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Optimization of Energy and Spectrum Sensing Using Orthogonal Frequency Division Multiple Access

Dr. Raghavendra Y M[1], Dr. Asha.M[2], Dr. Manjula.G[3], Dr. Latha.M[4], SwaranaLakshmi[5], Harshitha.R[6]
[1,3,4]Associate. Professor, Dept of ECE, GSSSIETW, Mysuru-570016, VTU, Karnataka, India.
[2,5,6] Assistant Professor, Dept of ECE, GSSSIETW, Mysuru-570016, VTU, Karnataka, India.
Emails: *raghavendra@gsss.edu.in[1], asha.m@gsss.edu.in[2], manjulag@gsss.edu.in[3], latha@gsss.edu.in[4], r.harshitha@gsss.edu.in[5], swarnalakshmikb@gsss.edu.in[6]*

Abstract

Orthogonal Frequency Division Multiple Access (OFDMA) has emerged as a cornerstone technology in modern wireless communication systems due to its ability to efficiently utilize spectrum resources. However, the dynamic nature of wireless environments demands robust spectrum sensing techniques to ensure efficient spectrum utilization and mitigate interference. The fundamentals of OFDMA and its significance in contemporary wireless network is initially discussed by offering high spectral efficiency, flexibility, and support for diverse services, making it a fundamental technology in standards such as LTE (Long-Term Evolution) and Wi-Fi. Its significance is expected to grow further with the deployment of 5G and beyond. This article presents a comprehensive analysis of Optimized energy detection-based spectrum sensing in OFDMA systems. Evaluated the system performance through simulation by considering parameters such as energy consumption, detection accuracy, and spectral efficiency. Finally, we provide insights into future research directions and emerging trends in spectrum sensing optimization for OFDMA systems, including cognitive radio networks, dynamic spectrum access, and fifth-generation (5G) wireless networks.

Keywords: *Detection accuracy; Energy consumption; Spectrum sensing; Spectral efficiency.*

1. Introduction

Orthogonal Frequency Division Multiple Access (OFDMA) has emerged as a pivotal technology in modern wireless communication systems, facilitating efficient spectrum utilization and enabling high-speed data transmission in diverse environments [1]. Its ability to divide the available spectrum into orthogonal subcarriers has revolutionized the design of wireless networks, offering flexibility, scalability, and robustness to accommodate the ever-increasing demand for wireless connectivity. However, the dynamic and heterogeneous nature of wireless environments presents significant challenges to the optimal operation of OFDMA systems. One of the key challenges lies in spectrum sensing, which is essential for detecting and identifying unused spectrum bands, mitigating interference, and enabling dynamic spectrum access. Efficient spectrum sensing not only enhances spectrum utilization but also improves the overall performance and reliability of wireless communication systems [2]. This article provides a comprehensive overview of recent advancements in the optimization of energy and spectrum sensing techniques in OFDMA systems. We begin by discussing the fundamental principles of OFDMA and its significance in modern wireless networks. The concept of spectrum holes in spectrum sensing relates to the availability of unused or underutilized frequency bands within the radio frequency spectrum. These unused bands, also known as white spaces, represent opportunities for efficient spectrum utilization, especially in dynamic spectrum access (DSA) and cognitive radio systems as shown in Figure 1 [3].

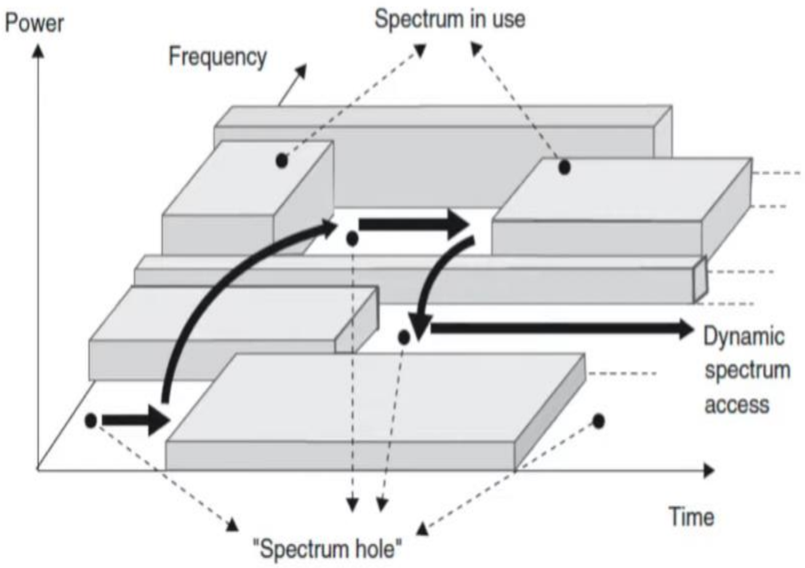

Figure 1 Concept of Spectrum Holes

Spectrum sensing techniques are used to detect these spectrum holes by identifying frequency bands where the primary licensed users are not actively transmitting. The detection of spectrum holes allows secondary users (unlicensed users or cognitive radio devices) to opportunistically access and utilize these idle frequency bands without causing interference to the primary users. The presence of spectrum holes can vary depending on factors such as time, location, and the behavior of primary users. Effective spectrum sensing algorithms and methodologies are essential for accurately detecting spectrum holes and enabling dynamic spectrum access. Techniques such as energy detection, cyclostationary feature detection, and machine learning-based classification are used to identify spectrum holes and facilitate efficient spectrum utilization in wireless communication systems. Additionally, recent research efforts focusing on the optimization of energy-efficient spectrum sensing algorithms are discussed, with an emphasis on enhancing detection accuracy while minimizing computational complexity and energy consumption. Moreover, we explore the synergies between spectrum sensing and other aspects of OFDMA system design, such as resource allocation, interference management, and cognitive radio functionalities. Insights from these studies provide valuable guidance for the development of integrated solutions that leverage spectrum sensing to enhance the overall efficiency and reliability of OFDMA-based wireless networks [4-5]. Figure 2 shows an Orthogonal Frequency Division Multiple Access (OFDMA) system with multiple users transmitting random data over multiple OFDMA symbols [6-8]. To generate OFDMA System 4 users, 64 subcarriers, 10 OFDMA Symbols used to transmit for each user. Random binary data is generated for each user using the randi function. Each user's data is represented as a matrix with dimensions [numUsers, numDataSymbols * numSubcarriers]. This ensures that each user has random data to transmit over multiple OFDMA symbols. The generated random data for each user is modulated using OFDMA. The OFDMA symbols variable is a three-dimensional array with dimensions [numUsers, numSubcarriers, numDataSymbols].

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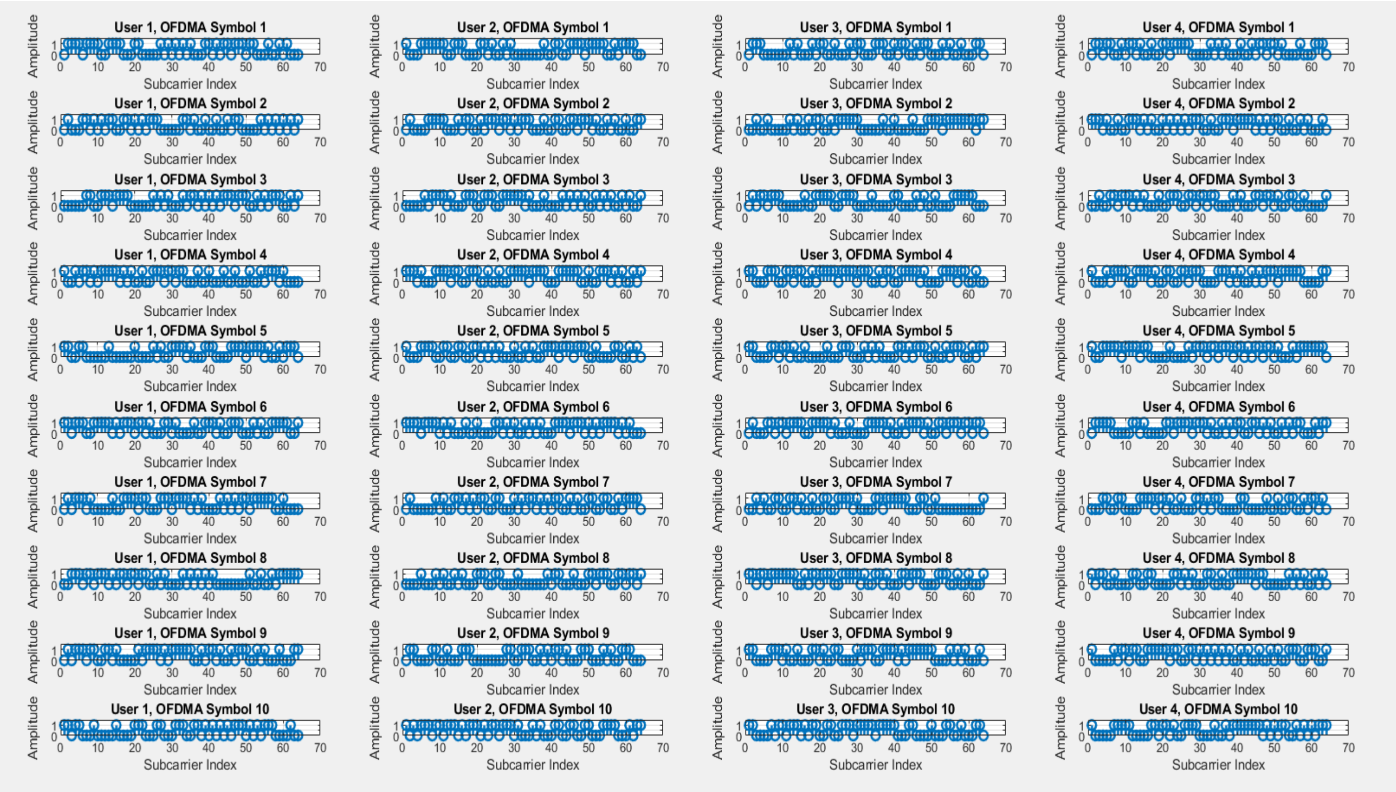

Figure 2 Basic OFDMA Systems

It represents the OFDMA symbols for each user over multiple OFDMA symbols. For each OFDMA symbol and each user, a subplot is created to plot the amplitude of the OFDMA symbols. The amplitude of each subcarrier for each user's OFDMA symbol is plotted using the stem function. The subplot titles indicate the user number and the OFDMA symbol number. The y-axis is limited to [0, 1.5] for better visualization, but you can adjust it as needed. Overall, figure1 visualize OFDMA symbols transmitted by multiple users in an OFDMA system. It's useful for understanding the distribution of data across subcarriers for each user over time.This paper is organized as follows: An overview of related work is given by section II. Section III explains about method used for implementation. Section IV describes about Simulation Results. Section V explains about novelty. Section VI provides future scope. And finally conclude the paper in section VII.

2. Related Work

1. Zheng et al. proposes an energy-efficient cooperative sensing scheme for cognitive radio networks based on OFDMA technology [9]. It explores the trade-offs between energy consumption and sensing performance, providing insights into the design of efficient spectrum sensing algorithms.

2. Zhenyu et al. investigate the problem of optimal energy allocation for spectrum sensing in OFDMA-based cognitive radio networks [10]. They formulate an optimization problem to minimize the energy consumption while ensuring reliable spectrum sensing, considering the dynamic nature of the wireless environment.

3. Yimin Zhang et al. proposes a cooperative spectrum sensing method based on sparse representation for OFDMA systems [11]. By exploiting the sparsity of the received signals, the proposed method achieves efficient spectrum sensing with reduced computational complexity, making it suitable for resource-constrained

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OFDMA devices.

4. Chunshan et al. present an energy-efficient cooperative spectrum sensing scheme for OFDMA cognitive radio networks, considering fairness among secondary users [12]. The proposed scheme optimizes energy allocation and transmission power while ensuring fairness in spectrum access, enhancing the overall efficiency of the cognitive radio network.

5. Zhang et al. explores the application of deep reinforcement learning (DRL) for spectrum sensing optimization in OFDMA-based cognitive radio networks [13]. By leveraging DRL techniques, the proposed method adaptively learns optimal spectrum sensing strategies, leading to improved spectrum utilization and network performance.

6. Huang et al. address the problem of robust cooperative spectrum sensing in OFDMA-based cognitive radio networks in the presence of unknown noise power [14]. They develop a robust sensing algorithm that mitigates the impact of noise uncertainty, improving the reliability and accuracy of spectrum sensing in practical scenarios.

7. Wu et al. propose a deep reinforcement learning-based spectrum sensing approach for OFDMA-based cognitive radio networks [15]. By training a deep neural network agent, the proposed method learns optimal sensing policies in a data-driven manner, demonstrating promising performance in dynamic and complex wireless environments.

8. Ali, H et al. provides a comprehensive overview of energy-efficient spectrum sensing techniques specifically tailored for Orthogonal Frequency Division Multiple Access (OFDMA) systems [16]. It discusses the trade-offs between energy consumption and sensing performance, highlighting the importance of optimizing energy efficiency while maintaining satisfactory detection accuracy.

9. Li, S et al. proposes a novel framework for joint optimization of energy efficiency and spectrum sensing performance in OFDMA networks [17]. By formulating an optimization problem that considers both energy consumption and detection accuracy as objective functions, the authors develop an efficient algorithm to find the optimal trade-off between these conflicting metrics. The proposed approach leverages machine learning techniques and adaptive sensing strategies to dynamically adjust sensing parameters based on channel conditions and traffic patterns, thereby achieving significant improvements in both energy efficiency and sensing performance.

10. Wang et al. investigates the application of machine learning techniques for optimizing spectrum sensing in OFDMA systems [18]. By utilizing historical sensing data and feedback from the environment, machine learning algorithms such as deep neural networks and reinforcement learning are employed to adaptively adjust sensing parameters and improve detection accuracy. The study explores various machine learning architectures and training strategies tailored for spectrum sensing tasks, demonstrating significant enhancements in sensing performance and energy efficiency compared to traditional approaches.

11. Zhao et al. proposes a cross-layer optimization framework for energy-efficient spectrum sensing in OFDMA-based cognitive radio networks [19]. By jointly considering physical layer sensing parameters, MAC layer protocols, and higher-layer cognitive functionalities, the authors develop a holistic optimization approach that maximizes both energy efficiency and spectrum utilization. The proposed framework integrates dynamic spectrum access, cooperative sensing, and adaptive transmission techniques to achieve synergistic benefits across different protocol

layers, resulting in improved overall system performance.

12. Zhang, L et al. discusses the security challenges associated with spectrum sensing in OFDMA systems and proposes techniques to enhance the robustness of sensing algorithms against malicious attacks and adversarial threats [20]. By leveraging cryptographic mechanisms, authentication protocols, and anomaly detection techniques, the study addresses vulnerabilities such as spoofing attacks, jamming, and collusion, ensuring the integrity and reliability of spectrum sensing operations in hostile environments.

13. Raghavendra Y.M et.al, introduces an energy optimization technique specifically tailored for CR-WSNs, focusing on the crucial aspect of spectrum sensing. The proposed technique deploys a two-stage sensing strategy involving a primary sensor and a secondary sensor. The primary sensor identifies the presence of primary users in the spectrum band, activating the secondary sensor only when a primary user is detected. The secondary sensor conducts [21].

14. more detailed sensing to ascertain the available bandwidth for subsequent data transmission. Machine learning algorithms are employed in the proposed technique to finely tune the energy consumption of the CR-WSN during the spectrum sensing process. Through simulation assessments, the effectiveness of the proposed technique is gauged, revealing significant reductions in the energy consumption of the CR-WSN while upholding a high level of accuracy in spectrum sensing.

15. These recent studies highlight the growing interest in optimizing spectrum sensing in OFDMA systems, addressing various aspects such as energy efficiency, detection accuracy, machine learning integration, cross-layer optimization, and security considerations. However, further research is to focus on optimization of energy in spectrum sensing using OFDMA Technology. Which will warranted to tackle remaining challenges and unlock the full potential of OFDMA technology in next-generation wireless networks.

3. Methodology

Figure 3 shows the block diagram of the Energy Detection-based Spectrum Sensing OFDMA system. Energy detection-based spectrum sensing is a fundamental technique used in cognitive radio systems to detect the presence of primary users (PU) and available spectrum opportunities.

Primary Users (PU): These are licensed users who have exclusive rights to operate in specific frequency bands.

Secondary Users (SU): These are unlicensed users who aim to opportunistically access spectrum not used by primary users.

Spectrum Sensing: It's the process of monitoring the spectrum to detect the presence or absence of primary users.

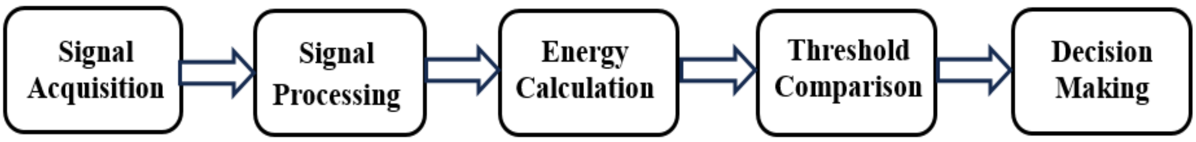

Figure 3 Block Diagram of the Energy Detection-Based Spectrum Sensing OFDMA System

3.1.Energy Detection Principle

Energy detection is a non-coherent sensing technique where the secondary user monitors the energy level in a particular frequency band to determine its occupancy. The presence of primary users in the spectrum results in a significant increase in energy levels compared to the noise floor. Energy detection

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compares the received signal energy with a predefined threshold to make a decision about spectrum occupancy.

3.2. Steps in Energy Detection-based Spectrum Sensing

Signal Acquisition: The secondary user receives signals from the environment using its receiver.

Signal Processing: The received signals are filtered, and the relevant frequency band is extracted. The signal is then digitized and processed to obtain its power or energy level.

Energy Calculation:

The energy of the received signal is calculated over a specific time window or frequency band. This energy calculation can be performed using simple metrics like squared magnitude or power of the received signal and is given by

Y=1/Ts ∫_0^Ts▒ 〖|r(t)|〗 ^2 dt

Where r(t) is the received signal which includes both primary user signal and the noise. The integral calculates the total energy in the received signal over the observation window Ts.

Threshold Comparison:

For energy detection-based spectrum sensing in an OFDMA system, the threshold (λ) can be set to achieve a desired minimum detection probability Pdmin

$$P_d = Q\left(\frac{\lambda - T_s(\sigma_n^2+\sigma_s^2)}{\sqrt{T_s}(\sigma_n^2+2\sigma_s^2)}\right) \geq P_d^{min}$$

Q(.) is the Q function representing the tail probability of the Gaussian distribution.

σ n2 is the noise power

σ s2 is the power of the primary user signal.

Ts is the sensing duration, representing the observation window over which energy is integrated.

Pdmin minimum desired detection probability.

The received signal Y is compared with the predefined threshold level λ.

Decision Making:

Based on the threshold comparison, a decision is made about spectrum occupancy. This decision is crucial for the secondary user to decide whether it can opportunistically transmit data without causing interference to primary users.

- If Y > λ, decide that the spectrum is occupied by primary user
- If Y < λ, decide that the spectrum is not occupied by primary user

3.3. Advantages and Challenges

Advantages:

- Energy detection is simple and can be implemented with low-complexity hardware.
- It's applicable in various environments and can detect both known and unknown signals.

Challenges:

- **Sensitivity to noise:** Performance can degrade in noisy environments.
- **Requires accurate threshold setting:** Proper threshold selection is critical for balancing detection performance and false alarm probability.
- **Performance trade-offs:** There's a trade-off between detection probability and false alarm probability, which may vary depending on the application requirements. In summary, energy detection-based spectrum sensing provides a straightforward method for secondary users to detect spectrum opportunities by monitoring the energy levels in the spectrum. While simple to implement, proper threshold selection and noise handling are essential for reliable performance in real-world scenarios.

4. Results

Figure 4 is a plot that visualize the optimization of energy and spectrum sensing using Orthogonal Frequency Division Multiple Access (OFDMA). Which illustrates energy threshold V/S energy consumption, spectral efficiency, detection accuracy. The following steps involved in MATLAB R2021A for simulation of an Orthogonal Frequency Division Multiple Access (OFDMA) system with energy detection-based spectrum sensing.

4.1. System Parameters

num-Subcarriers: Number of subcarriers in the OFDMA system.

num-Users: Number of users transmitting data over the system.

snr: Signal-to-noise ratio.

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Energy Threshold: Range of energy thresholds to be tested for spectrum sensing. It's generated using linspace() to create a vector of 20 equally spaced values between 5 and 15.

Initialization:
Three arrays (detection Accuracy, spectral Efficiency, energy Consumption) are initialized to store the results of the simulation.

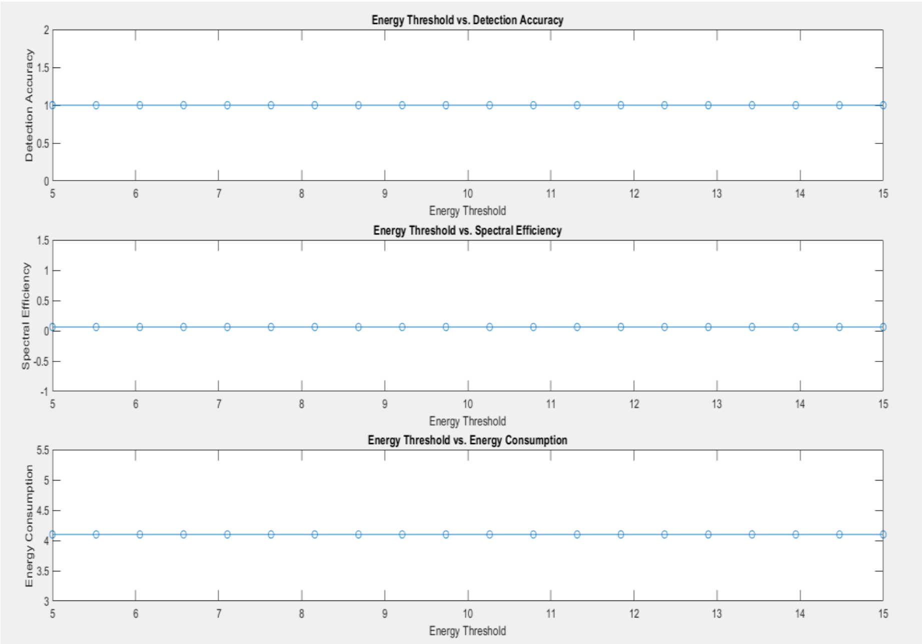

Figure 4 **Simulation Plot for Energy Detection-Based Spectrum Sensing OFDMA System**

4.2.Main Loop

The loop iterates over each energy threshold value. Inside the loop, random data symbols are generated for each user, modulated using QPSK modulation, and then assigned to subcarriers in the OFDMA frame. AWGN noise is added to the frame. Energy detection is performed to detect active subcarriers based on the current energy threshold. Detection accuracy, spectral efficiency, and energy consumption are calculated and stored in the respective arrays.

4.3. Plotting Results

- Three subplots are created in a single figure to visualize the results.
- The first subplot shows how detection accuracy varies with different energy thresholds.
- The second subplot illustrates the relationship between spectral efficiency and energy thresholds.
- The third subplot depicts how energy consumption changes with different energy thresholds.

4.4. Visualization

Finally, the figure with the three subplots is displayed. Overall, this steps in MATLAB demonstrates how changing the energy threshold affects detection accuracy, spectral efficiency, and energy consumption in an OFDMA system.

4.5. Novelty

In this study, we investigated the application of energy detection-based spectrum sensing for optimizing energy and spectrum sensing in Orthogonal Frequency Division Multiple Access (OFDMA) systems. We considered parameters such as energy consumption, detection accuracy, and spectral efficiency to evaluate the performance of the system through simulation and analysis. We explored a range of energy thresholds to determine their impact on detection accuracy, spectral efficiency, and energy consumption by modulating data symbols using QPSK modulation. The choice of energy threshold plays a crucial role in balancing detection performance and energy efficiency. Adjusting the energy threshold can optimize these parameters detection accuracy, spectral efficiency, and energy consumption. based on specific system requirements and operational constraints. Plots were generated to visualize the relationship between the energy threshold and the system's performance metrics. These plots provided insights into the trade-offs and helped in understanding the optimal operating points for the OFDMA system.

Future Scope

The future scope of energy detection-based spectrum sensing within OFDMA frameworks holds great promise for optimizing energy and spectrum allocation in wireless communication systems. By addressing current challenges and exploring new research directions, researchers and practitioners can unlock innovative solutions to enhance spectrum efficiency, improve system performance, and enable new applications and services in the era of 5G and beyond.

Conclusion

In this work, Optimized energy detection-based spectrum sensing is proposed. In this study, we investigated the application of energy detection-based spectrum sensing for optimizing energy and spectrum sensing in Orthogonal Frequency Division Multiple Access (OFDMA) systems. The energy detection-based spectrum sensing offers a practical approach for spectrum utilization in OFDMA systems. By carefully tuning the energy threshold, secondary users can effectively detect spectrum opportunities while minimizing energy consumption and maximizing spectral efficiency. Visualizing the performance metrics through plots facilitates decision-making and enables system designers to make informed choices regarding parameter settings for optimal system operation.

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