Power Spectral Density based Wireless Microphone Sensing

Technical Report

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Abstract of Technical Paper

The Federal Communications Commission (FCC) is proceeding with plans to open up the TV spectrum band ranging from 54MHz to 698MHz for unlicensed secondary devices. The unlicensed secondary devices will be required to operate on an opportunistic basis and avoid interference with primary devices in the TV band. Wireless microphones are one of the incumbent devices which occupy this frequency range. These devices are generally unlicensed and have high spatial and temporal variation. For successful communication between secondary devices it is important that they avoid interfering with wireless microphones.

The goal of this technical paper is to study the problem of detecting presence of wireless microphones. We study a detection algorithm based on the estimated power spectral density (PSD) of received wireless microphone signal as explained in [1]. The algorithm uses wireless microphone signal specific information such as modulation technique and operation modes to search for patterns in the estimated PSD. It is observed that in the PSD certain high power frequency bins are occupied in a certain pattern. In this algorithm we identify these high power frequency bins and make a decision on the presence of wireless microphones based on the number of such bins and their relative patterns. We present and compare three detection algorithms, OR rule, 2 out of N rule, and soft decision fusion rule. The comparison is based on the results from MATLAB simulations. These algorithms differ in the manner in which they combine the information observed in different frequency bins of the PSD. The results show that PSD based detectors is better than energy detectors and among PSD based detectors soft decision fusion rule has better performance.

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Chapter 1 : Introduction

1.1 Background Review

1.1.1 Wireless microphones

Wireless microphones are connected to the sound amplifying equipment wirelessly. Typically the distance between the two units is up to 100 meters. Given the short distance between the transmitter and receiver units, wireless microphones are low power devices. They operate in the TV spectrum band. Additionally majority of the wireless microphone operate on an unlicensed basis which means that they occupy any channel in the TV band provided they don't interfere with the TV signals.

1.1.2 Cognitive radios

Traditional spectrum allocation policy allocates fixed bandwidth to licensed devices. Because of this policy it has been observed that a significant amount of spectrum would remain vacant. The vacant spectrum frequencies would depend on the frequency channel, location and time at which it was observed. To improve spectrum utilization FCC has made plans to allow unlicensed users to occupy the vacant spectrum provided they don't interfere with the already existing primary users. These devices would access the spectrum in an opportunistic manner and have the capability to change their system parameters such as transmit power, transmission frequency depending on the surrounding conditions. Such radios are called cognitive radios. In order to implement cognitive radio technology, FCC has opened up the TV frequency bands for secondary unlicensed devices and IEEE has formed the 802.22 working group to propose standards for dynamic spectrum access.

1.1.3 Spectrum sensing for wireless microphones

One of the restrictions on the operation of secondary devices is that they should not interfere with the existing primary users which in the case of TV frequency band are TV stations, wireless microphones and other low power auxiliary devices. Thus secondary TV band devices need to be aware of the activity in the spectrum and they need to determine which frequency bands are occupied so that they don't transmit in those frequencies. This is called spectrum sensing. TV stations are fixed devices and occupy a fixed frequency range based on their location. Hence it is possible to map their spectral activity and store this information in a database. Majority of the wireless microphones are unlicensed and the usage pattern is not fixed. The spectral activity of wireless microphones has high spatial and temporal variation and it is not feasible to map their usage patterns in a database. To prevent interference with such devices it is necessary to sense the spectrum before transmission. In order to detect the presence of wireless microphones in low SNR's we require efficient spectrum sensing algorithms which require least sensing time. FCC has established minimum performance criteria for spectrum sensing based on the type of primary signal. Those minimum requirements need to be satisfied in the least required sensing time. Sensing time refers to the time taken by the spectrum sensor to collect received signal samples needed to decide if primary signal is present.

1.2 Dynamic spectrum access regulations

On September 23rd, 2010 FCC revised the rules for secondary TV band devices (TVBD's) accessing white spectrum in the TV band. In the revised document FCC approved the use of geo-location and database technology to access information about unused spectrum and spectrum sensing was removed as a mandatory requirement.

In the new regulations wireless microphones have been allocated 2 separate channels within which TV stations and TVBDs are not be permitted to operate. However 2 separate channels can carry up to 16 microphones which may not be sufficient for large events such as music concerts. In such scenarios there is a provision of getting additional licenses for wireless microphones by registering them with the database. Microphones operating outside these two channels are categorized as unlicensed microphones. Unlicensed microphones are generally used in companies, schools and churches and are not registered in the database. These microphones are offered no protection from interference from secondary devices. Spectrum sensing is still important in the context of unlicensed wireless microphones. It is essential that TVBD's scan and detect these unlicensed devices to communicate correctly. FCC still allows devices depending only on spectrum sensing provided they meet the minimum criteria for sensing. The minimum spectrum sensing criteria is given in table 1.1. The complete details of regulations on dynamic spectrum access can be found in [2] and a summary of changes in [3].

Primary signal	Detection threshold
ATSC digital TV signal	-114 dBm
NTSC analog TV signal	-114 dBm
Wireless microphone signal	-107 dBm

Table 1-1 Minimum spectrum sensing requirements for TVBD's

1.3 Literature Reviewed

Many spectrum sensing techniques were reviewed while preparing this technical paper. The section on energy detectors is based on the work done in [4] and [5]. The section on effect of noise uncertainty on the performance of energy detectors is based on [6]. In [1], the authors present a PSD based wireless microphone sensing technique which is thoroughly reviewed here. This technical paper implements the algorithm in [1]. The simulation parameters used for generating wireless microphone signals are taken from [7]. In [4] the concept of collaborative detection is explained which is applied for wireless microphone detection in this technical paper. An overview of wireless microphone detection techniques is given in [8].

Chapter 2 : Wireless Microphone Simulation

2.1 Wireless microphone characteristics

Wireless microphones operate in the TV band (TV channels 2 to 51 except channel 37). The operating frequencies are 54 MHz to 698 MHz. The transmission bandwidth is less than 200 kHz and the maximum transmit power is less than 50 mW. Typically wireless microphones employ analog frequency modulation (FM) for transmission. The transmitted FM signal s(t) is given by,

$$s(t) = A_c \cos[2\Pi f_c t + 2\Pi k_f \int_0^t m(\tau)\, d\tau]$$

where $m(t)$ is the voice signal assumed to be sinusoidal

f_c is the carrier frequency

k_f is the frequency sensitivity of the frequency modulator

A_c is the carrier signal amplitude

For simulating the operation of wireless microphones three modes of operation are considered. The simulation parameters and operation modes are taken from [7]. The operation modes are:

1. Silent wireless microphone:

This is the mode when the wireless microphone is turned ON but the speaker is not talking. In such cases the wireless microphone transmits an FM signal by modulating a supra-audible tone signal. In this mode the frequency deviation is ± 5 kHz and the voice signal is a sinusoidal signal of frequency 32 kHz.

2. Soft speaker wireless microphone:

This is the mode when the speaker is a soft speaker. In such cases the wireless microphone transmits an FM signal with a much lesser frequency deviation compared to the loud mode. In this mode the frequency deviation is ± 15 kHz and the voice signal is a sinusoidal signal of frequency 3.9 kHz.

3. Loud speaker wireless microphone:

This is the mode when the speaker is not a loud speaker. In this mode the frequency deviation is ± 32.6 kHz and the voice signal is a sinusoidal signal of frequency 13.4 kHz.

Two environmental conditions are defined to simulate the performance in Indoor and Outdoor conditions. In outdoor conditions we consider Line of sight transmission with no Rayleigh fading. For indoor environments, wireless microphone is passed through a single path Rayleigh fading channel. In this technical paper we consider the Outdoor, Line of sight simulation models. The simulation parameters used to generate these operation modes are summarized in Table 2.1.

	Silent	Soft speaker	Loud speaker
Tone frequency	32kHz	3.9kHz	13.4kHz
Frequency deviation	+/- 5kHz	+/- 15kHz	+/- 32.6kHz

Table 2-1 Simulation parameters of wireless microphone operating modes

2.2 Wireless microphone power spectral density

Figure 2.1, Figure 2.2 and Figure 2.3 show the baseband PSD's for different modes of operation of the wireless microphone. The received signal is down converted to baseband and does not include additive white Gaussian noise (AWGN). In the PSD the bandwidth is 200 kHz wide.

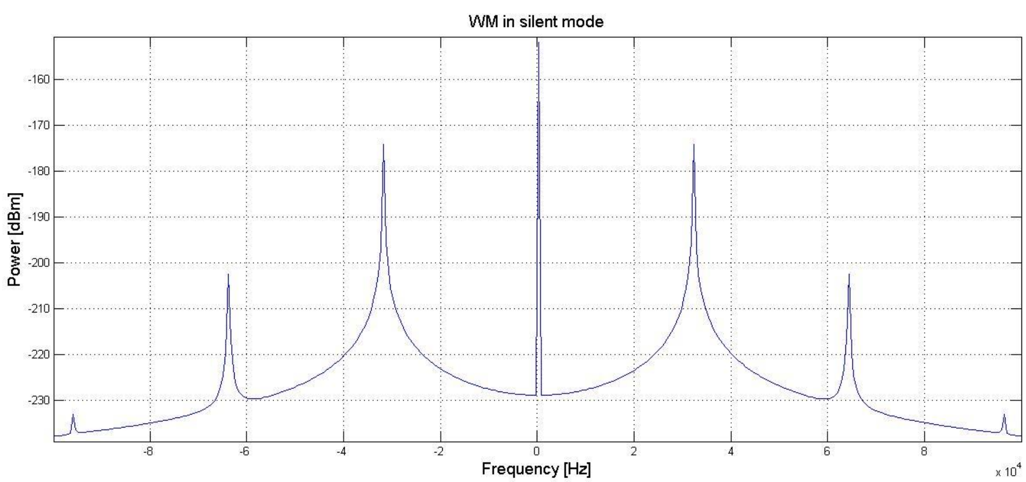

Figure 2-1 Wireless microphone in silent mode

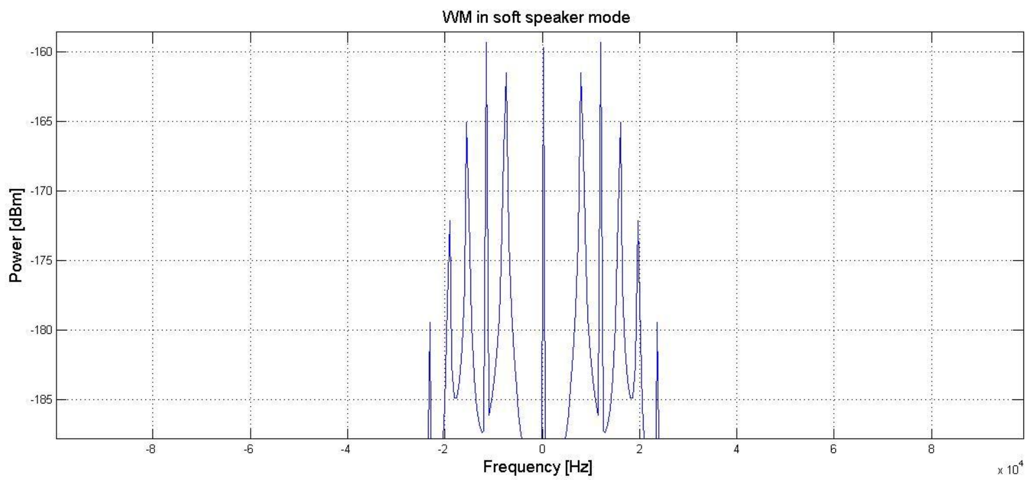

Figure 2-2 Wireless microphone in soft mode

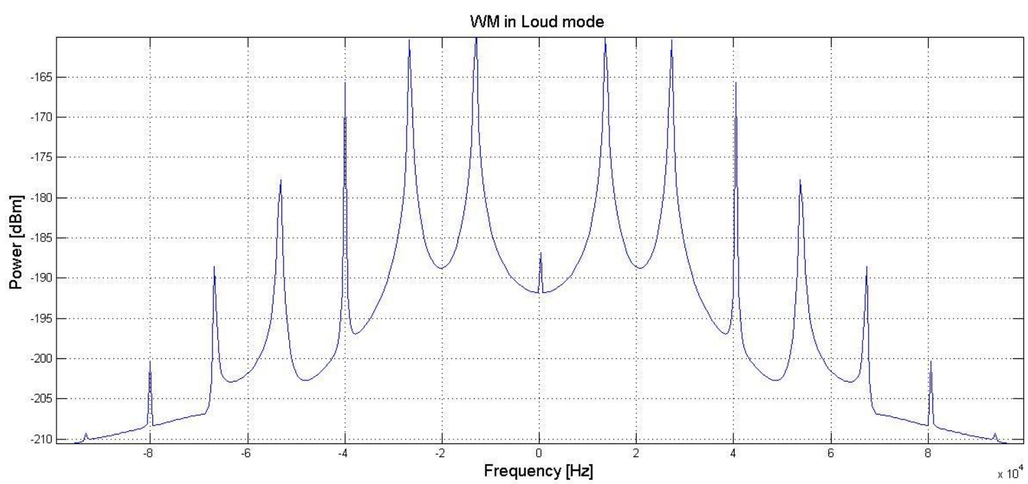

Figure 2-3 Wireless microphone in loud mode

From the above figures we observe the presence of high energy frequency bins. This feature of wireless microphones is used in the PSD based wireless microphone detection algorithm. The algorithm is explained in [1]. In the technical paper we implement the algorithm in [1] in MATLAB and explore some modifications to it by combining decisions from different frequency bins. The algorithm is explained in chapter 4.

Chapter 3 : Energy Detection

3.1 Problem Statement

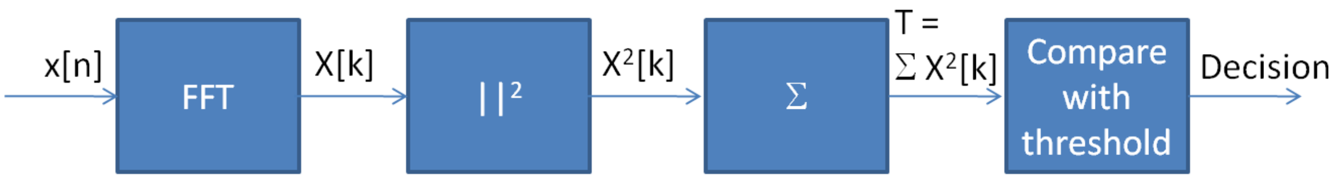

Figure 3-1 Block diagram of energy detector

Energy detector compares the energy of the received signal with the noise energy to determine the presence of signal. Energy detectors don't rely on type of received signal and don't use any signal specific information. Hence they are categorized under blind detection techniques. However energy detectors assume that the noise at the receiver is additive, white and Gaussian and its noise power value is known before detection. When a deterministic signal is present, the received signal consists of this signal and additive noise. The energy of received samples increases and is more than the noise energy. This is the basic principle behind the operation of energy detectors.

Figure 3.1 shows the block diagram of energy detector. In the first block Fast Fourier Transform (FFT) operation is performed on the received samples. The FFT samples are squared and normalized with the number of observed samples to give an estimate of the PSD. This technique of estimating the PSD is called the periodogram. The coefficients of periodogram are added up to measure the total energy in the bandwidth. This computed value is the test statistic which is compared to a threshold to determine the presence of signal. If test statistic is greater than threshold the signal is present else signal is absent. A detailed analysis on the performance of energy detectors can be found in [4] and [5]. In chapter 4 we present a PSD based detector for wireless microphones which is also based on the received signal energy but uses wireless microphone signal specific information. Since this detector is not a blind sensing technique it cannot be classified as energy detector.

3.2 Performance evaluation

3.2.1 Theoretical analysis

We consider two hypotheses in the analysis of energy detectors, the noise only case and the noise plus signal case. The two hypothesis can stated as follows:

$H_0 : x[n] = w[n]$ signal is absent,

$H_1 : x[n] = s[n] + w[n]$ signal is present,

where $n = 1, 2, \ldots N$ is the number of observed samples at the receiver,

N is the total number of samples observed, w[n] are the additive white Gaussian noise samples,

s[n] is the deterministic signal samples.

The distribution for x[n] is given as follows:

$x \sim N(0, \sigma_n^2)$ under H_0,

$x \sim N(0, \sigma_n^2 + \sigma_s^2)$ under H_1.

The test statistic is given by, $T = \Sigma\,(x[n])^2$ which is the total energy in frequency band. Since T is the summation of square of Gaussian random variables, it has chi-square distribution. Assuming the number of received samples is large we can apply the central limit theorem and simplify the distribution of received samples to a Gaussian distribution. The Gaussian assumption is more accurate as the number of samples increases because of greater averaging. In our simulations the number of samples is very large and the Gaussian assumption holds true.

The distribution for T is given as follows:

$T \sim N(N\sigma_n^2, 2N\sigma_n^4)$ under H_0

$T \sim N(N(\sigma_n^2 + \sigma_s^2), 2N(\sigma_n^2 + \sigma_s^2)^2)$ under H_1.

Therefore, P_d and P_f can be evaluated as follows:

$$P_f = Q\left(\frac{\gamma - N\sigma_n^2}{\sqrt{2N\sigma_n^4}}\right) \quad [4]$$

$$P_d = Q\left(\frac{\gamma - N(\sigma_n^2 + \sigma_s^2)}{\sqrt{2N(\sigma_n^2 + \sigma_s^2)^2}}\right) \quad [4]$$

3.2.2 Receiver operating curves

Parameter	Value
Sampling frequency	400 kHz
Sensing time	500 ms
AWG Noise power	-96 dBm
Bandwidth	200 kHz

Table 3-1 Simulation parameters for energy detector

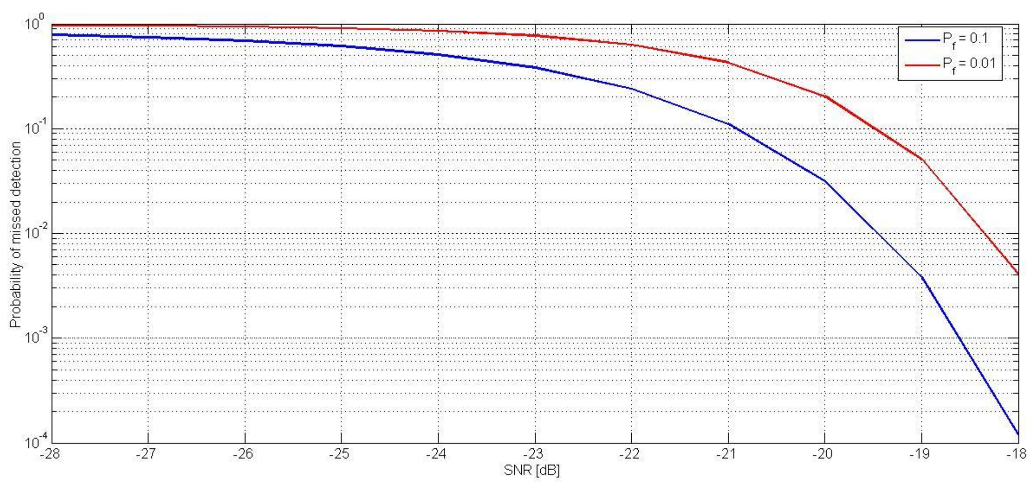

Figure 3-2 Performance of energy detector

Figure 3.2 shows the performance of energy detector. The simulation parameters are given table 3.1. The simulation parameters were chosen to match wireless microphone signal characteristics. Signal bandwidth of 200 kHz corresponds to the maximum bandwidth of wireless microphones. Sensing time of 500 ms was chosen to match the parameters used in PSD based wireless microphone detectors. The performance curves are generated using the Neyman Pearson method. Based on the probability of false alarm we set the threshold for detection. This value of threshold is used to calculate the probability of detection. As seen from the figure, energy detectors can detect wireless microphone signals at SNR = -21 dB for P_d = 90% and P_f = 10%.

3.3 Presence of Noise Uncertainty

Energy detectors assume noise to be AWGN. To calculate the threshold of detection it is necessary to know the value of noise power in the null hypothesis case. The performance curves shown above assume the noise variance is known accurately. However in the cases when there is uncertainty in the value of noise power, the performance of energy detector degrades. This is happens because the threshold of detection calculated is incorrect due to the noise uncertainty. It is important to understand the effect of noise uncertainty since it is difficult to estimate noise power accurately. Practically there might be situations when the performance of energy detectors differs from the expected results. This can be explained by an error in the estimated noise power. In [6] the authors evaluate the performance of energy detectors in case of noise uncertainty. This section explores the concept of SNR_{wall} explained in [6].

Noise uncertainty is defined as the difference in the estimated noise power value and the actual noise power and its unit is dB. There exists a value of noise uncertainty below which the energy detector has P_d = 0 i.e. there is no probability of detecting the signal. The value of SNR at which detection is not possible is called SNR_{wall}. The formula for SNR_{wall} is given in [4] and [6] as:

$$SNR_{wall} = 10 \times \log_{10} [10^{(\frac{x}{10})} - 1] \; dB \qquad [4]$$

where x is the noise uncertainty in dB.

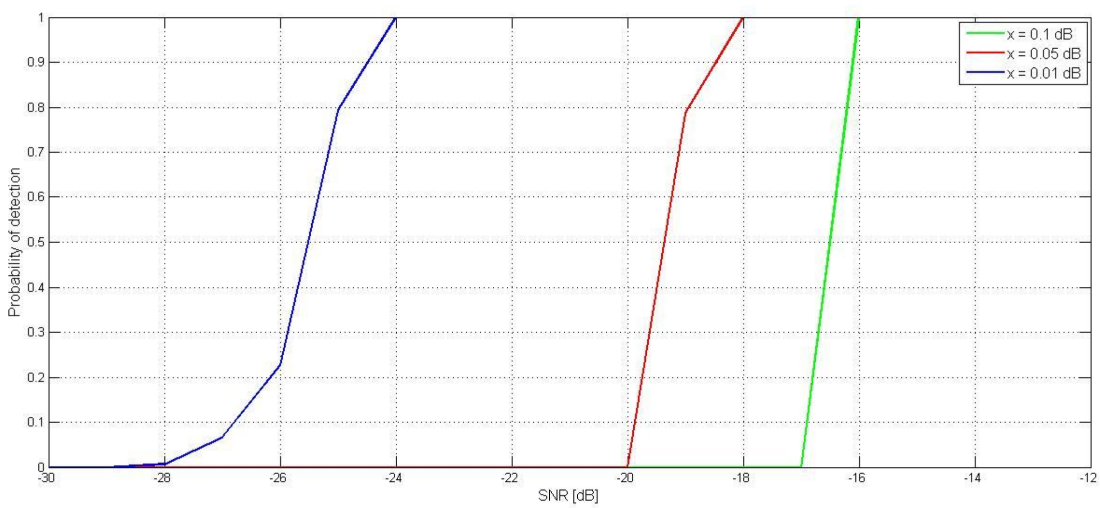

Figure 3-3 Performance of energy detector in presence of SNR wall

Noise uncertainty [dB]	SNR_{wall}
0.01	-26.37
0.05	-19.36
0.10	-16.33

Table 3-2 Calculated SNR_{wall} energy detectors

Parameter	Value
Sampling frequency	20 MHz
Sensing time	500 ms
Noise power	-96 dBm

Table 3-3 Simulation parameters for noise uncertainty simulation

Figure 3.3 shows MATLAB simulation results of the performance of energy detector in presence of noise uncertainty. The simulation parameters for this curve are the same as previous simulation and are given in Table 3.3. As seen from the performance curves, there is a SNR value below P_d becomes 0. The results from the figure verify the calculated values of SNR_{wall} summarized in Table 3.2.

Chapter 4 : PSD based Wireless Microphone Sensing

4.1 Introduction

The PSD of wireless microphones have important features which can be used to detect their presence in the spectrum. Since wireless microphones occupy a bandwidth of less than 200 kHz high energy peaks are observed in frequency bins. Figure 4.1 and figure 4.2 show the PSD of wireless microphones for silent and loud mode of operation. The PSD's were plotted from the database of wireless microphone signals provided by Qualcomm. In the case of silent wireless microphone the occupied bandwidth is close to 8 kHz and in the loud wireless microphone mode the occupied bandwidth is around 32 kHz. The bandwidth occupied by the wireless microphones depends on the frequency deviation factor used for frequency modulation. In the loud mode there is a larger frequency deviation and hence the bandwidth occupied is higher. In the silent mode, the speaker is not talking into the microphone and there is a low frequency deviation factor. As a result the occupied bandwidth is less.

Another feature of wireless microphone PSD's is the presence of sub-carrier frequencies because of frequency modulation. In the PSD shown in figure 4.1 we can see two peaks on either side of the main wireless microphone signal. These peaks are at ±32 kHz from the main lobe of the wireless microphone signal and correspond to the sub-carriers obtained by frequency modulation.

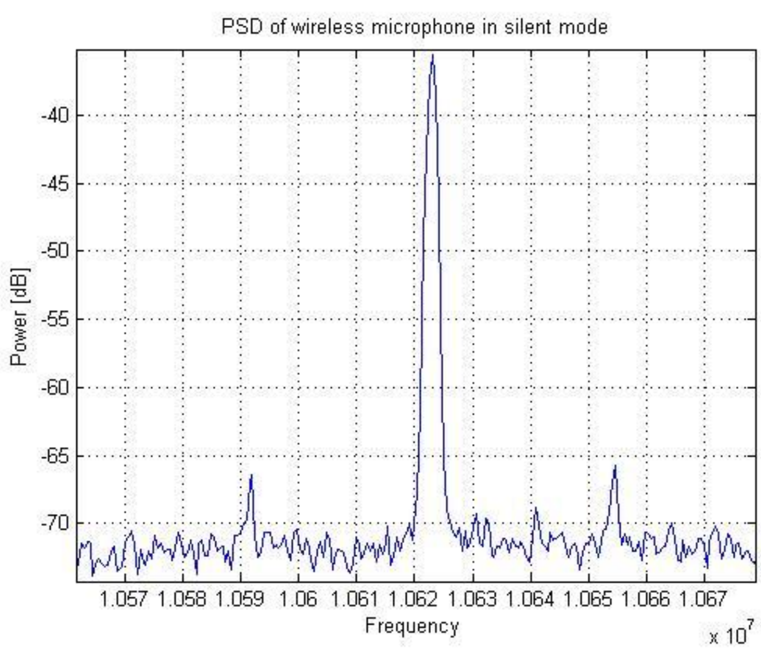

Figure 4-1 PSD of wireless microphone in silent mode

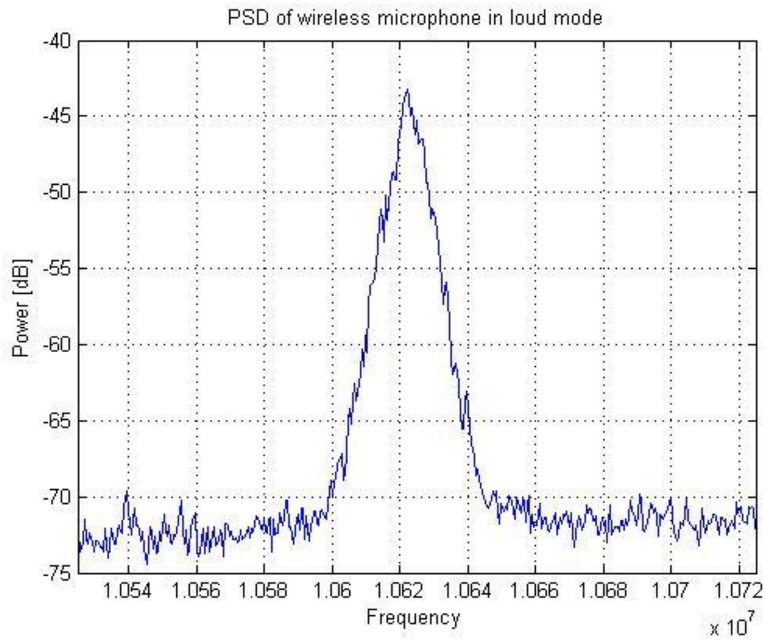

Figure 4-2 PSD of wireless microphone in loud mode

Using these features in the PSD we can improve the detection performance compared to energy detectors. In a PSD based detector we compare the energy in specific frequency bins with the noise energy in a single frequency bin. In this technical paper the term frequency bin refers to the resolution in the estimated received signal periodogram and corresponds to some bandwidth. By considering frequency bins with smaller bandwidth as compared to entire channel bandwidth used in energy detectors we are able to increase the signal-to-noise ratio for relevant frequencies and achieve better performance. Based on the received pattern of occupied frequency bins in the PSD we can distinguish wireless microphone from other received signal types. Another advantage of this approach is that we can detect the mode of operation of the microphone and estimate its center frequency. This approach is taken from the algorithm explained in [1].

4.2 Block diagram

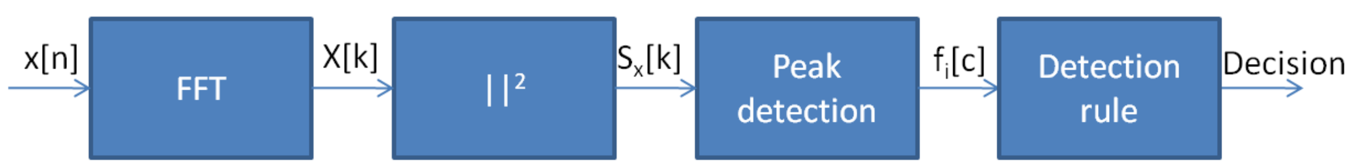

Figure 4-3 PSD based wireless microphone sensing block diagram

Figure 4.3 shows the block diagram of a PSD based WM detector. In the first block a FFT operation is performed on the received samples which are then squared. These steps are needed to calculate the periodogram of the received signal which is an estimate of the PSD. In the peak detection block we detect the presence of high peaks in the estimated PSD. We compare energy in the frequency bins of the PSD with a threshold to detect peaks. The threshold is determined based on the estimated value of noise power in a frequency bin. It is assumed that noise power is known before detection. Since the received PSD of a wireless microphone has high energy bins when we perform energy detection on a frequency bin basis, the received signal to noise ratio is high resulting in better detection performance. The output of peak detector is a list of frequency bins having energy greater than threshold. In the presence of colored noise peak detector is not able to differentiate between noise and the signal. Also spurious peaks may be triggered from out of band emissions of TV signals or other secondary transmissions. To reduce probability of false alarm the pattern of received peaks is compared with pre-defined masks. The pre-defined masks depend on the detection rule applied and signal parameters. Signal parameters are assumed based on the simulation parameters for wireless microphones [7]. Besides pattern masks we also explore fusion rules as a way to improve performance. Based on the number of peaks present in the PSD we can declare a wireless microphone to be present. The fusion rules we explore in this chapter are the OR rule and the 2 out of N rule. In the OR rule we declare a signal to be present even if a single frequency bin has a high energy value. In this fusion rule the probability of detection is the highest. However OR fusion rule also has a higher probability of false alarm which could be due to the presence of colored noise. To reduce probability of false alarm we explore the 2 out of N rule in which we declare a signal to be present if any two frequency bins have higher energy greater than threshold. In the decision rule block different implementations of fusion rules and pattern masks.

4.3 Theoretical analysis

For theoretical analysis we consider the scenario where signal is present with white Gaussian noise. In this scenario, the two hypothesis can stated as follows:

$H_0 : x[n] = w[n]$ signal is absent

$H_1 : x[n] = s[n] + w[n]$ signal is present

where n = 1, 2, … N is the number of observed samples at the receiver.

The distribution for x[n] is given as follows:

$x \sim N(0, \sigma_n^2)$ under H_0

$x \sim N(0, \sigma_n^2 + \sigma_s^2)$ under H_1.

The FFT operation is given by

$$X_k = \sum_{n=0}^{N-1} x_n \exp(-i2\pi k \frac{n}{N})$$

X_k is the summation of Gaussian random variables and its distribution is given as:

$X \sim N(0, N\sigma_n^2)$ under H_0

where N is the total number of samples.

The periodogram is calculated by squaring the FFT coefficients as shown below

$$S_x = \frac{abs(X_k)^2}{N}$$

The periodogram coefficients S_x will have a chi-square distribution. In order to apply central limit theorem we calculate the periodogram of received signal over multiple instances over time. Since the number of realizations is large, we can apply central limit theorem and assume the distribution to be Gaussian. The distribution of S_x is as follows:

$S_x \sim N(\sigma_n^2, \frac{\sigma_n^4}{M})$ under H_0

where M is the number of realizations of observed PSD.

Given the distribution of the frequency bins in the PSD we can calculate the threshold for peak detection using Neyman Pearson method.

Consider hypothesis H_0, which is the noise only case. When only noise is present the distribution of frequency bins in the periodogram depends only on the noise power. The probability of false alarm is given by,

$$P_f = Q\left(\frac{\gamma - \sigma_n^2}{\sqrt{\frac{\sigma_n^4}{M}}}\right).$$

The threshold for the peak detector is given by,

$Y = Q^{-1}(P_f) \times \sigma_n^2 \times \sqrt{M} + \sigma_n^2.$

Depending on the fusion rule applied, the cumulative probability of false alarm for the detector changes.

4.3.1 OR rule

In the OR fusion rule, we declare the signal to be present if any one of the frequency bins have higher energy than the threshold.

In the case of OR rule, the cumulative probability of false alarm is given by,

$P_{FA} = 1 – (1 – P_f)^{N}$.

4.3.2 2-out-of-N rule

In this fusion rule, we consider the signal to be present if at least 2 of the N frequency bins have higher energy than threshold.

In case of the two out of N rule, the probability of false alarm is given by,

$P_{FA} = 1 – (1 – P_f)^{N} – N \times P_f \times (1 – P_f)^{N-1}$.

4.3.3 Soft fusion rule

In soft fusion we combine the results from the different sources to define a single test statistic as opposed to the hard fusion rule in which we combine the decision's made from different sources.

In soft fusion rule, we pre-define patterns we expect to observe in the frequency bins of the estimated PSD. The pre-defined patterns are based on the simulation parameters defined in [7] and are hardcoded in the simulations. The aim of this simulation is compare the results with the 2 out of N fusion rule.

The cumulative decision statistic in the soft fusion rule is the total energy in the frequency bin pattern. Since the pattern exposes only the high energy frequency bins, it has the effect of increasing the signal to noise ratio at the receiver.

The cumulative probability of false alarm in this case depends on the pattern mask selected. For the loud mode, we define the pattern corresponding to 4 side frequencies. The probability of false alarm is given as,

$$P_f = Q\left(\frac{\gamma - 4\sigma_n^2}{4\sqrt{\frac{\sigma_n^4}{M}}}\right).$$

In this soft mode, the pattern is consists of center frequency and two side frequencies. Since we consider 3 frequency bins, the probability of false alarm is,

$$P_f = Q\left(\frac{\gamma - 3\sigma_n^2}{3\sqrt{\frac{\sigma_n^4}{M}}}\right).$$

In the silent mode, only the center frequency bin is considered in the mask. The probability of false alarm is,

$$P_f = Q\left(\frac{\gamma - \sigma_n^2}{\sqrt{\frac{\sigma_n^4}{M}}}\right).$$

The hard decision OR rule and soft decision have the same performance in case of silent microphone.

The cumulative probability of false alarm is then given by,

$P_{FA} = 1 – (1 – P_f)^N$.

4.4 Receiver operating curves

Parameter	Value
Sense time	500ms
Signal bandwidth	200kHz
FFT points	1000
Center frequency	6 MHz
Sampling frequency	20 MHz
Number of samples	1000

Table 4-1 Simulation parameters for PSD based detector

The simulation parameters used for PSD based wireles microphone detection are shown in table 4.1. The performance of this detector under different fusion rules are shown in the figures below.

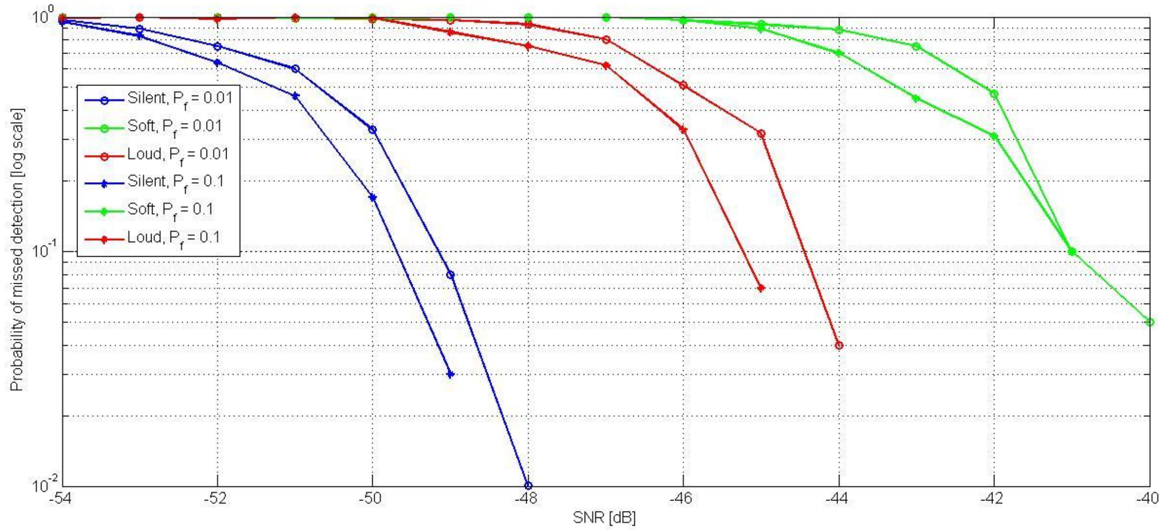

Figure 4-4 Receiver operating curves for OR fusion rule

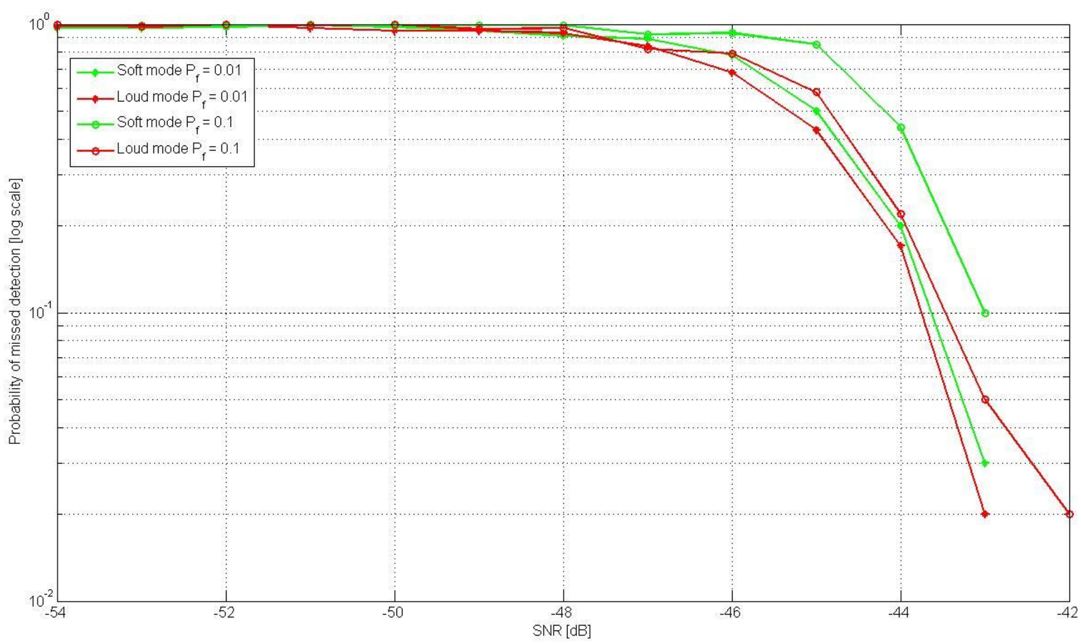

Figure 4-5 Receiver operating curves 2-out-of-N fusion rule

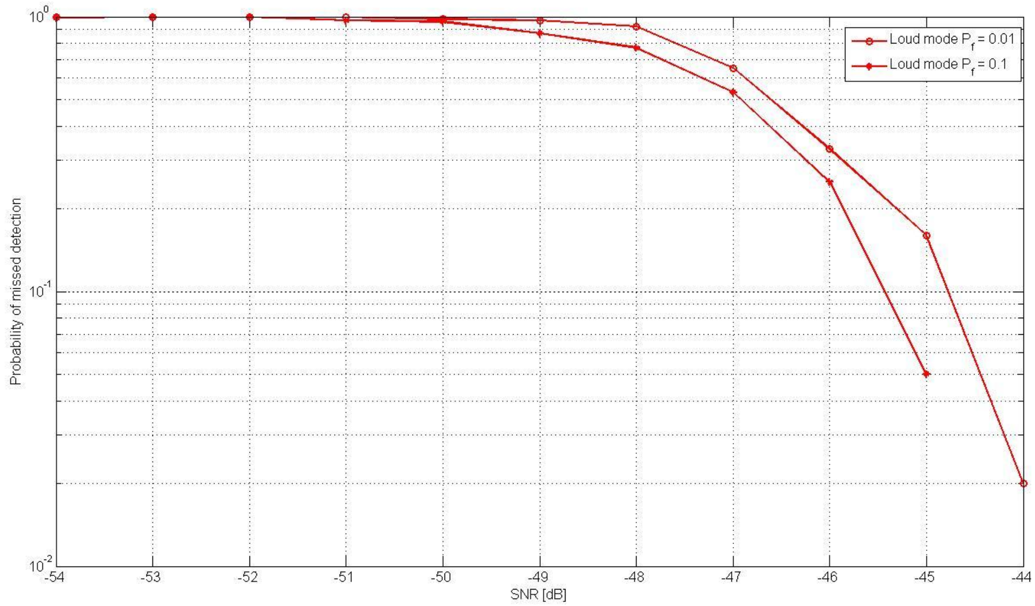

Figure 4-6 Receiver operating curves soft fusion rule

4.5 Summary

In this chapter, we presented a PSD based detection algorithm for wireless microphones. It is observed that this algorithm can give better performance compared to energy detectors because we use wireless microphone signal specific information. The observations from receiver operating curves shown in section 4.4 are summarized below:

1. As seen in Figure 4.3 in case of OR fusion rule, when the three operating modes of a wireless microphone are compared, silent mode have better performance compared to loud mode and soft mode. This can be explained by the fact that the frequency deviation is the smallest in the silent mode and the energy is mostly concentrated in the single center frequency bin. In OR rule type fusion, we declare the signal to be present if any one bin is above the threshold. Hence silent mode wireless microphone has better performance
2. In Figure 4.3 we observe loud mode wireless microphone has better detection compared to soft mode. This is because in the loud mode has higher peaks compared to soft mode.
3. If we consider combination rules, OR rule fusion has higher probability of detection and probability of false alarm. OR rule can be thought of as 1 out of N fusion rule. As we move towards majority combination rules, the probability of false alarm and detection, both reduce. For the same cumulative probability of false alarm the probability of detection should reduce because the detection rule is more stringent. However the 2 out of N rule has better performance compared to OR rule for the soft mode operation of wireless microphones. This is

because the PSD has a larger density of high energy peaks. Hence it's more probable to find two or more peaks above threshold compared to other operation modes.

4. For the 2 out of N fusion rule in Figure 4.4, silent microphone detection performance is poor because in this mode only a single frequency bin is occupied. The number of bins occupied depends on the frequency resolution of the estimated PSD.
5. In the loud mode case, the performance of 2 out of N rule is not as good as OR rule which is because of the lesser number of side frequency peaks observed in the PSD of loud mode microphone.
6. Soft rule fusion is presented in this technical paper to compare its performance with hard fusion rules such as the OR rule and the 2 out of N rule. In Figure 4.5 shows the performance of soft fusion rule for the loud mode. It is observed that the soft decision rule gives better performance than the corresponding hard decision rules.

Chapter 5 : Conclusion

5.1 Results

A comparison of all detection rules is shown in the table below. This results are shown for Probability of detection = 90% and Probability of false alarm = 10%.

Wireless microphone operation mode	Decision rule	SNR [dB]
	Energy detector	-21.4
Silent	OR	-54
Soft	OR	-45
Soft	2 out of N	-47
Loud	OR	-49
Loud	2 out of N	-47.5
Loud	Soft decision	-49.5

Table 5-1 Comparison of sensing techniques

5.2 Conclusion

In this technical paper, we presented a PSD based detection technique which can be used to detect wireless microphones. The detection algorithm exploits certain characteristics of wireless microphone to give better performance when compared to energy based detectors.

Based on the mode of operation of the wireless microphone, we observed different patterns in the received signal PSD which were used to generate three fusion rules. The results for OR rule type fusion, 2 out of N rule fusion were shown along with soft decision based pattern rule detection. To generate the pattern masks we assumed signal parameters for wireless signal modulation. By using this additional information the detection performance is improved even further.

References

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