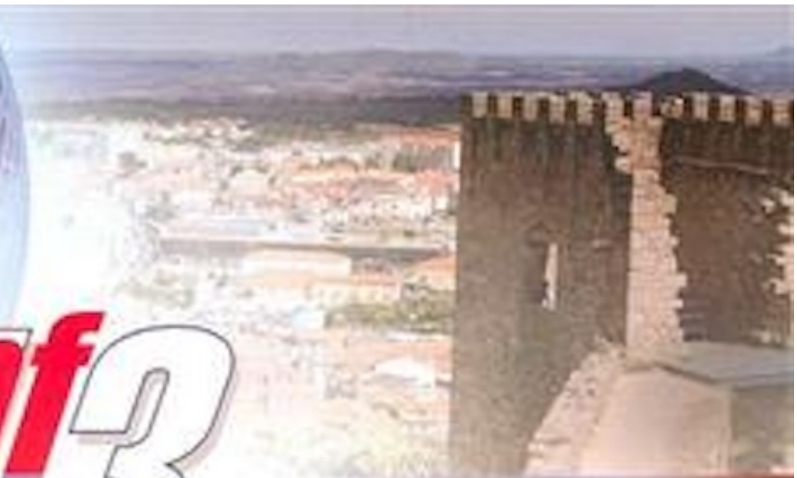

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Evaluation of Blind Sensing Techniques in Multiple Wireless Microphones Environments

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Abstract— **This work focuses on the evaluation of blind sensing techniques for the detection of multiple wireless microphones in the UHF band, by means of simulation. The metrics used for the comparisons include probability of detection, probability of false alarm and minimum SNR detected for a given observation time. As an example, simulation results showed that blind detection algorithms can sense multiple wireless microphone signals with SNR = -19 dB, in a Rayleigh channel environment, considering 100 ms sensing time, 90 % probability of detection and 10 % probability of false alarm. In these conditions, blind detection techniques suffer maximum SNR degradation of 3.5 dB, as compared with single wireless microphone scenarios.**

Keywords— Cognitive radio, Sensing algorithms, Frequency modulation, Wireless Microphones, TV White Spaces.

I. INTRODUCTION

Wireless microphones (WM) systems are one of the incumbent systems of the UHF band, so they need to be protected from interference of TV White Spaces (TVWS) devices. Although some countries already have implemented a geo-location database to coordinate the use of spectrum for programme-making, entertainment, special events (PMSE) [1], it cannot be assumed that all WM devices are registered in a geo-location database. So, the TVWS devices have to operate without information on primary users from the spectrum database, and need to identify occupied channels by primary users, i.e. WM, through sensing techniques.

From a previous work described in [2], we have shown that two algorithms, Covariance Absolut Value (CAV) [3] and Blindly Combined Energy Detection (BCED) [4], have showed good detection performance for single WM scenarios. The objective of this paper is to go further, and evaluate the performance of CAV and BCED in multiple WM scenarios. This paper is structured as follows: we first describe CAV and BCED algorithms in section II. We follow with a description of simulation scenarios with different geometries and propagation models in section III. Sensing metrics are also defined to evaluate the performance of CAV and BCED detection methods in section IV. Finally, conclusions are drawn and an outlook on plans for future work is provided.

II. BLIND SENSING ALGORITHMS

Blind detection algorithms rely on a statistical analysis, using covariance or eigenvalue matrix to identify the properties of a signal. They are independent of the noise power and require no information on source signal or noise power. Moreover, blind detection methods also have some immunity to synchronization error, fading and multipath, noise uncertainty, and unknown interference.

CAV belongs to a category of sensing algorithms known as Covariance based detection (CBD) [5]. CBD exploits the fact that the statistical covariance matrixes of received signal and noise are usually different, thus the distinguishing property can be used to detect whether the primary user exists or not. The covariance-based detections directly use the elements of the covariance matrix to construct detection methods, such as CAV methods. On the other and, BCED belongs to the category called Eigenvalue based detection (EBD) [6]. EBD algorithms are based on the analysis of eigenvalues of the covariance matrix.

CBD and EBD algorithms overcome the noise uncertainty problem [7] and can even perform better than Energy Detection (ED) [8] when the signals to be detected are highly correlated, as in the case of wireless microphone FM signals in a TV channel.

III. SIMULATION ENVIRONMENT

As primary users, most PMSE devices use analogue FM to transmit information between a WM and a wireless receiver. FM continues to be the preferred choice; due the nature of the application (voice transmission) that imposes tight specifications such as continuous transmission and very low delay [9]. A FM signal is generally described by,

$$s_{FM}(t) = A_c \cos\left[2\pi f_c t + 2\pi\Delta f \int_0^t m(u)\,du + \theta\right] \tag{1}$$

where θ is a random phase uniformly distributed on $(0\ ,\ 2\pi)$ and m(t) is the transmitted voice signal. $s_{FM}(t)$ is zero-mean and its amplitude $|m(t)| \leq 1$. The parameters A_c and f_c are carrier amplitude and carrier frequency, respectively. The constant Δf is the frequency deviation of an FM modulator, representing the maximum departure of the instantaneous frequency of the FM signal from the carrier frequency f_c. For simulation purposes, signal $s_{FM}(t)$ will be represented by its corresponding

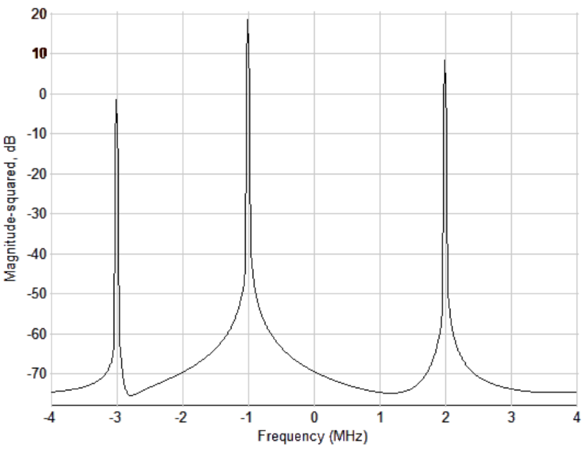


Figure 1. Power spectrum of WMs signals in a baseband representation

complex baseband signal, $s(t)$.

Document [10] suggests three WM operating conditions to test sensing algorithms: silent mode, soft speaker and loud speaker. Results from [2] have shown that soft speaker and loud speaker are the most challenging operational modes to detect. Without loss of generality, we choose to simulate WMs in soft speaker mode only. The amplitude of signal $m(t)$ is A_m = 1 for all cases. According to Carlson's Rule, the 90 % (one-sided) bandwidth is given by,

$$B_{90\%} = (1+\beta) f_m \qquad (2)$$

where $\beta = Am\,\Delta f / fm$ is the modulation index. Table I presents a summary of the parameters of soft speaker mode operation.

In real conditions, several WMs are allocated in a single TV channel. To replicate this scenario, The simulation model is defined over 8 MHz bandwidth (one DVB-T channel), with three WMs. Each WM signal has a different frequency and amplitude. Adding all WMs signals produces the signal $x(t)$:

$$x(t) = s(t) \times \left(\sum_{i=1}^{3} \sqrt{G_i} e^{-j\omega_i t} \right) \qquad (3)$$

The frequency shift is defined using the channel central frequency as a reference. The values are $\omega_1 = 2\pi \times (-1\times10^{-6})$ rad/s , $\omega_2 = 2\pi \times (2\times10^{-6})$ rad/s and $\omega_3 = 2\pi \times (-3\times10^{-6})$ rad/s . We set constant peak power gain for each WM, $G_1 = 20$ dB , $G_2 = 10$ dB and $G_3 = 0$ dB , as shown in the spectral representation of $x(t)$ in Fig. 1.

TABLE I. FM SIGNAL PARAMETERS AND BANDWIDTH

Operating mode	A_m (a.u.)	f_m (kHz)	Δf (kHz)	β	B90% (kHz)
Soft speaker	1	3.9	15	3.85	19

To test CAV and BCED sensing algorithm, we define two environmental conditions to simulate the propagation conditions of the radio path environment:

1) Outdoor, Line-Of-Sight (LOS)

WM systems are used in an outdoor environment where a Line Of Sight (LOS) transmission path between transmitter and receiver exists. Therefore, channel is modelled as AWGN with zero mean and variable variance σ_u^2.

2) Indoor, Rayleigh Faded

WMs systems are used indoors. Because the distance between transmitter and receiver is relatively short, a single-path Rayleigh fading channel is good enough to model the indoor channel. Therefore, a flat fading channel is used. Moreover, the maximum speed of the user is assumed to be ν = 0.6 m/s (walking velocity). At this speed, and a maximum carrier frequency of 790 MHz (upper limit of the UHF frequency band of interest), the Doppler shift is 1.58 Hz. Because the maximum Doppler shift is very small, the Doppler effect can be ignored. Hence, this channel is a single-path time-invariant (flat fading) channel [11]. We assume that mobile secondary users will provoke more interference to PMSE than fixed base stations (BS), since they can be located inside the same room as a WM receiver. Thus, BSs are not considered in this study. Table II presents a summary of the scenarios that are subject of study in this paper.

IV. METRICS

In this section, we present the metrics to evaluate the performance of sensing algorithms.

1) SNR

As stated in [12], a minimum detection threshold of -126 dBm over a 200 kHz bandwidth is necessary to avoid causing interference to WMs from TVWS devices. This value accounts for body loss and hidden terminal margin. For simulation purposes, the bandwidth was adjusted to 8 MHz, corresponding to a DVB-T channel, so the detection threshold becomes $-126 + 10\log\left(8\times10^6 / 2\times10^5\right) = -110$ dBm.

Correspondingly, the required SNR at the TVWS receiver can be calculated based on the receiver's noise figure (NF). USRP's software defined radios present a NF of 8 dB [13] in the UHF frequency band. Considering that the thermal noise power spectral density (PSD) is -174 dBm/Hz, the TVWS receiver's sensitivity over 8 MHz is,

$$-174 + 10\log_{10}\left(8\times10^6\right) + 8 = -97 \text{ dBm} \qquad (3)$$

TABLE II. SCENARIOS FOR SIMULATION

Scenario	Number of WMs	Channel type
i	1	AWGN
ii		Rayleigh
iii	3	AWGN
iv		Rayleigh

Hence, in 8 MHz bandwidth channel, a TVWS device needs to detect signals with $\text{SNR} = -110 - (-97) = -13$ dB. We set this value as a reference for minimum SNR performance for CAV and BCED sensing algorithms, for all simulation scenarios of Table II.

2) Detection Threshold

The WM signal is detected by comparing the output *d* of the sensing algorithm, with a threshold level (TH). Depending on the sensing technique, *d* is given by a test statistic. Test statistics used for CAV and BCED algorithms can be found in documents [3] and [4], respectively. Detection threshold TH is determined based on the given probability of false alarm (P_{fa}) and is also dependent on the sensing algorithm. TH is computed based on a heuristic method, using the following methodology:

i. Compute the test statistic of the sensed channel, when no primary signal is present (noise only);
ii. Repeat the simulation to create a histogram of the results;
iii. Compute the complementary cumulative density function (CCDF) from the histogram;
iv. Search for the threshold value associated with the desired probability of false alarm, from the CCDF.

3) False alarm and detection probabilities

The sensing problem is formulated as a binary hypothesis-testing problem,

$$\begin{aligned} H_0 &: x[n] = u[n] \\ H_1 &: x[n] = x[n] + u[n], \quad n = 1,2,\ldots N_s \end{aligned} \tag{4}$$

H_0 and H_1 are the hypotheses expressing the absence and presence of the WM, respectively, and N_s is the number of samples. The terms $x[n]$ and $u[n]$ are sampled versions of the WMs signals $x(t)$ and the noise $u(t)$ present in the system, respectively. We use the Neyman-Pearson criterion to design the hypothesis test, stated in terms of the probability of false alarm (P_{fa}) and the probability of detection (P_d) [9].

TABLE III. SNR PERFORMANCE (FOR PD = 90 % AND PFA = 10%).

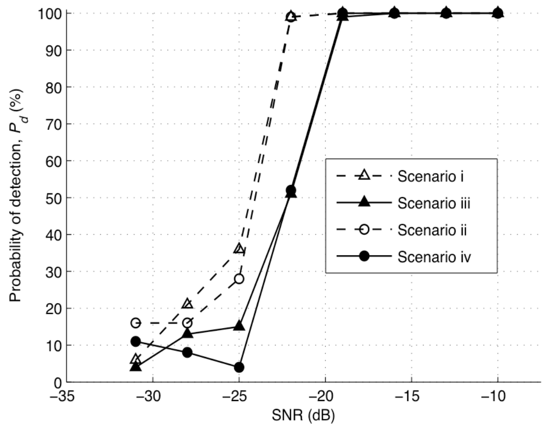
	Scenarios			
	i	**ii**	**iii**	**iv**
CAV	-22.5	-22.5	-19	-19
BCED	-23	-22.5	-20	-20

V. SIMULATION RESULTS AND DISCUSSION

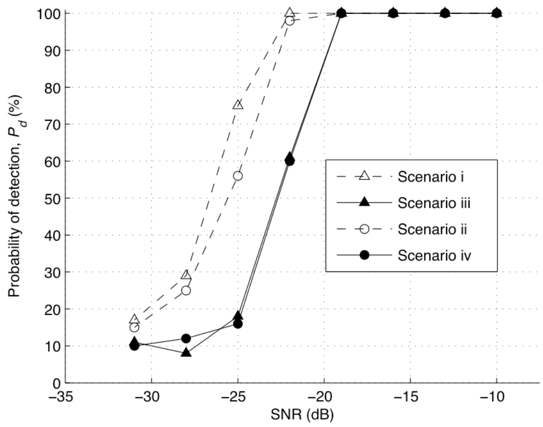
Each scenario is simulated several times (The number of simulations depends on the value of P_{fa}), for each SNR values between -35 dB and -10 dB. The signal sampling frequency $fs = 1 / Ts$ is 8 MHz. CAV and BCED methods use a signal length (N_s) with 200000 samples and a smoothing factor $L = 12$ [3]. Simulations where carried out with Simulink and Matlab software.

The performance of CAV and BCED detection techniques are characterized by plotting the probability of detection curve as a function of SNR, for a false alarm probability of 10 % and sensing time of 100 ms. The results are presented in Fig. 2a) and Fig. 2b). Both methods present performance degradation from one to three WMs scenarios. This is caused by the reduction of the correlation coefficient, used both by CAV and BCED methods, when several WM signals are present in a single DVB-T channel. Table III resumes the sensing performance of CAV and BCED algorithms in all scenarios, for P_d = 90%. The results on the table shows that SNR degradation is 3.5 dB for CAV, and between 2.5 dB and 3 dB for BCED, which confirm the superior robustness of BCED to adverse sensing environments [2]. However, all SNR values on Table III are lower than -19 dB, well below the reference value of -13 dB computed in section IV, which indicates that both CAV and BCED are effective methods to detect WMs in the presented scenarios.

Document [9] states that 90 % P_d for 10 % P_{fa} are minimum requirements for a sensing system. To analyze the performance of CAV and BCED with tighter requirement, we set new

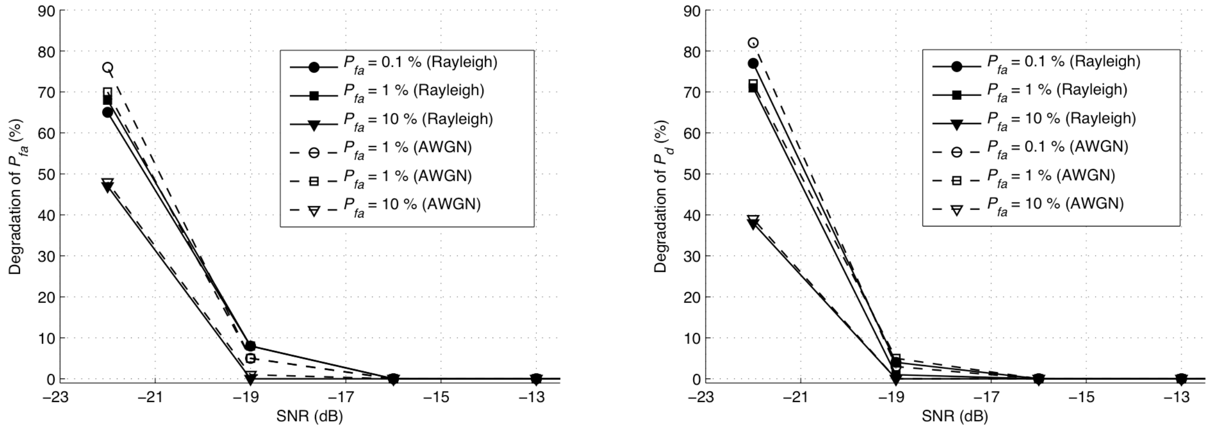


a)



b)

Figure 2. Probability of detection (P_d) as a function of SNR, for a) CAV and b) BCED sensing algorithms, in different scenarios: One WM (dashed lines) and three WMs (full lines) in AWGN (△) and Rayleigh (O) propagation channels.



a) b)

Figure 3. Degradation of P_d of a) CAV and b) BCED algorithms, from single WM to multiple WMs scenarios, for different values of P_{fa}. : 0.1 % (○), 1 % (□) and 10 % (▽). Full line: Rayleigh channel; Dashed line: AWGN channel.

simulations with 0.1 % and 1% P_{fa}, and present the degradation of P_d, from scenarios with one to three WMs. The results are presented in Fig3. a) and b) for CAV and BCED, respectively.

For SNR above -16 dB, and for all scenarios, there is no distinctive degradation of the performance of CAV and BCED, even with low values of P_{fa}. For SNR values between -16 dB and -19 dB, performance degradation starts to increase gradually. CAV degradation is higher than BCED, with a maximum value of 9 % in a Rayleigh environment with 0.1 % P_{fa}, as compared to 6 % for BCED in the same conditions. However, for SNR below -19 dB, there is a steep increase on the performance degradation of both CAV and BCED algorithms, and they are not capable to sense multiple WMs in a DVB-T channel with minimum accuracy, as compared with a single WM scenario.

VI. Conclusions

We presented the evaluation of blind sensing techniques (CAV and BCED) for the detection of multiple WMs in the UHF band, and compared the results with single WM scenarios. Simulation results show that CAV and BCED can sense multiple WMs signals with SNR as low as -19 dB, in a Rayleigh channel environment, considering 100 ms sensing time, 90 % probability of detection and 10 % probability of false alarm. In these conditions, blind detection techniques suffer maximum SNR degradation of 3.5 dB, as compared with single WM scenarios. For lower values of the probability of false alarm, down to 0.1 %, CAV and BCED algorithms are still able to detect WM signals with SNR of -16 dB, 3 dB below the required SNR of -13 dB. Future actions will involve sensing trials in real scenarios to test and validate this study.

Acknowledgment

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