Outage performance analysis of underlay cognitive cooperative NOMA network

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ABSTRACT

In this thesis, we study the cognitive cooperative non-orthogonal multiple access network with interference power constraint in underlay mode, where a primary receiver is situated at the communication range of the secondary network. In the cognitive secondary network, the secondary originating node transmits information with the cognitive close user directly and with the cognitive remote user by the aid of multiple relays under cognitive radio constraint. Secondary originating node sends the mixed message to the cognitive close user and to multiple relays via NOMA principle. Through the signal to interference plus noise ratio between secondary originating node and multiple relays, the best relay is opted to forward the decode signal to the cognitive remote user. In order to gauge the performance of the system accurately, the exact closed form formulas for the outage probabilities of the cognitive close user and the cognitive remote user are deduced respectively over Rayleigh fading channels. Experiment results indicate that power allocation has a great influence on the performance of system for NOMA network and it is an effective way for improving the performance of cognitive cooperative NOMA network that increasing the quantity of relays.

Keywords: Cognitive radio (CR), cooperative, non-orthogonal multiple access (NOMA), outage probability (OP)

1. INTRODUCTION

Due to the exponential growth of wireless transmission demands and large scale connection with the wide application of the fifth generation communication technology (5G), cognitive radio is proposed as the novel technology with high spectrum utilization to tackle the unprecedented challenges raised by the growth of the network size[1-3]. In the cognitive radio (CR) environment, the cognitive secondary network accesses the authorized spectrum of the primary user (PU) through the interweave protocol, the overlay protocol, or the underlay protocol to maximize the use of limited spectrum resource.[4-6]. In interweave mode, when perceiving spectrum hole of PU, secondary user (SU) is allowed to access the spectral of PU[4]. Different from interweave mode, overlay mode allows SU receives PU message and assists transmission of primary network to realize spectrum sharing[5]. If the interference generated by the SU does not affect the transmission of the PU, the SU sends signals in the same frequency band as the PU[6].

Non-orthogonal multiple access (NOMA) has been envisioned as a revolutionary technology on improving the spectrum efficiency in future wireless communication network, and is focused generally by field of modern communication [7]. Cooperative relay transmission is considered as a breakthrough technology in wireless network due to its high reliability and large scale connection[8]. Therefore, combining cooperative relay and NOMA is an effective to enhance communication coverage and spectrum utilization[9, 10]. In[9], the paper proposes a cooperative network based on NOMA, in which the performance of NOMA-based cooperative system with decode-and-forward (DF) schema and amplify-and-forward (AF) schema applied to selected relays is analyzed by deducing the capacity and outage probability (OP). In[10], the authors prove that NOMA-assistant massive multiple-input-multiple-output system are superior to the conventional cellular system and proposed the adaptive protocol which could choose schemes of cooperative NOMA, NOMA without cooperative and traditional orthogonal multiple access (OMA) according to the situation.

NOMA has advantages in terms of improving the spectrum efficiency, thus, combining NOMA and cooperative cognitive network is worthy to be envisioned[11-13]. In[11], an underlay cooperative cognitive network using DF protocol is analyzed, and the closed-form formulas of OP of PU and SU networks are calculated. In[12], a signal relaying node cooperative CR network is proposed, in which the cognitive secondary originating node communicates with the close and remote users

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through a DF relay by using the NOMA principle. In the study of[13], the authors proposed the protocol of selecting the optimal relay by signal-to-interference-plus-noise ratio (SINR) in the multi-relay cooperative CR network in AF mode.

2. SYSTEM AND CHANNEL MODEL

We research an underlay cognitive cooperative NOMA transmission network. In this model, a secondary originating node node (denoted by S), a cognitive close user (denoted by U_N), a cognitive remote user (denoted by U_F), K secondary relays (denoted by $R_i\,(1 \le i \le K)$) and a primary receiver (denoted by V) form the proposed network. The secondary originating node S transmits date to the close user U_N directly and communicate with the remote user U_F with the aid of the secondary relay R_i. The secondary originating node S sends the superposed signal of the cognitive close user U_N and the cognitive remote user U_F to U_N and the secondary relay R_i with transmission power P_S under the power limit imposed by the PU receiver. the secondary relay R_i decodes and forwards the signals of remote user U_F with transmission power P_{R_i}. We use h_{ij} and g_{ij} to define the Rayleigh fading coefficient of the channel and the instantaneous channel gain between i and j, $g_{ij} = \left|h_{ij}\right|^2$. g_{ij} follows exponential distributions with mean Ω_{ij}.

To avoid interfering with the primary network in cognitive radio environment environments, P_S can $P_{R_i}\,(1 \le i \le K)$ be expressed, respectively

$$P_S = \frac{I}{g_{SV}} \tag{1}$$

$$P_{R_i} = \frac{I}{g_{R_iV}} \tag{2}$$

where I is the predetermined interference constraints at the primary receiver V.

In phase-1, the secondary originating node S transmits the composite data $x_S = \sqrt{\alpha_1}x_N + \sqrt{\alpha_2}x_F$ on the same spectrum resource with the PU via NOMA scheme, in which x_N denotes the messages from the secondary originating node S to the cognitive close user U_N, and x_F denotes the messages which is intended to send to the cognitive remote user U_F. Particularly, the distances between the secondary originating node S and the cognitive close user is deemed to be closer than the cognitive remote user U_F. Hence, we distribute more power to the cognitive remote user U_F, such that $\alpha_1 < \alpha_2$. When the secondary originating node S fails to sends signals to the cognitive remote user directly, only the cognitive close user U_N and the relay $R_i\,(1 \le i \le K)$ can receive the composite messages transmitted. As such, the received SINR and SNR at the cognitive close user U_N for decoding signals x_F and x_N are the following

$$\gamma_{SN}^{x_F} = \frac{\alpha_2 P_S g_{SN}}{\alpha_1 P_S g_{SN} + N_0} \tag{3}$$

$$\gamma_{SN}^{x_N} = \frac{\alpha_1 P_S g_{SN}}{N_0} \tag{4}$$

The received SINR at the relay R_i for decoding signals x_F is indicated as

$$\gamma_{SR_i}^{x_F} = \frac{\alpha_2 P_S g_{SR_i}}{\alpha_1 P_S g_{SR_i} + N_0} \tag{5}$$

The relays with $\gamma_{SR_i}^{x_F} > \gamma_F$ form the decoding set D, and the best relay R_b with the highest $\gamma_{R_iU_F}^{x_F}\left(R_i \in D\right)$, is selected to forward signals of the cognitive remote user.

In phase-2, the selected best relaying node R_b forwards the messages of the cognitive remote user x_F when it succeed to decode the message of cognitive remote user x_F. Under the circumstances, the received instantaneous SNR at the cognitive remote user U_F for decoding signals x_F can be shown as

$$\gamma_{R_bF}^{x_F} = \frac{P_{R_b} g_{R_bF}}{N_0} \qquad (6)$$

3. OP

3.1 OP of the cognitive close user U_N

For U_N, in order to ensure that outage is not occur, it is necessary that U_N successfully decodes both the message of the cognitive remote user x_F and the message of the cognitive close user x_N. Hence, the exact formula of the OP of the close user U_N is shown as

$$P_{out}^{N} = 1 - \Pr\left(\gamma_{SN}^{x_F} > \gamma_F, \gamma_{SN}^{x_N} > \gamma_N\right) \qquad (7)$$

where $\gamma_F = 2^{2R_F} - 1$ is the predetermined decoding threshold for the cognitive remote user UF and RF representing the transmission rate of the cognitive remote user UF. It is the event that the cognitive close user can achieve the reliable communicate when the cognitive close user U_N can successfully decode both the signals x_F and x_N.

By using Equations (1), (3), (4), $\Pr\left(\gamma_{SN}^{x_F} > \gamma_F, \gamma_{SN}^{x_N} > \gamma_N\right)$ can be calculated as

$$\begin{aligned}
&\Pr\left(\gamma_{SN}^{x_F} > \gamma_F, \gamma_{SN}^{x_N} > \gamma_N\right) \\
&= \int_0^{\infty} \Pr\left(\frac{\alpha_2 (I/x) g_{SN}}{\alpha_1 (I/x) g_{SN} + N_0} > \gamma_F, \frac{\alpha_1 (I/x) g_{SN}}{N_0} > \gamma_N \middle| x\right) f_{g_{SV}}(x)\,dx \\
&= \begin{cases} 0 & \dfrac{\alpha_2}{\alpha_1} < \gamma_F \\ \exp\left(-\dfrac{\Delta_1 N_0 x}{I\Omega_{SN}}\right) & \dfrac{\alpha_2}{\alpha_1} > \gamma_F \end{cases}
\end{aligned} \qquad (8)$$

where $\Delta_1 = \max\left(\dfrac{\gamma_F}{\alpha_2 - \gamma_F\alpha_1}, \dfrac{\gamma_N}{\alpha_1}\right)$.

Substituting Equation (8) into Equation (7), the OP for the cognitive close user U_N is achieved.

3.2 OP of the cognitive close user U_F

For U_F, in order to ensure that outage is not occur, it is necessary that both the bast relay R_b and U_F successfully decodes the message of the cognitive remote user x_F. Hence, the exact formula of the OP of the close user U_F is shown as

$$P_{out}^{F,NDL} = \Pr\left(D = \varnothing\right) + \sum_{k=1}^{K}\sum_{D} \Pr\left(|D| = k\right)\Pr\left(\gamma_{R_bF}^{x_F} < \gamma_F\right) \qquad (9)$$

where $|D|$ means the quantity of relays in set D, and the corresponding probability $\Pr\left(|D|=k\right)$ can be indicated as

$$\begin{aligned}&\Pr\left(|D|=k\right)\\&=\int_0^\infty\left[1-\Pr\left(\frac{\alpha_2\left(I/x\right)g_{SR_i}}{\alpha_1\left(I/x\right)g_{SR_i}+N_0}>\gamma_F\left|x\right.\right)\right]^{K-k}\left[\Pr\left(\frac{\alpha_2\left(I/x\right)g_{SR_i}}{\alpha_1\left(I/x\right)g_{SR_i}+N_0}>\gamma_F\left|x\right.\right)\right]^{k}f_{g_{SV}}\left(x\right)dx\end{aligned}\tag{10}$$

where

$$\begin{aligned}&\Pr\left(\frac{\alpha_2\left(I/x\right)g_{SR_i}}{\alpha_1\left(I/x\right)g_{SR_i}+N_0}>\gamma_F\left|x\right.\right)\\&=\begin{cases}0 & \dfrac{\alpha_2}{\alpha_1}<\gamma_F\\ \exp\left(-\dfrac{\gamma_F N_0 x}{\left(\alpha_2-\gamma_F\alpha_1\right)I\Omega_{SR}}\right) & \dfrac{\alpha_2}{\alpha_1}>\gamma_F\end{cases}\end{aligned}\tag{11}$$

In Equation (9), $\Pr\left(D=\varnothing\right)$ can be calculated as

$$\begin{aligned}&\Pr\left(D=\varnothing\right)\\&=\int_0^\infty\left[1-\Pr\left(\frac{\alpha_2\left(I/x\right)g_{SR_i}}{\alpha_1\left(I/x\right)g_{SR_i}+N_0}>\gamma_F\left|x\right.\right)\right]^{K}f_{g_{SV}}\left(x\right)dx\\&=\sum_{k_2=0}^{K}\frac{C_K^{k_2}\left(-1\right)^{k_2}\left(\alpha_2-\gamma_F\alpha_1\right)I\Omega_{SR}}{\left(\alpha_2-\gamma_F\alpha_1\right)I\Omega_{SR}+k_2\gamma_F N_0\Omega_{SV}}\end{aligned}\tag{12}$$

In Equation (9), $\Pr\left(\gamma_{R_bF}^{x_F}<\gamma_F\right)$ can be calculated as

$$\begin{aligned}&\Pr\left(\gamma_{R_bF}^{x_F}<\gamma_F\right)\\&=\Pr\left(\max_{R_i\in D}\left(\gamma_{R_iF}^{x_F}\right)<\gamma_F\right)\\&=\left[1-\Pr\left(\frac{P_{R_i}g_{R_iF}}{N_0}>\gamma_F\right)\right]^{k}\end{aligned}\tag{13}$$

Finally, by the previous calculation, the OP for the cognitive remote user UF is achieved.

4. SIMULATION RESULTS

The systems parameters are set as following: $\Omega_{SN}=\Omega_{SR}=\Omega_{RF}=10dB, I=5dB, N_0=\dfrac{1}{\gamma}$.

Figure 1 describes the relationship between the OP of cognitive close user against SNR for $\Omega_{SN}=\left\{1dB,5dB,10dB\right\}$. Obviously, the OP of the cognitive close user augments with the increase of Ω_{SN} gaining. The reason is that there is the better channel conditions between secondary originating node and the cognitive close user when S N is higher. Therefore, it is clearly from figure that cognitive close users have advantage of outage performance when $\Omega_{SN} = 10dB$.

In Figure 2, we illustrate the exact OP of cognitive remote user versus SNR for power distribution coefficient of cognitive close user α_1 and the different number of relays K. Obviously, the OP of cognitive remote user decreases as gaining of the quantity of relays K, since secondary network achieves cooperative diversity with the increase of the quantity of relays. Meanwhile, as the reduction of the power distribution to the remote user while the augment of the power distribution to the cognitive close user in the NOMA cases, the increase of power distribution coefficient of cognitive close user α_1 results in increasing of OP of cognitive remote user.

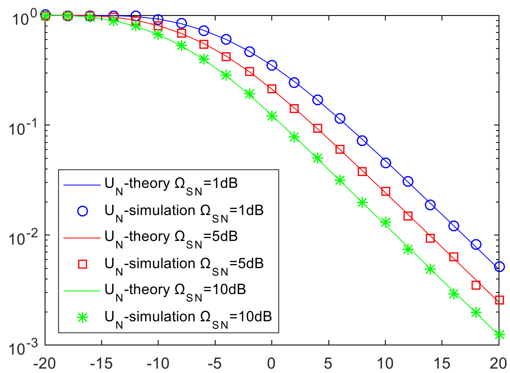

Figure 1. OP of cognitive close user against γ.

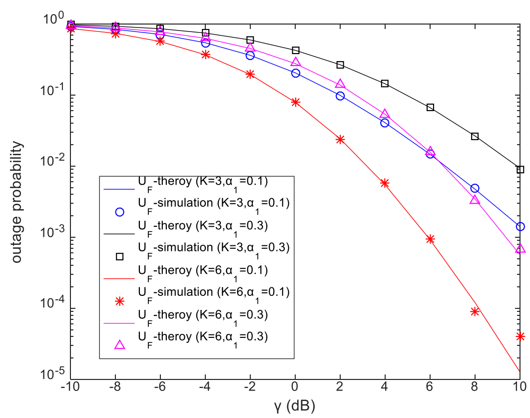

Figure 2. OP of cognitive remote user against γ.

The impact of OP of cognitive remote user due to the quantity of relays K is investigated in figure 3. According to the graphics , we can see that the quantity of relays $K = 2$ results in 6.627×10^{-2} , the quantity of relays $K = 4$ results in 7.945×10^{-3} and the quantity of relays $K = 6$ results in 2.313×10^{-4} until the system SNR $\gamma = 6dB$. The simulation results prove that the OP of cognitive remote user is decreased with the increase of the quantity of relays K , since this network implements the collaborative diversity.

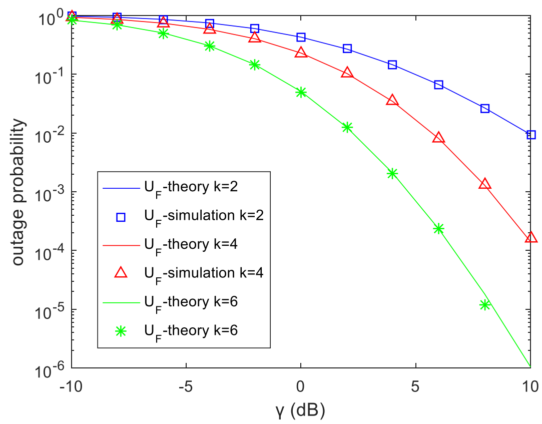

Figure 3. OP of cognitive remote user against γ.

5. CONCLUSION

In this thesis, we propose an underlay cooperative CR-NOMA network with primary interference power constraints. The secondary originating node sends the superposed signal to the cognitive close user and multiple relays. According to the SINR between the secondary originating node and the different relays, the best relay is chosen to forward the signal of the cognitive remote user. Further, we numerically evaluate the exact formulas of the OP of the cognitive close user and the cognitive remote user respectively. Finally, we conclude that it is logical and viable for improving the performance of system that power is properly distributed.

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