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Energy Harvesting Scheme for Dynamic Spectrum Access using Cognitive Radio Technology

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Abstract

In this paper, a hybrid energy harvesting strategy is proposed that maximizes energy collection by utilizing Radio Frequency (RF) energy obtained from both Primary Users (PU) and Secondary Users (SU), and accurately detecting their presence or absence in the channel. Specifically, it examines the captured energy vis-à-vis the planned transmission power, guaranteeing a wise deployment of available resources. The proposed approach efficiently incorporates external energy sources to fill up any gaps in energy availability, thus, bypassing the restrictions imposed by battery lifespans. The efficacy of this proposed strategy is carefully examined using large numerical simulations, which provide persuasive proof of its superiority over conventional methods.

Keywords: Energy Harvester, Battery life, Spectrum Access, Spectrum scarcity, cognitive Radio.

1. Introduction

In the increasingly interconnected world of wireless networks, the demand for uninterrupted communication and efficient energy utilization has become paramount. As the proliferation of wireless devices continues to expand, traditional power sources often prove insufficient to sustain these networks over extended periods, particularly in remote or challenging environments. Consequently, the concept of energy harvesting has emerged as a pivotal solution to address this pressing need. Energy harvesting involves the capture and conversion of ambient energy from the surrounding environment into usable electrical power. In wireless networks, where devices are often deployed in diverse and dynamic settings, energy harvesting offers a promising avenue to enhance sustainability, reliability, and autonomy. This introductory paragraph sets the stage for exploring the critical role of energy harvesting in ensuring the longevity and performance of wireless networks in various applications and scenarios.

Cognitive radio technology stands at the forefront of innovation in wireless networks, offering a suite of capabilities that can revolutionize energy harvesting practices. At its core, cognitive radio is characterized by its intelligence and adaptability, enabling devices to dynamically sense, analyze, and respond to their operating environment. One of the key ways cognitive radio technology can contribute to energy harvesting is through its spectrum awareness feature. By continuously monitoring the radio frequency spectrum, cognitive radios can identify unused or underutilized frequency bands, commonly referred to as spectrum white spaces. This awareness allows devices to opportunistically switch to frequencies with lower interference levels, thereby reducing energy consumption associated with overcoming signal degradation caused by interference. Additionally, cognitive radios can adjust their transmission parameters in real-time based on spectrum availability and channel conditions. This adaptive transmission capability ensures that devices operate at optimal power levels and modulation schemes, maximizing energy harvesting efficiency while maintaining reliable communication links.

Moreover, cognitive radio technology facilitates dynamic spectrum access, enabling devices to opportunistically utilize available spectrum resources. This flexibility allows devices to access spectrum bands with higher energy potential, further enhancing energy harvesting capabilities. Energy-aware networking protocols, specifically designed for cognitive radio networks, play a crucial role in optimizing energy harvesting strategies. These protocols leverage cognitive capabilities to intelligently manage energy resources, coordinate energy-efficient communication, and adapt network configurations to maximize overall energy utilization and network performance. Furthermore, cognitive radio networks can foster cooperative energy harvesting schemes, where devices collaborate to harvest energy collectively. By intelligently coordinating energy harvesting activities among neighboring devices, cognitive radio networks can mitigate energy imbalances across the network and ensure sustainable operation over extended periods.

In essence, cognitive radio technology offers a multifaceted approach to enhancing energy harvesting in wireless networks. Through spectrum awareness, adaptive transmission, dynamic spectrum access, energy-aware networking protocols, and cooperative energy harvesting schemes, cognitive radios enable more efficient utilization of ambient energy sources. This not only prolongs network operation and reduces reliance on traditional power sources but also contributes to the sustainability and autonomy of wireless communication systems in diverse environments and applications.

Paper Contribution

The main contributions of this paper are:

A hybrid energy harvesting scheme is proposed for cognitive radio networks.

The efficiency of the proposed approach for performance enhancement is demonstrated with extensive simulations.

The performance of the developed hybrid energy harvesting scheme is evaluated using key metrics such as energy harvesting efficiency, network throughput, spectrum utilization, and system reliability.

Paper Organization

The rest of the paper is organized as follows: in section II literature survey is discussed. In section III, the system model and proposed algorithm is discussed. Section IV discusses the results, section V concludes the work and section VI gives brief introduction to authors.

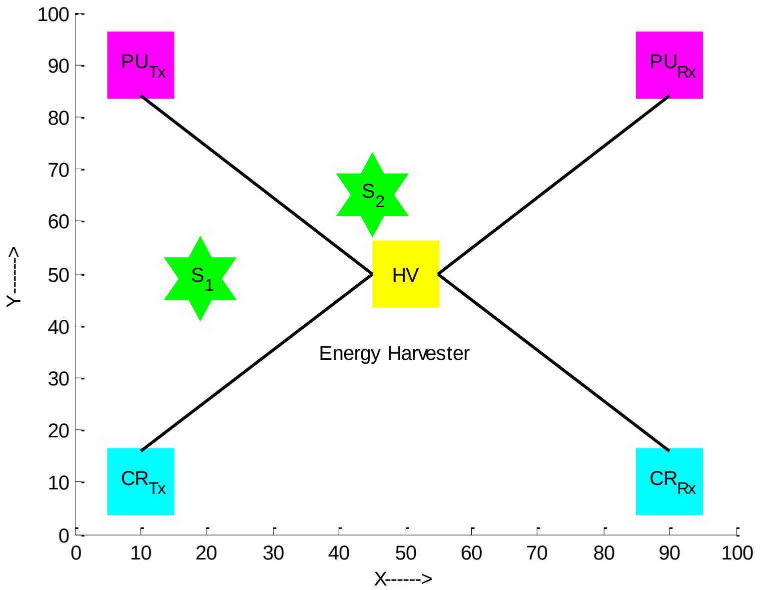
2. Literature Review

In [1], the authors have provided an in-depth review of energy harvesting techniques applicable to wireless sensor networks, covering various harvesting sources, conversion methods, and applications. It may also discuss challenges, opportunities, and future directions in the field. In [2], T. Charles Clancy et al have presented research conducted at Virginia Tech related to cognitive radio and networking, discussing various aspects such as spectrum sensing, dynamic spectrum access, cognitive radio architectures, and applications in wireless communication systems. A comprehensive overview of the state-of-the-art in energy harvesting technologies, covering different energy sources (e.g., solar, kinetic, RF) and their conversion mechanisms. It may also discuss recent advances, challenges, and potential applications. The work presented in [4], reviews the recent advances in energy-harvesting communication systems, discussing various aspects such as energy-harvesting techniques, system design considerations, protocols, and applications in wireless communication networks. The role of cognitive radio as an enabling technology for the Internet of Things (IoT), is discussed with a focus on how cognitive radio techniques can improve spectrum utilization, enhance connectivity, and support IoT applications. An overview of cognitive radio principles and applications, discussing concepts such as spectrum sensing, dynamic spectrum access, learning algorithms, and cognitive radio networks[6]. In [7], fundamental trade-offs are discussed on designing green wireless networks, considering factors such as energy efficiency, network performance, spectrum utilization, and environmental sustainability. In [8], the intersection of cognitive radio and sensor networks is explored while discussing potential applications, technical challenges, and emerging research trends in cognitive radio sensor networks. The work presented in [9] focuses on dynamic spectrum access techniques in cognitive radio networks, discussing modeling approaches, spectrum sensing methods, and exploitation strategies in the time domain. In [10], an integrated agent architecture for software-defined radio (SDR) systems, discusses the role of cognitive radio techniques in enabling flexible, adaptive, and autonomous radio communications.

3. Proposed System Model

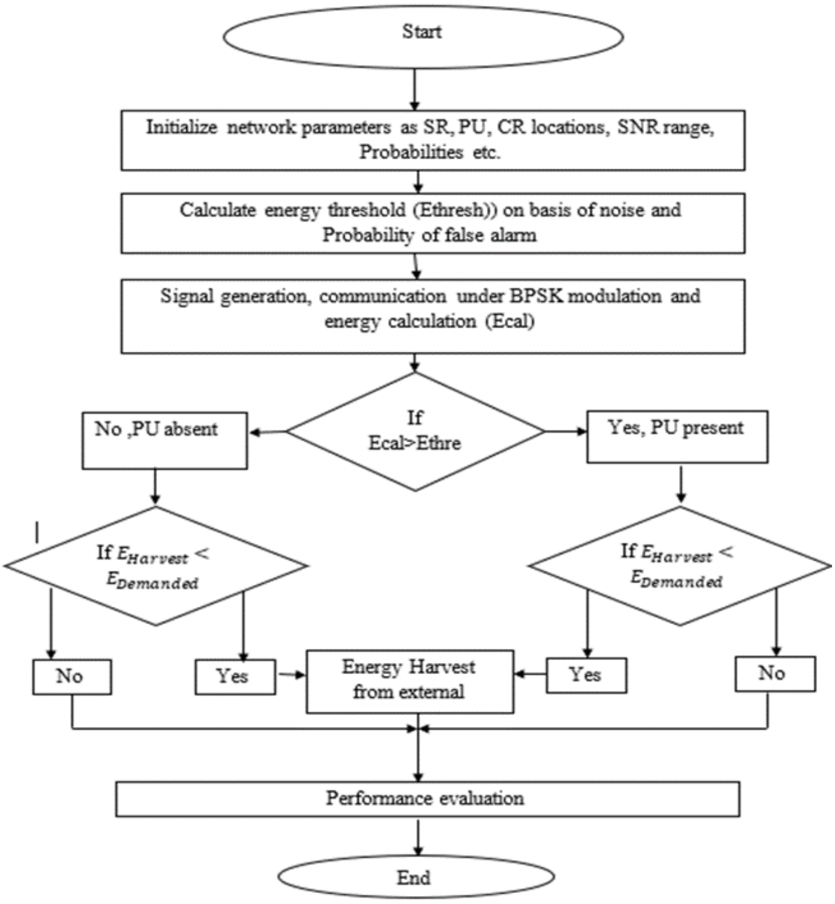
In our proposed system model, we're examining a dynamic communication situation where numerous entities interact to allow efficient data transmission. At the center of this configuration are the Primary User Transmitter (PU_Tx) and the Primary User Receiver (PU_Rx), active in transmitting and receiving vital information within the assigned spectrum. Alongside this primary communication link, we introduce the Secondary User Transmitter (SU_Tx) and the Secondary User Receiver (SU_Rx), establishing an alternative communication channel. The SU_Tx is designed to opportunistically exploit transmission opportunities, using the spectrum during periods of PU inactivity. This adaptive behavior is made feasible through the deployment of Cognitive Radio (CR) technology, allowing the SU_Tx to dynamically modify its transmission parameters to ensure compatibility with the spectrum's availability.

Fig. 1: System Model



3.1. Proposed Algorithm

Figure 2. Flow Diagram for Proposed Energy Harvesting Scheme



The stepwise explanation of the proposed scheme in fig. 2 is as follows:

Step 1: Initialize network parameters, primary and secondary users positions and probability of false alarm.

Step 2: Calculate the decision threshold based on the false alarm probability.

Step 3: Acquire the received signal from the shared channel.

Step 4: Compare received signal strength with the threshold.

Step 5: If PU is present, and harvested energy is less than the required energy for transmission, Turn ON the harvester and scavenge energy from PU RF signal.

Step 6: If PU is absent but other CR nodes are present in a channel and harvested energy is less than desired energy, harvest energy from CR nodes RF signals.

Step 7: If both, PU and CR noses are absent from the channel and harvested energy is less than the desired value, then use an external energy source for harvesting.

Step 8: Evaluate system performance in terms of throughput and energy harvesting.

4. Results and Discussion

In this section, simulated results are presented to validate the performance. Figure 3 illustrates the network throughput graph for the proposed energy harvesting scheme across different harvesting parameter values, while varying the SNR. The analysis reveals an intriguing impact of the harvesting parameter (α) on network throughput. Contrary to intuitive expectations, the results indicate a reduction in throughput as α increases, with the throughput being notably lower at α=0.2 compared to α=0.16. This unexpected trend suggests that while the integration of an external energy source has a positive effect on system performance, there exists an optimal range for the harvesting parameter that maximizes throughput. Remarkably, despite the decrease in throughput at higher α values, the proposed scheme outperforms the conventional approach. In the conventional system, throughput values vary between 0 and a maximum of 6.5, whereas in the proposed scheme, throughput ranges from 1 to approximately 33, representing a substantial improvement. These findings underscore the effectiveness of the proposed energy harvesting scheme in enhancing network throughput compared to conventional methods, despite the nuanced impact of the harvesting parameter on system performance. Further investigation into the underlying mechanisms driving these results could provide valuable insights for optimizing energy harvesting strategies in cognitive radio systems.

Fig. 3: Proposed Network Throughput Graph with Varying SNR at Different *α*

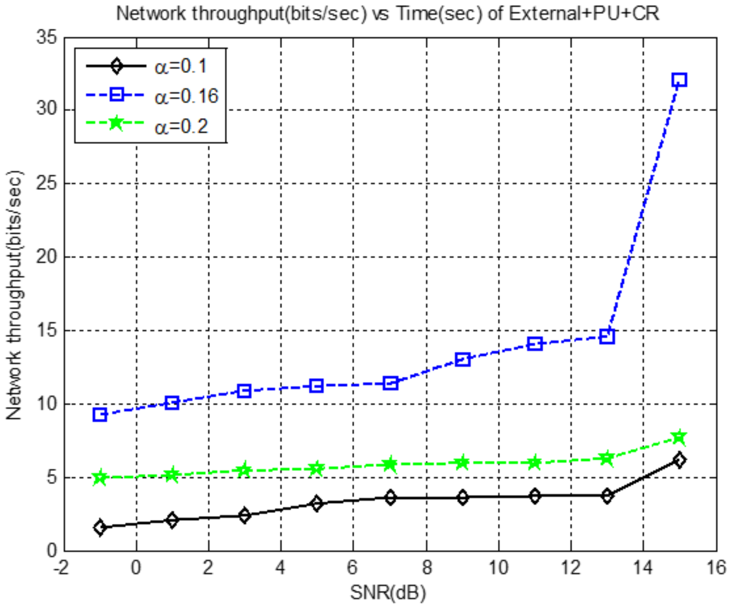


Fig. 4: Impact of varying α values in the proposed scheme

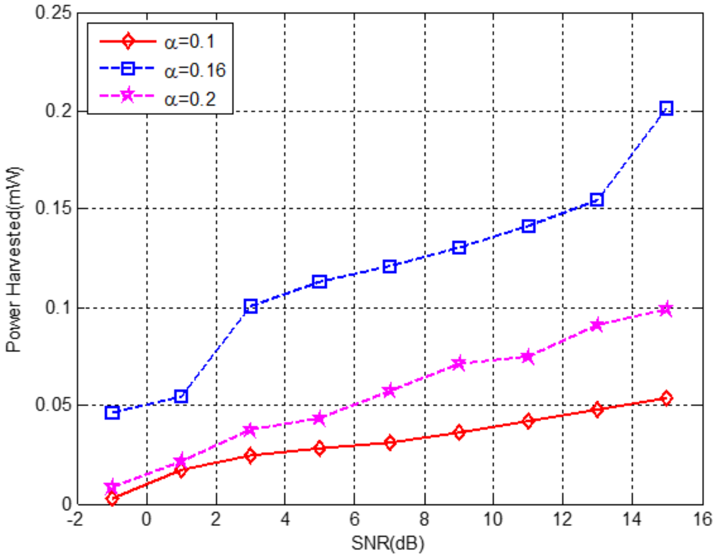


Figure 4 depicts the impact of varying α values in the proposed scheme, showing harvested power ranging from 0 to 0.2. The results exhibit distinct impacts at different α values: at α=0.1, the harvested power ranges from 0 to 0.05, at α=0.16, it varies between 0.05 to 0.2, and at α=0.2, it decreases to 0 to 0.1. Despite similarities in the trend of harvested power increasing with SNR, the proposed scheme yields higher harvested power values compared to the conventional system. These findings underscore the importance of effectively selecting α to optimize energy harvesting in the network, emphasizing the need for careful consideration of energy harvesting parameters to enhance system performance and sustainability.
In Figure 5, the evaluation of the proposed scheme in terms of power harvested by varying the α parameter is presented, with each curve representing different sources involved in power harvesting. The blue curve illustrates power harvested solely from cognitive radio (CR), while the pink curve depicts power harvested from primary users (PU). The green curve represents power harvested from a hybrid combination of PU and CR, and the red curve signifies power harvested from CR, PU, and an external source utilizing the proposed scheme. The analysis reveals distinct trends among these scenarios: notably, the power harvested solely from CR exhibits low values, with minimal increase as α varies, eventually reaching a static level, indicating insufficient energy for further harvesting. In contrast, the other three cases—harvesting from PU, a hybrid PU and CR combination, and the proposed scheme—exhibit increasing power curves, indicating the influence of α on harvested energy. The proposed system's curve consistently surpasses the others, with harvested power values ranging from 0.02 to 0.21, compared to approximately 0.02, 0.17, and 0.18 for maximum power harvested solely from CR, PU, and their hybrid combination, respectively. These findings underscore the efficacy of the proposed scheme in enhancing power harvesting capabilities, highlighting its potential to provide higher energy yields compared to alternative harvesting scenarios, and emphasizing its suitability for energy-constrained cognitive radio networks.

Fig. 5: Power harvested by varying the α

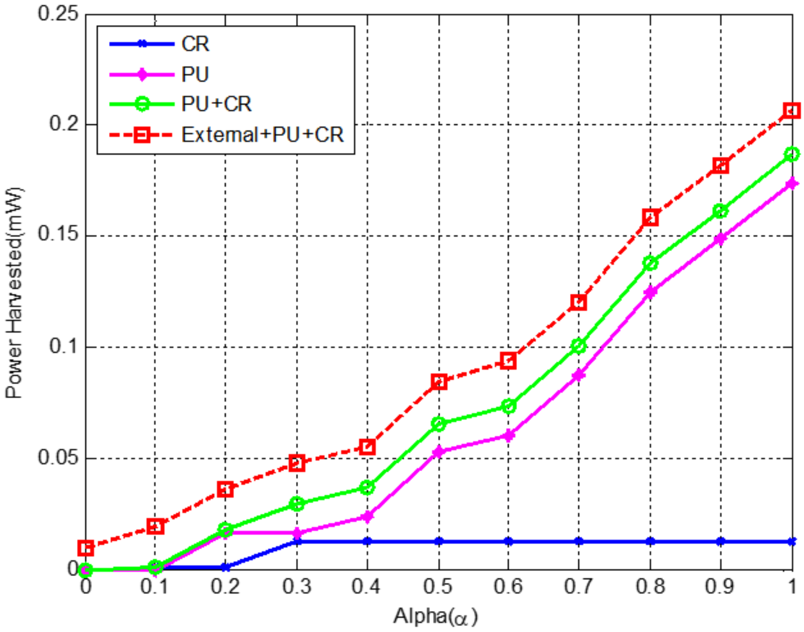


Figure 6. Comparison graph of Power Harvested with Varying Sensing Time

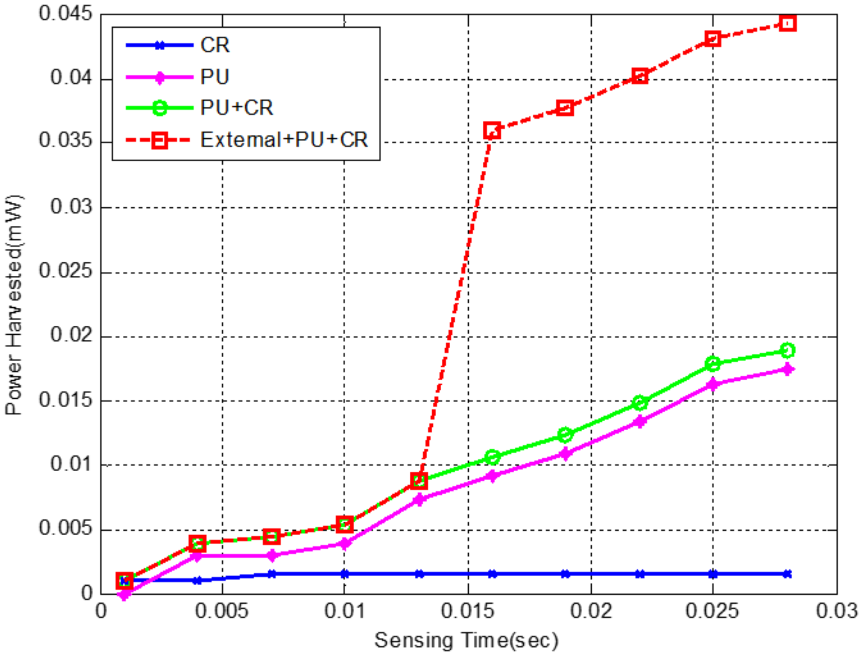


Figure 6 displays the resultant graphs illustrating power harvested with varying sensing times. Analysis from the simulation indicates that a shorter sensing time results in lower harvested power, while an increase in sensing time leads to a faster rate of power harvesting. This observation suggests that allocating more time for sensing allows the system to harvest more power from available resources to meet energy demands effectively. Comparing the proposed scheme with the other three models, it is evident that the proposed scheme demonstrates an increasing pattern of energy harvesting, akin to the PU+CR model. However, as the sensing time increases, the proposed scheme exhibits a more pronounced increase in harvested power, reaching up to 0.045, whereas it remains approximately at 0.017 and 0.018 for PU and PU+CR, respectively. This difference is attributed to the proposed system's ability to extract higher energy from both PU and CR sources, with the additional benefit of harvesting energy from an external source. Consequently, the overall harvested energy increases significantly with longer sensing times, highlighting the importance of optimizing sensing durations to maximize energy harvesting efficiency in cognitive radio systems.

5. Conclusion

In this paper, we have investigated the performance of a cognitive radio network by integrating an external power source alongside primary users (PU) and cognitive radios (CR) to enhance throughput and power harvesting capabilities. Through extensive simulation studies conducted in MATLAB, we developed a scenario deploying PU, CR, and external power sources within a 100x100 m² area. Analytical expressions were derived for the proposed scheme to facilitate analysis. Our investigation focused on varying parameters such as α, SNR, and sensing time to assess their impact on network throughput and power harvested. The results consistently demonstrated that the proposed scheme outperforms traditional approaches across all scenarios, exhibiting higher throughput and power harvesting capabilities. Specifically, the proposed scheme effectively utilized available resources, resulting in improved network throughput and power. These findings underscore the effectiveness of our proposed system in enhancing cognitive radio network performance. Through the presentation of simulated results, we have validated the efficacy of the proposed scheme in achieving superior throughput and power harvesting capabilities, thereby contributing valuable insights to the field of cognitive radio networks.

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