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V2X communication system with non-orthogonal multiple access: outage performance perspective

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ABSTRACT

To achieve low-latency and high-reliability (LLHR) for applications in the vehicle-to-everything (V2X) networks, the non-orthogonal multiple access (NOMA) is proposed for Long Term Evolution (LTE)as a promising technology. NOMA-V2X provides higher spectrum efficiency compared with the orthogonal multiple access (OMA) based V2X. The vehicles are expected to serve different services with variety of data transmission. The cluster of vehicles could be grouped to achieve better service from the transmitter sources. This study presents two-way relay assisted NOMA-V2X transmission by exploiting amplify-and-forward (AF) and full-duplex technique. We can benefits from potential applications of NOMA-V2X system with respect to serving massive users and adapting higher bandwidth efficiency. We derive expressions of outage probability to evaluate performance of two vehicles and to improve the quality of service (QoS) for the device with the poor channel conditions. The main investigation related two users' performance which provides guidelines to design practical system. These expressions are further verified by Monte-Carlo simulations.

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1. INTRODUCTION

As a candidate technique for forthcoming 5G networks, non-orthogonal multiple access (NOMA) network has recently drawn in considerable attentions [1]-[8]. In particular, the higher spectral efficiency benefits can be achieved by the deployment of NOMA and it outperforms the traditional orthogonal multiple access (OMA) scheme [1]-[3]. In practical NOMA systems, to achieve low complexity, the successive interference cancellation (SIC) decoding technique is needed to satisfy the performance of the NOMA system and it requires the user grouping as an important issue. In the recent works regarding NOMA system, the improved performance can be achieved as by employing relaying networks [4]-[7], [9]-[13] with NOMA to introduce new paradigm termed as cooperative NOMA [8]. Regarding system performance, the optimal sum rate [14], [15], and the minimal transmit power [16] are introduced with respect to the user grouping.

Recently, to provide smarter, safer and more efficient road traffic, vehicle-to-everything (V2X) communications have a lot of achievements in both academia and industry [16]–[18]. Three kinds of V2X networks including vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-pedestrian (V2P) are implemented to enable real-time traffic information exchange among infrastructure, vehicles, and pedestrians [19]–[21]. In such a V2X, low access efficiency and data congestion are caused by the fast growth of number of connected vehicles. The development of V2X communications need be tackled the challenges in vehicular networks such as [22], [23]. This paper considers the ability of two pairs of vehicle can be communicated via the Roadside Unit (RSU).

2. NETWORK ARCHITECTURE AND PROTOCOL DESCRIPTIONS

2.1. System architecture

Figure 1 depicts a scenario of AF relay assisted two-way NOMA-V2X systems, all nodes are with single antenna except for relay with two antennas for FD mode. The base stations (BSs) employ a RSU to serve group of two vehicles. In the multicasting scenario, RSU serves multiple users using NOMA. In this case, vehicles in the same group require to receive different information (e.g., vehicle-specific control information) from the BS. The source S_1, S_2 are able to send the corresponding signals x_1, x_2 (with power allocation factors α_1, α_2) to the RSU in the same time. The constraint of power allocation factors, i.e., $\alpha_1 > \alpha_2$ and $\alpha_1 + \alpha_2 = 1$. It can be shared by two source-destination $\mathrm{Group1} = \{\mathrm{S_1}, \mathrm{U_1}\}$ and $\mathrm{Group2} = \{\mathrm{S_2}, \mathrm{U_2}\}$ pairs. The transmit power at sources S_1, S_2 are the same, i.e. equals to P_s. The channels for links S_1-RSU, S_2-RSU, RSU-U_1 and RSU-U_2 are h_1, h_2, g_1, g_2.

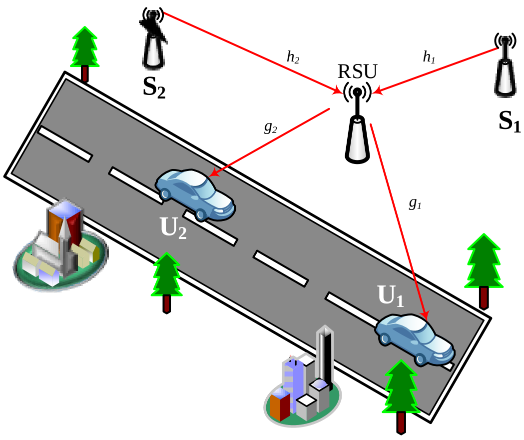

Figure 1. System model of NOMA V2X

2.2. SINR calculation

The received signal at RSU is given by

$$y_{\mathrm{RSU}} = \sqrt{\alpha_1 P_s} h_1 x_1 + \sqrt{\alpha_2 P_s} h_2 x_2 + P_{\mathrm{RSU}} f + \eta_{\mathrm{RSU}}, \tag{1}$$

where $\eta_{\mathrm{RSU}}$is AWGN noise with variance of σ_0^2. We call f as self-channel due to FD mode applied at the RSU. The received signal at $\mathrm{U_i}, (\mathrm{i} = 1, 2)$ can be expressed as follows:

$$y_{\mathrm{U_i}} = \sqrt{P_{\mathrm{RSU}}} \beta g_{\mathrm{i}} \left(\sqrt{\alpha_1 P_s} h_1 x_1 + \sqrt{\alpha_2 P_s} h_2 x_2 + \sqrt{P_{\mathrm{RSU}}} f + \eta_{\mathrm{RSU}} \right) + \eta_{\mathrm{U_i}}. \tag{2}$$

The amplify factor is defined as follows:

$$\beta = \frac{1}{\sqrt{\alpha_1 P_s |h_1|^2 + \alpha_2 P_s |h_2|^2 + P_{\mathrm{RSU}} |f|^2 + \sigma_0^2}}, \tag{3}$$

where $\rho_s \triangleq P_s/\sigma_0^2$ and $\rho_{\mathrm{RSU}} \triangleq P_{\mathrm{RSU}}/\sigma_0^2$ are transmission SNR of source and relay node, respectively.

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

$$\gamma_{\mathrm{U}_1}=\frac{\alpha_1\rho_s\rho_{\mathrm{RSU}}|g_1|^2|h_1|^2}{\alpha_2\rho_s\rho_{\mathrm{RSU}}|g_1|^2|h_2|^2+\rho_{\mathrm{RSU}}|g_1|^2+\alpha_1\rho_s|h_1|^2+\rho_{\mathrm{RSU}}\rho_{\mathrm{RSU}}|f|^2|g_1|^2+1}. \tag{4}$$

The received SINR for destination 2 to decode message x_1 is given by

$$\gamma_{\mathrm{U}_2\to 1}=\frac{\alpha_1\rho_{\mathrm{RSU}}\rho_s|g_2|^2|h_1|^2}{\alpha_2\rho_{\mathrm{RSU}}\rho_s|h_2|^2|g_2|^2+\rho_{\mathrm{RSU}}|g_2|^2+\alpha_1\rho_s|h_1|^2+\rho_{\mathrm{RSU}}\rho_{\mathrm{RSU}}|f|^2|g_2|^2+1}. \tag{5}$$

Destination 2 detects its own message with the following SINR.

$$\gamma_{\mathrm{U}_4}=\frac{\alpha_2\rho_{\mathrm{RSU}}\rho_s|h_2|^2|g_2|^2}{\rho_{\mathrm{RSU}}|g_2|^2+\alpha_1\rho_s|h_1|^2+\rho_{\mathrm{RSU}}\rho_{\mathrm{RSU}}|f|^2|g_2|^2+1}. \tag{6}$$

3. OUTAGE AND THROUGHPUT PERFORMANCE ANALYSIS

3.1. The outage probability for group 1

The outage probability is basic metric showing probability to SINR less than threshold value. In particular, the outage probability of group 1 can be written as:

$$\mathrm{OP}_{\Sigma_1}^{\mathrm{FD}}=\Pr\left(\gamma_{\mathrm{U}_1}<\gamma_0^1\right). \tag{7}$$

Next, $\mathrm{OP}_{\Sigma_1}^{\mathrm{FD}}$ can be computed as

$$\begin{aligned}\mathrm{OP}_{\Sigma_1}^{\mathrm{FD}}=&\Pr\left(\frac{\alpha_1\rho_s\rho_{\mathrm{RSU}}|g_1|^2|h_1|^2}{\alpha_2\rho_s\rho_{\mathrm{RSU}}|g_1|^2|h_2|^2+\rho_{\mathrm{RSU}}|g_1|^2+\alpha_1\rho_s|h_1|^2+\rho_{\mathrm{RSU}}\rho_{\mathrm{RSU}}|f|^2|g_1|^2+1}<\gamma_0^1\right)\\ =&\Pr\left(1,|g_1|^2\leq\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}}\right)+\Pr\left(|h_1|^2<\frac{\rho_{\mathrm{RSU}}|g_1|^2\left(\alpha_2\rho_s|h_2|^2+\rho_{\mathrm{RSU}}|f|^2+1\right)+1}{\alpha_1\rho_s\left(\frac{\rho_{\mathrm{RSU}}}{\gamma_0^1}|g_1|^2-1\right)},|g_1|^2>\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}}\right)\\ =&1-\frac{1}{\lambda_{g_1}}\int_{\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}}}^{\infty}\exp\left(-\frac{\rho_{\mathrm{RSU}}xX}{\lambda_{h_1}\alpha_1\rho_s\left(\frac{\rho_{\mathrm{RSU}}}{\gamma_0^1}x-1\right)}-\frac{x}{\lambda_{g_1}}-\frac{1}{\lambda_{h_1}\alpha_1\rho_s\left(\frac{\rho_{\mathrm{RSU}}}{\gamma_0^1}x-1\right)}\right)dx\end{aligned} \tag{8}$$

Putting $t=\frac{\rho_{\mathrm{RSU}}}{\gamma_0^1}x-1\Rightarrow x=\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}}(t+1)$ then $\mathrm{OP}_{\Sigma_1}^{\mathrm{FD}}$ has become

$$\begin{aligned}\mathrm{OP}_{\Sigma_1}^{\mathrm{FD}}=&1-\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_1}}\exp\left(-\frac{\gamma_0^1}{\lambda_{g_1}\rho_{\mathrm{RSU}}}-\frac{\gamma_0^1X}{\lambda_{h_1}\alpha_1\rho_s}\right)\\ &\times\int_0^{\infty}\exp\left(-\left(\frac{1}{\lambda_{h_1}\alpha_1\rho_s}+\frac{\gamma_0^1X}{\lambda_{h_1}\alpha_1\rho_s}\right)\frac{1}{t}-\frac{\gamma_0^1t}{\lambda_{g_1}\rho_{\mathrm{RSU}}}\right)dt\\ =&1-\exp\left(-\frac{\gamma_0^1}{\lambda_{g_1}\rho_{\mathrm{RSU}}}-\frac{\gamma_0^1X}{\lambda_{h_1}\alpha_1\rho_s}\right)2\sqrt{\frac{\gamma_0^1}{\lambda_{g_1}\rho_{\mathrm{RSU}}}\left(\frac{1}{\lambda_{h_1}\alpha_1\rho_s}+\frac{\gamma_0^1X}{\lambda_{h_1}\alpha_1\rho_s}\right)}\\ &\times K_1\left(2\sqrt{\frac{\gamma_0^1}{\lambda_{g_1}\rho_{\mathrm{RSU}}}\left(\frac{1}{\lambda_{h_1}\alpha_1\rho_s}+\frac{\gamma_0^1X}{\lambda_{h_1}\alpha_1\rho_s}\right)}\right)\end{aligned} \tag{9}$$

where $X = \left(\alpha_2\rho_s|h_2|^2 + \rho_{\mathrm{RSU}}|f|^2 + 1\right)$. Let $Y = \alpha_2\rho_s|h_2|^2 + \rho_{\mathrm{RSU}}|f|^2 \Rightarrow X = Y + 1$ then the outage probability of group 1 written again as follows

$$\begin{aligned}
\mathrm{OP}^{\mathrm{FD}}_{\Sigma_1}(Y) =& 1 - \mathrm{e}^{-\frac{\gamma_0^1}{\lambda_{g_1}\rho_r} - \frac{\gamma_0^1(Y+1)}{\lambda_{h_1}\alpha_1\rho_s}} 2\sqrt{\frac{\gamma_0^1}{\lambda_{g_1}\rho_{\mathrm{RSU}}}\left(\frac{1}{\lambda_{h_1}\alpha_1\rho_s} + \frac{\gamma_0^1(Y+1)}{\lambda_{h_1}\alpha_1\rho_s}\right)} \\
&\times K_1\left(2\sqrt{\frac{\gamma_0^1}{\lambda_{g_1}\rho_{\mathrm{RSU}}}\left(\frac{1}{\lambda_{h_1}\alpha_1\rho_s} + \frac{\gamma_0^1(Y+1)}{\lambda_{h_1}\alpha_1\rho_s}\right)}\right) \\
=& 1 - \mathrm{e}^{-\frac{\gamma_0^1 Y}{\lambda_{h_1}\alpha_1\rho_s} - \frac{\gamma_0^1}{\lambda_{g_1}\rho_{\mathrm{RSU}}} - \frac{\gamma_0^1}{\lambda_{h_1}\alpha_1\rho_s}} 2\sqrt{\frac{\gamma_0^1}{\lambda_{g_1}\rho_{\mathrm{RSU}}}\left(\frac{\gamma_0^1 Y}{\lambda_{h_1}\alpha_1\rho_s} + \frac{1}{\lambda_{h_1}\alpha_1\rho_s} + \frac{\gamma_0^1}{\lambda_{h_1}\alpha_1\rho_s}\right)} \\
&\times K_1\left(2\sqrt{\frac{\gamma_0^1}{\lambda_{g_1}\rho_{\mathrm{RSU}}}\left(\frac{\gamma_0^1 Y}{\lambda_{h_1}\alpha_1\rho_s} + \frac{1}{\lambda_{h_1}\alpha_1\rho_s} + \frac{\gamma_0^1}{\lambda_{h_1}\alpha_1\rho_s}\right)}\right) \\
=& 1 - 2\mathrm{e}^{-\vartheta_1 Y - \vartheta_2}\sqrt{\vartheta_3 Y + \vartheta_4}K_1\left(2\sqrt{\vartheta_3 Y + \vartheta_4}\right)
\end{aligned} \tag{10}$$

where $\vartheta_1 = \frac{\gamma_0^1}{\lambda_{h_1}\alpha_1\rho_s}$, $\vartheta_2 = \frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_1}} + \frac{\gamma_0^1}{\alpha_1\rho_s\lambda_{h_1}}$, $\vartheta_3 = \frac{\gamma_0^1\gamma_0^1}{\alpha_1\rho_s\rho_{\mathrm{RSU}}\lambda_{g_1}\lambda_{h_1}}$, $\vartheta_4 = \frac{\gamma_0^1}{\lambda_{g_1}\rho_{\mathrm{RSU}}}\left(\frac{1}{\lambda_{h_1}\alpha_1\rho_s} + \frac{\gamma_0^1}{\lambda_{h_1}\vartheta_1\rho_s}\right)$. $\mathrm{OP}^{\mathrm{FD}}_{\Sigma_1}$ can be calculated as

$$\begin{aligned}
\mathrm{OP}^{\mathrm{FD}}_{\Sigma_1} =& E_Y\left\{1 - 2\mathrm{e}^{-\vartheta_1 Y - \vartheta_2}\sqrt{\vartheta_3 Y + \vartheta_4}K_1\left(2\sqrt{\vartheta_3 Y + \vartheta_4}\right)\right\} \\
=& \int_0^\infty \left(1 - 2\mathrm{e}^{-\vartheta_1 Y - \vartheta_2}\sqrt{\vartheta_3 Y + \vartheta_4}K_1\left(2\sqrt{\vartheta_3 Y + \vartheta_4}\right)\right) f_Y(y)\,dy \\
=& \mathrm{OP}^{\mathrm{FD}}_{\Sigma_1 1} + \mathrm{OP}^{\mathrm{FD}}_{\Sigma_1,2}
\end{aligned} \tag{11}$$

We have

$$\begin{aligned}
F_Y(y) =& \int_0^Y f_Y(y)\,dy \\
=& \frac{1}{\lambda_f}\int_0^{\frac{y}{\rho_{\mathrm{RSU}}}} \mathrm{e}^{-\frac{x}{\lambda_f}}dx - \frac{1}{\lambda_f}\mathrm{e}^{-\frac{y}{\lambda_{h_2}\upsilon_2\rho_s}}\int_0^{\frac{y}{\rho_{\mathrm{RSU}}}} \mathrm{e}^{-\left(\frac{1}{\lambda_f\rho_r} - \frac{1}{\lambda_{h_2}\alpha_2\rho_s}\right)x}dx.
\end{aligned} \tag{12}$$

Here we look at two cases for CDF and PDF:

3.1.1. Case 1

If $\frac{1}{\rho_{\mathrm{RSU}}\lambda_f} - \frac{1}{\lambda_{h_2}\alpha_2\rho_s} \neq 0$, we have

$$F_Y(y) = 1 - \frac{\rho_{\mathrm{RSU}}\lambda_f}{\rho_{\mathrm{RSU}}\lambda_f - \alpha_2\rho_s\lambda_{h_2}}\mathrm{e}^{-\frac{y}{\rho_{\mathrm{RSU}}\lambda_f}} - \frac{\alpha_2\rho_s\lambda_{h_2}}{\alpha_2\rho_s\lambda_{h_2} - \rho_{\mathrm{RSU}}\lambda_f}\mathrm{e}^{-\frac{y}{\alpha_2\rho_s\lambda_{h_2}}}, \tag{13}$$

$$f_Y(y) = \frac{\mathrm{e}^{-\frac{y}{\rho_{\mathrm{RSU}}\lambda_f}}}{\rho_{\mathrm{RSU}}\lambda_f - \lambda_{h_2}\upsilon_2\rho_s} + \frac{\mathrm{e}^{-\frac{y}{\lambda_{h_2}\upsilon_2\rho_s}}}{\lambda_{h_2}\upsilon_2\rho_s - \rho_{\mathrm{RSU}}\lambda_f}. \tag{14}$$

$\mathrm{OP}^{\mathrm{FD}}_{\Sigma_1 1}$ can be computed as

$$\begin{aligned}\mathrm{OP}_{\Sigma_1 1}^{\mathrm{FD}} =&E_Y\left\{1-2\mathrm{e}^{-\vartheta_1 Y-\vartheta_2}\sqrt{\vartheta_3 Y+\vartheta_4}K_1\left(2\sqrt{\vartheta_3 Y+\vartheta_4}\right)\right\}\\ =&1-\frac{2\mathrm{e}^{-\vartheta_2}}{\rho_{\mathrm{RSU}}\lambda_f-\lambda_{h_2}\upsilon_2\rho_s}\theta_1-\frac{2\mathrm{e}^{-\vartheta_2}}{\lambda_{h_2}\upsilon_2\rho_s-\rho_{\mathrm{RSU}}\lambda_f}\theta_2\end{aligned} \tag{15}$$

where $\tau_1=\left(\frac{1}{\rho_{RSU}\lambda_f}+\vartheta_1\right)$,

$$\begin{aligned}\theta_1 \triangleq& \int_0^\infty \mathrm{e}^{-\tau_1 y}\sqrt{\vartheta_3 y+\vartheta_4}K_1\left(2\sqrt{\vartheta_3 y+\vartheta_4}\right)dy\\ =&\mathrm{e}^{\frac{\tau_1\vartheta_4}{\vartheta_3}}\left(\frac{\vartheta_3}{2{\tau_1}^2}\mathrm{e}^{\frac{\vartheta_3}{\tau_1}}\Gamma\left(-1,\frac{\vartheta_3}{\tau_1}\right)-\frac{1}{2}\sum_{m=0}^{M}\frac{(-\tau_1)^m{\vartheta_4}^{m+1}}{{\vartheta_3}^{m+1}}G_{1,3}^{2,1}\left(\vartheta_4|_{1,0,-m}^{-m}\right)\right),.\end{aligned} \tag{16}$$

By using the lase equation in [25], vol. 4, (3.16.2.4)], we have:

$$\begin{aligned}\tau_2 \triangleq& \int_0^\infty \mathrm{e}^{-\tau_1 y}\sqrt{\vartheta_3 y}K_1\left(2\sqrt{\vartheta_3 y}\right)dy\\ =&\frac{\vartheta_3}{2{\tau_1}^2}\mathrm{e}^{\frac{\vartheta_3}{\tau_1}}\Gamma\left(-1,\frac{\vartheta_3}{\tau_1}\right).\end{aligned} \tag{17}$$

and $\tau_3=\frac{1}{\vartheta_3}\int_0^{\vartheta_4}\mathrm{e}^{-\frac{\tau_1}{\vartheta_3}y}\sqrt{y}K_1\left(2\sqrt{y}\right)dy$. Putting $t=Cy\to y=\vartheta_4 t\to dy=\vartheta_4 dt$ when $y=0\to t=0$, $y=\vartheta_4\to t=1\to C=\frac{1}{\vartheta_4}$. Based on (18) we have:

$$\begin{aligned}\tau_3 =&\frac{\vartheta_4}{\vartheta_3}\int_0^1 \mathrm{e}^{-\frac{\tau_1\vartheta_4}{\vartheta_3}t}\sqrt{\vartheta_4 t}K_1\left(2\sqrt{\vartheta_4 t}\right)dt\\ =&\frac{1}{2}\sum_{m=0}^{M}\frac{(-\tau_1)^m{\vartheta_4}^{m+1}}{{\vartheta_3}^{m+1}}G_{1,3}^{2,1}\left(\vartheta_4|_{1,0,-m}^{-m}\right).\end{aligned} \tag{18}$$

Where the lase equation follows the fact that $e^x=\sum_{k=0}^{\infty}\frac{x^k}{k!}$ in [24], (1.211.1)] and $\int_0^1 x^\lambda(1-x)^{\mu-1}K_\nu\left(a\sqrt{x}\right)dx=\frac{2^{\nu-1}}{a^\nu}\Gamma\left(\mu\right)G_{1,3}^{2,1}\left(\frac{a^2}{4}|_{\nu,0,\frac{\nu}{2}-\lambda-\mu}^{\frac{\nu}{2}-\lambda}\right)$ in [24], (6.952.2)].
And

$$\begin{aligned}\theta_2 \triangleq& \int_0^\infty \mathrm{e}^{-\tau_4 y}\sqrt{\vartheta_3 y+\vartheta_4}K_1\left(2\sqrt{\vartheta_3 y+\vartheta_4}\right)dy\\ =&\mathrm{e}^{\frac{\tau_4\vartheta_4}{\vartheta_3}}\left(\frac{\vartheta_3}{2{\tau_4}^2}\mathrm{e}^{\frac{\vartheta_3}{\tau_4}}\Gamma\left(-1,\frac{\vartheta_3}{\tau_4}\right)-\frac{1}{2}\sum_{m=0}^{M}\frac{(-\tau_4)^m{\vartheta_4}^{m+1}}{{\vartheta_3}^{m+1}}G_{1,3}^{2,1}\left(\vartheta_4|_{1,0,-m}^{-m}\right)\right).\end{aligned} \tag{19}$$

where $\tau_4 = \frac{1}{\lambda_{h_2}\alpha_2\rho_s} + \vartheta_1$. By using the equation $x^{\nu/2}K_\nu\left(a\sqrt{x}\right) = \frac{\Gamma(\nu+1)}{(2p)^{\nu+1}}\mathrm{e}^{\frac{a^2}{4p}}\Gamma\left(-\nu, \frac{a^2}{4p}\right)$ in [25], vol. 4, eq. (3.16.2.4)], we can computed τ_5 :

$$\begin{aligned}\tau_5 &\triangleq \int_0^\infty \mathrm{e}^{-\tau_4 y}\sqrt{\vartheta_3 y}K_1\left(2\sqrt{\vartheta_3 y}\right)dy\\ &=\frac{\vartheta_3}{2{\tau_4}^2}\mathrm{e}^{\frac{\vartheta_3}{\tau_4}}\Gamma\left(-1, \frac{\vartheta_3}{\tau_4}\right),\end{aligned} \tag{20}$$

$$\begin{aligned}\tau_6 &=\frac{1}{\vartheta_3}\int_0^{\vartheta_4} \mathrm{e}^{-\frac{\tau_4}{\vartheta_3}y}\sqrt{y}K_1\left(2\sqrt{y}\right)dy\\ &=\frac{1}{2}\sum_{m=0}^{M}\frac{(-\tau_4)^m{\vartheta_4}^{m+1}}{{\vartheta_3}^{m+1}}G_{1,3}^{2,1}\left(\frac{4\vartheta_4}{4}|_{1,0,-m}^{-m}\right).\end{aligned} \tag{21}$$

3.1.2. Case 2:

If $\frac{1}{\rho_{\mathrm{RSU}}\lambda_f} - \frac{1}{\lambda_{h_2}\alpha_2\rho_s} = 0$, we have

$$F_Y\left(y\right) = 1 - \mathrm{e}^{\frac{-y}{\rho_{\mathrm{RSU}}\lambda_f}} - \frac{y}{\rho_{\mathrm{RSU}}\lambda_f}\mathrm{e}^{\frac{-y}{\lambda_{h_2}\alpha_2\rho_s}}, \tag{22}$$

$$f_Y\left(y\right) = \frac{y}{\lambda_Y\lambda_Y}\mathrm{e}^{\frac{-y}{\lambda_Y}}. \tag{23}$$

$\mathrm{OP}_{\Sigma_1,2}^{\mathrm{FD}}$ is given as

$$\begin{aligned}\mathrm{OP}_{\Sigma_1,2}^{\mathrm{FD}} &=E_Y\left\{1 - 2\mathrm{e}^{-\vartheta_1 Y-\vartheta_2}\sqrt{\vartheta_3 Y+\vartheta_4}K_1\left(2\sqrt{\vartheta_3 Y+\vartheta_4}\right)\right\}\\ &=1-\frac{2}{\lambda_Y\lambda_Y}\int_0^\infty \mathrm{e}^{-\left(\frac{-1}{\lambda_Y}-\vartheta_1\right)y-\vartheta_2}\left(\frac{1}{\vartheta_3}\left(y\vartheta_3+\vartheta_4\right)-\frac{\vartheta_4}{\vartheta_3}\right)\sqrt{\vartheta_3 y+\vartheta_4}K_1\left(2\sqrt{\vartheta_3 y+\vartheta_4}\right)dy\\ &=1-\theta_4+\theta_5.\end{aligned} \tag{24}$$

where

$$\begin{aligned}\theta_4 &=\tau_7\int_0^\infty \mathrm{e}^{-\tau_8 y}(\vartheta_3 y+\vartheta_4)^{3/2}K_1\left(2\sqrt{\vartheta_3 y+\vartheta_4}\right)dy\\ &=\tau_7\mathrm{e}^{\frac{\tau_8\vartheta_4}{\vartheta_3}}\left(\Delta_1-\Delta_2\right)\\ &=\tau_7\mathrm{e}^{\frac{\tau_8\vartheta_4}{\vartheta_3}}\left[\frac{\vartheta_3}{{\tau_8}^2}W_{-2,1/2}\left(\frac{\vartheta_3}{\tau_8}\right)-\frac{1}{2}\sum_{m=0}^{M}\frac{(-\tau_8)^m{\vartheta_4}^{m+2}}{{\vartheta_3}^{m+1}}G_{1,3}^{2,1}\left(\vartheta_4|_{1,0,-m}^{-m}\right)\right]\end{aligned} \tag{25}$$

By using the equation $\int_0^\infty x^{\nu/2}K_\nu\left(a\sqrt{x}\right)dx = \frac{p^{-\mu-1/2}}{a}\Gamma\left(\mu+\frac{\nu}{2}+1\right)\Gamma\left(\mu-\frac{\nu}{2}+1\right)\exp\left(\frac{a^2}{8p}\right)\times W_{-\mu-1/2,\nu/2}\left(\frac{a^2}{4p}\right)$ in [25], vol. 4, eq. (3.16.2.3)] and $\int_0^\infty x^{\nu/2}K_\nu\left(a\sqrt{x}\right)dx = \frac{\Gamma(\nu+1)}{(2p)^{\nu+1}}\exp\left(\frac{a^2}{4p}\right)\Gamma\left(-\nu, \frac{a^2}{4p}\right)$ in [25], vol. 4, eq. (3.16.2.4)], we can computed Δ_1, Δ_2:

$$\begin{aligned}\Delta_1 &= \int_0^\infty \mathrm{e}^{-\tau_8 y}{\vartheta_3}^{3/2}y^{3/2}K_1\left(2\sqrt{\vartheta_3 y}\right)dy\\ &=\frac{\vartheta_3}{{\tau_8}^2}W_{-2,1/2}\left(\frac{\vartheta_3}{\tau_8}\right),\end{aligned} \tag{26}$$

$$\begin{aligned}\Delta_2 =&\frac{1}{\vartheta_3}\int\limits_0^{\vartheta_4} \mathrm{e}^{-\frac{\tau_8}{\vartheta_3}y} y^{3/2} K_1\left(2\sqrt{y}\right)dy\\ =&\frac{1}{2}\sum_{m=0}^{M}\frac{\left(-\tau_8\right)^m {\vartheta_4}^{m+2}}{{\vartheta_3}^{m+1}} G_{1,3}^{2,1}\left(\vartheta_4|_{1,0,-m}^{-m}\right),\end{aligned} \tag{27}$$

and

$$\begin{aligned}\theta_5 =&\tau_7\vartheta_4\int\limits_0^{\infty} \mathrm{e}^{-\tau_8 y}\sqrt{\vartheta_3 y+\vartheta_4}K_1\left(2\sqrt{\vartheta_3 y+\vartheta_4}\right)dy\\ =&\mathrm{e}^{\frac{\tau_8\vartheta_4}{\vartheta_3}}\left(\frac{\tau_7\vartheta_4\vartheta_3}{2{\tau_8}^2}\mathrm{e}^{\frac{\vartheta_3}{\tau_8}}\Gamma\left(-1,\frac{\vartheta_3}{\tau_8}\right)-\frac{\tau_7}{2}\sum_{m=0}^{M}\frac{\left(-\tau_8\right)^m {\vartheta_4}^{m+2}}{{\vartheta_3}^{m+1}} G_{1,3}^{2,1}\left(\vartheta_4|_{1,0,-m}^{-m}\right)\right)\end{aligned} \tag{28}$$

where
$\tau_7 = \frac{2\mathrm{e}^{-\vartheta_2}}{\lambda_Y\lambda_Y\vartheta_3}, \tau_8 = \frac{1}{\lambda_Y}+\vartheta_1,\ \ \tau_9 = \frac{\vartheta_3}{2{\tau_8}^2}\mathrm{e}^{\frac{\vartheta_3}{\tau_8}}\Gamma\left(-1,\frac{\vartheta_3}{\tau_8}\right), \tau_{10} = \frac{1}{2}\sum\limits_{m=0}^{M}\frac{\left(-\tau_8\right)^m {\vartheta_4}^{m+1}}{{\vartheta_3}^{m+1}} G_{1,3}^{2,1}\left(\frac{4\vartheta_4}{4}|_{1,0,-m}^{-m}\right).$

3.2. The outage probability for group 2

The exact outage probability of group 2 can be written as

$$\mathrm{OP}_{\Sigma_2}^{\mathrm{FD}} =1-\Pr\left(\gamma_{\mathrm{U}_2\leftarrow 1}\geq\gamma_0^1,\gamma_{\mathrm{U}_2}\geq\gamma_0^2\right) \tag{29}$$

The outage probability in (29) can be computed as

$$\begin{aligned}\mathrm{OP}_{\Sigma_2}^{\mathrm{FD}} =&1-\Pr\left(\begin{array}{l}\frac{\alpha_1\rho_{\mathrm{RSU}}\rho_s|g_2|^2|h_1|^2}{\alpha_2\rho_{\mathrm{RSU}}\rho_s|h_2|^2|g_2|^2+\rho_{\mathrm{RSU}}|g_2|^2+\alpha_1\rho_s|h_1|^2+\rho_{\mathrm{RSU}}\rho_{\mathrm{RSU}}|f|^2|g_2|^2+1}\geq\gamma_0^1,\\ \frac{\alpha_2\rho_{\mathrm{RSU}}\rho_s|h_2|^2|g_2|^2}{\rho_{\mathrm{RSU}}|g_2|^2+\alpha_1\rho_s|h_1|^2+\rho_{\mathrm{RSU}}\rho_{\mathrm{RSU}}|f|^2|g_2|^2+1}\geq\gamma_0^2\end{array}\right)\\ =&1-\left(\mathrm{OP}_{\Sigma_2,1}^{\mathrm{FD}}+\mathrm{OP}_{\Sigma_2,2}^{\mathrm{FD}}\right).\end{aligned} \tag{30}$$

3.2.1. Case 1:

If $\max = \frac{1}{\frac{\alpha_1\rho_s}{\gamma_0^1}|h_1|^2-\alpha_2\rho_s|h_2|^2-1-\rho_{\mathrm{RSU}}|f|^2}$, we have:

$$\begin{aligned}\mathrm{OP}_{\Sigma_2,1}^{\mathrm{FD}} =&\int\limits_0^{\infty} f_{|f|^2}\left(z\right)dz\int\limits_{\frac{\gamma_0^2}{\alpha_2\rho_s}\left(\rho_{\mathrm{RSU}}z+1\right)}^{\infty} f_{|h_2|^2}\left(y\right)dy\\ &\times\underbrace{\int\limits_{\frac{\gamma_0^1}{\alpha_1\rho_s}\left(\alpha_2\rho_s y+\rho_{\mathrm{RSU}}z+1\right)}^{\frac{\gamma_0^1\alpha_2}{\alpha_1}\left(\frac{1}{\gamma_0^2}+1\right)y}\left(1-F_{|g_2|^2}\left(\frac{1}{\rho_{\mathrm{RSU}}}\frac{\alpha_1\rho_s x+1}{\frac{\alpha_1\rho_s}{\gamma_0^1}x-\alpha_2\rho_s y-\rho_{\mathrm{RSU}}z-1}\right)\right)f_{|h_1|^2}\left(x\right)dx,}_{\triangleq\Delta_4}\end{aligned} \tag{31}$$

Continuing the calculation process, we have

$$
\begin{aligned}
\mathrm{OP}_{\Sigma_2,1}^{\mathrm{FD}} &= \int_0^\infty f_{|f|^2}(z)\,dz \Bigg[\underbrace{\frac{1}{\lambda_{h_2}} \int_{\frac{\gamma_0^2}{\alpha_2\rho_s}(\rho_{\mathrm{RSU}}z+1)}^{\infty} \mathrm{e}^{-\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_2}}} \mathrm{e}^{-\left(\frac{\gamma_0^1\alpha_2}{\alpha_1\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)+\frac{1}{\lambda_{h_2}}\right)y} dy}_{\triangleq \vartheta_1} \\
&\quad \underbrace{- \frac{1}{\lambda_{h_2}} \int_{\frac{\gamma_0^2}{\alpha_2\rho_s}(\rho_{\mathrm{RSU}}z+1)}^{\infty} \mathrm{e}^{-\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_2}}} \mathrm{e}^{-\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)y} \mathrm{e}^{-\frac{\rho_{\mathrm{RSU}}\gamma_0^1}{\alpha_1\rho_s\lambda_{h_1}}z} \mathrm{e}^{-\frac{\gamma_0^1}{\alpha_1\rho_s\lambda_{h_1}}} dy}_{\triangleq \vartheta_2} \Bigg] \\
&= \underbrace{\frac{\mathrm{e}^{-\frac{\gamma_0^1\gamma_0^2}{\alpha_1\rho_s\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)-\frac{\gamma_0^2}{\alpha_2\rho_s\lambda_{h_2}}-\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_2}}}}{\lambda_{h_2}\left(\frac{\gamma_0^1\alpha_2}{\alpha_1\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)+\frac{1}{\lambda_{h_2}}\right)} \int_0^\infty \mathrm{e}^{-\left(\frac{\gamma_0^1\alpha_2}{\alpha_1\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)+\frac{1}{\lambda_{h_2}}\right)\frac{\rho_{\mathrm{RSU}}\gamma_0^2}{\alpha_2\rho_s}z} f_{|f|^2}(z)\,dz}_{\triangleq \vartheta_3} \\
&\quad \underbrace{- \frac{\mathrm{e}^{-\frac{\gamma_0^1}{\rho_r\lambda_{g_2}}-\frac{\gamma_0^1}{\alpha_1\rho_s\lambda_{h_1}}-\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)\frac{\gamma_0^2}{\alpha_2\rho_s}}}{\lambda_{h_2}\left(\frac{\alpha_2\gamma_0^1}{\alpha\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)} \int_0^\infty \mathrm{e}^{-\left(\frac{\rho_{\mathrm{RSU}}\gamma_0^1}{\alpha_1\rho_s\lambda_{h_1}}+\frac{\rho_{\mathrm{RSU}}\gamma_0^2}{\alpha_2\rho_s}\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)\right)z} f_{|f|^2}(z)\,dz}_{\triangleq \vartheta_4} \\
&= \frac{\mathrm{e}^{-\frac{\gamma_0^1\gamma_0^2}{\alpha_1\rho_s\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)-\frac{\gamma_0^2}{\alpha_2\rho_s\lambda_{h_2}}-\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_2}}}}{\lambda_{h_2}\lambda_f\left(\frac{\gamma_0^1\alpha_2}{\alpha_1\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)+\frac{1}{\lambda_{h_2}}\right)\left[\left(\frac{\gamma_0^1\alpha_2}{\alpha_1\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)+\frac{1}{\lambda_{h_2}}\right)\frac{\rho_{\mathrm{RSU}}\gamma_0^2}{\alpha_2\rho_s}+\frac{1}{\lambda_f}\right]} \\
&\quad - \frac{\mathrm{e}^{-\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_2}}-\frac{\gamma_0^1}{\alpha_1\rho_s\lambda_{h_1}}-\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)\frac{\gamma_0^2}{\alpha_2\rho_s}}}{\lambda_{h_2}\lambda_f\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)\left[\left(\frac{\rho_{\mathrm{RSU}}\gamma_0^1}{\alpha_1\rho_s\lambda_{h_1}}+\frac{\rho_r\gamma_0^2}{\alpha_2\rho_s}\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)\right)+\frac{1}{\lambda_f}\right]}.
\end{aligned} \tag{32}
$$

where $\Delta_4 = \frac{1}{\lambda_{h_1}}\mathrm{e}^{-\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_2}}} \int_{\frac{\gamma_0^1}{\upsilon_1\rho_s}(\upsilon_2\rho_s y+\rho_{\mathrm{RSU}}z+1)}^{\frac{\gamma_0^1\upsilon_2}{\upsilon_1}\left(\frac{1}{\gamma_0^2}+1\right)y} \mathrm{e}^{-\frac{x}{\lambda_{h_1}}}\,dx,$

$$
\vartheta_1 = \frac{\mathrm{e}^{-\frac{\gamma_0^1\gamma_0^2}{\alpha_1\rho_s\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)-\frac{\gamma_0^2}{\alpha_2\rho_s\lambda_{h_2}}-\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_2}}}\mathrm{e}^{-\left(\frac{\gamma_0^1\alpha_2}{\alpha_1\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)+\frac{1}{\lambda_{h_2}}\right)\frac{\rho_{\mathrm{RSU}}\gamma_0^2}{\alpha_2\rho_s}z}}{\frac{\gamma_0^1\alpha_2\lambda_{h_2}}{\alpha_1\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)+1},
$$

$$
\vartheta_2 = \frac{\mathrm{e}^{-\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_2}}-\frac{\gamma_0^1}{\alpha_1\rho_s\lambda_{h_1}}-\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)\frac{\gamma_0^2}{\alpha_2\rho_s}}\mathrm{e}^{-\left(\frac{\rho_{\mathrm{RSU}}\gamma_0^1}{\alpha_1\rho_s\lambda_{h_1}}+\frac{\rho_{\mathrm{RSU}}\gamma_0^2}{\alpha_2\rho_s}\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)\right)z}}{\lambda_{h_2}\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)},
$$

$$
\vartheta_3 = \frac{\mathrm{e}^{-\frac{\gamma_0^1\gamma_0^2}{\alpha_1\rho_s\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)-\frac{\gamma_0^2}{\alpha_2\rho_s\lambda_{h_2}}-\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_2}}}}{\lambda_{h_2}\lambda_f\left(\frac{\gamma_0^1\alpha_2}{\alpha_1\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)+\frac{1}{\lambda_{h_2}}\right)\left[\left(\frac{\gamma_0^1\alpha_2}{\alpha_1\lambda_{h_1}}\left(\frac{1}{\gamma_0^2}+1\right)+\frac{1}{\lambda_{h_2}}\right)\frac{\rho_{\mathrm{RSU}}\gamma_0^2}{\alpha_2\rho_s}+\frac{1}{\lambda_f}\right]},
$$

$$
\vartheta_4 = \frac{\mathrm{e}^{-\frac{\gamma_0^1}{\rho_{\mathrm{RSU}}\lambda_{g_2}}-\frac{\gamma_0^1}{\alpha_1\rho_s\lambda_{h_1}}-\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)\frac{\gamma_0^2}{\alpha_2\rho_s}}}{\lambda_{h_2}\lambda_f\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)\left[\left(\frac{\rho_{\mathrm{RSU}}\gamma_0^1}{\alpha_1\rho_s\lambda_{h_1}}+\frac{\rho_{\mathrm{RSU}}\gamma_0^2}{\alpha_2\rho_s}\left(\frac{\alpha_2\gamma_0^1}{\alpha_1\lambda_{h_1}}+\frac{1}{\lambda_{h_2}}\right)\right)+\frac{1}{\lambda_f}\right]}.
$$

3.2.2. Case 2:

If $\max = \frac{1}{\frac{\alpha_2 \rho_s}{\gamma_0^2}|h_2|^2 - 1 - \rho_{\mathrm{RSU}}|f|^2}$, we have:

$$\begin{aligned}
\mathrm{OP}_{\Sigma_2,2}^{\mathrm{FD}} &= \int\limits_0^\infty f_{|f|^2}(z)\,dz \int\limits_{\frac{\gamma_0^2}{\alpha_2\rho_s}(\rho_{\mathrm{RSU}}z+1)}^\infty f_{|h_2|^2}(y)\,dy \\
&\quad \times \underbrace{\int\limits_{\frac{\gamma_0^1\alpha_2}{\alpha_1}\left(\frac{1}{\gamma_0^2}+1\right)y}^\infty \left(1 - F_{|g_2|^2}\left(\frac{1}{\rho_{\mathrm{RSU}}}\frac{\alpha_1\rho_s x + 1}{\frac{\alpha_2\rho_s}{\gamma_0^2}y - \rho_{\mathrm{RSU}}z - 1}\right)\right) f_{|h_1|^2}(x)\,dx}_{\triangleq \Delta_3} \\
&= \frac{2\gamma_0^2}{\alpha_2\rho_s\rho_{\mathrm{RSU}}\lambda_f}\sum_{k=1}^\infty k\lambda_{g_2}^k(-\alpha_1\rho_s\lambda_{h_1})^{k-1}e^{-\Xi_4 - \frac{\gamma_0^2}{\alpha_2\rho_s\lambda_{h_2}}}\sqrt{\left(\frac{\Xi_2(1+E)}{\Xi_1\lambda_{g_2}}\right)^{k+1}\left(\frac{\rho_{\mathrm{RSU}}\Xi_2\Xi_5}{\Xi_1\lambda_{g_2}}\right)^{k+1}} \\
&\quad \times \int\limits_0^\infty \mathrm{e}^{-\left(\frac{1}{\lambda_f} + \frac{\Xi_1\rho_{\mathrm{RSU}}\rho_{\mathrm{RSU}}}{\Xi_2} + \frac{\rho_{\mathrm{RSU}}\gamma_0^2}{\alpha_2\rho_s\lambda_{h_2}}\right)z} z^{k+1} K_{k+1}\left(2\sqrt{\frac{\Xi_1(1+\rho_{\mathrm{RSU}}\Xi_5 z + \Xi_5)}{\Xi_2\lambda_{g_2}}}\right)dz.
\end{aligned} \tag{33}$$

where $\Xi_1 = \frac{\gamma_0^1\alpha_2}{\lambda_{h_1}\alpha_1}\left(\frac{1}{\gamma_0^2}+1\right)$, $\Xi_2 = \frac{\alpha_2\rho_s\rho_{\mathrm{RSU}}}{\gamma_0^2}$, $\Xi_4 = \frac{\rho_s\lambda_{h_1}\alpha_1\Xi_1}{\lambda_{g_2}\Xi_2} + \frac{\Xi_1\rho_{\mathrm{RSU}}}{\Xi_2}$, $\Xi_5 = \frac{\rho_s\rho_{\mathrm{RSU}}\lambda_{h_1}\alpha_1\Xi_1}{\Xi_2}$.

3.3. Throughput

The throughput in delay-limited transmission mode is given by

$$\begin{aligned}
\Upsilon_1 &= \left(1 - \mathrm{OP}_{\Sigma_1}^{\mathrm{FD}}\right)\mathrm{R}_1, \\
\Upsilon_2 &= \left(1 - \mathrm{OP}_{\Sigma_2}^{\mathrm{FD}}\right)\mathrm{R}_2.
\end{aligned} \tag{34}$$

4. RESULT AND DISCUSSION

Figures 2 and 3 demonstrate outage probability of two vehicles. It can be observed that outage probability improves significantly at high SNR. There is existence performance gap among two vehicles due to different power allocation factors. It is further confirmed that outage probability cannot improve at very high SNR regardless of changing target rates R_1, R_2. In these simulations, Monte-Carlo and analytical simulations are matched tightly and it confirmed our derivations are correct. Figure 4 examines impact of interference channel related to FD mode on outage probability. When changing λ_f from 0 (dB) to 30 (dB) outage probability becomes worse significantly. Figure 5 shows throughput versus transmit SNR ρ. Increasing ρ from -20 (dB) to 15 (dB), throughput increases significantly, but it meets the ceiling at high SNR region.

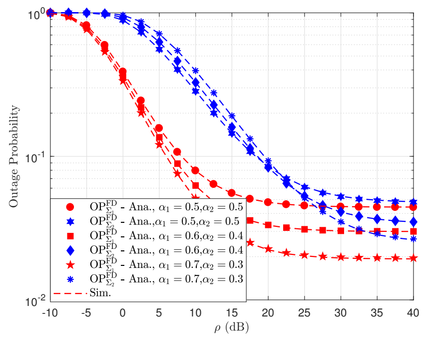

Figure 2. Outage probability: $\mathrm{R}_1 = 0.5$ bps/Hz, $\mathrm{R}_2 = 1$ bps/Hz.

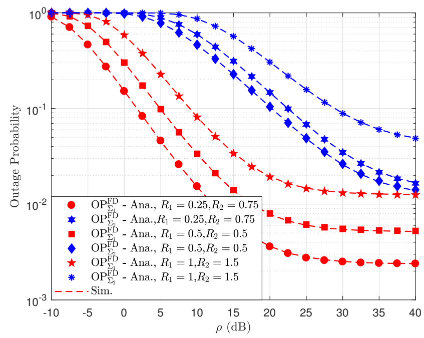

Figure 3. Outage probability: $\alpha_1 = 0.9$, $\alpha_2 = 0.1$.

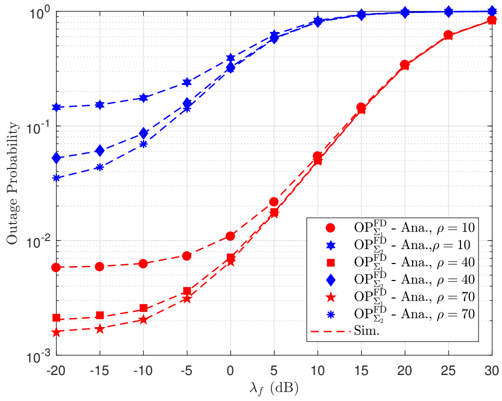

Figure 4. Outage probability: $\mathrm{R}_1 = 0.1$ bps/Hz, $\mathrm{R}_2 = 0.1$, $\alpha_1 = 0.9$, $\alpha_2 = 0.1$.

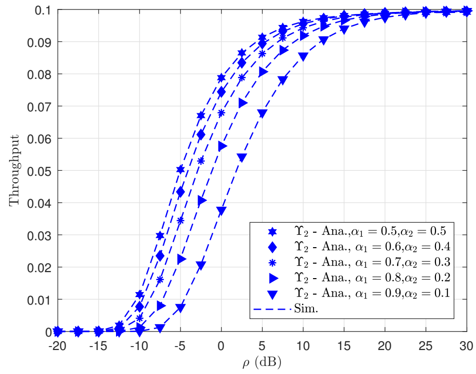

Figure 5. Throughput: $\alpha_1 = 0.9$, $\alpha_2 = 0.1$.

5. CONCLUSION

In this paper, two pairs of users in NOMA-V2X systems have been proposed for 5G cellular V2X communications. The fixed power allocation factors are applied to highlight different outage performance of each group of user. We provided exact expressions of outage probability to evaluate system performance. We show that the formulated expression is verified via simulations. Fortunately, it indicates reasonable performance of two vehicles in NOMA-V2X if self-interference channel is controlled well. Simulation results demonstrate that the proposed scheme exhibits better performance at high SNR at sources.

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