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Outage Performance of Cooperative Underlay Cognitive Radio Relay Based NOMA Networks with Energy Harvesting Capability

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Abstract

In this work, Non-orthogonal multiple access (NOMA) technology is considered in cognitive radio (CR) networks in which the secondary users can only access the utilized spectrum of the primary user such that the primary user can tolerate the interference created by the secondary network. On the other words, the combination of CR and NOMA (CR-NOMA) is a novel concept to enhance the spectrum efficiency and the reliability of the network communication. The relaying technology with capability of energy harvesting is also considered which can improve the outage performance. In this scheme, the proper relay harvests energy from the secondary transmitter while it transmits the data of the secondary transmitter to the corresponding receiver. With this regard, the network throughput is improved in outage behavior and imperfect successive interference cancellation (SIC) condition at two users. Hence, the proposed problem is maximizing the performance of the network by proper selection of the relay for data transmission, setting the transmission power of the selected relay and optimal power allocation coefficients to each user with constraints on the outage probability and the interference in the primary user communication. For solving the problem, an iterative low complexity algorithm is proposed using the convex optimization scheme and Karush–Kuhn–Tucker conditions to select the best relay for transmission and users' power allocation coefficients and also set the transmission power of the selected relay. Simulation results verify the effectiveness of the proposed algorithm for increasing almost 30 percent of the network performance in comparison to the bench mark algorithms in different conditions.

Keywords: NOMA-Cognitive Network; SIC Technique; Network Throughput; Convex Optimization Method; Probability of Outage.

1- Introduction

Non orthogonal multiple access (NOMA) is a technique for the fifth generation (5G) wireless communication in comparison with OMA approach. On the other words, NOMA-enabled user utilizes the available resources such as frequency/time/code which results in spectral efficiency, user fairness and low latency in spectrum access [1]. In the NOMA networks, the transmitter sends its signals to all receivers by allocating different fractions of its power to nodes with respect to the estimated channel conditions. On the other hand, more transmission power is assigned to the users with weaker channels while the users with strong channels have less transmission power coefficients. Therefore, the users with stronger channels perform a successive interference cancellation (SIC) technique to decode signals of the other users and obtain their own signals [2], [3]. In [4], the performance of NOMA is studied in partial channel state information (CSI). They also state the outage probability in a closed form expression and the average two users' sum rate is calculated. To improve the network performance, NOMA scheme with relay is considered especially when the users are far from the transmitter or the channel condition is weak [5]. In [6], [7] and [8], a cooperative NOMA network with relay is studied. It is shown that the performance of both non-cooperative NOMA and cooperative OMA are worse than the cooperative NOMA. On the other hand, the cooperative communication can enhance the reliability of the users especially cell-edge users [9].

Due to the development of the high data rate services, the fixed spectrum allocation is not useful and spectral efficient communication networks are required. In cognitive radio (CR) networks, the primary users have the exclusive rights

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to use the spectrum. However, in these networks, the primary network allows the frequency band is utilized by the secondary network with respect to the interference created by the secondary users on the primary user communications [10]. In [11], combination of NOMA and CR networks is utilized to ensure a reliable transmission from primary users and secondary users while the spectral efficiency is improved. This enhancement can be obtained by using cognitive radio networks based on NOMA technique when the secondary transmitter sends its NOMA messages to its secondary receivers on the licensed spectrum if the primary user can stand the inter- network interference created by the secondary users' communications. However, in NOMA technology, intra-network interference can also happen when several users access the same spectrum with different power levels. Therefore, a proper combination of NOMA and CR networks is required to decrease the interference and improve the spectrum utilization.

Energy efficiency is another important issue in these networks due to the energy constraints of devices [12]. Energy harvesting (EH) is a technique where the radio frequency (RF) signals are used as the sources for harvesting the energy of wireless devices [13]. In this case, the energy efficiency of cognitive radio networks can be enhanced by utilizing the energy harvesting techniques [14]. In [15], the energy efficiency is maximized by power transmission allocation in unmanned aerial vehicles based NOMA networks.

1-1- Related Works

In [9], outage probabilities of primary user and secondary users are derived under imperfect CSI and imperfect SIC in cooperative cognitive radio networks based NOMA. In [16], underlay CR- NOMA network is considered and the probability of outage is evaluated to show the performance of secondary NOMA users. In [17], the error rate performance of a NOMA based CR network is considered by relay selection with imperfect SIC. In [18], a NOMA network is proposed with capability of energy harvesting. In this paper, multiple groups are considered with two users in each group where the NOMA technique is applied in each group and OMA technique is applied for inter- group. In this paper the performance of the system is analyzed and a closed form expression is derived for outage probability with imperfect channel state information (ICSI) consideration. In [19], a cooperative CR network is studied and outage probability is derived with ICSI consideration. Optimal power allocation for two users is also obtained such that the fairness of outage probability is maintained for two users. In [20], a cooperative NOMA network underlay cognitive radio network is studied with imperfect SIC and the probability of outage is obtained for each secondary user. In [21], the problem of maximizing the minimum secrecy energy efficiency is proposed by time slot and secondary transmission power allocation under transmission security and reliability constraints in a CR-NOMA network with the capability of non-linear energy harvesting of the secondary users. In [22], the reliability and security performance of a cooperative NOMA cognitive radio network is studied in the existence of eavesdroppers. The connection outage secrecy outage probabilities of each primary user are derived with cooperative NOMA and non-cooperative NOMA. In [23], a distributed sequential coalition formation algorithm is proposed for user grouping and power allocation such that the minimum rate requirement of the primary user is satisfied. In [24], a cooperative underlay cognitive radio NOMA is considered and the outage probability for two secondary NOMA user is calculated under Nakagami-m fading channel. In [25], A CR-NOMA network is proposed for spectrum efficiency and an energy harvesting relay scheme is considered to forward the secondary transmitter messages to the secondary receivers. In this paper, the outage probability and the throughput network are obtained on imperfect SIC. In [26], the outage probability and the system throughput are derived while the effect of the power allocation coefficient of NOMA and energy harvesting parameters on outage with imperfection SIC are investigated. In [27], ergodic sum rate and outage probability of the network are investigated in full duplex and half duplex modes at secondary user. In [28], the outage probability is expressed while the network throughput is improved in imperfect SIC condition.

To the best of our knowledge, the above works have made efforts to solve a variety of problems in CR-NOMA networks while the outage probability is obtained. However, maximization of the network throughput and improvement of the outage probability and the interference created for the primary user communication are not considered simultaneously in these works. Therefore, this motivates us to explore the efficiency of the cognitive radio relay based NOMA networks by selecting the suitable relay, setting its transmission power and allocating power coefficients of the secondary users. A summary of the works is provided in table 1.

1-2- Motivation and Contributions

In this work, a CR-NOMA network is considered with the energy harvesting capability of the relays. On the other hand, the secondary transmitter is allowed to forward its messages to its secondary users via the proper relays such that the primary user can stand the interference created by the secondary user communications. We also note that the CR-NOMA network works with imperfect SIC over Rayleigh fading channel. Therefore, our proposed problem is maximizing the overall throughput of network by selecting the suitable relay, setting its transmission power and allocating power coefficients of the secondary users so that the outage probability of the secondary users and interference created for the primary user are improved. The main contributions of the paper are stated as

- A cognitive radio network is investigated, where the secondary source can use the licensed spectrum of the primary user and employs NOMA to forward its messages through the proper relay with energy harvesting capability to two secondary destinations through the Rayleigh fading channel.
- We formulate the problem of maximizing the network throughput by selecting the suitable relay, setting its transmission power and power allocation coefficients of the secondary users under the outage probability of the secondary users and interference created for the primary user communication constraints.
- The problem is solved using the convex optimization method and KKT conditions are applied to determine the optimal conditions. Then, an algorithm based on ellipsoid method is proposed to search the optimal solution for the problem which has polynomial complexity.
- Simulation results verify the efficiency of the proposed algorithm for improving the network throughput and outage probability of the secondary users and also interference created for the primary user communication.

This paper is stated as follows. In section 2, the system model is stated. The motivation and problem statement and its solution are stated in section 3. The proposed algorithm for solving the problem is stated in section 4. In Section 5, Simulation results are presented. Analysis of results are presented in section 6 while the conclusions are stated in section 7.

Table 1. Summery of the works

Proposed Works(Ref.)	***Year***	***Contributions***
[9],[18],[19] ,[20],[24]	2024,2018,2019 ,2019,2018	Outage probability is derived under imperfect SIC or imperfect CSI
[17]	2020	Error rate performance is considered by relay selection with imperfect SIC
[21]	2018	Minimum secrecy energy efficiency is maximized by time slot and secondary transmission power allocation under transmission security and reliability constraints with the capability energy harvesting of the secondary users
[22]	2019	Reliability and security performance of a cooperative NOMA-CR network is studied
[23]	2019	Power allocation is done such that the minimum rate requirement of the primary user is satisfied
[25], [26], [28]	2020,2024,2025	Outage probability and the throughput network are obtained on imperfect SIC
[27]	2023	Ergodic sum rate and outage probability of the network are investigated in FD/HD modes

2- System Model

A cooperative cognitive radio (CR)-NOMA network is considered with the capability of energy harvesting of the relays (Fig.1). Primary network includes one primary transmitter and one primary receiver while in secondary network, the secondary source selects a suitable relay from the N relay and forwards its messages to two NOMA users (U_1 and U_2). It should be noted that due to the poor channel condition or the long distances between the secondary transmitter and secondary receiver, the proper relay can receive the information and harvest the energy to forward the signal to the secondary users by decode-and-forward (DF) technique utilization.

The wireless channel model is the Rayleigh fading model. We also assume that all nodes (primary or secondary users) have one antenna with available CSI. However, SIC is done in the secondary user. According to the cognitive radio network scenario, transmission of the secondary network is only allowed if the primary user can tolerate the interference created by the secondary transmission on the primary user communication. Therefore, the restriction on the transmission power of the nth relay is stated as follows

$$P_{R_n} \leq \min\left(\frac{I_{th}}{|h_{R_nP}|^2}, {P_{R_n}}^H\right) \quad (1)$$

Where I_{th} is the interference temperature constraint on primary user while h_{R_nP} is the channel coefficient between the n th relay and primary receiver [29]. In NOMA transmission, the secondary source sends its signal $X_s(t) = \sqrt{\alpha_i P_s}\, x_i + n_R$ to the suitable relay. In this scheme, α_i is the portion of the transmission power P_s for the ith user with $\sum_{i=1}^{2} \alpha_i = 1$. x_i is the unit messages of the i th user and n_R is the additive white Gaussian noise (AWGN) between the secondary source and the proper relay with variance N_0.

We assume three time slots with the duration T. The first time slot with duration δT is considered for energy harvesting the selected relay and the second time slot with duration $(1-\delta)\frac{T}{2}$ is for transmitting data from the secondary source to the suitable relay. In the third duration, the signal to the corresponding users are transmitted using the selected relay [25]. In this case, the harvested energy at the suitable relay in the allocated time duration is obtained as [30]

$$E_s = \eta P_s \left|h_{R_nP}\right|^2 \delta T \tag{2}$$

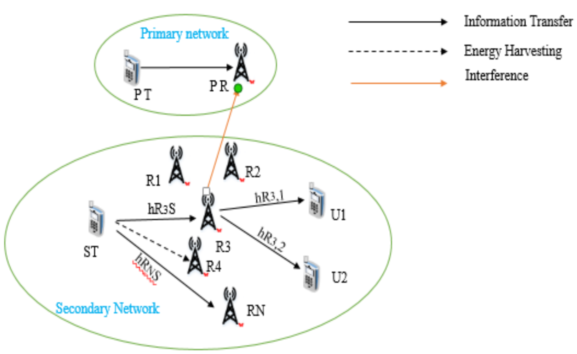

Fig.1 System Model

Where η is the energy conversion efficiency of the energy harvesting circuitry. Therefore, ${P_R}^H$ which is the maximum transmit power from the energy harvesting for the nth relay is given by

$${P_{R_n}}^H = \frac{E_s}{(1-\delta)\frac{T}{2}} \tag{3}$$

By assuming that $\alpha_1 < \alpha_2$ it is meant that more transmission power is allocated to U_2 while the channel coefficient of U_1 is stronger than U_2. Using the received signal via the selected relay, the signal-to-interference plus noise ratio (SINR) after considering x_1 as an interference is obtained as follows

$$\gamma_{R,2} = \frac{\alpha_2 P_s \left|h_{R_nS}\right|^2}{\alpha_1 P_s \left|h_{R_nP}\right|^2 + N_0(\varepsilon+1)} \tag{4}$$

And using imperfect SIC, the SINR after detection of x_2 is

$$\gamma_{R,1} = \frac{\alpha_1 P_s \left|h_{R_nS}\right|^2}{\alpha_2 P_s \left|g_{R_nS}\right|^2 + N_0(\varepsilon+1)} \tag{5}$$

Where $g_{RS} \sim CN(0, \xi\lambda_{R_nS})$ with $0<\xi<1$ where this metric indicates the residual interference level due to the imperfect SIC. In the second timeslot, the received signal at U_i $i=1,2$ is obtained as

$$y_i = h_{R_n,i}\sqrt{P_{R_n}}\left(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2\right) + I_P + n_i \tag{6}$$

Where $h_{R_n,i}$ is the channel model between the suitable relay and ith user while x_i is the message of the ith user and n_i is the additive white Gaussian noise (AWGN) of the ith user. $I_P \sim CN(0, N_0\epsilon)$ is the interference created from the primary user communication on the users and the relay communications [19]. In this case, using SIC implementation in U_1, x_2 detection and considering x_1 as a noise, the SINR is stated as

$$\gamma_{1,2} = \frac{\alpha_2 P_{R_n} \left|h_{R_n1}\right|^2}{\alpha_1 P_{R_n} \left|h_{R_n1}\right|^2 + N_0(\varepsilon+1)} \tag{7}$$

We also note SINR using imperfect SIC as follows

$$\gamma_1 = \frac{\alpha_1 P_{R_n} |h_{R1}|^2}{\alpha_2 P_{R_n} \left|g_{R_n1}\right|^2 + N_0(\varepsilon+1)} \tag{8}$$

Where g_{R_n1} is defined similar to g_{R_nS}. SINR at U_2 is also obtained as

$$\gamma_2 = \frac{\alpha_2 P_{R_n} \left|h_{R_n2}\right|^2}{\alpha_1 P_{R_n} \left|h_{R_n2}\right|^2 + N_0(\varepsilon+1)} \tag{9}$$

In Raleigh fading channel, for obtaining the outage probability, cumulative distributed function (CDF) and the probability density function (PDF) of the wireless channel h with mean λ are defined as

$$F_h(x) = 1 - e^{-\frac{x}{\lambda}} \tag{10}$$

And

$$f_h(x) = \frac{1}{\lambda} e^{-\frac{x}{\lambda}} \tag{11}$$

As we know, the probability of outage is very important metric to evaluate the performance; Therefore, the outage probability with imperfect SIC for x_1 is formulated as follows

$$Ou\_P_1 = 1 - P(\gamma_{R_n,2} > \gamma_{2,th}, \gamma_{R_n,1} > \gamma_{1,th}, \gamma_{1,2} > \gamma_{1,th}, \gamma_1 > \gamma_{1,th}) \tag{12}$$

Where $\gamma_{i,th}$ $i=1,2$ is the threshold corresponding to the target rate $R_{i,th}$ for two users. According to [25], we have

$$Ou\_P_1 = 1 - \mathrm{Z}_1 \times \mathrm{Z}_2 \tag{13}$$

Where Z_1 is expressed as follows

$$\mathrm{Z}_1 = \Upsilon_1 - \frac{\Upsilon_2 - \lambda_{R_nS}}{\Upsilon_3 \lambda_{PS} + \lambda_{R_nS}} \tag{14}$$

Where $\Upsilon_1 = \frac{\lambda_{R_nS}}{\Theta_1\lambda_{PS}+\lambda_{R_nS}}$, $\Upsilon_2 = \frac{\zeta_P}{\zeta_P+1}$ and $\Upsilon_3 = \frac{(\zeta_P+1)\Theta-\Theta_1}{\zeta}$.

We also have [25]

$$\Theta_1 = \frac{\gamma_{1,th}(\epsilon+1)}{\rho_I\alpha_1}, \Theta_2 = \frac{\gamma_{2,th}(\epsilon+1)}{\rho_I\alpha_2}, \Theta = \max(\Theta_1, \Theta_2) \quad (15)$$

And

$$\zeta_P = \gamma_{1,th}\,\zeta\bar{\alpha}\ ,\ \bar{\alpha} = \frac{\alpha_2}{\alpha_1} \quad (16)$$

Where $\rho_I = \frac{I_{th}}{N_0}$. Z_2 is also expressed as follows

$$Z_2 = A_1 + A_2 \quad (17)$$

Where A_1 is stated as[22],[25]

$$A_1 = \varrho_1\Psi(\Theta\chi_1 + C) - \frac{\Upsilon_2\lambda_1\Psi(\Upsilon_3\chi_1+C)}{\Upsilon_3\lambda_{PR}+\lambda_1} \quad (18)$$

And

$$A_2 = \Psi(\Theta\chi_1) - \Psi(\Theta\chi_1 + C) - \Upsilon_2\,\Psi(\Upsilon_3\chi_1) + \Upsilon_2\,\Psi(\Upsilon_3\chi_1 + C) \quad (19)$$

Where $\chi_i = \frac{\lambda_{SP}}{\kappa\lambda_i\lambda_{R_nS}}$, $C = \frac{\lambda_{SP}}{\kappa\lambda_{PR_n}\lambda_{R_nS}}$, $\Psi(x) = e^x(xE_1(-x) + e^{-x})$, $\varrho_i = \frac{\lambda_I}{\lambda_{PR}\Theta_i+\lambda_i}$ and $\kappa = \frac{2\eta\delta}{(1-\delta)}$. We also note the outage probability for x_2 which is calculated as follows [25]

$$Ou\_P_2 = 1 - P\left(\gamma_{R_n,2} > \gamma_{2,th}, \gamma_{R_n,1} > \gamma_{1,th}, \gamma_2 > \gamma_{2,th}\right) = 1 - Z_1 \times Z_3 \quad (20)$$

Where Z_3 is calculated as follows [22],[25]

$$Z_3 = \varrho_2\Psi(\Theta_2\chi_2 + C) + \Psi(\Theta_2\chi_2) - \Psi(\Theta_2\chi_2 + C) \quad (21)$$

As shown in (13) and (20) formulas, important parameters which impress on the probability of outage implementation are SINR threshold, power allocation coefficients and the channel gain parameters. Therefore, for evaluation of the network performance, the overall throughput is expressed as follows [25]

$$T_{total} = \left(1 - Ou_{P_1}\right)R_{th_1} + \left(1 - Ou_{P_2}\right)R_{th_2} \quad (22)$$

Where R_{th_1} and R_{th_2} are the fixed target rates in delay-limited mode.

3- Problem Formulation and Its Solution

In this section, our goal is maximizing the network throughput while the constraints on the outage probability of the secondary users and interference created for the primary user communication are satisfied such that suitable relay is selected to transmit the secondary source messages to the NOMA users, its transmission power is adjusted and the optimal power allocation coefficients of the secondary users are obtained. Therefore, our proposed problem is formulated as follows

$$maximize_{R_n, P_{R_n}, \alpha_i}\, T_{total} \quad (23)$$

$$S.t.\ \ Ou_{P_i} \le \beta\ \ \forall i = 1,2 \quad (23\text{-}1)$$

$$PUinterf = P_{R_n}|h_{R_nP}|^2 \le I_{th} \quad (23\text{-}2)$$

$$\sum_{i=1}^{2}\alpha_i \le 1 \quad (23\text{-}3)$$

The first constraint (23-1) shows the constraint on the probability of outage of each user while (23-2) states the constraint on the interference which the primary user can tolerate due to the secondary network communications. (23-3) represents that the sum of the power allocation coefficients of the secondary users is equal to one. Exhaustive search algorithm is optimum solution for the problem in which all possible states of the answer is tested and the best answer which maximizes T_{total} and satisfies the constraints of the problem is selected as the optimal solution. However, due to the complexity of this method, we consider an iterative algorithm based on convex optimization to find the local solution for the problem. According to KKT conditions, Lagrangian function is given by [31]

$$L(\mu_i, \upsilon, \eta) = -T_{total} + \mu_i\left(Ou_{P_i} - \beta\right) + \upsilon(PUinterf - I_{th}) + \eta\left(\sum_{i=1}^{2}\alpha_i - 1\right) \quad (24)$$

Where μ_i, υ and η are the Lagrangian multipliers which have non-negative values. In fact, by applying Lagrangian function, the problem is converted to an unconstraint problem. On the other hand, for minimizing $L(\mu_i, \upsilon, \eta)$ and maintaining the problem constraints, the optimal value of the Lagrangian multipliers should be determined. In this case, we propose an iterative algorithm with low complexity to obtain the optimal values of the multipliers, optimal relay, its transmission power and power allocation coefficients of the secondary users. For this purpose, we use the ellipsoid method to solve convex functions. In fact, by applying this method, the optimal solution for the problem is obtained in finite iterations which is polynomial in the input size. The parameters are updated in $i+1$ th iteration as

$$A_{i+1} = \frac{n^2}{n^2-1}\left(A_i - \frac{2}{n+1} A_i \tilde{g}_i \tilde{g}_i^T A_i\right) \quad (25)$$

And

$$x_{i+1} = x_i - \frac{1}{n+1} A_i \tilde{g}_i \quad (26)$$

Where $\tilde{g}_i = \frac{g_i}{\sqrt{g_i^T A_i g_i}}$ and g_i is the subgradient of $L(\mu_i, \upsilon, \eta)$ at the ellipsoid center x_i. The ellipsoid is halved in each iteration and one ellipsoid half is removed based on A_i. n is the unknown parameters' number [32]. Hence, the ellipsoid method can be candidate for multi-dimensional search methods.

4- Proposed Algorithm for Problem Solution

For solving the problem in (23), we consider an iterative algorithm. The proposed algorithm consists of the following steps in each iteration

- For each relay, the probability of outage for each user according to (13) and (20), the interference created by the secondary network to the primary user communication and therefore, the overall throughput are calculated.
- Lagrangian multipliers, $\alpha_i, i = 1,2$ and also transmission power of each relay(P_{R_n}) are updated using the ellipsoid method in (25) and (26).
- According to the previous step, the new values of T_{total}, probability of outage for each user and $PUinterf$ are calculated.
- The proposed algorithm terminates if the number of iterations reaches to the certain value or the convergence value of the algorithm is satisfied, Otherwise the algorithms goes to the first step and the algorithm is repeated again. We note that the result of increasing the number of iterations is more accuracy of the iterative algorithm.
- After stopping the algorithm, the relay which leads to more T_{total}, less probability of outage for each user and less interference for the primary user communication, is selected as the best relay. Pseudo code for our proposed algorithm which is named Power Allocation Coefficient Adjustment and Relay Selection (PACARS) is presented in Fig.2.

PACARS Algorithm

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iter =500;
Initialization:
$\mu_i \epsilon [\mu_{i_{min}}, \mu_{i_{max}}]$
$\upsilon \epsilon [\upsilon_{min}, \upsilon_{max}]$
$\eta \epsilon [\eta_{min}, \eta_{max}]$
$\alpha_i \epsilon [0,1]$
ξ is the small number
it = 1 %%number of iterations
While(($|\upsilon^{t+1} - \upsilon^{t}| > \xi$)|| (it < iter))
Calculate T_{total}, Ou_P for each user and $PUinterf$ for the primary user
Update μ_i, υ, $\eta$and α_i multipliers by applying the ellipsoid method
Recalculate T_{total} , Ou_P for each user and $PUinterf$ for the primary user.
it = it + 1
End While
According to T_{total} and constraints of the problem, the best relay is selected

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Fig.2. Pseudo code for the proposed algorithm

5- Results and Discussion

We utilize MATLAB software for simulation. We consider a square field with the length of 500 m in which the secondary users, secondary base station, primary user and relays are distributed randomly. Number of relays is set to 5. Rayleigh fading channel is assumed as the channel model which is presented as follows [33], [34]

$$h = 10^{\frac{-L}{20}}.\mathrm{g} \quad (27)$$

Where g is considered as a Gaussian random process with zero mean and unit variance for Raleigh fast fading. L states the path loss according to the free- space path loss (FPL) model . Another part is a real Gaussian random variable with zero mean and standard deviation 3 for large scale log-normal shadowing. Therefore, we have [35]

$$L = 20\log\left(\frac{\mathrm{d}4\pi f_c}{c}\right) + n \quad (28)$$

Where f_c is the carrier frequency, d states the distance between two corresponding users while c is the speed light. Simulation results are evaluated by averaging over 1000 independent simulation runs. The other required parameters are stated in Table 2.

Table 2. The value of the simulation parameters

Parameter	Value
R_{th_1}, R_{th_2}	0.5 BPCU
$\lambda_{SP}, \lambda_{PR_n}$	0.1
$\lambda_{SR_n}, \lambda_2$	1
λ_1	2
ζ	0.01
δ	0.1
η	0.9
ρ_I	0.5

To compare the results of the proposed algorithm, we propose other algorithms as the bench mark algorithms as follows

- Fixed Transmission Power of the Relays Algorithm: This algorithms is proposed to show the effectiveness of the selected relay transmission power in the network performance such as overall throughput, probability of outage of each user and interference created on the primary user communication.
- Random Relay Selection Algorithm: This algorithm is considered to show that the proper selection of the relay has an important role in improvement on the problem metrics in (23). This algorithm is selected due to its low complexity in implementation.
- Fixed Power Allocation Coefficients Algorithm: This algorithm is selected to show NOMA technology effectiveness, in improving the overall throughput, probability of outage of each user and interference created on the primary user communication.

Fig.3 shows the overall throughput versus different values of η. As we know, η is the energy conversion efficiency of the energy harvesting circuitry. Clearly, the proposed algorithm duo the proper selection the relay, setting its transmission power and power allocation coefficients of the secondary users, has the maximum value of this metric. However, the proposed algorithm with random relay selection has the minimum value. This algorithm presents the importance of the suitable relay selection for improving the network performance.

Fig.4 illustrates the outage probability versus different values of η. We note that all of the algorithms satisfy the constraint on the outage probability. However, the algorithm with the fixed power allocation coefficients for the users has the maximum value of this metric. In fact, this issue shows the importance of NOMA technology utilization in the performance improvement of the network.

Fig.5 presents the overall throughput for different values of ρ_I. Clearly by increasing ρ_I, the overall throughput is decreased due to the increasing the interference. Proposed algorithm with the power allocation factors setting has the maximum value of this parameter while the random relay selection algorithm has the minimum value. This shows the importance of the suitable relay selection in improving the performance of the network.

According to Fig.6, all algorithms satisfy the probability of outage constraint; however, the algorithm with fixed α, has the worst value of the outage probability. On the other words, NOMA technology has an important role for improving this metric.

Fig. 7 presents the overall throughput of the network for different values of δ. The algorithm with random relay selection has the worst value of this parameter. In fact, this figure shows the effect of the suitable relay selection in improving the throughput of the network. By increasing δ, the relays harvest more energy, therefore the selected relay has more transmission power. In this case, the overall throughput of the network also increases.

Fig.8 presents the outage probability for different values of δ. In fact, δ exhibits the balancing between the energy harvesting and information processing. Increasing δ leads to more time for energy harvesting. According to this figure, the algorithm with fixed α has more probability of outage since NOMA technology is not used in their network.

Fig.9 plots the overall throughput of the network for different values of ζ. In fact, ζ is the residual interference level due to the imperfect SIC. Therefore, by increasing ζ, the overall throughput is decreased. On the other hand, the highest value of the overall throughput is obtained in lowest value of ζ.

Fig.10 presents the convergence analysis for the proposed algorithm to find the optimal value of the Lagrangian parameter versus different iterations. In fact, this figure presents the steps of reaching the optimal values of the Lagrangian parameters. In figure, the convergence is evaluated according to overall network throughput for the steps that reach the optimal value of the Lagrangian parameters. In the 9th iteration, the optimal value of the Lagrangian parameter is obtained.

6- Analysis of Results

As it is clear in the previous section, the goal of the problem is maximizing the network throughput by selecting the suitable relay, setting its transmission power and allocating power coefficients of the secondary users while the outage probability and the interference created for the primary user communication are improved. Fig.3, Fig.5 , Fig.7 and Fig.9 illustrate the overall throughput enhancement in comparison to the bench marked algorithms by varying the energy conversion efficiency of the energy harvesting circuitry(η), interference effects(ρ_I), balancing between the energy harvesting and information processing(δ) and the residual interference level due to the imperfect SIC(ζ) parameters. In similar way, in Fig.4, Fig.6 and Fig.8, the proposed algorithm decreases the outage probability and improves this network metric. Fig.10 presents convergence analysis of the proposed algorithm to find the optimal value of the Lagrangian parameter in ellipsoid method. This figure states the iteration in which the optimal values of the Lagrangian parameters are obtained.

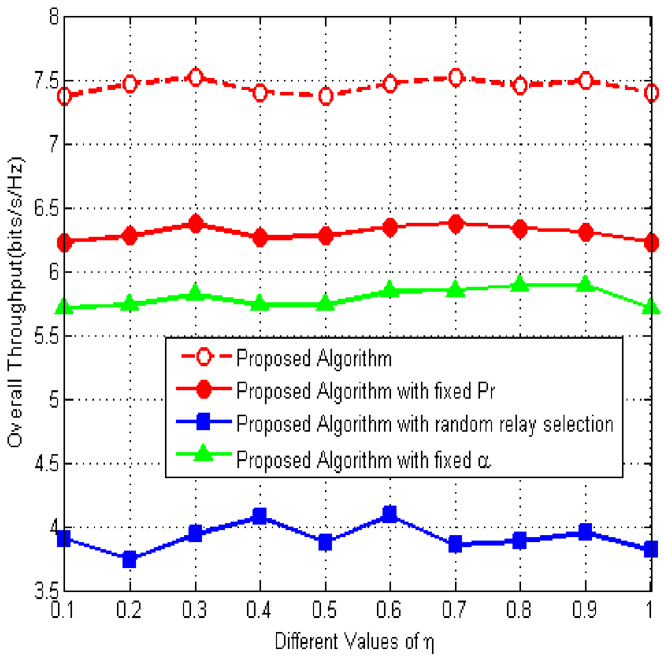

Fig.3. Overall throughput versus different values of η

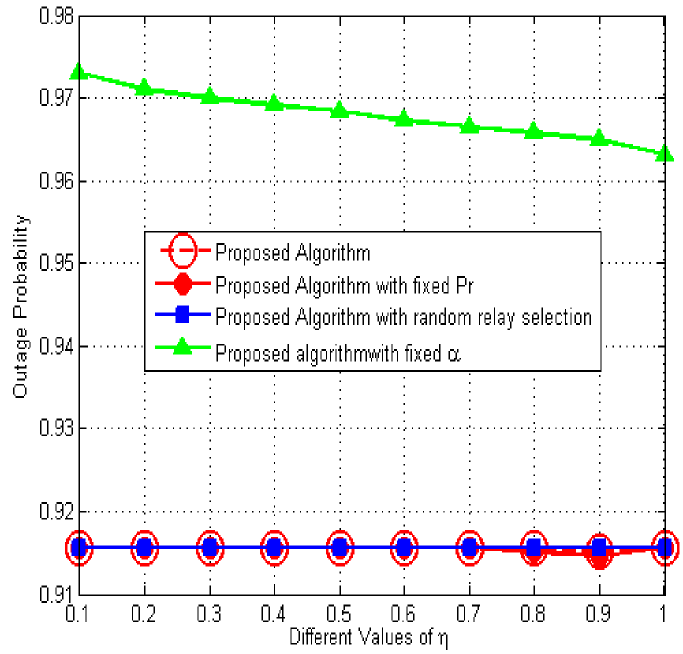

Fig.4. Outage probability for different values of η

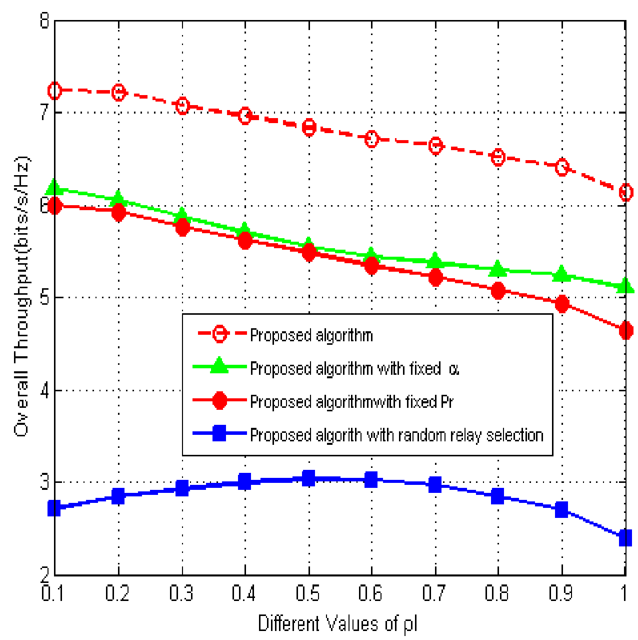

Fig.5. Overall throughput versus different values of ρ_I

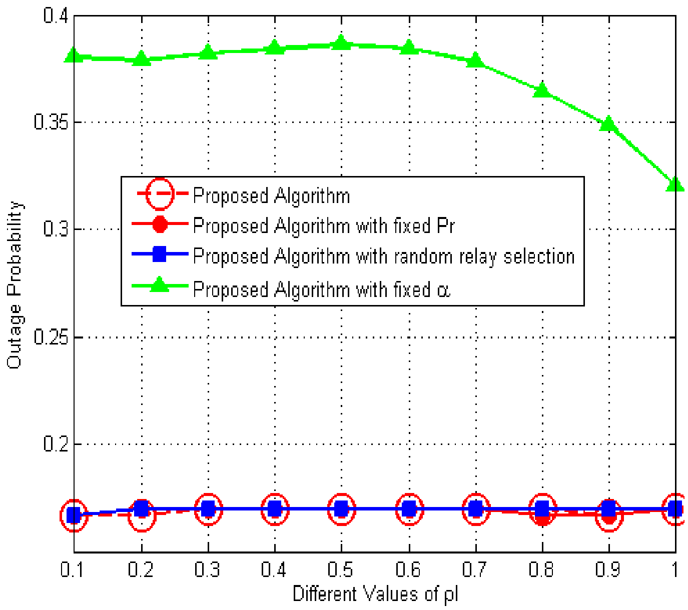

Fig.6. Outage probability for different values of ρ_I

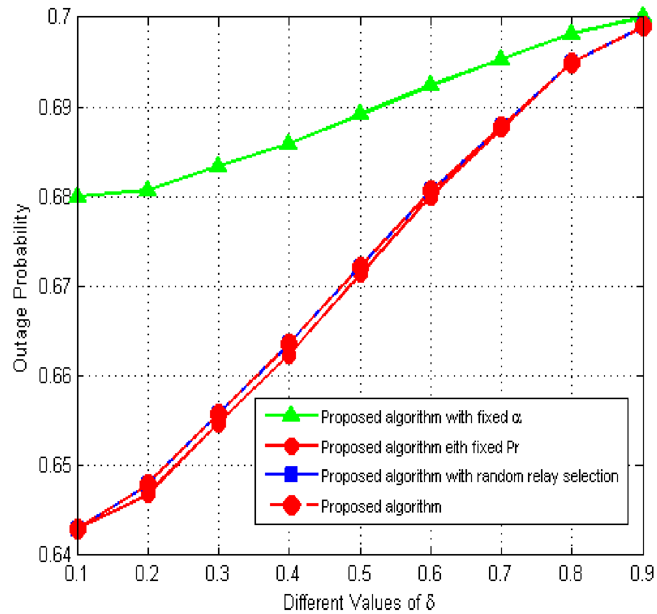

Fig.8. Outage probability versus different values of δ

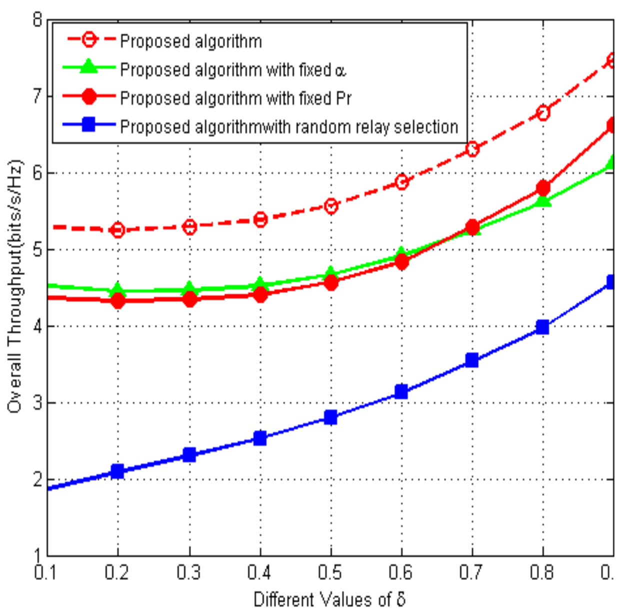

Fig.7. Overall throughput versus different values of δ

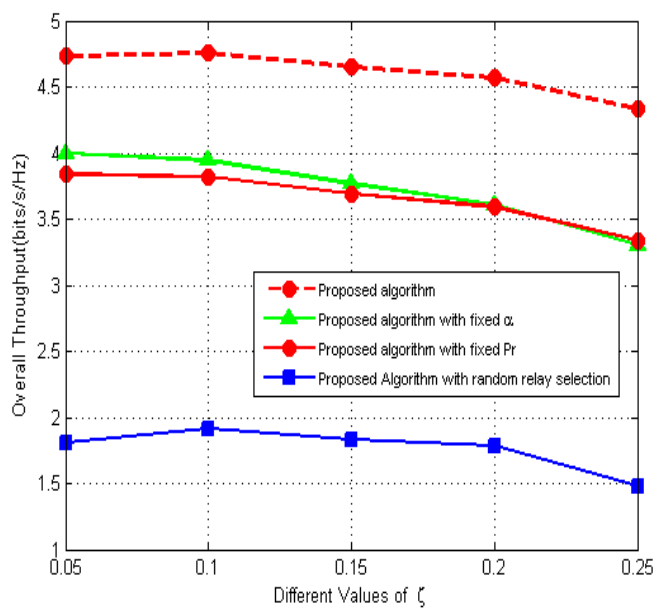

Fig.9. Overall throughput versus different values of ζ

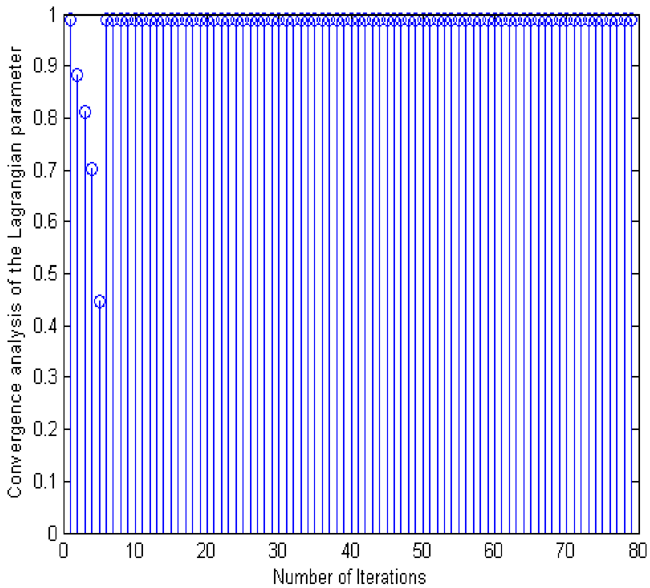

Fig.10. Convergence analysis of the Lagrangian parameter versus different iterations

7- Conclusions

In this work, performance of a cooperative CR-relay based NOMA network is investigated in term of the throughput, outage probability and interference tolerated by primary user in Rayleigh fading channels. The problem of maximizing the network throughput is proposed to select the proper relay with the energy harvesting capability, set the transmission power of the selected relay and optimize the power allocation coefficients to each user with constraints on the outage probability and the interference created for the primary user communication. The problem is solved based on convex optimization method and KKT conditions. Numerical results validate the efficiency of the proposed iterative algorithm in comparison to the bench mark algorithms for different values of energy conversion efficiency of the energy harvesting circuitry (η) , interference effects (ρ_I) , balancing between the energy harvesting and information processing (δ) and the residual interference level due to the imperfect SIC(ζ). The problem investigation for Nakagami-m fading channel and multiple users can be considered for the future work of this paper.

References

[1] S. M. R. Islam, N. Avazov, O. A. Dobre and K. Kwak, "Power-domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and Challenges," IEEE Communications Surveys & Tutorials, Vol.9, No.2,2017,pp. 721-742.

[2] S. Zhang, B. Di, L. Song, and Y. Li, "Radio resource allocation for nonorthogonal multiple access (NOMA) relay network using matching game, " IEEE Int. Conf. Commun. (IEEE ICC), Kuala Lumpur, Malaysia, 2016, pp. 1-6.

[3] Y. Saito, A. Benjebbour, Y. Kishiyama, and T. Nakamura, "System level performance evaluation of downlink non-orthogonal multiple access (NOMA), " IEEE Annu. Symp. Pers. Indoor Mobile Radio Commun. (IEEEPIMRC), Japan,2015.

[4] Z. Yang, Z. Ding, P. Fan, and G. K. Karagiannidis, "On the performance of non-orthogonal multiple access systems with partial channel information , " IEEE Trans. Commun., Vol.64,No.2,2016, pp.654-667.

[5] T. Do, DB. de Costa, TQ. Doung, B. An B, "Improving the performance of cell-edge users in NOMA systems using cooperative relaying," IEEE Trans. Commun., Vol.66, No.5,2018, pp. 1883–1901.

[6] Z. Ding, M. Peng and H. V. Poor, "Cooperative Non-Orthogonal Multiple Access in 5G Systems, " IEEE Commun. Lett., Vol.19,No.8,2015, pp. 1462- 1465.

[7] M. Ghamari Adian, "A novel resource allocation algorithm for heterogeneous cooperative cognitive radio networks, " Journal of Information Systems and Telecommunication (JIST) ,Vol.5, No.2, 2017, pp.138-145.

[8] M. Ghamari Adian, " Joint relay selection and power allocation in MIMO cooperative cognitive radio networks, " Journal of Information Systems and Telecommunication(JIST),Vol.3, No.1,2015, pp.29-40.

[9] Z.Doorbash, A. Jamshidi, G. Javidi and A. Sheybani , "Cooperative NOMA in cognitive radio networks: A study on imperfevt CSI, SIC and hardware imparements over Nakagami-m- fading channel, " Physical Commun. Vol.64, 2024.

[10] Q. Nhat Le, D.-Th. Do, B. An, "Secure wireless powered relaying networks: Energy harvesting policies and performance analysis, " International Journal of Commun. Sys., Vol.30, No.18,2017, pp. 1936 – 1947.

[11] H. Bany Salameh, Sh. Abdel-Razeq and H. l-Obiedollah, " Integration of cognitive radio technology in NOMA-based 5BG networks: State of art, challenges and enabling technologies, "IEEE Access, Vol.11,2023, pp. 12949 – 12962.

[12] F. Zhou, Z. Li, N. C. Norman, J. Cheng, and Y.Wang, "Resource allocation in wideband cognitive radio with SWIPT: Max-min fairness guarantees, " Proc. IEEE GLOBECOM, USA, 2016.

[13] H. Zhang, S. Huang, C. Jiang, K. Long, V.C.M. Leung, H. V. Poor "Energy efficient user association and power allocation in millimeter wave- based ultra dense networks with energy harvesting base stations, " IEEE J. Sel. Areas Commun., Vol.35, No.9,2017, pp. 1936–1947.

[14] Y. Chen, N. Zhao, and M.-S. Alouini, "Wireless energy harvesting using signals from multiple fading channels, " IEEE Trans. Commun., Vo.65,No.11, 2017,pp. 5027–5039.

[15] S.H. Mostafavi-Amjad , V. Solouk and H. Kalbkhani , "Energy-efficient user pairing and power allocation for granted uplink-NOMA in UAV communication systems, " Journal of Information Systems and Telecommunication (JIST) , Vol.10, No. 4, 2022, pp.312-323.

[16] S. Arzykulov, G. Nauryzbayev, T. A. Tsiftsis and B. Maham, "Performance analysis of underlay cognitive radio

nonorthogonal multiple access networks, " IEEE Trans. on Vehi. Tech., Vol.68, No.9, 2019,pp.9318-9322.

[17] L. Bariah, S. Muhaidat and A. Al-Dweik, "Error performance of NOMA based cognitive radio networks with partial relay selection and interferencep constraints, " IEEE Trans. on Communications, Vol.68, No.2,2020, pp.765-777.

[18] Y. Zhang, and J. Ge. "Impact analysis for user pairing on NOMA based energy harvesting relaying networks with imperfect CSI, " IET Commun., Vol. 12, No. 13, 2018, pp. 1609-1614.

[19] S. Arzykulov, T. A. Tsiftsis, G. Nauryzbayev and M. Abdallah, "Outage Performance of Cooperative Underlay CR-NOMA With Imperfect CSI, " IEEE Commun. Letters, Vol.23, No.1, 2019,pp. 176 – 179.

[20] G. Im and Jae Hong Lee, "Outage probability for cooperative NOMA systems with imperfect SIC in cognitive radio networks, " IEEE Commun. Letters, Vol.23,No.4,2019,pp. 692 – 695.

[21] D. Wang and S. Men, "Secure energy efficiency for NOMA based cognitive radio networks with nonlinear energy harvesting," IEEE Access, Vol. 6, 2018,pp. 62707 – 62716.

[22] B. Li, X. Qi, K. Huang, Z. Fei, F. Zhou, R.Q.Hu, "Security-Reliability Tradeoff Analysis for Cooperative NOMA in Cognitive Radio Networks, " IEEE Trans. Commun., Vol.67, No.1,2019, pp. 83-96.

[23] W. Liang, K. D.Wang, J. Shi , L. Li and G. K. Karagiannidis, "Distributed sequential coalition formation algorithm for spectrum allocation in underlay cognitive radio networks, "IEEE Access, Vol.7, 2019,pp.56803 – 56816.

[24] G. Nauryzbayev, S. Arzykulov, T. A. Tsiftsis and M. Abdallah, "Performance of cooperative underlay CR-NOMA networks over nakagami-m channels, " IEEE International Conference on Communications Work-shops (ICC Workshops), USA, 2018,pp.1-6.

[25] D. THUAN Do, A. Tu Le and B. Moo Lee, "NOMA in cooperative underlay cognitive radio networks under imperfect SIC, " IEEE Access, Vol.8, 2020, pp. 86180 – 86195.

[26] P. Gosh, S. Dhar Roy and S.Kundu, "Outage of cooperative NOMA with an energy harvesting relay in an underlay cognitive radio network, "International journal of Commun. Sys., Vol.37, No.8, 2024.

[27] X. Li, X.Gao, Sh. Ahmed Shaikh, M. Zeng, G. Huang, N. Muhammad Faseeh Qureshi and D. Qiao, " NOMA-based cogtive radio network with hybrid FD/HD rlay in industry 5.0, "Journal of King Saud University- Comp. and Infor. Sciences, Vol.35, No.6, 2023.

[28] D. Samanta, Ch. Kumar De and A. Chandra , "Performance analysis of NOMA based hybrid cognitive radio network assist by full- duplex relay, " Telecommun. Sys. Journal, Vol.88, No.37, 2025.

[29] S. Arzykulov, G. Nauryzbayev and T. A. Tsiftsis, "Underlay Cognitive Relaying System Over α - μ Fading Channels, " IEEE Commun. Lett., Vol.21,No.1, 2017,pp 216–219.

[30] Dinh-Thuan Do, H.-S. Nguyen, "A tractable approach to analyze the energy-aware two-way relaying networks in presence of co-channel interference, " EURASIP Journal on Wirel. Commun. and Netw., 2016.

[31] S. Boyd, L. Vandenberghe Convex Optimization. Cambridge, U.K.: Cambridge Univ. Press, 2004.

[32] W. Yu, R. Lui , "Dual methods for nonconvex spectrum optimization of multicarrier systems, " IEEE Trans. Commun, Vol.54,No.7,2006, pp. 1310-1322.

[33] B. Sklar, "Rayleigh fading channels in mobile digital communication systems part1: Characterization, " IEEE Commun. Mag., Vo.35,No.9, 1997,pp.136-146.

[34] Y. Ma, D. I. Kim, Zh. Wu, "Optimization of ofdma-based cellular cognitive radio networks, " IEEE Trans. on Commun., Vol.58, No.8, 2010,pp.2265 - 2276 .

[35] M.Najimi, A.Ebrahimzadeh, S.M.Hosseini Andargoli and A. Fallahi, " A novel sensing nodes and decision node selection method for energy efficiency of cooperative sepectrum sensing in cognitive sensor networks, " IEEE Sens. Jour., Vol.13, No.5, 2013,pp. 1610-1621.