ISSN (e): 2250 – 3005 || Volume, 15 || Issue, 5|| May – 2025 ||
International Journal of Computational Engineering Research (IJCER)

Efficient Wideband Spectrum Sensing using PDF Analysis on Randomly Sampled Data for Cognitive Radio Networks

S.Kanimozhi [1], K.Mahalakshmi [2]
Professor,
Annai College of Engineering and Technology, Kumbakonam, India
Associate Professor,
Annai College of Engineering and Technology, Kumbakonam, India

Abstract
Cognitive Radio (CR) technology dynamically utilizes spectrum bands by identifying unused frequencies and enabling secondary users to transmit without interfering with primary users. Traditional sensing methods often demand high sampling rates, which increase complexity and latency. This paper presents a probability density function (PDF)-based technique that utilizes randomly sampled data to detect spectral opportunities efficiently. The proposed method reduces the need for time-referenced sampling and enhances sensing performance, as validated through MATLAB simulations.
Keywords: Cognitive Radio, Spectrum Sensing, PDF, Random Sampling, Wideband Detection

---

Date of Submission: 22-04-2025 Date of acceptance: 03-05-2025

I. Introduction

The explosive growth in wireless communication has rendered static spectrum allocation insufficient. Cognitive radios aim to solve this by allowing unlicensed users (SUs) to utilize idle licensed spectrum without affecting primary users (PUs). For this, spectrum sensing must be both accurate and fast to prevent interference and maximize spectrum efficiency.[1][2]

This work proposes an alternative to conventional high-rate sensing methods. By leveraging the statistical characteristics of received signals via PDF estimation, the system identifies spectral holes using fewer samples, thus reducing sensing time and computational cost.

Traditional wideband spectrum sensing techniques require high-rate ADCs to satisfy Nyquist criteria, which significantly increases the hardware cost and power consumption of Cognitive Radio (CR) systems. To overcome this, random sampling techniques such as Compressed Sensing (CS) and histogram-based detection have gained attention. These methods exploit the sparse occupancy nature of wideband spectra and allow CRs to infer spectrum usage with fewer measurements, enabling efficient and low-complexity sensing.[3][4]

II. Spectrum Sensing Techniques

Several techniques exist for detecting spectrum occupancy, each with specific benefits and drawbacks:

Energy Detection estimates signal presence based on received signal power. It's simple and easy to implement, requiring no prior knowledge of the signal. However, it is highly sensitive to noise uncertainty, which can lead to false detections. Additionally, its performance degrades significantly under low Signal-to-Noise Ratio (SNR) conditions. It also cannot differentiate between noise and signals of interest.

Cyclostationary Detection exploits the periodic features of modulated signals, differentiating them from noise. It is highly effective in environments with strong noise interference and can distinguish between noise and modulated signals even at low SNR. On the downside, it requires significant computational resources and longer observation times due to the complexity of processing cyclic features. The technique also assumes a certain periodicity that may not always be present.

Matched Filter Detection offers high detection speed and optimal performance when prior information about the signal is available. It can detect weak signals effectively, making it suitable for high-reliability applications. However, it requires complete knowledge of the primary user signal and separate receivers for different signal types, limiting its practicality in dynamic environments. It also consumes more power and adds complexity due to the need for synchronization.

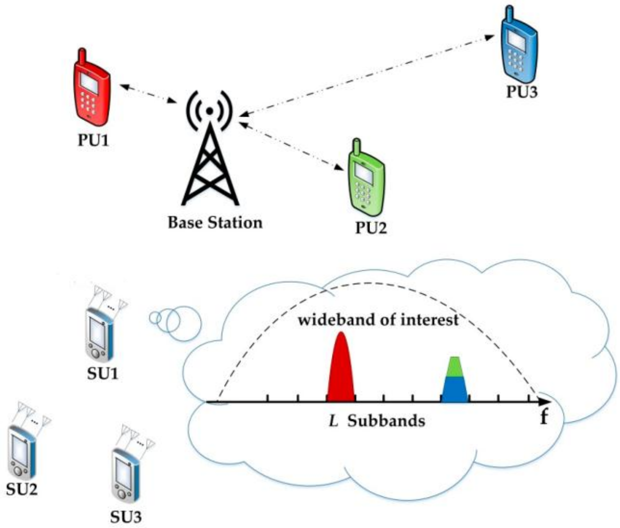

Fig 1 CR system Model [5]

III. Incorporating Compressed Sensing and Histogram Methods in CR

Research shows that compressed sensing (CS) and histogram-based analysis provide a powerful combination for efficient spectrum sensing in cognitive radio systems[6]. CS allows CRs to sense wideband signals at sub-Nyquist rates, relying on the sparsity of signal occupancy in frequency bands. Reconstruction algorithms can then identify active frequencies without acquiring the full signal.

On the other hand, histogram-based techniques, particularly those analyzing the PDF of randomly sampled data, allow signal detection without the need for time synchronization. Such approaches can quickly and accurately infer the presence of primary users based on signal amplitude distributions, even in noisy environments.

These techniques contribute significantly to reducing the hardware and computational requirements of wideband sensing, making real-time, low-power CR implementations more feasible.

IV. Proposed Method: PDF-Based Detection with Random Sampling

This section introduces a novel spectrum sensing technique based on statistical analysis of randomly sampled signal data. Unlike conventional methods that rely on time-referenced or structured sampling, the proposed approach eliminates the need for precise timing, thereby reducing system complexity and processing requirements.

The technique operates by collecting randomly sampled signal amplitudes over a defined observation window. These samples are used to construct a histogram, which is then smoothed to estimate the Probability Density Function (PDF) of the signal. This PDF reflects the underlying statistical structure of the received signal and varies depending on whether a primary user (PU) is present or not.

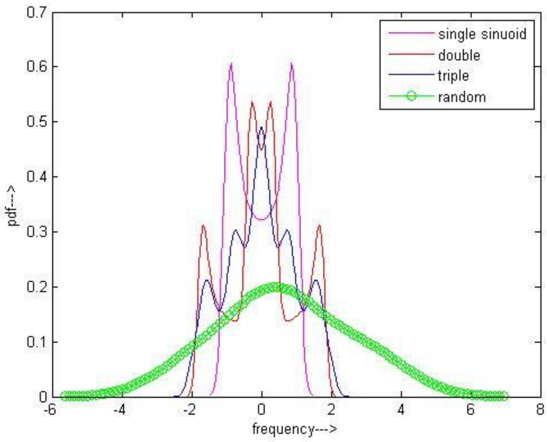

Fig 2. PDF of signals

Compressed sensing (CS) has been widely adopted in wideband spectrum sensing to enable sub-Nyquist sampling, leveraging the inherent sparsity of spectrum occupancy[3]. However, traditional CS approaches typically require knowledge of the sample time indices to accurately reconstruct the original signal. In contrast, our method avoids this requirement by focusing solely on amplitude-based statistical features derived from non-uniformly sampled data.

To make a sensing decision, the estimated PDF is compared against a predefined decision threshold (λ). A decision variable (Λ), computed from the shape or deviation of the estimated PDF, determines whether the signal corresponds to noise or contains a primary user component. The decision rule is defined as:

$$Pf=P(\Lambda \geq \lambda | H0)$$

$$Pm=P(\Lambda < \lambda | H1)$$

The detection performance is evaluated based on two key metrics:

- Probability of False Alarm (Pf): Probability of detecting a PU when none is present.
- Probability of Missed Detection (Pm): Probability of failing to detect a PU when one is present.

These error probabilities are given by:

$$\mathrm{pm} = \int_{\Lambda \geq \lambda}^{\infty} P(\mathrm{x})\mathrm{dx} \quad \rightarrow (1)$$

$$\mathrm{pf} = \int_{-\infty}^{\Lambda \leq \lambda} P(\mathrm{w})\mathrm{dx} \quad \rightarrow (2)$$

Fig.2 illustrates the PDFs obtained from different signal types, including a single sinusoid, a combination of sinusoids, and random signals. Each signal type produces a distinct PDF pattern, enabling reliable detection through statistical comparison.

The proposed method aligns with recent developments in compressed sensing and non-uniform sampling strategies. By leveraging the statistical distribution of signal amplitudes, the system achieves efficient spectrum sensing with fewer samples and reduced computation, while maintaining strong detection reliability in noisy environments.

V. Performance Metrics and Simulation Results

The performance is evaluated using probabilities of false alarm (Pf) and missed detection (Pm). MATLAB simulations involved different signal types (sinusoidal, multi-tone, and random) with additive Gaussian noise. Receiver Operating Characteristic (ROC) curves were plotted to analyze the trade-off between Pf and Pm under various antenna gains and SNR levels.

Fig.3 presents the trade-off between the probability of false alarm and the probability of missed detection, reflecting the decision-making performance.

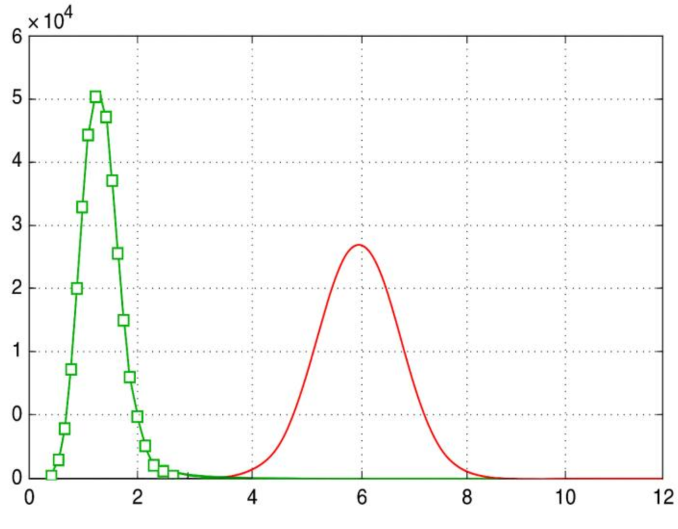

Fig.3. probability of false alarm and the probability of missed detection

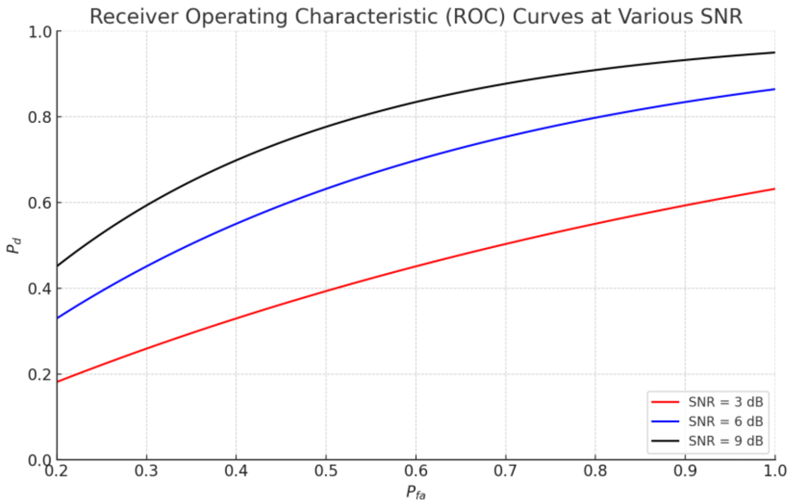

Fig.4 Receiver operating characteristics

Fig. 4 shows the Receiver Operating Characteristic (ROC) curves for different antenna gain values, highlighting how the receiver performs under varying gain conditions. Results show that this method performs reliably even in noisy environments, outperforming energy detection in terms of robustness and threshold reliability.

VI. Conclusion

In this paper, we proposed an efficient wideband spectrum sensing technique for cognitive radio networks based on probability density function (PDF) estimation from randomly sampled data. This approach eliminates the need for time-referenced sampling, thereby reducing both computational complexity and power consumption. Simulation results using MATLAB confirm that the method performs reliably across various signal types, even under noisy conditions, and demonstrates superior robustness compared to traditional energy detection. The ROC curves also highlight the improved trade-off between false alarm and missed detection probabilities. Given its low complexity and noise resilience, this technique offers practical potential for real-time deployment in dynamic cognitive radio environments. Future work could explore its hardware implementation and performance in real-world spectrum conditions.

References

[1] I. J Mitola, GQ Maguire, Cognitive radio: making software radios more personal. IEEE personal Commun J. 6(4), 13–18 (1999). doi:10.1109/98.788210

[2] S Haykin, Cognitive radio: brain-empowered wireless communications. IEEE J Sel Areas Commun. 23(2), 201–220 (2005)

[3] Caiyun Huang, Random Sampling and Signal Reconstruction Based on Compressed Sensing, Sensors & Transducers, Vol. 170, Issue 5, May 2014, pp. 48-53

[4] Frank A. Boyle et al., Statistical Signal Processing Conference 2007.

[5] Qiuyuan Lu, Shengzhi Yang and Fan Liu, Wideband Spectrum Sensing Based on Riemannian Distance for Cognitive Radio Networks, Sensors*17*(4), 661, pp. 01–18,2017

[6] Hongjian Sun, Wei-Yu Chiu, A. Nallanathan, **Adaptive Compressive Spectrum Sensing for Wideband Cognitive Radios,** IEEE Communications Letters, Nov 2012, vol. 16(11), 1812-1815

[7] A. Sahai, N. Hoven, S.M. Mishra and R. Tandra, “Fundamental tradeoffs in robust spectrum sensing for opportunistic frequency reuse” in First IntlWorkshop on Tech. and Policy for Accessing Spectrum, Aug 2006.

[8] David Donoho, “Compressed Sensing,” IEEE Transactions on Information Theory, Vol. 52, (4), 1289 – 1306, April 2006.

[9] Emmanuel Candès, Justin Romberg and Terence Tao, “Robust Uncertainty Principles: Exact Signal Reconstruction from Highly Incomplete Frequency Information,” IEEE Trans. Information Theory, 52(2), 489 – 509, Feb. 2006

[10] J. Haupt, R. Nowak, “Signal Reconstruction from NoisyRandom Projections,” Submitted to IEEE transactions onInformation Theory, March 2005.

[11] Emmanuel Candès and Justin Romberg, “Practical SignalRecovery from Random Projections,” (preprint, 2004)