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Channel Capacity for NOMA Weak Channel User and Capacity Region for NOMA with Gaussian Mixture Interference

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Abstract

Non-orthogonal multiple access (NOMA) has been considered for the fifth generation (5G) mobile networks to provide high system capacity and low latency. We calculate the channel capacity for the weak channel user in NOMA and the channel capacity region for NOMA. In this paper, Gaussian mixture channel is compared to the additive white Gaussian noise (AWGN) channel. Gaussian mixture channel is modeled when we assume the practical signal modulation for the inter user interference, such as the binary phase shift keying (BPSK) modulation. It is shown that the channel capacity with BPSK inter user interference is better than that with Gaussian inter user interference. We also show that the channel capacity region with BPSK inter user interference is larger than that with Gaussian inter user interference. As a result, NOMA could perform better in the practical environments.

Key words : Non-orthogonal multiple access, successive interference cancellation, power allocation, channel capacity, binary phase shift keying

Ⅰ. Introduction

Recently, non-orthogonal multiple access (NOMA) has received significant attention for the fifth generation (5G) mobile networks due to high system capacity and low latency [1-4]. In this paper, the inter user interference is modeled as Gaussian mixture noise, instead of Gaussian noise in the standard NOMA. Section II defines the system and channel model. In Section III, the channel capacity for the NOMA weak channel user and the capacity region for NOMA are calculated. In Section IV, we present and discuss the results. The paper is concluded in Section V.

Ⅱ. System and Channel Model

Assume that the channel gains are h_1 and h_2 with $|h_1| > |h_2|$ and for the total transmit power P and the power allocation factor α with $0 \le \alpha \le 1$, αP is allocated to the user-1 signal s_1 and $(1-\alpha)P$ is allocated to the user-2 signal s_2, with $E[|s_1|^2] = E[|s_2|^2] = 1$. The superimposed signal is expressed by

$$x = \sqrt{\alpha P}s_1 + \sqrt{(1-\alpha)P}s_2 \tag{1}$$

Then the received signals of the user-1 and the user-2 are represented as

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$$\begin{aligned} r_1 &= |h_1|x + n_1 \\ &= |h_1|(\sqrt{\alpha P}s_1 + \sqrt{(1-\alpha)P}s_2) + n_1 \\ &= |h_1|(\sqrt{\alpha P}s_1 + (|h_1|\sqrt{(1-\alpha)P}s_2 + n_1) \\ r_2 &= |h_2|x + n_2 \\ &= |h_2|(\sqrt{\alpha P}s_1 + \sqrt{(1-\alpha)P}s_2) + n_2 \\ &= |h_2|(\sqrt{(1-\alpha)P}s_2 + (|h_2|\sqrt{(1-\alpha)P}s_1 + n_2) \\ &= |h_2|\sqrt{(1-\alpha)P}s_2 + n_3 \end{aligned} \tag{2}$$

where n_1 and $n_2 \sim N(0, N_0/2)$ are additive white Gaussian noise (AWGN) and N_0 is one-sided power spectral density. The notation $N(\mu, \Sigma)$ denotes the normal distribution with mean μ and variance Σ. In addition, n_3 is defined as

$$n_3 = |h_2|\sqrt{\alpha P}s_1 + n_2 \tag{3}$$

For the binary phase shift keying (BPSK) modulation, with $s_1 \in \{+1, -1\}$, the probability density function (PDF) of n_3 is given by

$$p_{N_3}(n_3) = \frac{1}{2}\frac{1}{\sqrt{2\pi N_0/2}}e^{-\frac{(n_3 - |h_2|\sqrt{\alpha P})^2}{2N_o/2}} + \frac{1}{2}\frac{1}{\sqrt{2\pi N_0/2}}e^{-\frac{(n_3 - |h_2|\sqrt{\alpha P})^2}{2N_o/2}} \tag{4}$$

Note that if the inter user-2 interference s_1 is modeled as the BPSK modulation, then n_3 is no more Gaussian noise, but Gaussian mixture noise. On the other hand, in the standard NOMA, the inter user-2 interference s_1 is modeled as Gaussian modulation. In this case, n_3 is simply Gaussian with the normal distribution, which is given by

$$n_3 \sim N(0, |h_2|^2\alpha P + N_0/2) \tag{5}$$

In the standard NOMA, the successive interference cancellation (SIC) is performed only on the user-1. Then the received signals are given by

$$\begin{aligned} y_1 &= |h_1|\sqrt{\alpha P}s_1 + n_1 \\ y_2 &= r_2 \end{aligned} \tag{6}$$

III. Channel Capacity for NOMA Weak Channel User and Channel Capacity Region for NOMA

The channel capacity is defined as [5]

$$C = \max_{p_X(x)} H(y) - H(y \mid x) \tag{7}$$

where $p_X(x)$ is the input PDF, the entropy of x is $H(x) = -E_x[\log_2 p_x(x)]$, $y = x + n$ and n is AWGN. For Gaussian noise, the channel capacities in bit/s/Hz for the user-1 and the user-2 are simply calculated as [5]

$$C_1 = \frac{1}{2}log_2\left(1 + \frac{|h_1|^2\alpha P}{N_0/2}\right) \tag{8}$$

and

$$C_2^{(Gaussian)} = \frac{1}{2}log_2\left(1 + \frac{|h_2|^2(1-\alpha)P}{|h_2|^2\alpha P + N_0/2}\right) \tag{9}$$

However, for the Gaussian mixture noise model, the channel capacity calculation for the user-2 is different from the equation (9). Now we start with the fact that the sum of independent Gaussian random variables (RVs) is still Gaussian, i.e.,

$$\begin{aligned} r_2 &= |h_2|\sqrt{(1-\alpha)P}s_2 + (|h_2|\sqrt{\alpha P}s_1 + n_2) \\ &= \underbrace{(|h_2|)\sqrt{(1-\alpha)P}s_2 + n_2)}_{sum\ of\ independent\ Gaussian\ RVs} + |h_2|\sqrt{\alpha P}s_1 \end{aligned} \tag{10}$$

with

$$(|h_2|\sqrt{(1-\alpha)P}s_2 + n_2) \sim N(0, |h_2|^2(1-\alpha)P + N_0/2) \tag{11}$$

Then the channel capacity for the user-2 is calculated as

$$\begin{aligned} C_2^{(Gaussian\ mixture)} &= \max_{p_{s_2}(s_2)} H(r_2) - H(r_2|s_2) \\ &= \int_{-\infty}^{\infty} p_{R_2}(r_2)\log_2 p_{R_2}(r_2)dy_1 \\ &+ \int_{-\infty}^{\infty} p_{N_3}(n_3)\log_2 p_{N_3}(n_3)dy_3 \end{aligned} \tag{12}$$

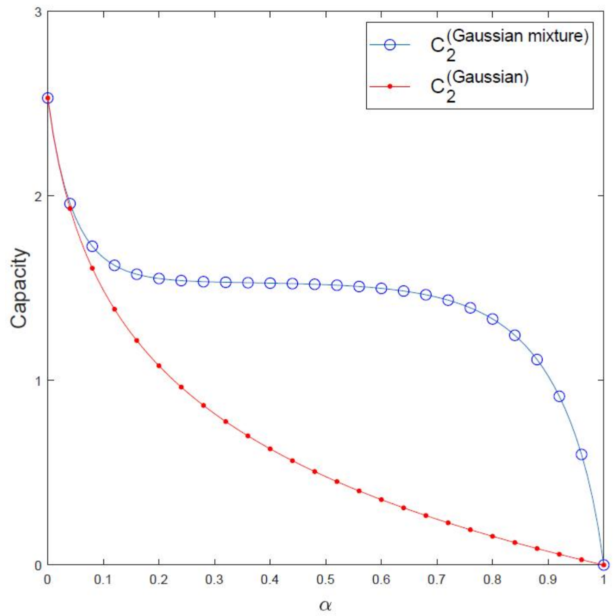

Fig. 1. Channel capacities of Gaussian mixture noise and Gaussian noise for the NOMA weal channel user.

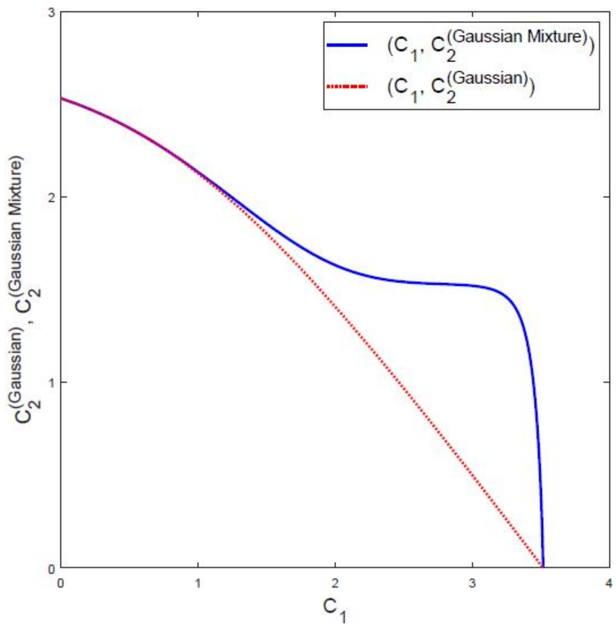

Fig. 2. Channel capacity regions of Gaussian mixture noise and Gaussian noise for NOMA.

where $p_{R_2}(r_2)$ is calculated as $p_{R_2}(r_2)$

$$= \frac{1}{2} \frac{1}{\sqrt{2\pi(|h_2|\sqrt{(1-\alpha)P}+N_0/2)}} e^{-\frac{(r_2 - |h_2|\sqrt{\alpha}P)^2}{2|h_2|\sqrt{(1-\alpha)P}+N_0/2}} \quad (13)$$

$$+ \frac{1}{2} \frac{1}{\sqrt{2\pi(|h_2|\sqrt{(1-\alpha)P}+N_0/2)}} e^{-\frac{(r_2 - |h_2|\sqrt{\alpha}P)^2}{2|h_2|\sqrt{(1-\alpha)P}+N_0/2}}$$

and $p_{N_3}(n_3)$ is already defined in the previous section for Gaussian mixture noise model.

IV. Results and Discussions

Assume that the channel gains are $|h_1| = 1.8$ and $|h_2| = 0.9$. The total transmit signal power to one-sided power spectral density ratio is $P/N_0 = 20$. The channel capacities of Gaussian mixture and Gaussian noise for the NOMA weak channel user are shown in Fig. 1, with different power allocations, $0 \le \alpha \le 1$. As shown in Fig. 1, the capacity of Gaussian mixture noise is better than that of Gaussian noise for the entire operating range of the power allocation factor. In addition, the channel capacity regions of Gaussian mixture and Gaussian noise for NOMA are shown in Fig. 2. As shown in Fig. 2, the capacity region of Gaussian mixture noise is larger than that of Gaussian noise.

V. Conclusion

We calculated the capacity for the NOMA weak channel user and the capacity region for NOMA under Gaussian mixture interference model. It was shown that the capacity for the NOMA weak channel user became better and the capacity region was enlarged with such assumption. Consequently, there could be a possibility that NOMA could perform better in the practical surroundings.

References

[1] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li, and K. Higuchi, "Non-orthogonal multiple access (NOMA) for cellular future radio access," in *Proc. IEEE 77th Vehicular Technology Conference (VTC Spring)*, pp. 1-5, 2013. DOI: 10.1109/VTCSpring.2013.6692652

[2] Z. Ding, P. Fan, and H. V. Poor, "Impact of

user pairing on 5G nonorthogonal multiple-access downlink transmissions," *IEEE Trans. Veh. Technol.*, vol. 65, no. 8, pp. 6010-6023, 2016.
DOI: 10.1109/TVT.2015.2480766

[3] Y. Saito, A. Benjebbour, Y. Kishiyama, and T. Nakamura, "System-level performance evaluation of downlink non-orthogonal multiple access (NOMA)," *Proceedings of Personal Indoor and Mobile Radio Communications (PIMRC)*, 2013.
DOI: 10.1109/PIMRC.2013.6666209

[4] L. Dai, B. Wang, Y. Yuan, S. Han, C.-L. I, and Z. Wang, "Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends," *IEEE Communications Magazine*, vol. 53, no. 9, pp. 74-81, 2015.
DOI: 10.1109/MCOM.2015.7263349

[5] C. E. Shannon, "A Mathematical Theory of Communication," *The Bell System Technical Journal*, vol. 27, no. 3, pp. 379-423, 1948.
DOI: 10.1002/j.1538-7305.1948.tb01338.x