Achievable Rate of Relay Assisted Cooperative Opportunistic-NOMA under Rician Fading Channels

1\textsuperscript{st} Pranav Kumar Jha, 3\textsuperscript{rd} D. Sriram Kumar
Dept. of Electronics and Communication Engineering
National Institute of Technology, Tiruchirappalli
Tamil Nadu 620 015, India
jha_k.pranav@live.com, srk@nitt.edu

2\textsuperscript{nd} S Sushmitha Shree
Dept. of Electronics and Communication Engineering
Thiagarajar College of Engineering, Madurai
Tamil Nadu 625 020, India
sushmithasriram@gmail.com

Abstract—The achievable rate of an Opportunistic Non-Orthogonal Multiple Access (O-NOMA) based Cooperative Relaying System (CRS) with Channel State Information (CSI) available at the transmitter end is analyzed under Rician fading channels. It is shown that, O-NOMA-based CRS achieves a better achievable rate than Conventional-NOMA-based CRS and results are verified through Monte Carlo simulations.

Keywords—Non-orthogonal Multiple Access, Rician Fading Channels, Average Achievable Rate

I. INTRODUCTION
Non-orthogonal multiple access (NOMA) became a key techniques to enhance the spectral efficiency for the wireless multi-user communication systems [1]. For multiple user access, NOMA utilizes the power domain and superposition coding, which helps the source to send data signals at different power levels for different receivers using the same time and bandwidth [2]. As a consequence, practically, CRS NOMA can be realized as one of the promising technique to achieve high spectral efficiency for the fifth generation (5G) communication wireless systems.

Opportunistic-NOMA (O-NOMA) based CRS with CSI available at the source end under Rician fading channels are studied in order to achieve the further improvement in the performance but, at the expense of system overhead and complexity, where a source, a decode-and-forward relay, and a destination is considered for the implementation purpose [3, 4]. For opportunistic transmission, CSI for the source-to-relay and source-to-destination links is exploited and transmitter instantaneously decides the best transmission path from the direct transmission and the cooperative NOMA transmission [5] using relay. The average achievable rates of the O-NOMA-based CRS is compared with the conventional NOMA (C-NOMA) based CRS presented in [6] for different power allocation coefficients.

II. ACHIEVABLE RATE CALCULATIONS
A CRS is considered for the analysis purpose which is shown in Fig. 1, where a source (S) sends data signal directly destination (D) using relay (R). The channel coefficients of S-to-D, S-to-R, and R-to-D links are considered as $h_{SD}$, $h_{SR}$, and $h_{RD}$, respectively, which are assumed to be independent Rician random variables with average channel powers of $\Omega_{SD}^2$, $\Omega_{SR}^2$ and $\Omega_{RD}^2$, respectively. Let $\lambda_{SD} \triangleq |h_{SD}|^2$, $\lambda_{SR} \triangleq |h_{SR}|^2$, $\lambda_{RD} \triangleq |h_{RD}|^2$, $\rho = \frac{P_T}{\sigma^2}$ and $C(x) \triangleq \log_2(1 + x)$, where $\rho$ is the transmit SNR. The transmit power of S and R is considered to be the same as $P_S = P_R = P$ [3]. Following the fact that the end-to-end achievable rate of decode-and-forward relaying is dominated by the weakest link [7], and using [3, 7–10], the achievable rate of the O-NOMA-based CRS can be calculated as follows [3]:

If $\lambda_{SD} < \lambda_{SR}$,

\begin{equation}
C^{Pro} = \frac{1}{2} \min \{ \log_2(1 + \gamma_{SD,s1}^C), \log_2(1 + \gamma_{SR,s1}^C) \} \\
+ \frac{1}{2} \min \{ \log_2(1 + \gamma_{SR,s2}^C), \log_2(1 + \gamma_{RD,s2}^C) \},
\end{equation}

which can be modified as CSI is available at the source end [5]

\begin{equation}
C^{Pro} = \frac{1}{2} \min \{ \log_2(1 + \gamma_{SD,s1}^C) \} \\
+ \frac{1}{2} \min \{ \log_2(1 + \gamma_{SR,s2}^C), \log_2(1 + \gamma_{RD,s2}^C) \},
\end{equation}

else,

\begin{equation}
C^{Pro} = \log_2(1 + \gamma_{SD,s1}^D).
\end{equation}
In (1), the first and the second parts represent the achievable rates of symbols $s_1$ and $s_2$, respectively. In the first part of (1), $\log_2(1 + C_{SR,s_1})$ is needed to consider that the relay decodes symbol $s_1$ successfully using SIC, but in (2), it is deleted as $\lambda_{SD} < \lambda_{SR}$. There is one half spectral efficiency penalty for relaying in (2) but no spectral efficiency penalty is carried for the direct transmission in (3) as the source transmits an independent data symbol directly to the destination for a given time slot when $\lambda_{SD} > \lambda_{SR}$. With the help of (2) and (3), the achievable average rate of the O-NOMA-based CRS can be calculated as

$$C^{Pro} = \frac{1}{2} \log_2(1 + \lambda_{SD} \rho) - \frac{1}{2} (1 + a_2 \lambda_{SD} \rho)$$

else,

$$C^{Pro} = \log_2(1 + \lambda_{SD} \rho).$$

Now, using (4) and (5), the total achievable sum rate of O-NOMA-based CRS is given as

$$C^{Pro} = \frac{1}{2} \log_2(1 + \lambda_{RD} \rho) - \frac{1}{2} (1 + a_2 \lambda_{RD} \rho)$$

$$+ \frac{1}{2} \log_2(1 + \min\{a_2 \lambda_{SR}, \lambda_{RD}\})$$

$$+ \log_2(1 + \lambda_{SD} \rho).$$

III. NUMERICAL RESULTS AND DISCUSSIONS

In this section, numerical results are presented to verify the results using Monte Carlo simulations. Figs. 3 presents the achievable rate analysis of $s_1$, $s_2$ and the equivalent achievable sum rate of the O-NOMA-based CRS and the C-NOMA-based CRS for different values of the power allocation coefficient $a_2$ of $s_2$. Moreover, the parameters used for simulations are considered as $K_{SR} = K_{RD} = 4$, $K_{SD} = 3$ and $\Omega_{SD} = 4$. As $s_2$ gets more power, the achievable rate for $s_2$ increases and the rate for $s_1$ decreases with the increase in $a_2$.

In Fig. 3 SNR is set as 20 dB and $\Omega_{SR} = \Omega_{RD} = 7$. Now, when $a_2$ increases from 0.1 to 0.4. It can be noticed that the achievable rate of $s_1$ decreases from 10.87 bit/s/Hz to 9.920 bit/s/Hz and $s_2$ increases from 4.123 bit/s/Hz to 5.043 bit/s/Hz for O-NOMA-based CRS whereas, for C-NOMA-based CRS, $s_1$ decreases from 1.63 bit/s/Hz to 0.656 bit/s/Hz and the increment in $s_2$ remains to be the same as O-NOMA-based CRS because of the CSI information available at the source. Achievable sum rates of O-NOMA-based CRS and C-NOMA-based CRS are 15.2 bit/s/Hz and 5.758 bit/s/Hz, respectively at $a_2 = 0.1$.

IV. CONCLUSIONS

In this paper, the achievable analysis of O-NOMA-based CRS is studied under Rician fading channels and results are compared with the conventional C-NOMA. Analytical results shows that the O-NOMA-based CRS achieves higher achievable rate than the C-NOMA-based CRS. Furthermore, the average rate performance of the proposed O-NOMA-based CRS achieves more rate with the increasing power allocation co-efficient $a_2$ of $s_2$. Hence, the O-NOMA-based CRS can be more suitable than the C-NOMA-based CRS.

REFERENCES

[1] Z. Ding, Z. Yang, P. Fan, and H. V. Poor, “On the performance of non-orthogonal multiple access in 5G systems with randomly deployed users,” *IEEE Signal Processing Letters*, vol. 21, no. 12, pp. 1501–1505, 2014.

[2] H. T. Do and S.-Y. Chung, “Linear beamforming and superposition coding with common information for the gaussian mimo broadcast channel,” *IEEE Transactions on Communications*, vol. 57, no. 8, 2009.

[3] J.-B. Kim and I.-H. Lee, “Capacity analysis of cooperative relaying systems using non-orthogonal multiple access,” *IEEE Communications Letters*, vol. 19, no. 11, pp. 1949–1952, 2015.

[4] M. Xu, F. Ji, M. Wen, and W. Duan, “Novel receiver design for the cooperative relaying system with non-orthogonal multiple access,” *IEEE Communications Letters*, vol. 20, no. 8, pp. 1679–1682, 2016.

[5] I.-h. Lee and H. Lee, “Achievable rate analysis for opportunistic non-orthogonal multiple access-based cooperative relaying systems,” Journal of information processing systems, vol. 13, no. 3, pp. 630–642, 2017.

[6] R. Jiao, L. Dai, J. Zhang, R. MacKenzie, and M. Hao, “On the performance of noma-based cooperative relaying systems over rician fading channels,” *IEEE Transactions on Vehicular Technology*, 2017.

[7] C. Danae, “Technical specification group radio access network,” Technical report, Technical report, Spreading and Modulation, http://www. 3gpp. org, Tech. Rep., 1999.

[8] Z. Bai, “Evolved universal terrestrial radio access (eutra); physical layer procedures,” 3GPP, Sophia Antipolis, Technical Specification 36.213 v. 11.4. 0, 2013.

[9] Z. Ding, M. Peng, and H. V. Poor, “Cooperative non-orthogonal multiple access in 5G systems,” *IEEE Communications Letters*, vol. 19, no. 8, pp. 1462–1465, 2015.

[10] J.-B. Kim and I.-H. Lee, “Non-orthogonal multiple access in coordinated direct and relay transmission,” *IEEE Communications Letters*, vol. 19, no. 11, pp. 2037–2040, 2015.