

Enhancing Energy Efficiency In Noma-Supported Cognitive Radio Networks For 5g

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Abstract— This paper investigates energy efficiency (EE) performance of a non-orthogonal multiple access (NOMA)-based cognitive radio (CR) system for 5G communications. The proposed system incorporates Relays aided by unmanned aerial vehicles (UAVs), which operate through a phase of energy harvesting (EH) followed by numerous decode-and-forward (DF) communication stages. During the energy harvesting phase, UAV relays collect energy as of a dedicated power beacon (PB) to maintain sustainable operations. The secondary transmitter (ST) employs a harvested energy to communicate with the first UAV relay with the help of NOMA, while the primary transmitter (PT) transmits to the primary receiver (PR) under interference limitations. Following relays utilize the DF method to send the messages to their intended location.

We obtained the Signal-to-interference-plus-noise ratio (SINR) expressions, throughput alongwith energy efficiency across various system components. Simulations conducted in MATLAB assess how power allocation, interference constraints, and relay energy usage influence energy efficiency. The findings reveal that improving power allocation and interference management significantly boosts energy efficiency while maintaining reliable communication. This research offers guidance on creating NOMA-based CR systems that are both energy-efficient and spectrum-efficient for 5G and future networks.

Keywords– Energy Efficiency, Cognitive Radio, Unmanned Aerial Vehicles, Energy Harvesting, Decode-and-Forward, Spectrum Efficiency, Power Allocation

I. INTRODUCTION

As wireless communication systems advance rapidly with 5G and beyond, attaining high spectral and energy efficiency (EE) has emerged as a significant challenge. NOMA have become the notable technology to enhance spectrum efficiency by enabling multiple users to simultaneously utilize the same frequency resources via power-domain multiplexing [1,2]. In the presence of both licensed and unlicensed users, Cognitive Radio (CR) systems simultaneously improve spectrum efficiency by enabling dynamic spectrum access [3]. The Energy Efficiency (EE) of NOMA-Based Cognitive Radio Systems for 5G Communication describes how well these systems use energy to transmit data while balancing spectrum efficiency, power consumption, and Quality of Service (QoS) in a highly dynamic wireless environment. A new method for optimizing resource use and guaranteeing energy-efficient communication is presented by a mixture of NOMA with CR[4].

UAVs have been added like relay nodes to CR-NOMA systems in order to improve their coverage and performance even more. UAV-assisted relays facilitate energy-efficient data transmission, enhance line-of-sight (LoS) communication, and offer flexible deployment. But because UAVs have limited energy, Energy Harvesting (EH) systems are necessary to extend their operational life. By using EH-powered UAV relays, reliance on external power sources is decreased and sustainable and self-sufficient operation is made possible [5].

Several UAVs serve as relays in this study's proposed EH-enabled, UAV-assisted, NOMA-based CR system. UAVs gather energy by a specialized power beacon (PB) during an energy harvesting stage of the communication process. This is followed by several decode-and-forward (DF) communication phases. While the primary receiver (PR) and primary transmitter (PT) are connected. while being constrained by interference, The energy is used by the secondary transmitter. that has been captured to send private messages via NOMA[6]. DF relaying is used by the following UAV relays to guarantee dependable data transfer. NOMA allows several users to be multiplexed over a specific resource, with each user receiving varying power according on their quality of service. Low power coefficients are assigned to strong channel

gain, while high power coefficients are assigned to weak channel gain [7]. One slot in NOMA can be utilized by multiple users, which increases interference. Additionally, we must eliminate the interference at the receiver, which adds to the complexity. Allocating power to each customer in downlink is essentially the largest challenge. due to the fact that every user's distance from the station varies [8]. The base station must determine how much power should be distributed to users 1, 2, etc. The channel gain has determined from user's distance from the base station, following which power is distributed to each user and the coding is completed. Superposition coding is the process by which all of the coding is combined at the receiver [9].

II. RELATED WORK

For energy harvesting (EH)-based cognitive mobile relay networks, the authors propose a power control technique that involves installing a decode-and-forward (DF) relay on an unmanned aerial vehicle (UAV) to facilitate communication between the secondary user (SU). According to the model, the SU transmitter's sole power source is an infinitely large energy-harvesting battery. The study addresses a throughput maximization problem to maximize the transmit powers of the SU and the mobile relay [1,2,]. In this study, an energy-constrained UAV-borne secondary node harvests radio-frequency energy from the primary source and broadcasts both its own information signal and the signal of the primary user using the Non-Orthogonal Multiple Access (NOMA) technique [3]. This article examines the impact of poor successive interference cancellation (SIC) in NOMA and hardware impairments (HIs), which are inevitable in real-world systems and affect signal processing. [2]. Considering system performance and security constraints, this paper examines the throughput performance of a cognitive radio (CR) system based on non-orthogonal multiple access (NOMA) and multiple UAV assisted relays [6]. An energy harvesting (EH) with many communication phases are included inside a proposed new communication protocol. UAV relays gather energy from a power PB during the EH phase [7]. In the first communication phase, a secondary transmitter interferes with a primary receiver (PR) that is speaking with a terrestrial base station by using the energy collected to broadcast private messages to the first UR via NOMA [8]. URs relay signals using the decode-and-forward technique in later communication stages. A hybrid search approach that combines CGA and particle swarm optimization (PSO) is suggested in order to maximize system performance. It maximizes secondary network throughput while respecting performance and security requirements by optimizing configurations of UAV relay and power allocation in NOMA [9,10]. A leakage probability at the EAV, the primary network's outage probability and the throughput of the secondary network are among the important metrics that are analyzed [11]. The findings show how UAV-assisted NOMA-based CR systems can enhance network security and efficiency [12].

This study proposes the strong network of cooperatives with An unmanned aerial vehicle (UAV) equipped with an active intelligent reflecting surface (A-IRS) to enhance air-to-ground communication [13]. The technology combines the mobility of UAVs with the signal amplification and reflection capabilities of the A-IRS to dynamically improve communication performance in complex settings. This innovative architecture offers a flexible and efficient means of optimizing air-to-ground communication by addressing problems such as signal attenuation and coverage limitations [14]. The performance of outages on CR's secondary network with NOMA while taking Rayleigh fading into account was discovered by the authors in [15]. They have adopted the new CR-D2D NOMA system paradigm, which takes into account two crucial technologies: CR and device-to-device. Two users are given different power allocation factors in order to achieve the outage probability [16]. An effective relay precoder and power allocation architecture for a cognitive relay network using NOMA was proposed in this research [17, 18]. Additionally, they suggested a method that uses the convex approximation and minimization and maximization techniques to provide the best possible design [19, 20].

1. METHOD

We consider a single primary base station that serves primary customers and a secondary base station that uses cognitive radio to opportunistically access the primary spectrum. Multiple secondary users are serve through secondary base station via nonorthogonal multiple access. Here PU Transmit Power: P_p SU Transmit Power: P_s (allocated among NOMA users) [21, 22]

Channel Gains: h_p for the primary user (PU) h_1, h_2, \dots, h_N for secondary users (SU1, SU2, ..., SUN)
Noise Power: σ^2

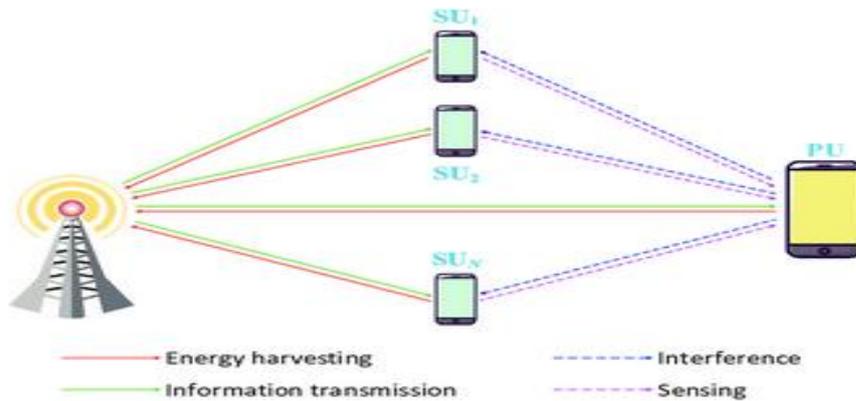


Fig. 1. Cognitive Radio Network based on NOMA with primary and secondary transmitters

In order to improve performance, we suggest a unique EH-powered, UAV-assisted, NOMA-based CR system for 5G communication that integrates numerous relay nodes. [2,3]

Energy Efficiency Analysis: Taking interference limits into account, we develop closed-form formulas for energy efficiency, throughput, and SINR.

Power Allocation Optimization: so as to ensure optimal resource usage to primary and secondary networks, we assess how power allocation affects EE performance [23].

We run comprehensive simulations to confirm the suggested system's energy efficiency advantages, emphasizing important trade-offs between spectral efficiency and power usage.

This is how the remainder of the paper is organized: Section II review related work on NOMA with CR and UAV-assisted communication. Section III presents the system model and mathematical formulation. And also discusses the performance analysis, including SINR, throughput, and energy efficiency. Discussions and simulation results are presented in Section IV. Lastly, Section V wraps up the work by offering suggestions for further study avenues..

In power-domain NOMA, users are assigned different power levels based on their channel conditions. The received signal at the base station.

$$y = \sum_{i=1}^N \sqrt{\alpha_i P_S} h_i x_i + n \quad \text{.....(1)}$$

where x_i is the signal for the i th SU. α_i is the power allocation coefficient for the i th user. [24]

$N \sim \text{CN}(0, \sigma^2)$ is additive white Gaussian noise (AWGN).

The power allocation follows:

$$y(t) = \sum_{i=1}^N \alpha_i = 1, \quad 0 < \alpha_1 < \alpha_2 < \dots < \alpha_N$$

For Successive Interference Cancellation (SIC), the SINR for the i th user is [25]:

$$\text{SINR}_i = \frac{\alpha_i P_S |h_i|^2}{\sum_{j=i+1}^N \alpha_j P_S |h_j|^2 + \sigma^2} \quad \text{.....(2)}$$

The achievable rate for the i th SU is:

$$R_i = \log_2(1 + \text{SINR}_i) \quad \text{.....(3)}$$

Cognitive Radio detects spectrum holes using an energy detection technique:

$$Y = \sum_{k=1}^M |r_k|^2 \quad \text{.....(4)}$$

where: r_k is the received signal sample. M is the number of samples.

The detection probability (P_d) and false alarm probability (P_f) determine the effectiveness of spectrum sensing:

$$P_d = Q\left(\frac{\lambda - M\sigma^2}{\sqrt{2M\sigma^4}}\right) \quad \text{.....(5)}$$

$$P_f = Q\left(\frac{\lambda - M\sigma^2}{\sqrt{2M\sigma^4}}\right) \quad \text{.....(6)}$$

where: $Q(\cdot)$ is the Q-function. λ is the detection threshold. For efficient spectrum sensing, P_d should be high (to detect PUs accurately), and P_f should be low.

We aim to maximize the sum rate of SUs while ensuring that: PUs get their minimum required rate R_{pmin} . The power budget constraint is satisfied.

$$\text{Max}_{\alpha_1, \dots, \alpha_N} \sum_{i=1}^N R_i$$

$$R_p \geq R_p^{\min} \quad \dots\dots(7)$$

$$\sum_{i=1}^N \alpha_i P_S \leq P_{\max} \quad \dots\dots(8)$$

$$0 < \alpha_1 < \alpha_2 < \dots < \alpha_N < 1$$

The throughput for a user k in the NOMA-EH-CR system is

$$R_k = \log_2 \left(1 + \frac{P_k h_k}{N_0 \sum_{j \neq k} P_j h_j} \right) \dots\dots(9)$$

Where P_k is the power allocated to user k. h_k is the channel gain of user k. N_0 is the noise power, P_j is the power of interfacing users in the NOMA network [26].

For multi UAV relaying throughput is further modified based on relay efficiency.

$$R_{\text{relay}} = \frac{1}{2} \log_2 \left(1 + \frac{P_r h_r}{N_0} \right) \dots\dots(10)$$

Where P_r and h_r are the power and channel gain of the relay (UAV)

2. RESULTS AND DISCUSSION

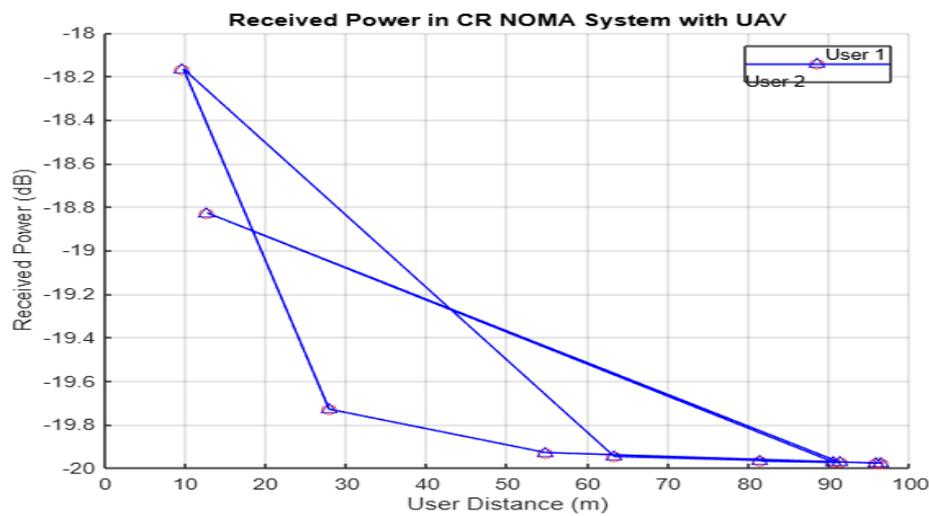


Fig. 2. User distance vs received power

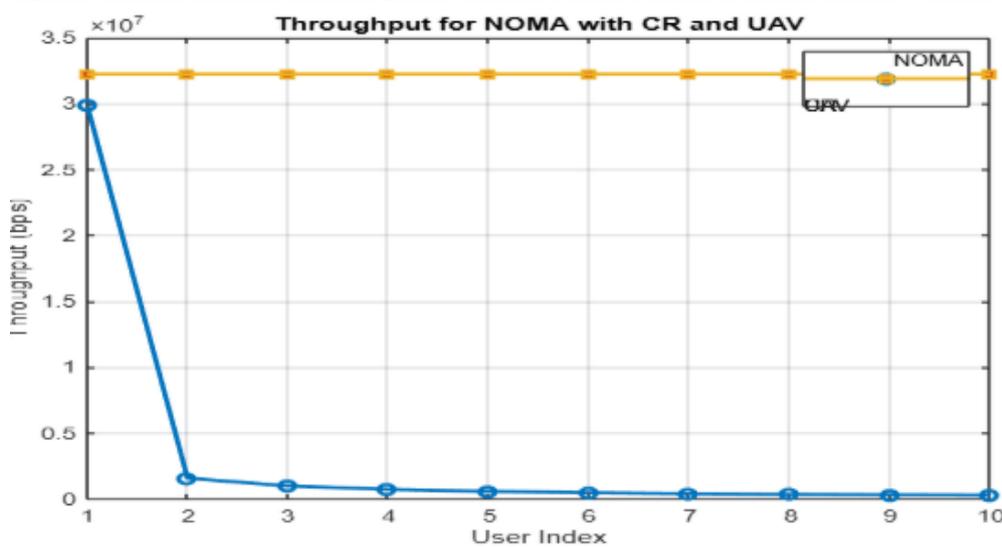


Fig. 3. Throughput of NOMA with CR and UAV

In figure 2 the users' distances from the UAV are shown on the X-axis. The received power is shown on the Y-axis in decibels (dB). To illustrate how the received power varies with distance, two lines are plotted, one for each user. Figure 3 simulates realistic wireless channels using Rayleigh fading uses a path-loss model with a three exponent. It calculates the throughput for NOMA with Cr and UAV. Figure 4 plots

the power harvested for both CU and UAV against distance. It shows the average power harvested in the command window.

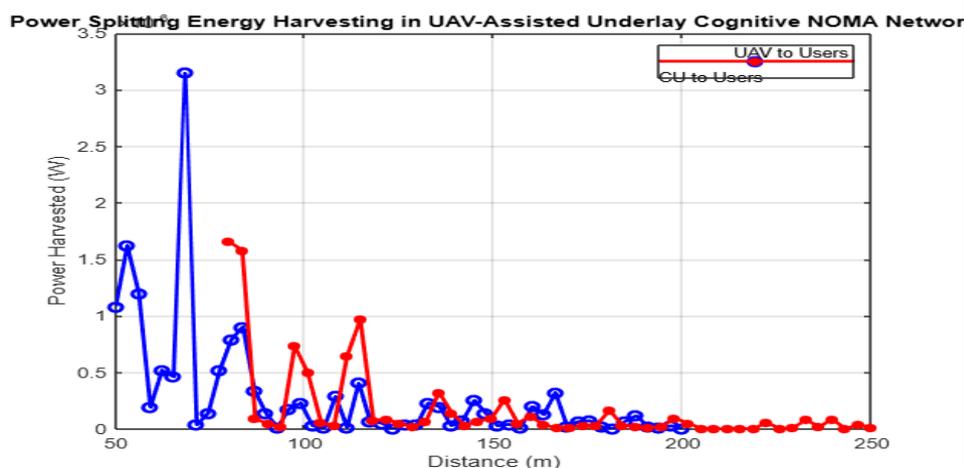


Fig. 4. The power harvested against distance

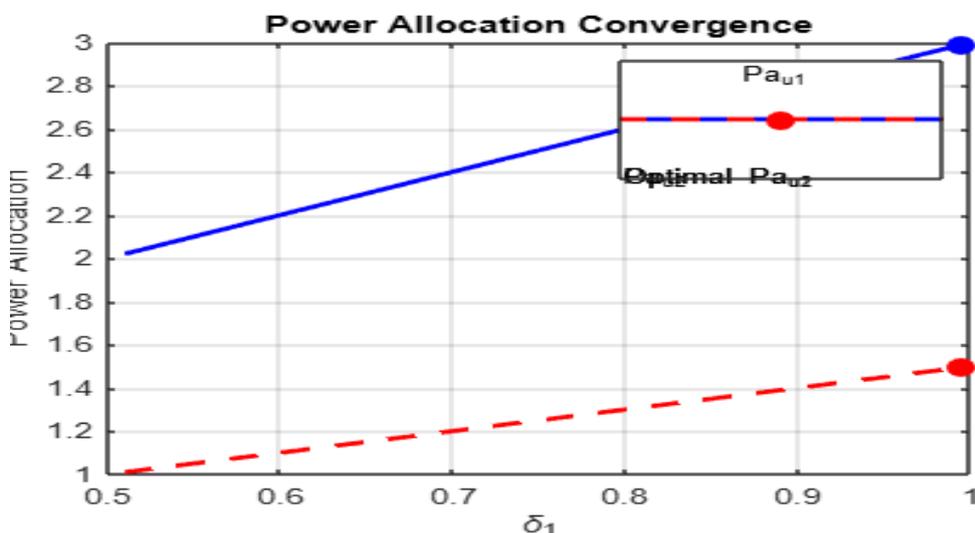


Fig. 5. Random channel fluctuations with power allocation

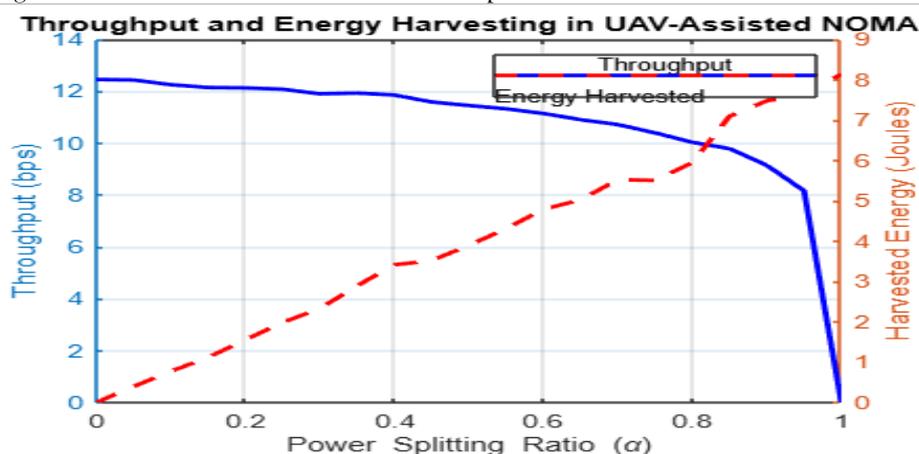


Fig. 6. Random channel fluctuations with throughput

Figure 6 shows random channel fluctuations cause the throughput to fluctuate. Multi-UAV relaying helps user transmissions, which increases throughput overall. Fairness in the NOMA scheme is impacted by power allocation in which users with better channels are given less power. EH supports sustainability by UAVs that can operate for longer energy they capture. In an underlay cognitive radio environment, these outputs are used for simulating and plotting throughput for a NOMA-based, multi-UAV-assisted relay system with energy harvesting.

3. CONCLUSION

A Cognitive Radio (CR) system based on NOMA's energy efficiency (EE) with UAV-assisted relays for 5G communication was examined in this research. The suggested approach enables UAV relays to function in an energy-efficient manner by combining an energy harvesting (EH) phase with several decode and forward (DF) communication phases. Whereas A primary base station (PBS) serve its primary users (PUs), the secondary base station uses NOMA to serve numerous secondary users (SUs) with the least amount of interruption to the primary network. We calculated and examined important performance indicators, such as energy efficiency, throughput as well as SINR. All results of the simulation showed that while interference limits at PUs must be carefully addressed to preserve system function, optimal power allocation greatly improves energy efficiency. The results demonstrate that EH mechanisms and UAV-assisted relaying can successfully improve network sustainability, making the suggested system a viable option for next energy-efficient 5G and beyond networks.

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