CSE400 - Section 1

Group-11

Spectrum Sensing in Cognitive Radio Using Cyclostationary Features

Wireless spectrum is a finite resource, yet large portions of licensed frequency bands remain unused for extended periods. Traditional fixed spectrum allocation policies lead to significant inefficiency in how we utilise available bandwidth.

Cognitive Radio Networks offer a solution by enabling unlicensed (secondary) users to access spectrum when licensed (primary) users are inactive. The key challenge is spectrum sensing: reliably detecting whether a primary user is present without causing harmful interference. This becomes particularly difficult when signals are weak, noise levels are uncertain, and decisions must be made from limited samples.

Our project examines spectrum sensing for OFDM signals under realistic noise uncertainty conditions, where conventional energy detectors struggle to perform reliably.

PROJECT OVERVIEW

Objective and Scope

Binary Detection Problem

Our objective is to determine whether an OFDM primary user signal is present in a frequency band based solely on received noisy samples. This is formulated as binary hypothesis testing:

- H_0: Only noise is present
- H_1: Signal plus noise is present

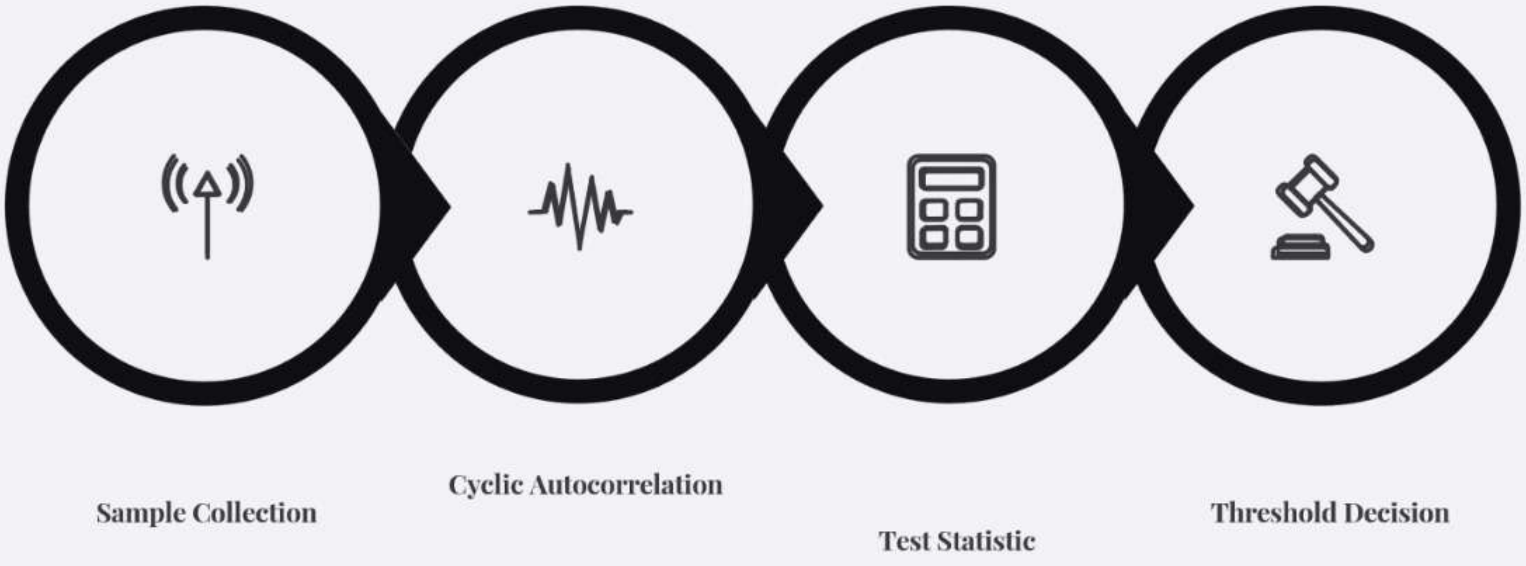
We focus purely on detection, not signal decoding or channel estimation.

Approach

We employ a cyclostationary-based detection method designed to operate reliably when noise variance is imperfectly known — a scenario where simple energy detectors fail catastrophically.

At this milestone, we emphasise understanding the probabilistic framework rather than complete mathematical derivations or implementation specifics.

System Overview



The detection system operates in four sequential stages. First, the cognitive radio receiver collects discrete-time samples from the wireless channel, which may contain only noise or a mixture of noise and OFDM signal. Next, these samples are processed to estimate cyclic autocorrelation values at specific time lags and cyclic frequencies, capturing periodic statistical patterns introduced by OFDM cyclic prefixes.

A test statistic is then computed by combining information across multiple cyclic frequencies. Finally, this statistic is compared against a predetermined threshold to make the binary decision about primary user presence. This architecture enables robust detection even under challenging noise conditions.

Sources of Uncertainty

Additive Noise

Received samples are corrupted by random additive noise that fundamentally limits signal detection capability.

Unknown Noise Variance

In practice, noise power is not perfectly known, creating significant challenges for algorithms that rely on accurate noise estimates.

Finite Sample Effects

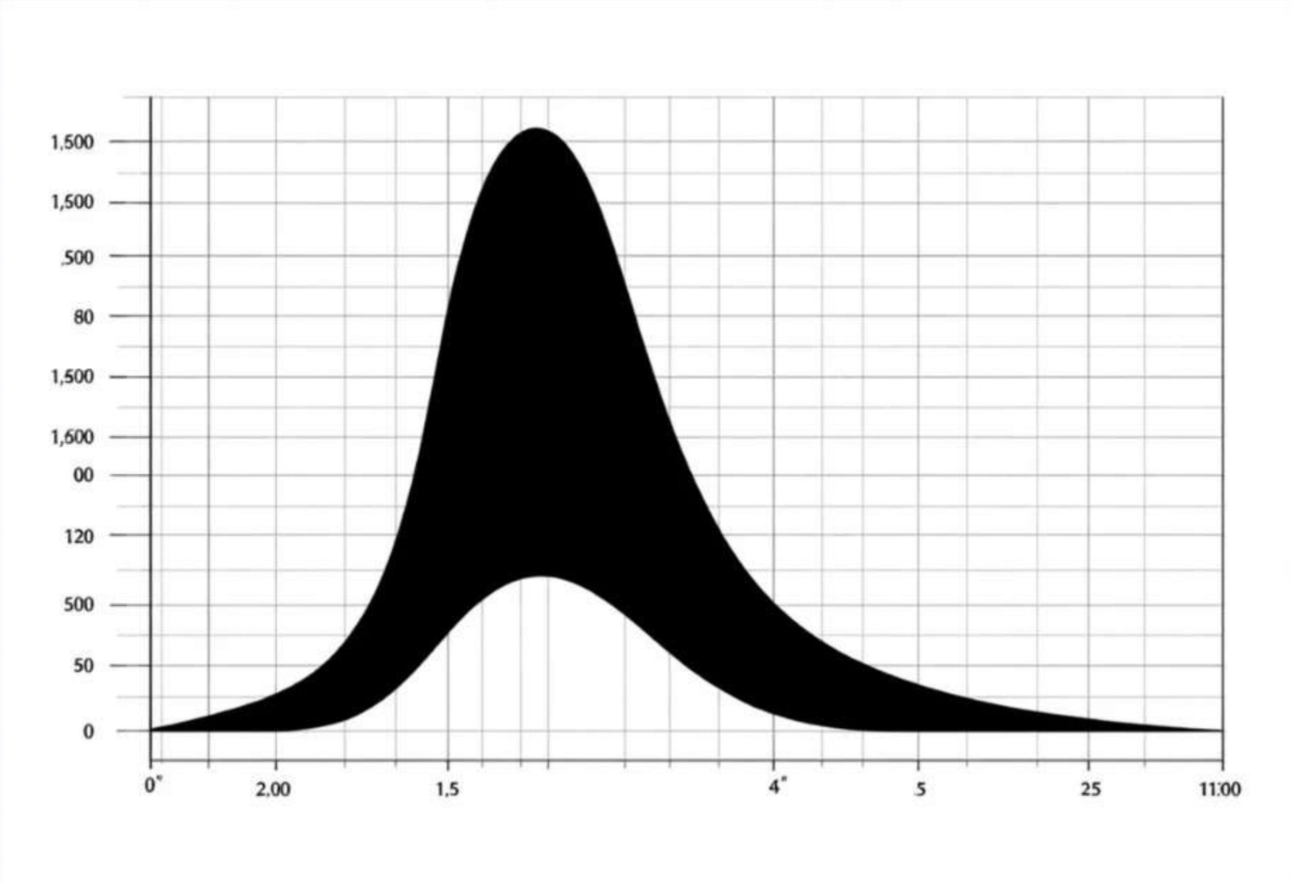
Limited sample availability introduces estimation errors in autocorrelation calculations, affecting detection accuracy.

Channel Variability

Real wireless environments introduce unpredictable variability from channel conditions and interference sources.

These multiple sources of uncertainty motivate the use of cyclostationary features rather than simple energy-based detection methods, which are particularly vulnerable to noise power mismatches.

Key Random Variables



Stochastic Elements

Several important random variables characterise this detection problem:

- **Received signal samples:** Random due to both transmitted symbol randomness and additive noise
- **Noise samples:** Modelled as independent random variables with unknown variance
- **Cyclic autocorrelation estimates:** Random quantities computed from finite data samples
- **Test statistic:** A random variable whose distribution determines detection performance
- **Detection decision:** A random outcome dependent on threshold crossing

Understanding the probabilistic behaviour of these variables is essential for analysing detector performance and reliability.

Probabilistic Models and Assumptions

Core Assumptions

Tractable analysis requires carefully chosen assumptions that balance mathematical simplicity with realistic modelling.

These assumptions enable detector designs that remain effective even when noise power is imperfectly characterised.

- ### Noise Model

  Noise samples are zero-mean and independent, but variance is unknown — reflecting real deployment conditions.

- ### Hypothesis Behaviour

  Under H_0 (noise only), signals exhibit no cyclostationary structure. Under H_1 (signal present), OFDM cyclic prefixes introduce periodic correlations.

- ### Multi-Frequency Advantage

  Using multiple cyclic frequencies provides more reliable evidence than single-frequency analysis, improving robustness.

Probabilistic Reasoning and Inference

Pattern Recognition

Noise alone produces no periodic statistical patterns, but OFDM signals create distinctive cyclostationary structure.

Feature Detection

By searching for periodic patterns in received signals, we infer signal presence without relying solely on energy measurements.

Ratio-Based Testing

A ratio-based test statistic cancels out unknown noise variance, making decisions robust under uncertainty.

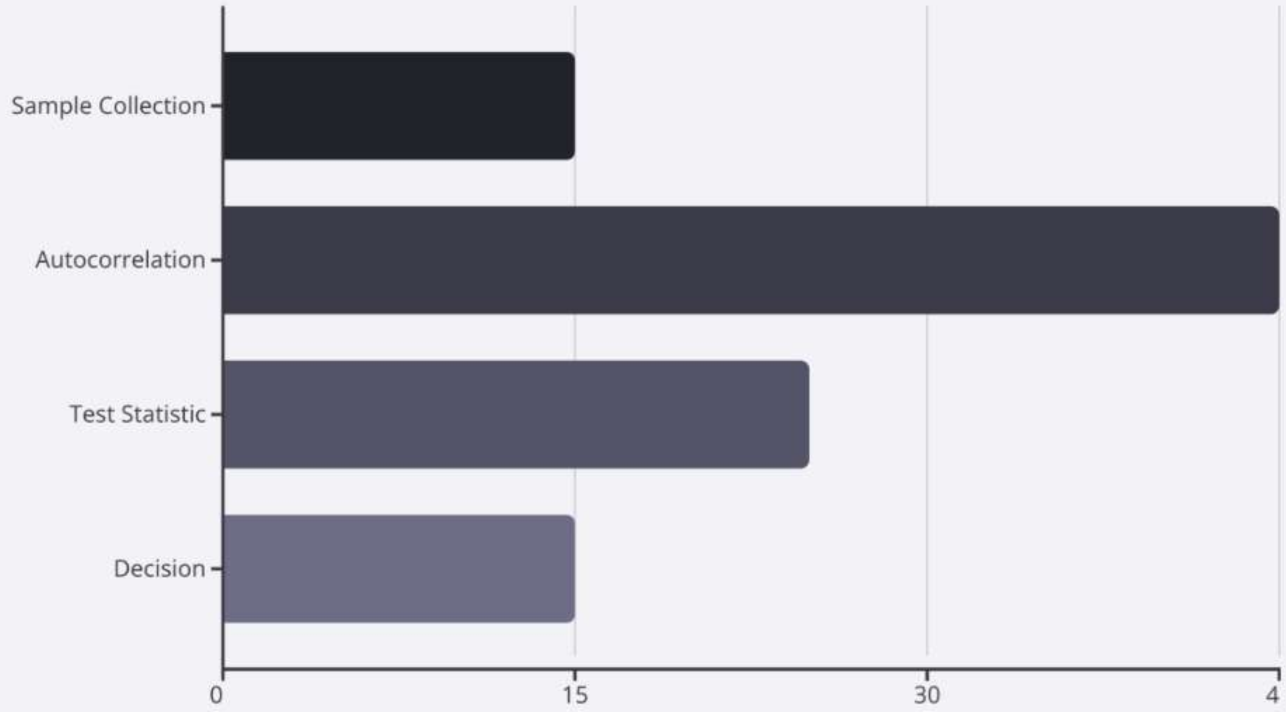
The detector's logic is straightforward: instead of measuring total energy (which depends heavily on noise power), we check whether cyclostationary structure exists consistently across multiple cyclic frequencies. This fundamental shift in approach provides resilience against noise uncertainty that would otherwise cripple conventional energy detectors.

Practical Implementation

Simulation Framework

The detector is evaluated through comprehensive simulations that model realistic operating conditions:

- OFDM signals with various modulation schemes (QPSK, 16-QAM) are generated and combined with additive noise
- Noise variance uncertainty is explicitly modelled rather than assumed perfectly known
- Test statistics are computed over numerous Monte Carlo trials to estimate detection and false alarm probabilities
- Thresholds are selected to maintain predetermined false alarm rates



Whilst simplifying assumptions are necessary for initial analysis, they remain reasonable approximations for understanding fundamental detector behaviour.

Current Limitations and Research Gaps

Simplified Noise Model

Current analysis assumes noise independence and stationarity, which may not fully capture real-world noise characteristics including coloured noise or impulsive interference.

Large-Sample Approximations

Theoretical performance analysis relies on asymptotic approximations that may not accurately predict behaviour with practical finite sample sizes.

Channel Effects

Multipath fading, frequency-selective channels, and realistic propagation conditions are not fully incorporated into the current model framework.

Interference Scenarios

The presence of other interfering signals, adjacent channel leakage, and non-Gaussian noise sources require further investigation and modelling refinement.

We acknowledge these limitations transparently and plan to address them systematically in subsequent project milestones as our understanding deepens.

FUTURE WORK

Planned Improvements and Next Steps

01

Refined Probabilistic Models

Develop more sophisticated noise and channel models whilst relaxing current simplifying assumptions.

02

Finite Sample Analysis

Investigate how limited sample sizes affect detection reliability and establish practical operating guidelines.

03

System Model Clarity

Improve documentation of probabilistic dependencies and statistical relationships within the detection framework.

04

Experimental Validation

Implement and test detector performance using realistic signal traces and measured noise characteristics.

Team Coordination

Our reviewer will ensure consistency across documentation, mathematical models, and experimental implementations. The GitHub manager will maintain version control and facilitate collaboration as we progress through subsequent milestones.

This structured approach ensures steady progress whilst maintaining rigorous probabilistic foundations for our spectrum sensing research.

Summary of Our Understanding

Decision Under Uncertainty

Spectrum sensing is fundamentally a decision-making problem, navigating inherent uncertainties in the radio environment.

Cyclostationary Advantage

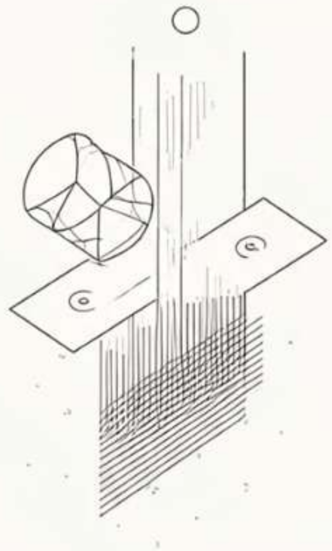
We leverage cyclostationary features for reliable signal detection, effectively differentiating structured signals from random noise.

Enhanced Robustness

Utilising multiple cyclic frequencies significantly boosts detector robustness, particularly against uncertain noise variance.

Clear Probabilistic Basis

Despite ongoing model evolution, the project's robust probabilistic foundation is firmly established, guiding further development.



Thank You