Autocorrelation based spectrum sensing technique for cognitive radio application

Sandhya Pattanayak\textsuperscript{1a)}, Palaniandavar Venkateswaran\textsuperscript{2}, and Rabindranath Nandi\textsuperscript{2}

\textsuperscript{1} Department of Electronics and Communication Engineering, Narula Institute of Technology, Kolkata 700109, India
\textsuperscript{2} Department of Electronics and Telecommunication Engineering, Jadavpur University, Kolkata 700032, India
\textit{a)} sandhya.pattanayak@yahoo.com

Abstract: A spectrum sensing technique based on the detection of the audio FM and wireless microphone signals in the TV band is proposed. Our method autocorrelates the signal that enables a formulation of the new decision making index in terms of a ratio $A_r$. Thereby an algorithmic interpretation with $A_r$ as an index, one identifies the white space. This method reduces the probability of false alarm and mitigates the disadvantages of other spectrum sensing techniques.

Keywords: spectrum sensing, cognitive radio, autocorrelation

Classification: Terrestrial Wireless Communication/Broadcasting Technologies

References

1 Introduction
Recent literature indicates that wireless data traffic would increase to hundreds of petabyte/month within this decade; hence a spectrum crunch is evident [1]. The CR autonomously exploits locally unused spectrum and enables opportunistic spectrum sharing with secondary user as a solution [1, 2, 3, 4, 5, 6].

By FCC directives [5] unused TV band of a particular geographical location may be allotted to secondary users. A TV band is occupied with a digital signal, analog signal or a wireless microphone signal. Detection of low SNR wireless microphone signals in the channel is difficult [6]; hence we propose a spectrum sensing algorithm that detects a low SNR primary signal in the band.

We derive a decision making index ratio $A_r$, formulated by autocorrelation of the received signal. $A_r$ is defined as the difference of the peak value at markers of lag-0 and lag-1; that is normalized with respect to the marker peak value at lag-0. Thereby we conclude:

Channel status-occupied: $A_r < 1$ ↔ Channel white space: $A_r \approx 1$
2 Literature survey

The literature contains [7, 8, 9, 10] spectrum sensing techniques, e.g., energy detection [8, 11, 12] and feature detection [13, 14] based on the hypothesis.

\[
H_0 : y(t) = n(t) \\
H_1 : y(t) = hx(t) + n(t)
\]

where \(x(t)\) is primary signal, \(n(t)\) is additive white Gaussian noise, \(h\) is channel gain. \(H_0\) is null hypothesis indicating white space and \(H_1\) indicates that channel is occupied with a primary signal [12].

Prototypes for spectrum sensing of TV channel were developed following FCC guidelines [15, 16] but found to have high false alarm rate [17, 18]. It is shown that the proposed technique reduces the false alarm rate and increases the probability of detection.

3 Problem formulation

A modified autocorrelation based spectrum sensing technique for TV band is proposed, so as to identify the presence of low SNR (−30 dB) wireless microphone signals and, to reduce false alarm rate. The wireless microphone FM signals are the low power secondary licensed users which occupy bandwidth of 200 KHz. Similarly in analog TV, the audio signal uses FM thereby this technique can be applied for both. The proposed modified autocorrelation technique with index-\(A_r\) can detect FM signals in the TV band and also probability of false alarm reduces.

Using MATLAB an FM signal over channel 6 of an analog TV transmission system having carrier frequency 87.75 MHz, baseband frequency 10 KHz and having a maximum frequency deviation of 25 KHz is generated, same as the wireless microphone signals in the TV band. The FM signal is [19]:

\[
x(t) = A_c \cos[2\pi f_c t + 2\pi f_d \int_0^t m(t) dt + \theta]
\]

where \(m(t)\) is baseband signal, \(\theta\) is random phase, \(A_c\) is carrier amplitude, \(f_c\) denotes carrier frequency, \(f_d\) is frequency deviation. The noise in channel is assumed to be white with mean zero and variance \(\sigma^2\). The FM signal is affected by noise and multipath Rayleigh fading with 3 multipaths having delay 0 ns, 0.1 ns and 0.2 ns. For simulation purpose SNR is taken over range: −30 dB to 30 dB. The noise power is taken over range: 10 dBm–40 dBm. As the CR scans the channel to perform spectrum sensing, a noisy faded FM signal will be received if occupied or will receive only noise if a white space. In the proposed algorithm, the signal received is sampled at rate \(f_s\), and autocorrelation with 20 lags is performed with lag time \(\tau = 10 \mu s\) [17], given as:

\[
R_r[m] = \frac{1}{N_r} \sum_{n=0}^{N_r-1} r[n + m] r[n]
\]

\(N_r\) is number of samples. For correlation delay \(\tau\) taken in the range 0 ≤ \(\tau\) ≤ 10 \(\mu s\) and \(f_c\) taken more than \(\Delta f\), results in phase variation dominated by the carrier frequency and the phase variation due to the integral term in FM wave can be ignored [17]. The FM signal and noise are independent and identically distributed.
of each other, so autocorrelation is also independent of each other. The autocorrelation of noise is [17]:

$$R_w[m] = \frac{1}{N_w} \sum_{n=0}^{N-1} w[n + m]w[n] = 0$$

for \( m \neq 0 \)  \( \quad (5) \)

In Fig. 1(a) the autocorrelation of a noisy FM signal; Fig. 1(b) shows autocorrelation of only noise. From Fig. 1(a) it is seen that the autocorrelation of a noisy FM signal has the highest peak at the marker-lag 0; the consecutive marker-lags of the peak values are reducing, hence the ratio of \( A_r \) is less than 1. The peak values of the autocorrelation are periodic as the FM signal has high correlation but reduce slowly because of the presence of noise [20]. For a white space where channel has only noise, ratio-\( A_r \) is nearly equal to 1 as at lag-0 the peak value is present and at lag-1 the peak value is nearly zero; this ascertains the randomness in the signal as stated in Eq. (5). The randomness in a signal is ascertained by computing autocorrelations at varying time lags.

So the proposed decision making ratio \( A_r \) is the ratio between the difference of peak value at lag 0 and lag 1 and the peak value of lag 0:

$$A_r = \frac{(R_r[0] - R_r[1])}{R_r[0]}$$

\( \quad (6) \)

It is found that for a channel occupied with primary signal, ratio \( A_r \) is less than 1 and when the channel is vacant the ratio is nearly equal to 1; hence Ratio \( A_r \) is an indicator to perform spectrum sensing. Autocorrelation coefficient at lag 1 is considered as it shows high autocorrelation for a non random signal [20]. Fig. 2(a) shows the MATLAB simulated value of \( A_r \) for only noise in channel and a noisy FM waveform in the channel. The graph shows that \( A_r \) is 0.73 for a noisy FM signal for a range of SNR from −30 dB to 30 dB. The value of \( A_r \) is nearly equal to 1 for only noise in channel. Therefore \( A_r \) can be used for identifying whether the channel is a white space or not, but augmented with a proper threshold.
4 Threshold setting for an AWGN channel

Threshold for proposed technique is determined for a particular channel by finding \( A_r \) of an adjacent channel or guard band which has only noise in it. So this value \( A_r \) becomes the threshold \( T_{Ar} \). As the algorithm states, channel is said to be occupied by a primary signal if \( A_r \) is less than threshold \( T_{Ar} \) and white space is identified when \( A_r \) is more than or equal to \( T_{Ar} \).

4.1 Algorithm:

Step 1: TV band is scanned and autocorrelated
Step 2: \( A_r \) is determined
Step 3: If \( A_r \geq T_{Ar} \) then channel is vacant & If \( A_r < T_{Ar} \) then channel is occupied

4.2 Performance and results

The performance of the proposed algorithm is evaluated by Probability of false alarm (\( Pfa \)) and Probability of detection (\( Pd \)). In this scenario a false alarm occurs when \( A_r \) of noise in the channel becomes less than the threshold \( T_{Ar} \). The \( Pfa \) is determined by 10000 Monte-Carlo simulations as stated in Eq. (7) and threshold range being from 0.1 to 1:

\[
Pfa = \frac{\text{Number of times the Ratio } A_r > \text{ threshold } T_{Ar}}{10000}
\]  

Noise in the channel is generated over the range: 10 dBm–40 dBm. In Fig. 2(b) the \( Pfa \) for threshold \( T_{Ar} \) is plotted for different noise power; it is seen that for

\[0.1 \leq T_{Ar} \leq 0.9 : Pfa \to 0,\]

for \(0.9 \leq T_{Ar} \leq 1 : Pfa \to 0.4\) which can be avoided.

The \( Pfa \) of this algorithm is independent of SNR, noise uncertainty, number of samples and number of lags.

Now \( Pd \) for the proposed algorithm is analyzed for a channel occupied with a low SNR primary signal. The noise over an adjacent frequency is captured, autocorrelated and threshold \( T_{Ar} \) is determined. \( Pd \) is determined by 10000 Monte-Carlo simulations:

\[
Pd = \frac{\text{Number of times the Ratio } A_r < \text{ threshold } T_{Ar}}{10000}
\]  

Ratio \( A_r \) of the signal captured over the channel is compared with threshold \( T_{Ar} \). For \( A_r < T_{Ar} \), channel is occupied with a primary signal else a white space. It is found from simulations that a signal with SNR of −30 dB can be detected by this technique. Fig. 3(a) shows the performance of the algorithm for \( Pd \) which is found to be 0.7 for a primary signal at SNR −30 dB signal, 0.95 for −22 dB primary signal and 1 for −20 dB primary signal.

The number of times that the \( A_r \) and \( T_{Ar} \) change randomly is averaged over 10000 simulations. The effective quantisation as per Eq. (8) is not smooth. Randomness of noise in low SNR signal causes the fluctuation of \( A_r \) and \( T_{Ar} \); this attributes to the non-smooth nature of the graph in Fig. 3(a) covering the low SNR range of the axis. Fig. 3(b) shows comparative study [21] of \( Pd \) wherein improved result over other schemes is observed. The \( Pd \) is determined for a \( Pfa \) of 0.1 as
recommended for WRAN and the threshold for each technique has to be slightly varied to meet the Pfa requirement [21]. We observe that the proposed autocorrelation based method with index $A_r$ is able to detect a low SNR signal in channel at low Pfa.

5 Conclusion

An autocorrelation based spectrum sensing technique is presented; noted features are:

- Pfa here is less as compared to energy detection technique
- $Pd$ of low SNR signals improves over other methods
- In energy detection false alarm rate is dependent on noise uncertainty [11]; here noise uncertainty does not limit the performance.