $g_1[n]=(-1)^n g_0[N-1-n]$. If $g_0[n]$ satisfies some mild technical conditions [2], we can use an iterative algorithm to find the function $\phi_{01}(t)=\sqrt{2}\sum_n g_0[n]\phi_{01}(2t-nT_0)$ for an arbitrary interval T_0. Subsequently, we can define the family of functions ϕ_{lm}, $l\geq 0$, $1\leq m\leq 2^l$ in the following (binary) tree-structured manner:

$$\begin{cases}\phi_{l+1,2m-1}(t)=\sum_n g_0[n]\phi_{lm}(t-nT_l)\\ \phi_{l+1,2m}(t)=\sum_n g_1[n]\phi_{lm}(t-nT_l)\end{cases}$$

where $T_l=2^l T_0$. For any given tree structure, the function at the *leafs* of the tree form a *wavelet packet.*

Wavelet packets have a finite duration, $(N-1)T_l$ and are self- and mutually-orthogonal at integer multiples of dyadic intervals. Therefore, they are suitable for subband analysis: a generic signal $x(t)$ can be then decomposed on the wavelet packet basis and represented as a collection of coefficients belonging to orthogonal subbands. Therefore, the total power of $x(t)$ can be evaluated as sum of the contributes of each subband which can be separately computed in the wavelet domain [4]. Let S_k be the k-th subband; if we denote by $\{c_{k,i}\}$ the wavelet coefficients of S_k, the power contribute of S_k is $P_k=\frac{2^l}{(N-1)T_l}\sum_i c_{k,i}^2$.

Figure 1 shows an example of a binary tree decomposition (Fig.1a) and the relevant symbolic subband structure (Fig.1b). It is noticeable how for $l>1$ (i.e., packet composed by more than 4 leafs) in the frequency Fourier domain the wavelet packets are not ordered as in the corresponding tree.

A drawback to WMRA as described so far is the higher computational complexity compared to classical Fourier subband analysis. Computational burden is here reduced by deploying IIR polyphase filter banks [3]. It is shown that, whereas the computational complexity of the WMRA based on IIR polyphase filters is of the same order of the state-of-the-art FFT algorithms, the number of mathematical operations is lower [4].

SPECTRUM SENSING IN THE 700-MHz TV BAND

The 52-69 channels in the 700-MHz TV band extend from 698-806 MHz. Each of the 18 channels is 6 MHz wide. Therefore, to cope with the above constraints we consider an initial band 192 MHz wide starting from 698 MHz and ending at 890 MHz, which includes the 52-69 TV channels under analysis. A 5-level (i.e., $l=5$) depth wavelet decomposition tree is performed on this “enlarged” band producing $2^l=32$ subbands each 6 MHz wide. Only 18 selected leafs of the resulting 32, match with the 52-69 TV channels and, thus, have to be considered. The matching process is performed taking into account the discrepancy between the TV channels order in the Fourier domain and the corresponding subbands order in the wavelet domain. Fig. 2 shows the complete tree for the case under discussion and highlights the labeling of the effective 18 UHF channels.

Within each identified subband the power level is estimated in the wavelet domain, as described in the previous section,

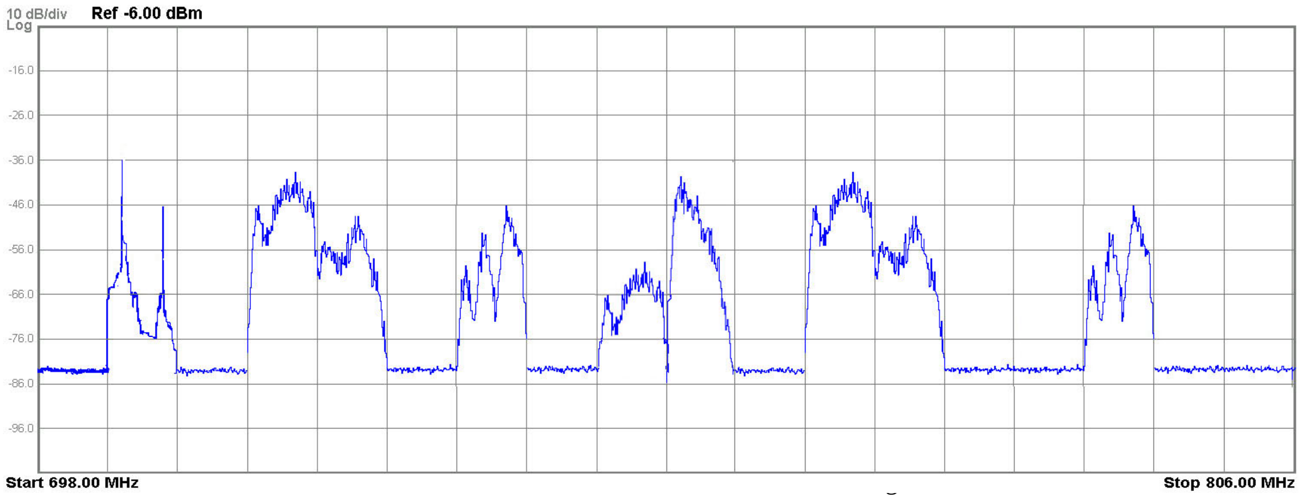


Figure 3. Generated input signal in the 700 MHz-TV band.

and then compared to opportune threshold values so as to identify spectrum opportunities, namely the “white spaces”. We set up several tests considering a wide set of possible transmissions systems operating in the selected channels. Our method is classified as an energy detection technique and therefore we did not consider spread spectrum transmission systems which need more complex cyclostationary feature detection, but at cost of high complexity. The transmission has been simulated in the presence of AWGN according to the technique of equivalent baseband simulation. The selection of the power threshold is made by considering the average noise level on the 700-MHz UHF band. We conducted experiments using a software platform based on Simulink and Matlab scientific software. Measurements on real scenario have been performed by means of a Vector Signal Analyzer (VSA) which extracts the in band noise floor of -80 dBm and acquire real TV signals both from DVB-T and analog TV PAL technologies. The results of the analysis are given as input to a Vector Signal Generator (VSG) which generates randomly variable transmission scenarios. An example of a complex generated signal is presented in figure 3, which spreads over 18 TV channels. Figure 4 shows the simulation test bed.

The wavelet decomposition performed on the simulated input signals generated a series of wavelet coefficient in the 32 resulting subbands. The resulting wavelet coefficients of the first 18 subbands are then used to calculate the relative power for each of these subbands, as described in the previous section. Based on the noise value in the analyzed 700 MHz frequency band, the decision on the status of each subband is taken, marking it as free or occupied.

The simulation identified accurately the free subbands: 1,3,6,8,11,14,15,17,18. The results were crosschecked also with a classical method of power calculation, based on a FFT subband analysis of the input signal performed via VSA.

CONCLUSIONS

In this paper we have presented a spectrum sensing algorithm based on wavelet subband analysis for the 700 MHz UHF TV band. Although encouraging, the obtained results show that this energy detection method has to be refined especially concerning the noise threshold taken in consideration when discarding the free and occupied subbands. The signals used for the simulation are well-defined in terms of signal excursion from band to band, but taken into consideration that the frequency band under analyze is used not only by primary, but also by unlicensed secondary users, further test scenarios have to be taken into consideration in future research.

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