

# OFDM-OQAM AS SPECTRUM SENSING TECHNIQUE

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## ABSTRACT

Spectrum sensing is a key function for the dynamic spectrum access. Filter bank-based multi-carrier communication techniques have been proposed as potential candidates for the physical layer of secondary users since can be used for both data communication and spectrum sensing with no additional cost. In this paper we evaluate one of these techniques, OFDM-OQAM, from the point of view of its misdetection probability as a function of the SNR and considering the multipath effect in the channel. It is showed that OFDM-OQAM outperforms the periodogram for low SNR values.

**Keywords:** Spectrum sensing, Dynamic Spectrum Access, OFDM-OQAM, filter bank

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## OFDM-OQAM COMO TÉCNICA DE SENSADO DEL ESPECTRO

### RESUMEN

*El sensado del espectro es una función clave para acceder a éste dinámicamente. Diversas técnicas de comunicación multiportadora basadas en bancos de filtros han sido propuestas como candidatas potenciales para la capa física de usuarios secundarios, ya que pueden ser usadas tanto para la comunicación de datos como para el sensado del espectro sin un costo adicional. En este artículo se evalúa una de estas técnicas, OFDM-OQAM, desde el punto de vista de su probabilidad de no detección como función de la relación señal a ruido y considerando el efecto multitrayectoria del canal. Se muestra que OFDM-OQAM presenta un mejor desempeño que el periodograma para valores bajos de relación señal a ruido.*

**Palabras clave:** Sensado del espectro, acceso dinámico al espectro, OFDM-OQAM, bancos de filtros

## 1. INTRODUCTION

It has been shown that several licensed bands of the radio-electric spectrum have on average a low percentage of use [1], [2]. This is associated with the existence of idle time-frequency blocks called “white spaces”, in which the primary (licensed) signal is not present. The access to those spectral resources by a secondary (non-licensed) user under the constraint of not interfering with the primary user is known as Dynamic Spectrum Access (DSA) [3]. This technology is considered a potential solution to improve the spectrum usage and to satisfy the increasing demand of bandwidth for wireless communication services. A clear example of this is the IEEE 802.22 standard for Wireless Regional Area Networks (WRANs), the first standard proposed to use DSA in TV bands [4].

The success of DSA depends on the reliable detection of white spaces, which allows potential secondary sources to use the spectrum without interfering with the primary signal. The key operation behind DSA is the spectrum sensing, performed by the Secondary User (SU) to decide whether a specific primary channel is vacant and, consequently, if it could be used for data transmission. This decision has to satisfy some requirements related to time, error probability and sensitivity. For instance, the IEEE 802.22 standard specifies a sensing time of 2 seconds, a detection probability of 0.9, a false alarm probability of 0.1 and a receiver sensitivity of -116 dBm for digital TV signals [4].

Energy detection is a basic spectrum sensing technique [5] in which the energy detector or radiometer compares the received signal energy with a threshold. If the measured energy is above the threshold, the detector decides that the primary signal is present. The signal energy estimation can be done through spectral estimation, and this in turn, can be accomplished by a filter bank. Filter bank-based multi-carrier (FBMC) communication techniques have been proposed as candidates for the physical layer of the SU since they can be used for both data communication and spectrum sensing with no additional cost [6].

This paper presents a performance evaluation of a filter bank-based OFDM-OQAM technique in the spectrum sensing stage when it is used as energy detector. This FBMC technique was first evaluated in the context of spectrum sensing by Farhang in [7]

from a spectral point of view. The focus of this work is the Receiver Operating Characteristic (ROC) curve, represented by the probability of misdetection as a function of the signal to noise ratio (SNR). The evaluation was done by simulation but the test signals are RF field ensembles captured under difficult transmission conditions. We compare OFDM-OQAM with the periodogram and show that OFDM-OQAM exhibits a better performance mainly for low values of SNR.

In [8], Sheik and Bing used a similar approach to evaluate their proposed DFT filter bank (DFB) for spectrum sensing. They computed the misdetection probability versus the SNR for a fixed false alarm probability of 0.05. The simulation was, however, limited to an AWGN channel. In the present work, instead, the multipath effect is considered by the nature of the signals used in the simulation, which is a more realistic approach for a wireless environment.

The rest of this paper is structured as follows. In Section 2 we give a brief review of the spectrum sensing problem. Section 3 presents the OFDM-OQAM implementation used. The simulation methodology is explained in Section 4. We report the numerical results in Section 5 and the conclusions are stated in Section 6.

## 2. THE SPECTRUM SENSING PROBLEM

The reliable detection of white spaces is a mandatory functionality in the physical layer of the SU to avoid interfering the primary user communication. This functionality is known as spectrum sensing. The SU has to analyze the input signal during a period (the sensing time) and decide whether the primary signal is present. In this process the spectrum sensing technique must satisfy some constraints of error probability, time and sensitivity.

The type of spectrum sensing technique used depends on the information the secondary user has about the primary signal. If the structure of the signal is completely unknown the best option is the energy detector or radiometer. In this technique the input signal energy is compared with a threshold value to decide if the primary signal is present. If the measured signal energy is greater than the threshold the primary channel is declared as occupied.

When the primary signal has some statistical or cyclic characteristics, like a pilot tone in DVB-T or a cyclic prefix in OFDM, the feature detector is a better option for spectrum sensing. In this technique some frequency or time features are exploited to determine if the primary user is present. For instance, [9] presents algorithms that detect OFDM signals based on the existence of pilot tones in the frequency domain.

In general, the spectrum sensing problem can be formulated as a binary hypothesis testing problem [5]:

$$\begin{aligned} H_0: y[n] &= w[n] \\ H_1: y[n] &= hs[n] + w[n] \end{aligned} \quad (1)$$

Where  $H_0$ , the null hypothesis, is the event in which the signal received by the SU,  $y[n]$ , is only noise, denoted by  $w[n]$ , and modeled as Additive White Gaussian Noise (AWGN) with zero mean and variance  $\sigma^2$ .  $H_1$  is the alternative hypothesis and in this case the primary signal,  $s[n]$ , is present and affected by  $h$ , the channel gain, and added with the noise.

According to the specific spectrum sensing method used, a test statistic  $\Lambda(y)$  is defined and its value is compared with a threshold  $\gamma$  to decide  $H_0$  or  $H_1$ . If  $\gamma$  is greater than  $\Lambda(y)$  then the SU decides  $H_1$ , else decides  $H_0$ . This can be written as

$$\Lambda(y) \begin{cases} > \gamma & H_0 \\ < \gamma & H_1 \end{cases} \quad (2)$$

In this decision process, however, the SU can make two kinds of errors: a misdetection or a false alarm. A misdetection occurs when the SU decides the primary signal is not present when it actually is. A false alarm takes place when the SU decides the primary signal is present when in fact it is not. Both the probability of false alarm ( $P_{fa}$ ) and the probability of misdetection ( $P_{md}$ ) have to be small. A low probability of misdetection is mandatory in order to avoid interference with the primary user, and a low false alarm probability is required to maximize the spectrum usage.

### 3. OFDM-OQAM IMPLEMENTATION

OFDM-OQAM is a multi-carrier communication technique with near-optimal properties concerning to multipath [10]. Fig. 1 shows the OFDM-OQAM demodulator architecture used in this work, which is a filter bank-based scheme suggested by Siohan in [11]. The parameters of the system are defined as follows:

$L$  is the prototype filter length

$K$  is the number of carriers

$M$  is the decimation factor and is equal to  $K/2$ .

$\alpha = \lceil (L-1)/M \rceil$ , where  $\lceil \cdot \rceil$  denotes the ceiling function

$\beta = \alpha M - L + 1$

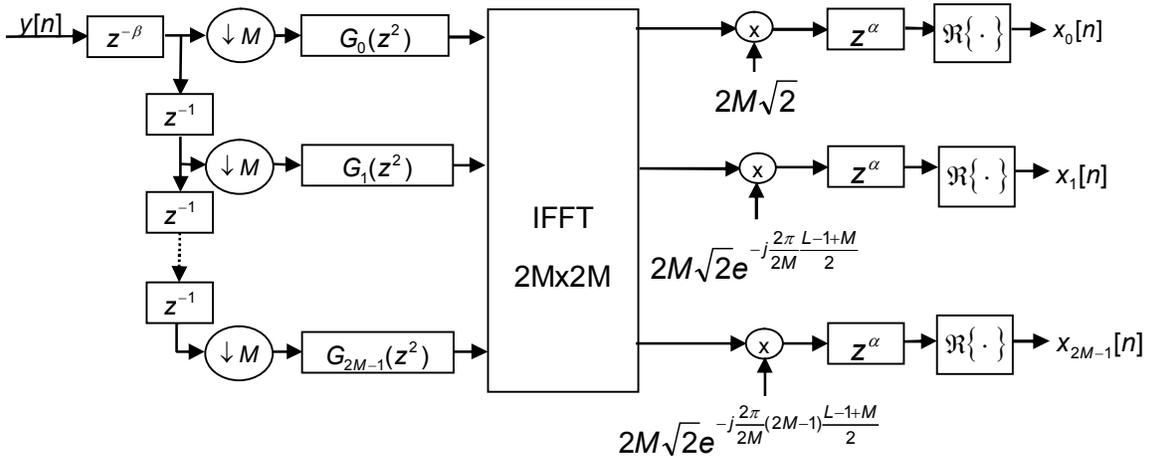


Fig.1. OFDM-OQAM demodulator

$G_i(z)$  is the  $i$ -th polyphase component  
 $\alpha$  is a reconstruction delay and  $\beta$  is a delay that has to be considered at the transmitter output or at the receiver input  
 $\Re\{\cdot\}$  extracts the real part of its argument  
 $x_i[n]$  is the output signal at  $i$ -th band of the OFDM-OQAM receiver

The input signal is first delayed by a factor  $\beta$  and then through a delay chain it is divided in  $2^*M$  sub-band signals. Each of these signals is decimated by a factor  $M$  and low-pass filtered by the corresponding polyphase component. A  $2^*M$ -point IFFT is applied at the output of the  $2^*M$  polyphase components, each sub-band signal is scaled by a different complex number and the first  $\alpha$  samples are dropped because of the reconstruction delay. Finally, the real part of each sub-band signal is taken.

The prototype filter is a root Nyquist filter with a roll-off factor of 1 and was designed following the method proposed by Farhang in [12].

#### 4. SIMULATION METHODOLOGY

The simulation methodology is based on the first simulation scenario defined by the IEEE 802.22 working group for evaluating the performance of spectrum sensing techniques [13]. The main objective of this scenario is to compute ROC curves for an SU carrying out local spectrum sensing. These curves represent the  $P_{md}$  as a function of the SNR, with the sensing time, the  $P_{fa}$  and the multipath channel characteristics as parameters.

The multipath effect in the wireless channel is considered in the simulation because of the nature of the input data. A group of 12 field ensembles recommended by Tawil in [13] were used. These ensembles are a subset of 50 Digital TV (DTV) captured signals recorded in Washington D.C., and in New York City to test DTV receivers under difficult transmission conditions [14].

In the following subsections we will explain the simulation steps applied to OFDM-OQAM.

##### A. Setting the sensing time

The sensing time it is the time required to achieve a given probability of detection. This time is set to a

value lower than two seconds and determines the number of samples that will be taken from the input signal.

##### B. Setting the threshold level

OFDM-OQAM is used as radiometer, and the test statistic is therefore the power of  $y[n]$ , given by

$$\Lambda(y) = \frac{1}{N} \sum_{i=0}^{K-1} \sum_{n=0}^{N-1} |x_i[n]|^2 \quad (3)$$

where  $N$  is the number of output samples in each band of the demodulator.

The threshold value  $\gamma$  is computed for a desired probability of false alarm. This probability can be expressed as

$$P_{fa} = P(\Lambda(y) > \gamma | H_0) \quad (4)$$

Under  $H_0$  the  $x_i[n]$ 's are a set of i.i.d Gaussian random variables with zero mean and variance  $\sigma^2/K$ . By the Central Limit Theorem  $\Lambda(y)$  also has a Gaussian distribution with the following parameters,

$$\Lambda(y) \sim N(\sigma^2, 2 \frac{\sigma^4}{KN}) \quad (5)$$

Using this approximation (4) can be rewritten as

$$P_{fa} = Q(\gamma_0) \quad (6)$$

where  $Q(\cdot)$  is the Q-function and  $\gamma_0$  is given by

$$\gamma_0 = \sqrt{\frac{KN}{2}} \frac{(\gamma - \sigma^2)}{\sigma^2} \quad (7)$$

From (6) and (7) we find the expression to compute the threshold for a desired false alarm probability,

$$\gamma = \sqrt{\frac{2}{KN}} \sigma^2 Q^{-1}(P_{fa}) + \sigma^2 \quad (8)$$

**C. Setting the SNR value**

A fixed noise power of -95.2 dBm is used when the signal bandwidth is 6 MHz [13]. The input signal is scaled to achieve the desired SNR value.

**D. Processing the DTV signal**

A number of samples equivalent to the sensing time is taken from a field ensemble, demodulated from IF to baseband, scaled to achieve the desired SNR value, and passed through the OFDM-OQAM demodulator. The output power on each band of the demodulator is computed and then the power of all bands is summed to get the total power, as expressed in (3). The total power is compared to the threshold and a misdetection is counted if the test statistic is lower.

**E. Computing the misdetection probability**

Step D is repeated for all of the 12 field ensembles to average the multipath effect and up to complete a total of  $10^5$  iterations. Finally the number of misdetections is divided by  $10^5$  to compute the misdetection probability.

**5. NUMERICAL RESULTS**

For OFDM-OQAM we used 256 carriers and a prototype filter length equals to 1536. As a matter of comparison the simulation methodology explained in section IV was also applied for the periodogram with a rectangular window. This spectral estimator was also implemented as a filter-bank, as it is suggested in [7], with scalar polyphase components equal to its window coefficients. The number of bands (the IFFT size) for the periodogram is equal to the OFDM-OQAM case.

Fig. 2 presents the probability of misdetection as a function of the SNR for both OFDM-OQAM and the periodogram when the sensing time is 0.2 ms and the false alarm probability is 0.1. OFDM-OQAM has a better performance when the SNR is between -25 dB and -8 dB, as it is expected since its proved superiority as spectral estimator [6].

In fig. 3 the same comparison is made, in this case with a sensing time of 0.7 ms. With this result it is verified that a greater sensing time implies a better performance.

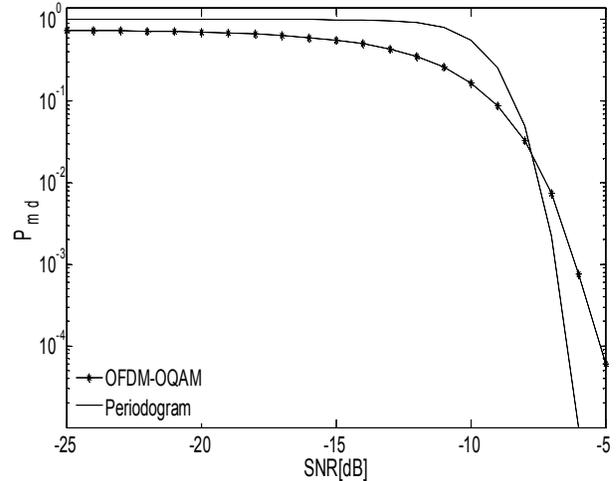


Fig. 2. Misdetection probability vs SNR for OFDM-OQAM and for the periodogram, with a fixed false alarm probability of 0.1 and a sensing time of 0.2 ms.

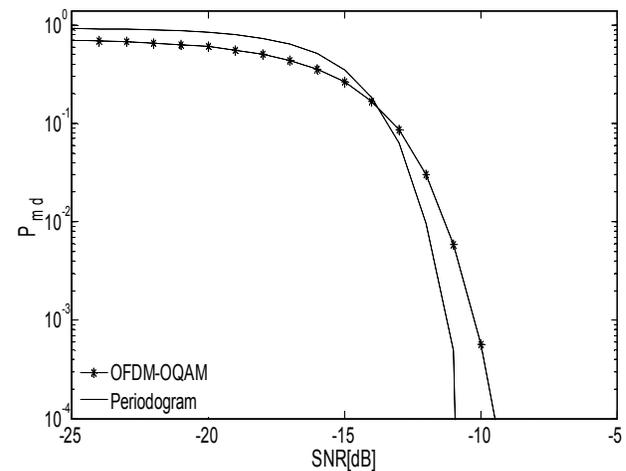


Fig. 3. Misdetection probability vs SNR for OFDM-OQAM and for the periodogram, with a fixed false alarm probability of 0.1 and a sensing time of 0.7 ms.

**6. CONCLUSIONS**

OFDM-OQAM was evaluated as power detector in the context of spectrum sensing from the perspective of its ROC curve and it is showed that has better performance than the periodogram for low SNR. This result match with the comparison made by Farhang in [6] from a spectral estimation point of view.

Although has been showed that the power detector is a very limited sensing technique due the noise

uncertainty [15]-[16], the results presented here show that OFDM-OQAM can be a good alternative in recent works where the energy detection is used as a coarse sensing technique in a two-stage scheme [17]-[19].

Finally it is important to remember that a remarkable characteristic of OFDM-OQAM is the dual functionality that offers for a secondary user for both data communication and spectrum sensing. This can also make a difference in the overall computational load.

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