An Adaptive Wavelet-based Scale Space Filtering Algorithm for Spectrum Sensing in Cognitive Radio

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***Abstract*—This paper introduces a novel application of an enhanced Wavelet-based Scale Space Filtering (WSSF) algorithm called Adaptive WSSF (AWSSF). The AWSSF concept was conceived to improve Spectrum Sensing (SS) in Cognitive Radio (CR). The algorithm is based on a novel adaptation of the WSSF and Otsu's algorithm (from Image Processing). The AWSSF decomposes the estimated signals into different scale levels by using Wavelet Transformation (WT) theory. Thereafter, it directly multiplies samples from adjacent scales towards reducing the noise samples, while simultaneously increasing the true Licensed User (LU) signals. Furthermore, we adapted Otsu's multi-threshold algorithm for use in the AWSSF to compute the optimum threshold value for the different decomposition levels towards filtering the wavelet coefficients. During evaluation in the low Signal to Noise Ratio (SNR) region, the AWSSF algorithm was compared to the traditional ED, and shown to perform better. We also compared with other WT based approaches at SNR = -10dB, and the AWSSF achieved better results. The AWSSF met the performance requirement of the IEEE 802.22 standard as compared to other approaches, and thus considered viable for application in CR.**

***Index Terms*—Wavelet Transform, spectrum sensing, cognitive radio, Otsu threshold, energy detector, Adaptive**

I. Introduction

The wireless communication industry is now faced with the challenge of spectrum scarcity. This is due to the recent increase in the development and deployment of new wireless technologies [1], [2]. The implication of spectrum scarcity is that the current user perceived Quality of Service (QoS) will slowly degrade in the nearest future resulting in increased user dissatisfaction and revenue loss for the industry.

Towards addressing this problem, Cognitive Radio (CR) has been proposed [3]. This proposal is based on research findings showing that allocated spectrum (to Licensed Users (LUs)) are widely underutilized in different geographical areas at different times. Towards exploiting these underutilized bands, CRs are expected to sense their spectral environment (spectrum sensing) and to optimally adjust their transmission parameters for purpose of interference-free communication.

Consequently, Spectrum Sensing (SS) is a fundamental function in CR, and it is currently receiving quite a lot of attention from CR researchers. However, one major problem in SS focuses on how to improve detection performance in low Signal to Noise Ratio (SNR) conditions (typically less than 0dB). The popularly proposed Energy Detector (ED) fails in this low SNR region. Thus, despite its appealing features such as fast sensing, low complexity and ease of deployment, it is not yet deployed (for poor performance in low SNR region).

In our attempt to improve detection in the low SNR region, we have developed and investigated the novel application of the Wavelet Transform (WT) and the Otsu's multi-threshold algorithm in constructing the AWSSF. In the original WSSF, when the spectrum is sensed, the WSSF algorithm computes the wavelet coefficients associated with the signal. It then directly multiplies the wavelet coefficients across different scales, during which the noise samples diminish, while the signal components gain prominence due to their inherent correlation. However, the WSSF algorithm, uses a static threshold approach, thus leading to the need for manual adjustments whenever the input data changes. Therefore, whenever the dataset changes in a sensing period, the algorithm will perform poorly due to the inability of the threshold to adapt.

Consequently, we propose here an integration of Otsu's multi-threshold algorithm, adapted from its use in Image Processing for use in the AWSSF in CR. To the best of the authors knowledge, this adaptation has never been done, as such; this novel construction of the AWSSF has led to an improved performance in low SNR region for SS. For demonstration purpose, we provide performance comparison with the ED and other Wavelet based techniques, and show that the AWSSF will be a great potential for CR deployment.

The rest of the paper is organized as follows: We discuss the relevant literature sources in Section II; this is followed by an overview of WSSF and Otsu's algorithm in Section III. Our proposed AWSSF is presented in Section IV. The results and the discussion can be seen in Section V; while the conclusions are drawn in Section VI.

II. BRIEF REVIEW OF RELATED WORKS

WT has been widely used in CR [4]–[8]. One early work was that of Tian and Giannakis [5], who proposed and applied WT in a fashion similar to what is called the WSSF algorithm. However, it is noted that the WSSF had already been proposed by Xu *et al.*, in [9]. But in [5], Tian *et al.*, established

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