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Research paper

Energy Efficiency Optimization in Cooperative Spectrum Sensing by NOMA

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Abstract

Energy efficiency improvement is a major point of concern in cooperative scenario of cognitive radio networks, so as to compensate the overhead occurred due to power consumed by multiple numbers of secondary users. Non-orthogonal multiple access (NOMA) is a potential technique to get the higher spectrum efficiency for 5G systems. The basic feature of NOMA is to utilize the same channel, time and code but at different power levels, which results in higher spectrum efficiency (SE). In this article, firstly the cognitive radio (CR) inspired NOMA is generalized by multiple primary users. Then, energy efficiency (EE) is optimized for the proposed system. An efficient algorithm is proposed for the non-convex fractional programming problem. Simulation results show the superior performance over conventional multiple accesstechniques.

Keywords: *Cognitive radio, Non-orthogonal multiple access (NOMA), Cooperative NOMA, Energy efficiency.*

1. Introduction

Non-orthogonal multiple access has emerged as the promising technique to improve SE of future 5G communication systems [1]–[3]. In comparison to conventional multiple access (CMA) techniques, NOMA is empowered by the superposition coding, distinct power allocation and successive cancellation of interference [4]. That is why it has been emerged as more spectral efficient technique for future 5G systems. In third Generation Partnership Project Long Term Evolution (3Gpp-LTE)NOMA was applied for downlink system [5]. The application of NOMA has been illustrated in [6]–[8].

Moreover, cognitive radio is another approach to improve SE, proposed by [9], [10]. In CR networks multiple secondary users (SUs) opportunistically utilize the licensed or primary users (PUs) spectrum by spectrum sensing, detection and allocation. Initially, NOMA inspired CR has been proposed by[4], [7], [11].

2. Related work

The research in [4] indicates that within multiple users, a user with better channel will be a secondary user and poorer channel as primary user. The secondary user will try to occupy the channel of the primary user. Further, NOMA for underlay cognitive radio networks of large scale was also applied in [11].

Apart from SE, EE is also drawing the attention of researchers as communication technology is responsible for 5% of the total world energy consumption [12]. As of now, very few researches are available in the field of NOMA with respect to EE in cognitive radio networks [13]. In [14],[15]author proposed EE optimization for fading MIMO inspired by non-orthogonal multiple access.

The aforementioned observations, leads us to motivate the study of EE improvement in NOMA inspired CRNs.

The existing CR-NOMA proposed in [4] is generalized by considering one base station (BS), one PU and SU. A user, associated with strong channel is regarded as SU and PU with weak channel conditions. This unlicensed SU can take on the spectrum with the condition of less interference to PU. The main objective of this paper is to maximize the EE with the constraint of quality of service of PU or the licensed user. Here, the problem is formulated as the non- convex fractional programming problem.

Further in the paper, system model is briefed in section 3. In section 4, problem formulation and solution is given. Section 5 illustrated the simulation results. Finally, the conclusion is discussed in section 6.

3. System model

In the system model, downlink transmission with one BS with two antennas, working simultaneously for two users (PU and SU) is considered. Both the users are equipped with antennas. Let the channel between PU and BS & SU and BS is flat with quasi-static fading. In this research, is it assumed that SU has better channel as compared to PU, hence it access the PU spectrum by NOMA with the constraint of non degradation of PU performance. The user 1 is PU and user 2 is SU. For a generalized CR-NOMA framework, the M users are served by a single BS simultaneously inspired by NOMA with the condition of providing quality of service to rest M-1 PU.

Let the BS transmits the message x_1 to PU and x_2 to SU at the same frequency and same time slot but different power level. The BS is transmitting the superposition of weighted symbols $\{w_M x_M\}_{M=1}^{2}$.The received signal is a combination of the desired message plus interference plus additive noise. Mathematically, the

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observations received at the PU and SUcan be represented, respectively as

$$y_1 = h_1^H w_1 x_1 + h_1^H w_2 x_2 + n_1$$
$$y_2 = h_2^H w_2 x_2 + h_2^H w_1 x_1 + n_2 \quad (1)$$

where, the first component of equation (1) is message, second is interference produced by the other message and the third one is noise, $n_1$and n_2 are additive Gaussian noise with zero mean and variance σ^2. The channel vector, h_M can be represented as $h_M = g_M \overline{d_M^{\frac{-a}{2}}}$, where$g_M \sim \mathcal{CN}(0, I_2)$, d_M is distance between BS and the M^{th} user, and *a*is the path loss exponent.

Further to implement NOMA in CRNs scenario, successive interference cancellation (SIC) is used so that the partial interference can be removed[14], [16]. Here, we have assumed that PU is far from the BS while SU isnear to BS hence SU is strong user and PU is weak. In SIC decoding technique, PU will decode the message $x_1$by taking SU interference as noise. While SU will first decode the message x_1 treating the interference by x_2 as noise then cancel the $x_1$part from the received one. Thus, it will decode the x_2 from the remaining message. The user's decoding ability is given by its signal to interference - noise ratio (SINR)[17]. The general form of representation of SINR when, M = 1, 2 and $1 \le i \le M$ isgiven by

$$SINR_M^i = \frac{|h_M^H w_i|^2}{\sum_{j=i+1}^{2} |h_M^H w_j|^2 + \sigma^2} \quad (2)$$

The above condition will be true, provided SU will decode the messages intended for the PU.

4. Problem Formulation and Solution

4.1 EE Maximization Problems

Here, the EE maximization problem is formed as the ratio of maximum achievable sum rate and total power consumed and represented as

$$EE \triangleq \frac{R_t}{P_t + P_c} \quad (3)$$

where, R_t is the sum rate in bits/sec/Hz, transmit power $P_t \triangleq \sum_{M=1}^{2} \|w_M\|_2^2$ and P_c circuit consumption power. The total achievable sum rate is the sum of PU rate and SU rate. The PU sum rate is given by

$$R_{PU} \triangleq log_2(1 + L_1) \quad (4)$$

where, L_1 is the SINR threshold for the decoding ofx_1.

In the SU decoding, SIC and predefined order will be used so that interference due to other user could be removed. Hence, the SU sum rate is formulated as

$$R_{SU} \triangleq log_2\left(1 + \frac{|h_2^H w_2|^2}{\sigma^2}\right) \quad (5)$$

Accordingly, the problem of EE maximization can be formulated as

$$\max_{w_1, w_2} EE$$
$$\text{s.t. } SINR_1^1 \ge L_1, M = 1$$
$$\sum_{M=1}^{2} \|w_M\|_2^2 \le P_{tot} \quad (6)$$

Here, the first constraint will give the QoS required for successful transmission of PU and the second constraint will give the transmit power requirement. The problem defined in equation (7) is a non-convex fractional programming problem.

4.2 Proposed Algorithm

The problem defined in (6) is further explored by putting the values of SINR and is given as

$$\max_{w_1, w_2} EE$$
$$\text{s. t. } |h_1^H w_1|^2 \ge L_1(|h_1^H w_2|^2 + \sigma^2),\ M = 1$$
$$|h_2^H w_1|^2 \ge L_1(|h_2^H w_2|^2 + \sigma^2),\ M = 2$$
$$\sum_{M=1}^{2} \|w_M\|_2^2 \le P_{tot} \quad (7)$$

The above problem given in (7) is non-convex problem. This type of non – convex fractional programming problem can be solved by the Dinkelbach's algorithm[18].But the computational complexity of this algorithm is very high. Hence, convex approximation is used to solve this problem. Further to explore the hidden convexity, the problem (7)can be rewritten in term of auxiliary variabless and *u* as

$$\max_{w_1, w_2, s, u} s$$
$$\text{s. t. } R_{PU} + R_{SU} \ge \sqrt{su}$$
$$P_t + P_c \le \sqrt{u} \quad (8)$$

If *v* is taken as auxiliary variable which is used to indicate the target SINR for the M^{th} user and *r* is the data rate of *v* (data rate of SU), then$\frac{|h_M^H w_M|^2}{\sigma^2} \ge v$, and $1 + v \ge 2^r$.The squared EE can be interpreted by the *s* and squared power can be termed as *u*. With the explanations given above the original fractional programming problem can be approximated as convex by using Taylor's approximation with iterations and can be formulated for n^{th} iteration as

$$\max_{w_1, w_2, s, u, v, r} s$$
$$\text{s. t. } \frac{yT(\emptyset_{M,M}, \emptyset_{M,M}^n)}{\sigma^2} \ge v \quad (9)$$

where, $|h_M^H w_i|^2 = \emptyset_R{}^2 + \emptyset_I{}^2$, $\emptyset_{M,i} \triangleq \left[\emptyset_{M,i}{}^R + \emptyset_{M,i}{}^I\right]^T$ and $y(\emptyset_{M,i})$ is Euclidian norm of real vector. $yT(\emptyset_{M,M}, \emptyset_{M,M}^n)$ is 1st order- Taylor's approximation. Considering this, the approximations of the constraints are

$$yT(\emptyset_{M,M}, \emptyset_{M,M}^n) \ge L_1(|h_1^H w_2|^2 + \sigma^2), \qquad M = 1$$
$$yT\left(\emptyset_{M,i}, \emptyset_{M,i}^n\right) \ge L_1(|h_2^H w_2|^2 + \sigma^2),\ M = 2 \quad (10)$$

$$\emptyset_{M,i}^n \triangleq [Re\{(h_M^H w_i)^{n-1}\}, Im\{(h_M^H w_i)^{n-1}\}]^T \quad (11)$$

$$u^{(n)} = \left(\sum_{M=1}^{2} \left\|w_M^{n-1}\right\|_2^2 + P_c\right)^2 \quad (12)$$

$$s^{(n)} = \frac{\{R_{PU} + log_2(1 + \frac{|h_2^H w_2|^2}{\sigma^2})\}^2}{u^{(n)}} \quad (13)$$

The proposed algorithm shown in Algorithm1, gives the EE optimization method. Firstly, the initial values of $\left\{w_M^{(0)}\right\}_{M=1}^{2}$, $s^{(0)}, u^{(0)}, v^{(0)}, r^{(0)}$ are taken. Then, equation (9) is solved for n=0. In step 5, update n=n+1 and then solve the equations (11), (12), and (13) for the updated value of n. Lastly, the loop is terminated when reach the convergence. Further, the optimized values are obtained.

Algorithm 1 CR NOMA for EE optimization

1. **Initialization:** $\left\{w_M^{(0)}\right\}_{M=1}^{2}, s^{(0)}, u^{(0)}, v^{(0)}, r^{(0)}$.
2. n = 0.
3. **repeat**
4. solve the equation (9).
5. n=n+1.
6. solve equation (11), (12) and (13) for updated n.
7. **stop** when reach the convergence.

5. Simulation Results

The performance of the system has been illustrated in this section by comparing the NOMA with the conventional TDMA tech-

nique. The simulation parameters used for MATLAB are given in table1:

Table 1: Simulation parameters

Parameters	d	fs	a	σ^2	P_c	d_1	R_{PU}
Values	40 m	300000 0 Hz	3.5	-80 dB m	30 Wat t	50 m	2 bits/Hz/ s

In figure 1, EE versus transmission power is illustrated for NOMA and TDMA. Moreover, the comparison of NOMA and conventional TDMA (used in exhaustive search method and sub-optimal algorithm in []) is also presented. Figure 1 shows the superior performance of the NOMA technique over the conventional TDMA in terms of EE. At the transmission power 0.2 Watt, the EE for NOMA is 0.998 bits/Hz/Joule, whereas 0.6 bits/Hz/Joule for sub-optimal. It is clearly visible from the graph that an increase in transmission power results in decrease of EE. However, the maximum EE for NOMA achieved at 0.1 Watt power.

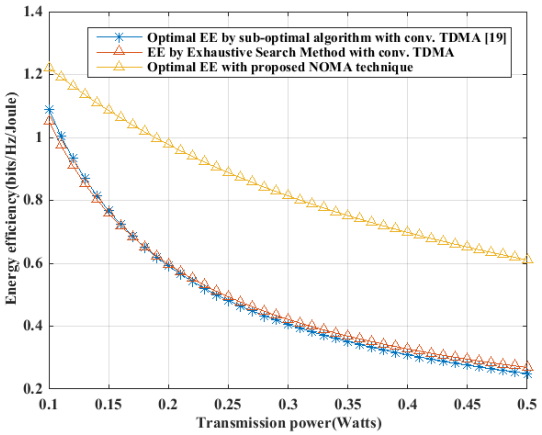


Fig. 1: EE versus transmission power.

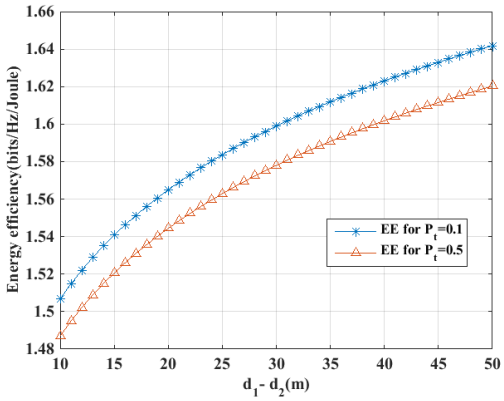


Fig. 2: EE versus difference in distance of PU and SU, to the BS

Figure 2 shows the impact of location of PU and SU from BS on EE. Here, it is assumed that the d_1 is fixed and d_2 is varying. Both the distances are calculated from the BS. It is depicted in the figure2 that increase in the difference of distance results in increase in EE. It means, SU is going closer to the BS as difference is increasing. The important conclusion from the figure is, near –far-effect between PU and SU gives more benefit to the NOMA technique, which further increase its applications.

6. Conclusions

In this paper, the EE maximization problem with downlink NOMA technique is studied. Here, BS equipped with two antennas, one PU and one SU have considered. Application of NOMA technique in cognitive radio is discussed. CR-NOMA technique will further increase the application of CR into 5G systems. Further, the EE is maximized for the NOMA and compared with otherexisting conventional multiplexing techniques. Results reveal the superior performance of the proposed method. EE maximization problem for multiple PU and multiple SU with MIMO for different fading channels can be considered as future scope.

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