School of Engineering and Applied Science (SEAS), Ahmedabad University

B.Tech(ICT) Semester V: Wireless Communication (CSE 311)

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- Base Article Title:

  1) B. Soni, D. K. Patel, Y. L. Guan, S. Sun, Y. C. Chang, and J. M.-Y. Lim, "Performance Analysis of NOMA aided Cooperative Relaying over α-η-κ-μ Fading Channels," 2020 National Conference on Communications (NCC), 2020.

  2) Our New Article title: Spectrum Utilization of Cognitive Radio Networks using NOMA

Introduction to Innovation Framework

Motivation

The current framework does not make the use of Cognitive Radio Networks (CRNs) along with NOMA. The goal of CRNs is to provide high Spectral Efficiency (SE) and high Quality of Service (QoS) to both Primary User (PU) and Secondary User (SU).
In order to achieve desired functionalities of power domain concept in NOMA at the receiver, channel gain difference between users should be adequate. This limits effective number of users.
Integrating CR (Cognitive Radio) networks with NOMA can improve system capacity and hence can increase the number of users as compared to traditional NOMA.

Benefits of using CRNs (Cognitive Radio Networks) with NOMA

- Cognitive radio (CR) [10], [11] as an emerging technology is proposed to provide high spectrum in which SUs are allowed to access the spectrum when PU is absent. It can achieve the highest accuracy when the probability of Detection is the highest and probability of false alarm is the lowest.

- Low false alarm probability indicates highly reliable detection of the idle channel, while high detection probability means highly accurate detection on the presence of the PU (Primary User). The sensing time decides the detection performance, which can be increased to decrease false alarm probability and improve detection probability.

- Cognitive radio (CR) provides high Spectral Efficiency (SE) . It can enable the secondary network (unlicensed network) to access the licensed frequency bands of the primary network by using adaptive transmission strategies while protecting the quality of service (QoS) of the primary one.

- Non-orthogonal multiple access (NOMA) techniques improve Spectral Efficiency (SE) and user connectivity density . Unlike the conventional orthogonal multiple access (OMA) techniques, NOMA techniques allow multiple users to simultaneously access the network at the same time and the same frequency band by using non-orthogonal resources, such as different power levels or low-density spreading codes.

- In CR-NOMA, occasionally, the unlicensed secondary users (SU) can be served the same quality of service (QoS) conditions as the licensed primary users (PU)

- It can achieve higher spectral effect because both PU and SU can work well using the same spectrum at the same time.

- CRNs with NOMA leverage secure transmission techniques. Due to the broadcast nature of NOMA and the open nature of CR, malicious NOMA SUs may exist and illegitimately access PUs' frequency bands or change the radio environment. As a result, a legitimate SU is unable to use frequency bands of a PU. Thus, secure transmission techniques are of crucial importance which are provided by CRNs with NOMA.

1 New Performance Analysis

- **System Model/Network Model**

  The below image comprises the system model of this article. The explanation of the model is followed after the figure.

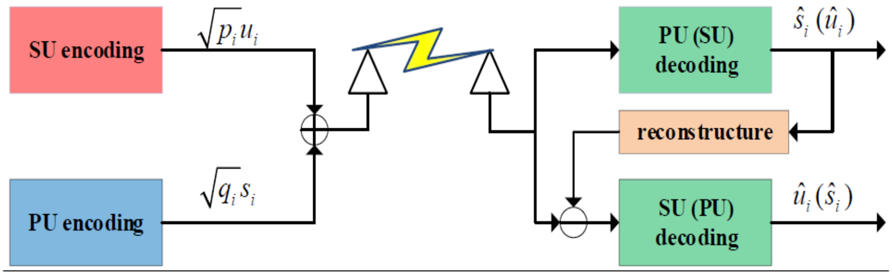

Figure 1: System model for CR NOMA

In the above system model, PU is defined as the Primary User and SU is defined as the Secondary user. Primary User is a user who has higher priority or legacy rights on the usage of a specific part of the spectrum. A user who has a lower priority is called the Secondary User.

We consider a SU and a PU covering N subchannels in the 5G communications, where the SU can share the spectrum with the PU without disturbing the normal communication of the PU. The SU can access the spectrum of the PU only when the absence of the PU is detected by spectrum sensing.

The SU can share the spectrum with the PU by NOMA when the PU is present. The SU and the PU transmit data in subchannel i with the power pi and qi. As shown in the above figure, the receiver has two kinds of decoding modes : **PFDM and SFDM**

  - **PFDM** : The PU signal is firstly decoded and reconstructed, and then the SU signal is decoded by canceling the reconstructed PU signal from the received signal. The throughput of the SU can be guaranteed, but the throughput of the PU may be decreased due to the interference caused by the SU.

- **SFDM** : The SU signal is firstly decoded and reconstructed, and then the PU signal is decoded by removing the reconstructed SU signal from the received signal. The throughput of the PU can be ensured, but the throughput of the SU will be reduced because of the interference from the PU.

- List of symbols and their description (see the table below for your reference)

Symbol	**Description**
P_d	Probability of detection
P_f	Probability of false alarm
τ	Subchannel Sensing Time
g_i	gi is the subchannel gain between PU transmitter and receiver
p_i	The power with which the SU transmit data in subchannel i
q_i	The power with which the PU transmit data in subchannel i
σ_i	The noise power in subchannel i
$\delta_i(t)$	Normalized noise signal
M	Number of Samplings
$H0$	The Hypothesis that denotes the absence of PU
$H1$	The Hypothesis that denotes the presence of PU
f_s	The sampling Frequency
ρ	Detection Threshold

- **Detailed derivation of performance metric-I**

Here we consider the PFDM mode. In this mode, The PU signal is firstly decoded and reconstructed, and then the SU signal is decoded by canceling the reconstructed PU signal from the received signal.

The subchannel sensing time τ impacts the spectrum sensing performance of the SU directly.

Energy detection is often used to detect the PU, which compares the PU signal 's energy statistics to a preset threshold and calculates the presence of the PU if the energy statistic is above the threshold.

The sensing signal $y_i(m)$ at the SU in subchannel i is given as follows:

$$y_i(t)=\begin{cases} g_i(t)\sqrt{q_i}s_i(t)+\sqrt{\sigma_i}\delta_i(t), H_1 & ,m=1,2,\ldots,M \\ \sqrt{\sigma_i}\delta_i(t), H_0 \end{cases} \tag{1}$$

But if we consider the distance between the channel as d_i then we can rewrite the equations as,

$$y_i(t)=\begin{cases} \frac{g_i(t)}{\sqrt{1+d_i^T}}\sqrt{q_i}s_i(t)+\sqrt{\sigma_i}\delta_i(t), H_1 & ,m=1,2,\ldots,M \\ \sqrt{\sigma_i}\delta_i(t), H_0 \end{cases} \tag{2}$$

In the above equation, $\delta_i(t)$ is the normalized noise signal, M is the number of samplings, $H0$ and $H1$ denote the absence and presence of the PU (Primary User) respectively.Also in d_i^T, T is the path loss exponent Suppose the sampling frequency is f_s then we have $M=\tau f_s$

Now we calculate the energy statistic of the sensing signal. It is given as follows:

$$\Phi\left(y_i\right)=\frac{\sum_{t=1}^{M}\left\|y_i(t)\right\|^2}{M} \tag{3}$$

Since $y_i(t)$ for $t=1,2....M$ are independently and identically distributed, according to the Central Limit Theorem, $\phi(y)$ obeys the Gaussian distribution at large M as follows:

$$\Phi\left(y_i\right)\sim\begin{cases} \mathcal{N}\left(\left(q_i\left(\frac{g_i^2}{1+d_i^T}\right)+\sigma_i\right), \frac{\left(q_i\left(\frac{g_i^2}{1+d_i^T}\right)+\sigma_i\right)^2}{M}\right), H_1 \\ \mathcal{N}\left(\sigma_i, \frac{\sigma_i^2}{M}\right), H_0 \end{cases} \tag{4}$$

False alarm Probability and Detection Probability are defined to measure the spectrum sensing performance. **False alarm probability** denotes the probability that the energy statistic is above the threshold at $H0$, which decides the spectrum utilization ability of the SU. The **False Alarm Probability** is given as follows:

$$P_f=P_r\left(\Phi\left(y_i\right)>\rho \mid H_0\right)=Q\left(\left(\frac{\rho}{\sigma_i}-1\right)\sqrt{\tau f_s}\right) \tag{5}$$

In the above equation, ρ is defined as the detection threshold. **Detection probability** indicates the probability that the energy statistic is below the threshold at H1, which determines the ability of discovering the PU. Thus the **Probability of Detection** is given as:

$$P_d = P_r\left(\Phi\left(y_i\right) > \rho \mid H_1\right) = Q\left(\left(\frac{\rho}{q_i\left(\frac{g_i^2}{1+d_i^T}\right)+\sigma_i} - 1\right)\sqrt{\tau f_s}\right) \tag{6}$$

Now to plot the graph for P_d vs P_f , we will first find the value of ρ. From eq(4) we can make ρ the subject to find its value. According to eq.5

$$\rho = \sigma_i\left(\frac{Q^{-1}(P_f)}{\sqrt{\tau f_s}} + 1\right) \tag{7}$$

We can substitute the value of ρ in equation (6) to find the value of P_d for different constant values of P_f.So in equation (8), we got the formula for P_d in terms of P_f

$$P_d = Q\left(\left(\frac{\sigma_i\left(\frac{Q^{-1}(P_f)}{\sqrt{\tau f_s}} + 1\right)}{q_i\left(\frac{g_i^2}{1+d_i^T}\right)+\sigma_i} - 1\right)\sqrt{\tau f_s}\right) \tag{8}$$

2 New Numerical Results

2.1 Simulation Framework

For producing graph of P_d vs P_f we will use equation no(8). For the simulations we consider value of noise power in sub-channel σ_i=0.01mW , sub-channel sensing time τ=20ms , sampling frequency f_s=500Hz ,SNR (in dB) is 30dB, power of PU sub-channel q_i=10mW ,g_i is the channel gain and the channels obey the NakaGami fading.

The parameter m is called the 'shape factor' of the Nakagami or the gamma distribution.So we vary value of m to see the effect on Pd.Also we vary the distance between channel d_i^T.

2.2 Figures with description

- **Graph of Pd vs Pf for varying distance**

  As the distance between BTS and user increases, Channel gain decreases. Due to which the signal strength decreases. Hence it becomes hard to sense the signal as the user moves away from the Base Station. Therefore we can infer that Pd will keep on decreasing as the distance between Base Station and User increases.

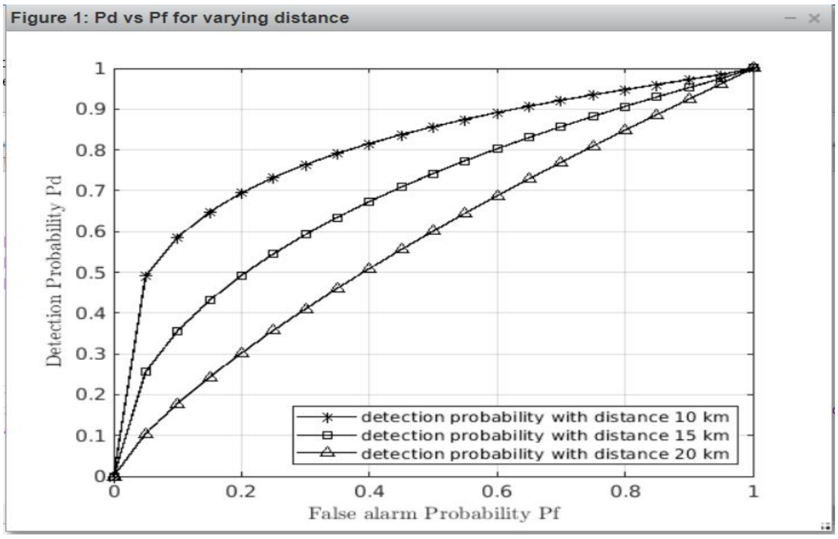

Figure 2: Pd vs Pf for varying distance

- **Graph of Pd vs Pf for varying m in fading channel**

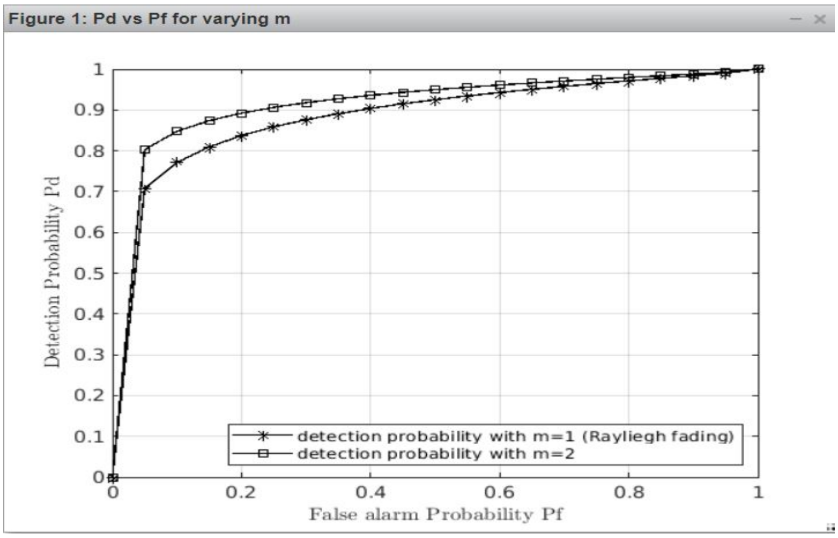

Figure 3: Pd vs Pf with varying m

As we increase the factor " m " , we can see that the value of Probability of Detection (Pd) increases.

The m parameter relates the amplitudes of strong and weak components. Rayleigh fading is obtained when m=1. For m ¿ 1, the fluctuations of the signal strength reduce compared to Rayleigh fading and hence Pd increases.

- **ROC curve for the Cognitive radio**

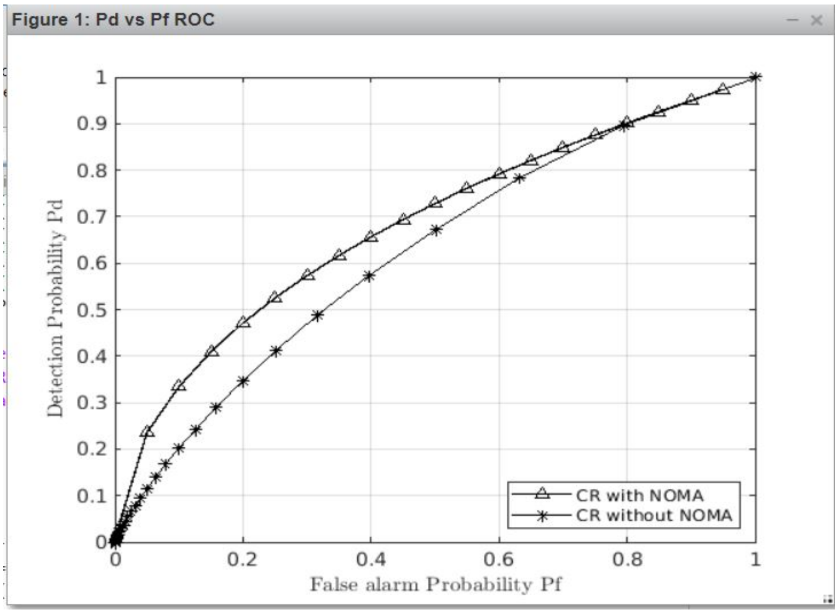

Figure 4: ROC curve for Cr noma

An ROC curve (receiver operating characteristic curve) is a graph showing the performance of a classification model at all classification thresholds.

In Our figure it can be clearly observed from the ROC curve of CR with NOMA and CR without NOMA , that the performance of CR with NOMA is better as compared to CR without NOMA.

Hence, to sum up, Using CR along with NOMA helps in improving the traditional CR's performance.

3 Contribution of team members

3.1 Technical contribution of all team members

The Technical contribution of the group members is given in the table below

Tasks	**Varshil Shah**	**Vidit Vaywala**	**Hemil Shah**	**Kahaan Patel**
Brainstorming about innovation	✓	✓	✓	✓
Derivation of P_f	✓	✓		
Derivation of P_d			✓	✓
System Modelling	✓	✓	✓	✓
Matlab Coding and Commenting	✓	✓	✓	✓
Identifying limitations of base article	✓	✓	✓	✓
Plotting the Distance Curve (Fig 2)	✓	✓		
Plotting the ”m” Curve (Fig 3)			✓	✓
Plotting the ROC Curve (Fig 4)	✓	✓	✓	✓

3.2 Non-Technical contribution of all team members

The non-technical contribution of all team members is given below

Tasks	**Varshil Shah**	**Vidit Vaywala**	**Hemil Shah**	**Kahaan Patel**
Report Writing - Introduction			✓	
Report Writing - New Performance Analysis	✓	✓		
Report Writing Section 2 and 3	✓	✓		✓
Managing Deadlines			✓	✓
Preparing relevant MIRO frames	✓	✓	✓	✓
Preparing and editing the video	✓	✓	✓	✓