IoT 기반 NOMA 시스템에서 근거리 사용자의 Outage 성능 향상을 위한 연구

웬 민 뜨엉, 김성환*
울산대학교

nguyenminhtuongtuong@gmail.com, sungkim@ulsan.ac.kr*

Outage Improvement for Near User in IoT-Based Non-Orthogonal Multiple Access System

Tuong Nguyen Minh, Sunghwan Kim*
University of Ulsan

Abstract

In this paper, we show that the high outage phenomenon experienced by the strong user in the work of [2] can be reduced by using previously decoded signal obtained from the successive interference cancellation process. The corresponding performance is also derived and validated by Monte-Carlo simulation.

Ⅰ. Introduction

Non-Orthogonal Multiple Access (NOMA) has been known for its capability for supporting massive connectivity [1]. The recent work of [2] proposed an IoT-based NOMA system with higher ergodic sum capacity comparing to traditional orthogonal multiple access. This work, however, reports a high outage performance problem of the strong user (near user) by relay interference. In this paper, we illustrate that it is possible to reduce this interference under the assumption that the near user has already successfully decoded the far user signal.

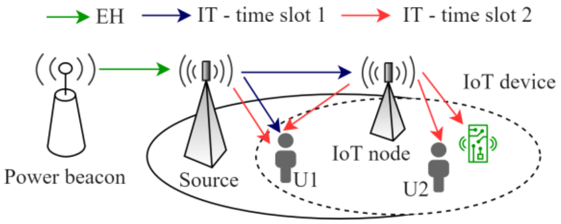

Fig. 1 System Model

Ⅱ. System Model

We extent a recent work of NOMA-based IoT system [2] by considering an energy harvesting source (S) that harvests energy from a power beacon (B) to enhance direct communication with near user (U1) and with far user (U2) under the assistance of a master IoT node (R) serving an IoT device (U3) while acting as a decode-and-forward relay for S, as shown in Fig. 1.

We denote h_{XY} and d_{XY} as the channel coefficients and the distance between node $X \in \{B, S, R\}$ and $Y \in \{\mathrm{S}, \mathrm{R}, \mathrm{U1}, \mathrm{U2}, \mathrm{U3}\}$ with all h_{XY} considered as independent under Rayleigh flat fading. As a consequent, h_{XY} is modelled after complex Gaussian random variable $CN(0, \lambda_{XY})$. Therefore, the corresponding channel gain $|h_{XY}|^2$ is exponentially distributed with parameter $\lambda_{XY} = d_{XY}^{-\alpha}$, where α is the pathloss exponent. Also, the additive noise at all receiver Y is $CN(0, \sigma^2)$.

A. Energy harvesting (EH) phase

In this timeslot, S harvests energy from B for a κT fraction within the coherent time T and then exploit the harvested energy for sending signal in the first and second timeslot with the transmit power of:

$$P_S = \frac{1}{2}\frac{\eta_S \kappa T P_B |h_{BS}|^2}{(1-\kappa)T/2} = \frac{1}{2}\nu P_B |h_{BS}|^2, \nu = \frac{\eta_S \kappa}{(1-\kappa)} \quad (1)$$

where $\eta_S \in (0,1)$ denotes the energy conversion efficiency of S, P_B is the transmit power of B, and $\kappa \in (0,1)$ is the time-splitting (TS) coefficient [3]. Note that the transmit duration for time slot 1 and time slot 2 is $(1-\kappa)T/2$.

B. Information transmission (IT) phase

In the first time slot of IT, S broadcasts a superimposed signal $\sum_{i=1}^{2}\sqrt{a_i P_S}x_i$, where a_i denotes the power allocation (PA) of $\mathrm{U}i, i \in \{1,2\}$ with $a_1 < a_2, a_1 + a_2 = 1$. Following NOMA principle, the signal-to-interference-plus-noise ratio (SINR) for decoding x_2 at U1 and R can be expressed as

$$\gamma_W^{x_2} = \frac{a_2 P_s |h_{SW}|^2}{a_1 P_s |h_{SW}|^2 + \sigma^2}, W = \{\mathrm{U1}, \mathrm{R}\} \quad (2)$$

U1 performs successive interference cancellation (SIC) by decoding and subtracting x_2, it then decodes its signal x_1 with the signal-to-noise ratio (SNR) as $\gamma_W^{x_1} = a_1 P_s |h_{SW}|^2 / \sigma^2$. In the second timeslot, S transmits $\hat{x}_1$ to U1 while R employs NOMA protocol to multiplex x_2 along with IoT device's signal x_3 with the transmit power P_R. The receive signal at U1 is now written as

$$y = \sqrt{P_S}\hat{x}_1 h_{SU1} + \left(\sqrt{P_R \tau_2 x_2} + \sqrt{P_R \tau_3 x_3}\right) h_{RU1} + n \quad (3)$$

This NOMA signal interferes with $\hat{x}_1$ and leads to a high outage problem reported by the work of [1]. To partially weaken this interference the following PA is selected $\tau_2 = a_2, \tau_3 = 1 - \tau_2$ so that the interference x_2 that was decoded earlier from (2) can be subtracted from (3) with P_R known. This is safe for the NOMA users U2 and U3 since their SIC decoding order does not vary with PA [2]. After subtracting x_2 from (3), U1 decodes $\hat{x}_1$ with the SINR

$$\gamma_{U1}^{\hat{x}_1} = \frac{0.5 v \rho_B |h_{SU1}|^2}{\rho_R |h_{RU1}|^2 \tau_3 + 1} \quad (4)$$

Where $\rho_B = P_B / \sigma^2$ and $\rho_R = P_R / \sigma^2$.

III. Outage Probability Evaluation

Given the target rate r for $\hat{x}_1$, the corresponding outage probability (OP) is:

$$\begin{aligned} OP_{U1}^{\hat{x}_1} &= 1 - \Pr\left[\left(\frac{(1-\kappa)T}{2}\right)^{-1} \log\left(1 + \gamma_{U1}^{\hat{x}_1}\right) > r\right] \\ &= 1 - \Pr\left[\gamma_{U1}^{\hat{x}_1} > \iota\right] \\ &= 1 - \int_0^\infty \int_0^\infty \int_{\frac{\iota(\rho_R z + 1)}{0.5 v \rho_B x}}^\infty g(y,z,x)\, dy\, dz\, dx \qquad (5) \\ &= 1 - \int_0^\infty \frac{A e^{-\frac{\iota}{A x \lambda_{SU_1}}} x \lambda_{SU_1} f_{|h_{BS}|^2}(x)}{A x \lambda_{SU_1} + \rho_R \tau_3 \iota \lambda_{RU_1}} dx \end{aligned}$$

Where $\iota = 2^{2^{-1} r (1-\kappa) T}$, $A = 0.5 v \rho_B$ and $g(y,z,x)$ is the joint PDF $f_{|h_{SU1}|^2, |h_{RU1}|^2, |h_{BS}|^2}(y,z,x)$.

IV. Simulation

A Monte-Carlo simulation for 10^6 channel realizations is conducted with the following position B, S, R and U1 as (0, 0), (0.2, 0), (0.5, 0) and (0.2, -0.2) respectively with $\rho_R = 10$ dB, $r = 0.5$ bit per second per Hertz, $\kappa = 0.5$, $\eta_S = 0.9$ and $\alpha = 3$. The outage expression in (5) has no closed-form but can be numerically evaluated easily at $\tau_3 = 0.2, 0.5, 0.8$. Result in Fig. 2 shows that the expression from (5) has been validated by simulation and the OP performance is better than the naïve scheme from [2].

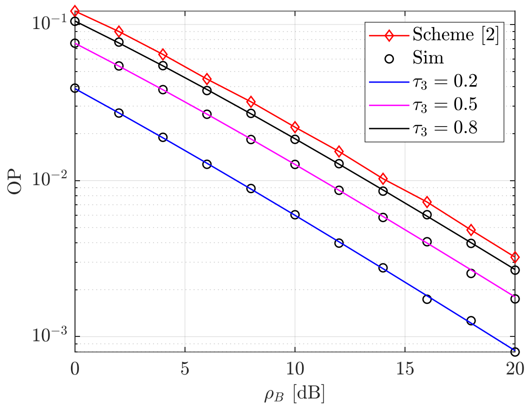

Fig. 2 OP versus ρ_B

IV. Conclusion

In this work, we show that the performance loss of the near user in an IoT-based NOMA system can be compensated albeit not entirely. The outage expression of the compensated performance is derived and validated by simulation. Hence, it can be used to evaluate or optimizing the outage performance with respect to the time-splitting coefficient introduced by the energy harvesting process.

ACKNOWLEDGMENT

This work was supported by the Research Program through the National Research Foundation of Korea (NRF-2019R1A2C1005920).

References

[1] M. Vaezi, R. Schober, Z. Ding, and H. V. Poor, Non-orthogonal multiple access: Common myths and critical questions, *IEEE Wirel. Commun.*, vol. 26, no. 5, pp. 174-180, Sept. 2019.

[2] T. T. Nguyen, T. V. Nguyen, T. H. Vu, D. B. da Costa, and C. D. Ho, IoT-based coordinated direct and relay transmission with non-orthogonal multiple access, *IEEE Wireless Commun. Lett.*, vol. 10, no. 3, pp. 503-507, March. 2021.

[3] T. Nguyen and B. An, Cognitive multihop wireless powered relaying networks over Nakagami-m fading channels, *IEEE Access*, vol. 7, pp. 154 600-154 616, Oct. 2019.