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User grouping-based multiple access scheme for IoT network

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ABSTRACT

The internet of things (IoT) in 5G and beyond wireless systems is interesting topic since IoT network will be platform to develop applications in the future. IoT will open a door for smart services and new wireless architecture. In this study, we consider multiple access technique applied in two-way cooperative scheme, namely two-way non-orthogonal multiple access (TW-NOMA). We derive expressions of outage probability for considered system using amplify-and-forward (AF) relay protocol, and we show that fixed power allocation factors and target rates are main impacts on performance of AF TW-NOMA. We finally extend many scenarios to evaluate performance of two-user model and outage probability in a two-user scenario are numerically verified. It is confirmed that simulation results show that AF TW-NOMA provides better data rates and user fairness.

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1. INTRODUCTION

Recently, wireless communications have been developing fast in the world. The fifth-generation (5G) technology has become a most interesting and challenging topic in wireless research in the context of wireless technology. In practice, the demand for system capacity and spectrum efficiency has grown fast to satisfy the rapid development of services and applications in internet of things (IoT) since the traditional orthogonal multiple access (OMA) has not been met the IoT's needs [1-3]. The emerging networks together with NOMA are interesting topics in recent years [4-14]. In OMA, considering frequency division or time division scheme, only one user can be assigned a single radio resource, while multiple users can be shared resource in NOMA. At transmitter side, NOMA uses non-orthogonal transmission to actively introduce interference between users, and at receiver side achieves demodulation signals through the successive interference cancellation (SIC).

In order to satisfy the heavy needs for cellular services, NOMA is implemented with massive multiple-input multiple-output (MIMO) [15-17]. NOMA-based two-way relay network is studied with secrecy considerations, in which two users employ trusted relay to transmit/receive their NOMA signals with existences of single and multiple eavesdroppers [18]. The authors in [19] investigated two way-full duplex (TW-FD) relay assisted cognitive radio NOMA (CR-NOMA) networks. Furthermore, the self-interference (SI) of FD can be regarded as a potential source for relay to harvest energy to enhance system energy efficiency. Uplink NOMA transmission has been studied in recent works [20-28]. The authors in [20] presented NOMA -based cognitive radio with power allocation strategies designed for uplink transmission and such system benefits from MIMO.

Motivated by [18, 19] this paper examines TW-NOMA using amplify and forward (AF) relay protocol to serve user group in IoT system with fairness requirement.

2. SYSTEM MODEL

We consider a scenario for IoT system as Figure. 1, in which a group of users as transmitters (S_1 and S_2) intend to communicate with their corresponding destinations (D_1 and D_2) through relay$R$. $h_n(n = 1,2)$ is the channel coefficient from the transmitter $S_n(n = 1,2)$ to relay and $g_n(n = 1,2)$ is the channel coefficient from relay to the destination $D_n(n = 1,2)$. It can be ignored the direct links between sources and destinations because of very poor channel conditions and/or physical links.

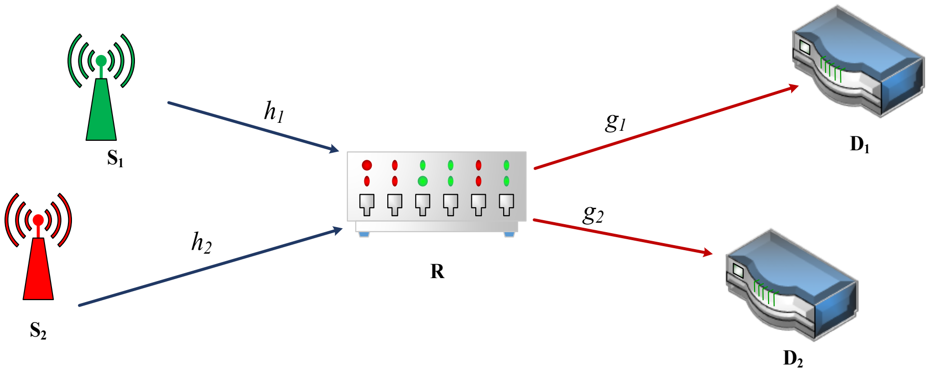

Figure 1. System model of multiple access for IoT

The received signal at relay can be given as:

$$y_R = v_1 P_s h_1 + v_2 P_s h_2 + \eta_R \tag{1}$$

where P_S denote the transmission power at the source, η_R stands for the additive Gaussian noise (AWGN) at R with zero mean and variance N_0. The received signal at D_k, $k \in \{1,2\}$. can be expressed as follows;

$$y_{D_k} = \sqrt{P_r} G g_k \left(\sqrt{v_1 P_s} h_1 + \sqrt{v_2 P_s} h_2 + \eta_r\right) + \eta_{D_k} \tag{2}$$

The amplify factor is defined as follows;

$$G = \frac{1}{\sqrt{v_1 P_s |h_1|^2 + v_2 P_s |h_2|^2 + \sigma_0^2}} \tag{3}$$

The SINR at destination 1 in order to decode its own data can be written by;

$$\gamma_{D_1}^{\text{HD}} == \frac{v_1 \rho_s \rho_r |g_1|^2 |h_1|^2}{v_2 \rho_s \rho_r |g_1|^2 |h_2|^2 + \rho_r |g_1|^2 + v_1 \rho_s |h_1|^2 + 1} \tag{4}$$

where $\rho_s \triangleq \frac{P_s}{\sigma_0^2}$ and $\rho_r \triangleq \frac{P_r}{\sigma_0^2}$ are transmission SNR of source and relay node, respectively. Then, SINR for D_2 is computed to decode signal x_1 can be computed by:

$$\gamma_{D_2 \leftarrow 1}^{\text{HD}} = \frac{v_1 \rho_r \rho_s |g_2|^2 |h_1|^2}{v_2 \rho_r \rho_s |h_2|^2 |g_2|^2 + \rho_r |g_2|^2 + v_1 \rho_s |h_1|^2 + 1} \tag{5}$$

D_2 detects its own message with the following SINR:

$$\gamma_{D_2}^{\text{HD}} = \frac{v_2 \rho_r \rho_s |h_2|^2 |g_2|^2}{\rho_r |g_2|^2 + v_1 \rho_s |h_1|^2 + 1} \tag{6}$$

3. SYSTEM PERFORMANCE ANALYSIS

3.1. Performance of user 1 (D_1) in cooperative NOMA with AF relaying scheme

The outage probability of user D_1 can be defined as the probability that its instantaneous data rate falls below a predefined target data rate. In the scenario of FD mode, we provide following results:
Proposition 1: The closed-form expression of outage probability at user 1 (D_1)

$$\mathrm{OP}_1^{\mathrm{HD}} = Pr\left(\gamma_{D_1}^{\mathrm{HD}} < \gamma_0^1\right) \tag{7}$$

where $\gamma_0^i = 2^{2R_i} - 1, \forall i \in (1,2)$
Proof:
In which, it can be computed components as:

$$\begin{aligned}
\mathrm{OP}_1^{\mathrm{HD}} &= \Pr\left(\frac{\upsilon_1\rho_s\rho_r|g_1|^2|h_1|^2}{\upsilon_2\rho_s\rho_r|g_1|^2|h_2|^2+\rho_r|g_1|^2+\upsilon_1\rho_s|h_1|^2+1} < \gamma_0^1\right)\\
&= \Pr\left(1,|g_1|^2 \le \frac{\gamma_0^1}{\rho_r}\right) + \Pr\left(|h_1|^2 < \frac{\rho_r|g_1|^2\left(\upsilon_2\rho_s|h_2|^2+1\right)+1}{\upsilon_1\rho_s\left(\frac{\rho_r}{\gamma_0^1}|g_1|^2-1\right)}, |g_1|^2 > \frac{\gamma_0^1}{\rho_r}\right)\\
&= \int_0^{\frac{\gamma_0^1}{\rho_r}} f_{|g_1|^2}(x)\,dx + \int_{\frac{\gamma_0^1}{\rho_r}}^{\infty} F_{|h_1|^2}\left(\frac{\rho_r xX+1}{\upsilon_1\rho_s\left(\frac{\rho_r}{\gamma_0^1}x-1\right)}\right) f_{|g_1|^2}(x)\,dx\\
&= \frac{1}{\Omega_{g_1}}\int_0^{\frac{\gamma_0^1}{\rho_r}} \exp\left(-\frac{x}{\Omega_{g_1}}\right)dx + \frac{1}{\Omega_{g_1}}\int_{\frac{\gamma_0^1}{\rho_r}}^{\infty}\exp\left(-\frac{x}{\Omega_{g_1}}\right)dx - \frac{1}{\Omega_{g_1}}\int_{\frac{\gamma_0^1}{\rho_r}}^{\infty}\exp\left(-\frac{\rho_r xX+1}{\Omega_{h_1}\upsilon_1\rho_s\left(\frac{\rho_r}{\gamma_0^1}x-1\right)} - \frac{x}{\Omega_{g_1}}\right)dx\\
&= 1 - \frac{1}{\Omega_{g_1}}\int_{\frac{\gamma_0^1}{\rho_r}}^{\infty}\exp\left(-\frac{\rho_r xX+1}{\Omega_{h_1}\upsilon_1\rho_s\left(\frac{\rho_r}{\gamma_0^1}x-1\right)} - \frac{x}{\Omega_{g_1}}\right)dx
\end{aligned} \tag{8}$$

It is noted that substituting $t = \frac{\rho_r}{\gamma_0^1}x - 1 \Rightarrow x = \frac{\gamma_0^1}{\rho_r}(t+1)$then outage probability of D_1 has become;

$$\begin{aligned}
\mathrm{OP}_1^{\mathrm{HD}} &= 1 - \frac{\gamma_0^1}{\rho_r\Omega_{g_1}}\int_0^{\infty} e^{-\frac{\gamma_0^1(t+1)X}{\Omega_{h_1}\upsilon_1\rho_s t} - \frac{\gamma_0^1(t+1)}{\Omega_{g_1}\rho_r} - \frac{1}{\Omega_{h_1}\upsilon_1\rho_s t}}dt\\
&= 1 - \frac{\gamma_0^1}{\rho_r\Omega_{g_1}} e^{-\frac{\gamma_0^1}{\Omega_{g_1}\rho_r} - \frac{\gamma_0^1 X}{\Omega_{h_1}\upsilon_1\rho_s}} \int_0^{\infty} e^{-\left(\frac{1}{\Omega_{h_1}\upsilon_1\rho_s} + \frac{\gamma_0^1 X}{\Omega_{h_1}\upsilon_1\rho_s}\right)\frac{1}{t} - \frac{\gamma_0^1 t}{\Omega_{g_1}\rho_r}}dt
\end{aligned} \tag{9}$$

After the calculation steps we have;

$$\begin{aligned}
\mathrm{OP}_1^{\mathrm{HD}} &= 1 - e^{-\frac{\gamma_0^1}{\Omega_{g_1}\rho_r} - \frac{\gamma_0^1 X}{\Omega_{h_1}\upsilon_1\rho_s}}\, 2\sqrt{\frac{\gamma_0^1}{\Omega_{g_1}\rho_r}\left(\frac{1}{\Omega_{h_1}\upsilon_1\rho_s} + \frac{\gamma_0^1 X}{\Omega_{h_1}\upsilon_1\rho_s}\right)}\, K_1\left(2\sqrt{\frac{\gamma_0^1}{\Omega_{g_1}\rho_r}\left(\frac{1}{\Omega_{h_1}\upsilon_1\rho_s} + \frac{\gamma_0^1 X}{\Omega_{h_1}\upsilon_1\rho_s}\right)}\right)\\
&= 1 - e^{-\frac{\gamma_0^1}{\Omega_{g_1}\rho_r} - \frac{\gamma_0^1 (Y+1)}{\Omega_{h_1}\upsilon_1\rho_s}}\, 2\sqrt{\frac{\gamma_0^1}{\Omega_{g_1}\rho_r}\left(\frac{1}{\Omega_{h_1}\upsilon_1\rho_s} + \frac{\gamma_0^1 (Y+1)}{\Omega_{h_1}\upsilon_1\rho_s}\right)}\, K_1\left(2\sqrt{\frac{\gamma_0^1}{\Omega_{g_1}\rho_r}\left(\frac{1}{\Omega_{h_1}\upsilon_1\rho_s} + \frac{\gamma_0^1 (Y+1)}{\Omega_{h_1}\upsilon_1\rho_s}\right)}\right)\\
&= \int_0^{\infty}\left(1 - 2\exp\left(-\varphi_1 Y - \varphi_2\right)\sqrt{\varphi_3 Y + \varphi_4}\, K_1\left(2\sqrt{\varphi_3 Y + \varphi_4}\right)\right) f_Y(y)\,dy
\end{aligned} \tag{10}$$

where $\varphi_1 = \frac{\gamma_0^1}{\Omega_{h_1}\upsilon_1\rho_s}$, $\varphi_2 = \frac{\gamma_0^1}{\Omega_{g_1}\rho_r} + \frac{\gamma_0^1}{\Omega_{h_1}\upsilon_1\rho_s}$, $\varphi_3 = \frac{\gamma_0^1\gamma_0^1}{\Omega_{g_1}\Omega_{h_1}\upsilon_1\rho_s\rho_r}$and $\varphi_4 = \frac{\gamma_0^1}{\Omega_{g_1}\rho_r}\left(\frac{1}{\Omega_{h_1}\upsilon_1\rho_s} + \frac{\gamma_0^1}{\Omega_{h_1}\upsilon_1\rho_s}\right)$.

We have PDF and CDF of Y can be written as;

$$F_Y(y) = \int_0^Y f_Y(y)dy = 1 - e^{-\frac{\upsilon_2\rho_S y}{\Omega_{h_2}}} \tag{11}$$

and

$$f_Y(y) = \frac{1}{\Omega_{h_2}} e^{-\frac{\upsilon_2\rho_S y}{\Omega_{h_2}}} \tag{12}$$

When the outage performance of D_1 can be shown as:

$$\begin{aligned}
\mathrm{OP}_1^{\mathrm{HD}} &= \int_0^\infty \left(1 - 2\mathrm{e}^{-\varphi_1 y - \varphi_2}\sqrt{\varphi_3 y + \varphi_4} K_1\left(2\sqrt{\varphi_3 y + \varphi_4}\right)\right) f_Y(y)dy \\
&= 1 - 2\int_0^\infty f_Y(y)\mathrm{e}^{-\varphi_1 y - \varphi_2}\sqrt{\varphi_3 y + \varphi_4} K_1\left(2\sqrt{\varphi_3 y + \varphi_4}\right)dy \\
&= 1 - \frac{2\mathrm{e}^{-\varphi_2}}{\Omega_{h_2}} \underbrace{\int_0^\infty e^{-\left(\frac{\upsilon_2\rho_s}{\Omega_{h_2}} + \varphi_1\right)y}\sqrt{\varphi_3 y + \varphi_4} K_1\left(2\sqrt{\varphi_3 y + \varphi_4}\right)dy}_{\triangleq \Psi_1}
\end{aligned} \tag{13}$$

Ψ_1 can be calculated as;

$$\begin{aligned}
\Psi_1 &\triangleq \int_0^\infty \mathrm{e}^{-\tau_1 y}\sqrt{\varphi_3 y + \varphi_4} K_1\left(2\sqrt{\varphi_3 y + \varphi_4}\right)dy \\
&= \mathrm{e}^{\frac{\tau_1\varphi_4}{\varphi_3}}\left(\frac{\varphi_3}{2\tau_1^2}\mathrm{e}^{\frac{\varphi_3}{\tau_1}}\Gamma\left(-1, \frac{\varphi_3}{\tau_1}\right) - \frac{1}{2}\sum_{m=0}^{M}\frac{(-\tau_1)^m \varphi_4^{m+1}}{\varphi_3^{m+1}} G_{1,3}^{2,1}\left(\varphi_4 \,\middle|\, {}^{-m}_{1,0,-m}\right)\right),
\end{aligned} \tag{14}$$

where $\tau_1 = \frac{\upsilon_2\rho_S}{\Omega_{h_2}} + \varphi_1$ and the lase equation follows the fact that $e^x = \sum_{k=0}^{\infty}\frac{x^k}{k!}$ in [[29], eq. (1.211.1)] and $\int_0^1 x^\lambda (1-x)^{\mu-1} K_\nu(a\sqrt{x})dx = \frac{2^{\nu-1}}{a^\nu}\Gamma(\mu) G_{1,3}^{2,1}\left(\frac{a^2}{4} \,\middle|\, {}^{\frac{\nu}{2}-\lambda}_{\nu,0,\frac{\nu}{2}-\lambda-\mu}\right)$ in [[29], eq. (6.952.2)].
This completes the proof.

3.2. Performance of user D_2 in cooperative NOMA with AF relaying scheme

To consider performance of user of D_2, the related outage probability can be given by;
Proposition 2: The closed-form expression of outage probability at user D_2 can be given by:

$$\mathrm{OP}_2^{\mathrm{HD}} = 1 - Pr\left(\gamma_{U_4 \leftarrow 1}^{HD} \geq \gamma_0^1, \gamma_{U_4}^{HD} \geq \gamma_0^2\right) \tag{15}$$

Proof:
It can be computed that:

$$\begin{aligned}
\mathrm{OP}_2^{\mathrm{HD}} &= 1 - \Pr\left(\frac{\upsilon_1\rho_r\rho_s|g_2|^2|h_1|^2}{\upsilon_2\rho_r\rho_s|h_2|^2|g_2|^2 + \rho_r|g_2|^2 + \upsilon_1\rho_s|h_1|^2 + 1} \geq \gamma_0^1, \frac{\upsilon_2\rho_r\rho_s|h_2|^2|g_2|^2}{\rho_r|g_2|^2 + \upsilon_1\rho_s|h_1|^2 + 1} \geq \gamma_0^2\right) \\
&= 1 - \Pr\left(|g_2|^2 \geq \frac{1}{\rho_r}\left(\upsilon_1\rho_s|h_1|^2 + 1\right)\max\left(\frac{1}{\frac{\upsilon_1\rho_s}{\gamma_0^1}|h_1|^2 - \upsilon_2\rho_s|h_2|^2 - 1}, \frac{1}{\frac{\upsilon_2\rho_s}{\gamma_0^2}|h_2|^2 - 1}\right)\right) \\
&= 1 - \left(\mathrm{OP}_{2,1}^{\mathrm{HD}} + \mathrm{OP}_{2,2}^{\mathrm{HD}}\right)
\end{aligned} \tag{16}$$

We can computed $\mathrm{OP}_{2,1}^{\mathrm{HD}}, \mathrm{OP}_{2,2}^{\mathrm{HD}}$ as follows:

$$\mathrm{OP}_{2,1}^{\mathrm{HD}} = \Pr\left(\begin{array}{l} |g_2|^2 \ge \frac{1}{\rho_r} \frac{\upsilon_1 \rho_s |h_1|^2 + 1}{\frac{\upsilon_1 \rho_s}{\gamma_0^1} |h_1|^2 - \upsilon_2 \rho_s |h_2|^2 - 1}, \\ \frac{\gamma_0^1}{\upsilon_1 \rho_s}\left(\upsilon_2 \rho_s |h_2|^2 + 1\right) < |h_1|^2 < \frac{\gamma_0^1 \upsilon_2}{\upsilon_1}\left(\frac{1}{\gamma_0^2} + 1\right)|h_2|^2, \\ |h_2|^2 > \frac{\gamma_0^2}{\upsilon_2 \rho_s} \end{array} \right)$$

$$= \int_{\frac{\gamma_0^2}{\upsilon_2 \rho_s}}^{\infty} f_{|h_2|^2}(y)\,dy \underbrace{\int_{\frac{\gamma_0^1}{\upsilon_1 \rho_s}(\upsilon_2 \rho_s y + 1)}^{\frac{\gamma_0^1 \upsilon_2}{\upsilon_1}\left(\frac{1}{\gamma_0^2}+1\right) y} \left(1 - F_{|g_2|^2}\left(\frac{1}{\rho_r} \frac{\upsilon_1 \rho_s x + 1}{\frac{\upsilon_1 \rho_s}{\gamma_0^1} x - \upsilon_2 \rho_s y - 1}\right)\right) f_{|h_1|^2}(x)\,dx.}_{\triangleq \Delta_4} \quad (17)$$

Then, we analyze $\mathrm{OP}_{2,1}^{\mathrm{HD}}$ as;

$$\begin{aligned} \mathrm{OP}_{2,1}^{\mathrm{HD}} &= \int_{\frac{\gamma_0^2}{\upsilon_2 \rho_s}}^{\infty} e^{-\frac{\gamma_0^1}{\rho_r \Omega_{g2}}} \left[e^{-\frac{\gamma_0^1 \upsilon_2}{\upsilon_1 \Omega_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right) y} - e^{-\frac{\upsilon_2 \gamma_0^1}{\upsilon_1 \Omega_{h_1}} y} e^{-\frac{\gamma_0^1}{\upsilon_1 \rho_s \Omega_{h_1}}} \right] f_{|h_2|^2}(y)\,dy \\ &= \frac{1}{\Omega_{h_2}} \int_{\frac{\gamma_0^2}{\upsilon_2 \rho_s}}^{\infty} e^{-\frac{\gamma_0^1}{\rho_r \Omega_{g2}}} e^{-\left(\frac{\gamma_0^1 \upsilon_2}{\upsilon_1 \Omega_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right) + \frac{1}{\Omega_{h_2}}\right) y} dy - \frac{1}{\Omega_{h_2}} \int_{\frac{\gamma_0^2}{\upsilon_2 \rho_s}}^{\infty} e^{-\frac{\gamma_0^1}{\rho_r \Omega_{g2}}} e^{-\left(\frac{\upsilon_2 \gamma_0^1}{\upsilon_1 \Omega_{h_1}} + \frac{1}{\Omega_{h_2}}\right) y} e^{-\frac{\gamma_0^1}{\upsilon_1 \rho_s \Omega_{h_1}}} dy \\ &= \frac{e^{-\frac{\gamma_0^1 \gamma_0^2}{\upsilon_1 \rho_s \Omega_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right) - \frac{\gamma_0^2}{\upsilon_2 \rho_s \Omega_{h_2}} - \frac{\gamma_0^1}{\rho_r \Omega_{g2}}}}{\Omega_{h_2}\left(\frac{\gamma_0^1 \upsilon_2}{\upsilon_1 \Omega_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right) + \frac{1}{\Omega_{h_2}}\right)} - \frac{e^{-\frac{\gamma_0^1}{\rho_r \Omega_{g2}} - \frac{\gamma_0^1}{\upsilon_1 \rho_s \Omega_{h_1}} - \left(\frac{\upsilon_2 \gamma_0^1}{\upsilon_1 \Omega_{h_1}} + \frac{1}{\Omega_{h_2}}\right)\frac{\gamma_0^2}{\upsilon_2 \rho_s}}}{\Omega_{h_2}\left(\frac{\upsilon_2 \gamma_0^1}{\upsilon_1 \Omega_{h_1}} + \frac{1}{\Omega_{h_2}}\right)} \end{aligned} \quad (18)$$

where $\Delta_4 = \frac{1}{\Omega_{h_1}} e^{-\frac{\gamma_0^1}{\rho_r \Omega_{g_2}}} \int_{\frac{\gamma_0^1}{\upsilon_1 \rho_s}(\upsilon_2 \rho_s y + 1)}^{\frac{\gamma_0^1 \upsilon_2}{\upsilon_1}\left(\frac{1}{\gamma_0^2}+1\right) y} e^{-\frac{x}{\Omega_{h_1}}} d\,x$ and

$$\begin{aligned} \mathrm{OP}_{2,2}^{\mathrm{HD}} &= \Pr\left(|g_2|^2 \ge \frac{1}{\rho_r} \frac{\upsilon_1 \rho_s |h_1|^2 + 1}{\frac{\upsilon_2 \rho_s}{\gamma_0^2} |h_2|^2 - 1}, |h_1|^2 > \frac{\gamma_0^1 \upsilon_2}{\upsilon_1}\left(\frac{1}{\gamma_0^2}+1\right)|h_2|^2, |h_2|^2 > \frac{\gamma_0^2}{\upsilon_2 \rho_s} \right) \\ &= \int_{\frac{\gamma_0^2}{\upsilon_2 \rho_s}}^{\infty} f_{|h_2|^2}(y)\,dy \underbrace{\int_{\frac{\gamma_0^1 \upsilon_2}{\upsilon_1}\left(\frac{1}{\gamma_0^2}+1\right) y}^{\infty} \left(1 - F_{|g_2|^2}\left(\frac{1}{\rho_r} \frac{\upsilon_1 \rho_s x + 1}{\frac{\upsilon_2 \rho_s}{\gamma_0^2} y - 1}\right)\right) f_{|h_1|^2}(x)\,dx}_{\triangleq \Delta_3} \\ &= \frac{2\gamma_0^2}{\upsilon_2 \rho_s \rho_r} \sum_{k=1}^{\infty} k \Omega_{g_2}^k \left(-\upsilon_1 \rho_s \Omega_{h_1}\right)^{k-1} e^{-\frac{\gamma_0^2}{\upsilon_2 \rho_s \Omega_{h_2}}} \sqrt{\left(\frac{\varpi_2 (1+\varpi_4)}{\varpi_1 \Omega_{g_2}}\right)^{k+1}} K_{k+1}\left(2\sqrt{\frac{\varpi_1 (1+\varpi_4)}{\varpi_2 \Omega_{g_2}}}\right) \end{aligned} \quad (19)$$

where

$$\begin{aligned}\Delta_3 &= \int_{\frac{\gamma_0^1\upsilon_2}{\upsilon_1}\left(\frac{1}{\gamma_0^2}+1\right)y}^{\infty}\left(1-F_{|g_2|^2}\left(\frac{1}{\rho_r}\frac{\upsilon_1\rho_s x+1}{\frac{\upsilon_2\rho_s}{\gamma_0^2}y-1}\right)\right)f_{|h_1|^2}(x)dx\\
&=\frac{1}{\Omega_{h_1}}\int_{\frac{\gamma_0^1\upsilon_2}{\upsilon_1}\left(\frac{1}{\gamma_0^2}+1\right)y}^{\infty}\mathrm{e}^{-\frac{1}{\rho_r\Omega_{g2}}\frac{\upsilon_1\rho_s x+1}{\frac{\upsilon_2\rho_s}{\gamma_0^2}y-1}}\,\mathrm{e}^{-\frac{x}{\Omega_{h_1}}}dx\\
&=\frac{\gamma_0^2}{\upsilon_2\rho_s\rho_r}\int_0^{\infty}\frac{\Omega_{g_2}t}{\upsilon_1\rho_s\Omega_{h_1}+\Omega_{g_2}t}\mathrm{e}^{-\frac{1+\rho_s\Omega_{h_1}\upsilon_1 A\left(\frac{t}{\varpi_2}+\frac{\rho_r}{\varpi_2}\right)}{\Omega_{g_2}t}-\left(\frac{t}{\varpi_2}+\frac{\rho_r}{\varpi_2}\right)\varpi_1}dt\\
&=\frac{\gamma_0^2}{\upsilon_2\rho_s\rho_r}\int_0^{\infty}\frac{\Omega_{g_2}t}{\upsilon_1\rho_s\Omega_{h_1}+\Omega_{g_2}t}\mathrm{e}^{-\varpi_3}\,\mathrm{e}^{-(1+\varpi_4)\frac{1}{\Omega_{g_2}t}-\frac{\varpi_1 t}{\varpi_2}}dt,
\end{aligned}\tag{20}$$

where $\varpi_1=\frac{\gamma_0^1\upsilon_2}{\Omega_{h_1}\upsilon_1}\left(\frac{1}{\gamma_0^2}+1\right), \varpi_2=\frac{\upsilon_2\rho_s\rho_r}{\gamma_0^2}, \varpi_3=\frac{\rho_s\Omega_{h_1}\upsilon_1\varpi_1}{\Omega_{g_2}\varpi_2}+\frac{\varpi_1\rho_r}{\varpi_2}, \varpi_4=\frac{\rho_s\rho_r\Omega_{h_1}\upsilon_1\varpi_1}{\varpi_2}$.
Then, we have:

$$\begin{aligned}\mathrm{OP}_2^{\mathrm{HD}} &= 1-\mathrm{OP}_{2,1}^{\mathrm{HD}}-\mathrm{OP}_{2,2}^{\mathrm{HD}}\\
&=1-\frac{\mathrm{e}^{-\frac{\gamma_0^1\gamma_0^2}{\upsilon_1\rho_s\Omega_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)-\frac{\gamma_0^2}{\upsilon_2\rho_s\Omega_{h_2}}-\frac{\gamma_0^1}{\rho_r\Omega_{g2}}}}{\Omega_{h_2}\left(\frac{\gamma_0^1\upsilon_2}{\upsilon_1\Omega_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)+\frac{1}{\Omega_{h_2}}\right)}+\frac{\mathrm{e}^{-\frac{\gamma_0^1}{\rho_r\Omega_{g2}}-\frac{\gamma_0^1}{\upsilon_1\rho_s\Omega_{h_1}}-\left(\frac{\upsilon_2\gamma_0^1}{\upsilon_1\Omega_{h_1}}+\frac{1}{\Omega_{h_2}}\right)\frac{\gamma_0^2}{\upsilon_2\rho_s}}}{\Omega_{h_2}\left(\frac{\upsilon_2\gamma_0^1}{\upsilon_1\Omega_{h_1}}+\frac{1}{\Omega_{h_2}}\right)}\\
&\quad-\frac{2\gamma_0^2}{\upsilon_2\rho_s\rho_r}\sum_{k=1}^{\infty}k\Omega_{g_2}^k\left(-\upsilon_1\rho_s\Omega_{h_1}\right)^{k-1}\mathrm{e}^{-\frac{\gamma_0^2}{\upsilon_2\rho_s\Omega_{h_2}}}\sqrt{\left(\frac{\varpi_2(1+\varpi_4)}{\varpi_1\Omega_{g_2}}\right)^{k+1}}K_{k+1}\left(2\sqrt{\frac{\varpi_1(1+\varpi_4)}{\varpi_2\Omega_{g_2}}}\right)
\end{aligned}\tag{21}$$

This completes the proof.

3.3. Throughput of user D_1, D_2

Based on outage probability achieved, we can compute throughput in delay-limited mode for D1 and D2 respectively as;

$$\Xi_1^{\mathrm{HD}}=(1-\mathrm{OP}_1^{\mathrm{HD}})R_1,\tag{22}$$

$$\Xi_2^{\mathrm{HD}}=(1\text{-}\mathrm{OP}_2^{\mathrm{HD}})R_2\tag{23}$$

4. SIMULATION RESULT

In this section, we present numerical results to evaluate analytical expressions calculated in previous sections. Figure 2 demonstrates outage probability versus transmit SNR at source. It can be seen that the outage probability decreases significantly at high SNR region. Performance gaps of two users are resulted from different power allocation factors. However, the outage probability curves meet saturation when SNR is greater than 40 (dB). It is further confirmed that exact and simulation results are matched very well. In Figure 3 and Figure 4, similar trends of outage probability for two users can be observed as varying target rates. Figure 5 shows that throughput in delay-limed transmission mode depend on outage probability at low SNR region. When SNR is greater than 25 (dB) the throughout only depends on target rate. It can be seen throughput goes to ceiling at high SNR region.

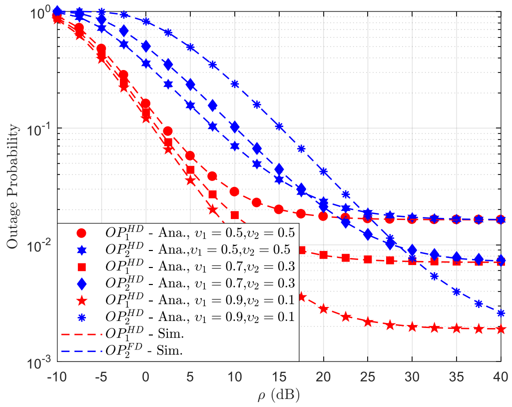

Figure 2. Outage performance
($R_1 = R_2 = 0.1$ bps/Hz)

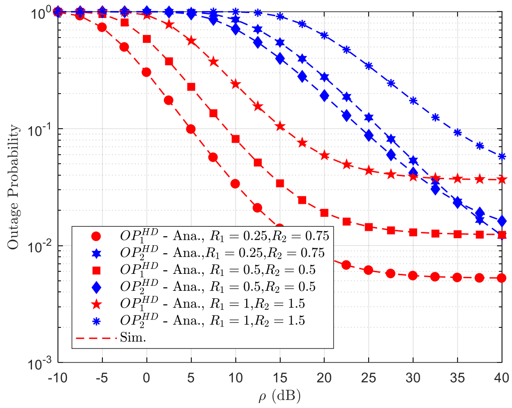

Figure 3. Outage performance
($\upsilon_1 = 0.9, \upsilon_2 = 0.1$)

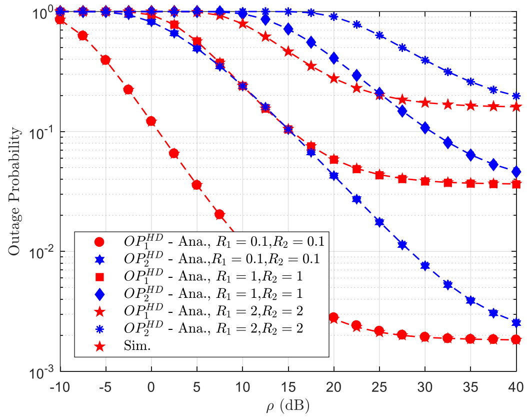

Figure 4. Outage performance
($\upsilon_1 = 0.9, \upsilon_2 = 0.1$)

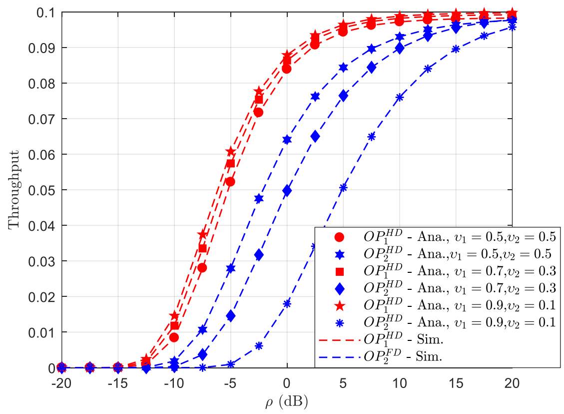

Figure 5. Throughput
($R_1 = R_2 = 0.1$ bps/Hz)

5. CONCLUSION

In this paper, we have investigated the two-way scheme for the cooperative NOMA system with the user group. For the considered AF cooperative relaying mode, the outage probabilities have been derived in closed-form for the two users. Simulation results reported different performance of two pair of users and these numerical results have verified the superior outage performance achieved by AF NOMA two-way mode and AF without direct links.

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