Performance Evaluation of Cooperative Communications over Fading Channels in Vehicular Networks

Caslav Stefanovic* (1), Marco Pratesi(2), and Fortunato Santucci (2)
(1) University of Pristina, Faculty of Natural Sciences and Mathematics, Kosovska Mitrovica, Serbia
(2) University of L'Aquila – Dept. DISIM and Centre of Excellence DEWS, L'Aquila, Italy

Abstract

This paper provides channel modeling and performance evaluation study of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) cooperative communications in urban non-line-of-sight (NLOS) multipath fading environments. The proposed model investigates three different scenarios: *i*) V2V communications enabled by parallel cooperative dual-hop amplify-and-forward (AaF) vehicle-relaying, *ii*) V2V communications enabled by dual-hop AaF road-side-unit (RSU) relaying on one link and direct V2V communications on another link, *iii*) V2I communications enabled by dual-hop AaF vehicle-relaying on one link and direct V2I communications on another link. We derive relevant statistics for the output signal envelope and related system performance, e.g. the level crossing rate and average fade duration for varying outage threshold. Numerical results are presented for different sets of channel parameters.

1. Introduction

Vehicular wireless networks operate in rapidly time varying channels often characterized by increased mobility of all vehicular network nodes. The vehicular nodes are on the same height and thus waves are exposed to double scattering phenomena. The vehicular network channel models that fits well with experiments are often modeled as the product of two or more random variables (RVs) [1, 3]. Among the last one to be proposed for V2V is double generalized gamma (DGG) distribution modeled as the product of two α-μ RVs [1].

On the other hand recent studies have been focused on cooperative relaying to improve overall system performances [4, 5]. The main purpose of V2V cooperative relaying is to use the capabilities of spatial diversity while relying on the existing vehicular network nodes. In particular, cooperative relaying with selection schemes is studied in [1]. The selection schemes are characterized by relatively lower implementation complexity what could be of interest in cooperative vehicular communications over fading channels, since increased vehicle mobility and specific channel environments determine additional propagation impairments which often suggest lower design complexity of vehicular transceiving systems.

In order to address complex AaF dual-hop V2V fading environments by considering more general channel models, we examine Level-Crossing-Rate (LCR) and Average-Fade-Duration (AFD) of V2V dual-hop AaF cooperative vehicle-relay system with selection combining (SC), modeled as a multiple products of two independent but not necessarily identical double generalized gamma (DGG) fading processes. The performance evaluation of the proposed model extends to three different scenarios that include cooperative vehicular communications with direct V2V and V2I links.

2. V2V Communications with Vehicle Relay

Figure 1 shows the V2V dual-hop AaF relay system (boxed) as well as a cooperative V2V dual-hop AaF relay system model.

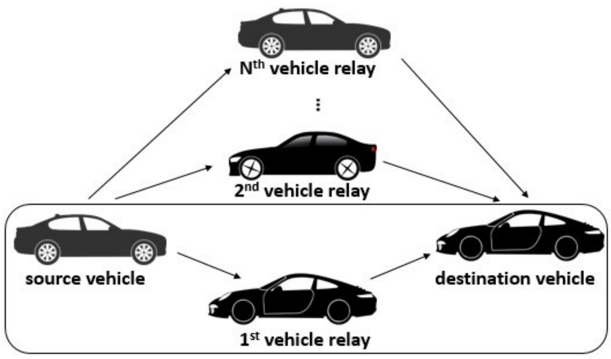

Figure 1. Main alternatives for V2V communications with mobile relay: AaF dual-hop communications with single vehicle relay **(boxed)** and cooperative AaF dual-hop communications with multiple vehicle relays.

Starting with the V2V dual-hop relay communications, we model signal envelope at the output as a product of two DGG random processes ($z_{sd_1} = z_{sr} z_{rd}$, where the dependence on the time t is omitted for easier notation throughout the paper). The signal envelope from source-vehicle to relay-vehicle (the first section) is denoted with z_{sr} and modeled as the product of two generalized Gamma RVs ($z_{\mathrm{sr}} = x_{\mathrm{sr}_1} x_{\mathrm{sr}_2}$) and the signal envelope from vehicle-relay to destination-vehicle (the second section) is denoted with z_{rd} and modeled as the product of two other generalized Gamma RVs, ($z_{rd} = x_{\mathrm{rd}_1} x_{\mathrm{rd}_2}$). Further, generalized Gamma RVs are expressed by non-linearity parameter α and Nakagami-m RVs, y_{sr_1}, y_{sr_2}, y_{rd_1} and y_{rd_2} [6]:

$$z_{\mathrm{sd}_1} = z_{\mathrm{sr}} z_{\mathrm{rd}} = x_{\mathrm{sr}_1} x_{\mathrm{sr}_2} x_{\mathrm{rd}_1} x_{\mathrm{rd}_2} = \left(y_{\mathrm{sr}_1} y_{\mathrm{sr}_2} y_{\mathrm{rd}_1} y_{\mathrm{rd}_2}\right)^{\frac{2}{\alpha}} \quad (1).$$

with the following Probability-Density-Functions (PDFs), respectively [7]:

$$p_{y_{\mathrm{sr}_i}}\left(y_{\mathrm{sr}_i}\right) = \frac{2}{\Gamma\left(m_{\mathrm{sr}_i}\right)} \left(\frac{m_{\mathrm{sr}_i}}{\Omega_{\mathrm{sr}_i}}\right)^{m_{\mathrm{sr}_i}} {y_{\mathrm{sr}_i}}^{2m_{\mathrm{sr}_i}-1} e^{-\frac{m_{\mathrm{sr}_i} {y_{\mathrm{sr}_i}}^2}{\Omega_{\mathrm{sr}_i}}} \quad (2).$$

$$p_{y_{\mathrm{rd}_i}}\left(y_{\mathrm{rd}_i}\right) = \frac{2}{\Gamma\left(m_{\mathrm{rd}_i}\right)} \left(\frac{m_{\mathrm{rd}_i}}{\Omega_{\mathrm{rd}_i}}\right)^{m_{\mathrm{rd}_i}} {y_{\mathrm{rd}_i}}^{2m_{\mathrm{rd}_i}-1} e^{-\frac{m_{\mathrm{rd}_i} {y_{\mathrm{rd}_i}}^2}{\Omega_{\mathrm{rd}_i}}} \quad (3).$$

where $i = 1,2$; m_{sr_1} and m_{sr_2} are source-relay Nakagami-m severity parameters given in (2) while m_{rd_1} and m_{rd_2} are relay-destination Nakagami-m severity parameters given in (3). Further, source-relay average powers of y_{sr_1} and y_{sr_2} are Ω_{sr_1} and Ω_{sr_2}, respectively, while relay-destination average powers of y_{rd_1} and y_{rd_2} are denoted as Ω_{rd_1} and Ω_{rd_2}, respectively.

The PDF $p_{z_{\mathrm{sd}_1}}\left(z_{\mathrm{sd}_1}\right)$ at the output of the considered V2V dual-hop system can be written as [7]:

$$p_{z_{\mathrm{sd}_1}}\left(z_{\mathrm{sd}_1}\right) = \int_0^\infty dy_{\mathrm{sr}_2} \int_0^\infty dy_{\mathrm{rd}_1} \int_0^\infty \frac{\frac{\alpha}{2} {z_{\mathrm{sd}_1}}^{\frac{\alpha}{2}-1}}{y_{\mathrm{sr}_2} y_{\mathrm{rd}_1} y_{\mathrm{rd}_2}} p_{y_{\mathrm{sr}_1}}\left(\frac{{z_{\mathrm{sd}_1}}^{\frac{\alpha}{2}}}{y_{\mathrm{sr}_2} y_{\mathrm{rd}_1} y_{\mathrm{rd}_2}}\right) \times p_{y_{\mathrm{sr}_2}}\left(y_{\mathrm{sr}_2}\right) p_{y_{\mathrm{rd}_1}}\left(y_{\mathrm{rd}_1}\right) p_{y_{\mathrm{rd}_2}}\left(y_{\mathrm{rd}_2}\right) dy_{\mathrm{rd}_2} \quad (4).$$

The Cumulative-Distribution-Function (CDF) of z_{sd_1} can then be expressed as [7]:

$$F_{z_{\mathrm{sd}_1}}\left(z_{\mathrm{sd}_1}\right) = \int_0^{z_{\mathrm{sd}_1}} p_{z_{\mathrm{sd}_1}}(r) dr \quad (5).$$

The LCR $N_{z_{\mathrm{sd}_1}}$ at the output of V2V AaF dual-hop relay system can be expressed by resorting to the general formula [7]:

$$N_{z_{\mathrm{sd}_1}} = \int_0^\infty \dot{z}_{\mathrm{sd}_1} p_{z_{\mathrm{sd}_1} \dot{z}_{\mathrm{sd}_1}}\left(z_{\mathrm{sd}_1} \dot{z}_{\mathrm{sd}_1}\right) \mathrm{d}\dot{z}_{\mathrm{sd}_1} \quad (6).$$

We extend the above model to a cooperative dual-hop AaF relay network, consisting of *N* parallel vehicle-relays branches with selection combining (SC), according to Figure 1. The CDF ${F_{z_{\mathrm{sd}}}}^{(I)}(z_{\mathrm{sd}})$ at the output of a SC scheme with *N* independent identically distributed (i.i.d) branches is:

$${F_{z_{\mathrm{sd}}}}^{(I)}(z_{\mathrm{sd}}) = \left(F_{z_{\mathrm{sd}_1}}(z_{\mathrm{sd}})\right)^N \quad (7).$$

After extensive mathematical manipulations, that are not reported here, the LCR ${N_{z_{\mathrm{sd}}}}^{(I)}(z_{\mathrm{th}})$ can be finally expressed as a function of the variable (outage) threshold z_{th}:

$${N_{z_{\mathrm{sd}}}}^{(I)}(z_{\mathrm{th}}) = N\, N_{z_{\mathrm{sd}_1}}(z_{\mathrm{th}}) \left(F_{z_{\mathrm{sd}_1}}(z_{\mathrm{th}})\right)^{N-1} \quad (8).$$

while the AFD $AFD^{(I)}(z_{th})$ can be easily obtained as [7]:

$$AFD^{(I)}(Z_{th}) = \frac{{F_{z_{\mathrm{sd}}}}^{(I)}(z_{\mathrm{th}})}{{N_{z_{\mathrm{sd}}}}^{(I)}(z_{\mathrm{th}})} \quad (9).$$

3. V2V and V2I Communications with Direct V2V and RSU Relay links

This section includes a direct V2V source-destination link as well as a fixed road-side-unit (RSU) relay. We then examine V2V and V2I communications over SC in scenarios where dual-hop AaF relaying is supported by direct V2V and V2I communications.

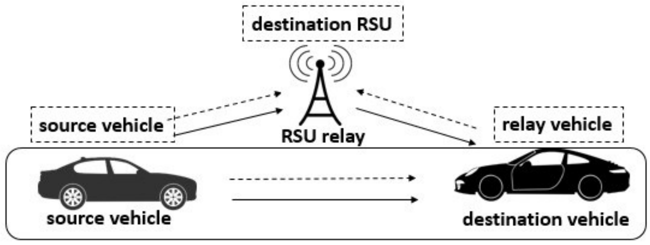

Figure 2. Main alternatives for V2V/V2I communications with RSU relay: direct V2V communications **(boxed),** V2V communications assisted by AaF RSU-relay and direct link **(straight line)** and V2I communications assisted by AaF vehicle-relay and direct V2I link **(dashed line).**

The direct V2V link shown in Figure 2 (boxed) is modeled as the product of two generalized Gamma RVs. The signal at the output of V2V destination vehicle can be written as the product of two α-μ RVs, x_{sd_1} and x_{sd_2}:

$$z_{\mathrm{sd}_2} = x_{\mathrm{sd}_1} x_{\mathrm{sd}_2} = \left(y_{\mathrm{sd}_1} y_{\mathrm{sd}_2}\right)^{\frac{2}{\alpha}} \quad (10).$$

where $y_{\mathrm{sd}_i}, i = 1,2$ are Nakagami-m RVs with the following PDFs, respectively [7]:

$$p_{y_{\mathrm{sd}_i}}\left(y_{\mathrm{sd}_i}\right) = \frac{2}{\Gamma\left(m_{\mathrm{sd}_i}\right)} \left(\frac{m_{\mathrm{sd}_i}}{\Omega_{\mathrm{sd}_i}}\right)^{m_{\mathrm{sd}_i}} {y_{\mathrm{sd}_i}}^{2m_{\mathrm{sd}_i}-1} e^{-\frac{m_{\mathrm{sd}_i}}{\Omega_{\mathrm{sd}_i}} {y_{\mathrm{sd}_i}}^2} \quad (11).$$

where $m_{\mathrm{sd}_i}, i = 1,2$ are Nakagami-m severity parameters of the first and second RV, respectively, while $\Omega_{\mathrm{sd}_i}, i = 1,2$ are related to the average powers of $y_{\mathrm{sd}_i}, i = 1,2$, respectively. The PDF at the output of the direct V2V system, can be expressed as [7]:

$$p_{z_{\mathrm{sd}_2}}\left(z_{\mathrm{sd}_2}\right) = \int_0^{\infty} \frac{\frac{a}{2} z_{\mathrm{sd}_2}{}^{\frac{a}{2}-1}}{y_{\mathrm{sd}_2}} p_{y_{\mathrm{sd}_1}}\left(\frac{z_{\mathrm{sd}_2}{}^{\frac{a}{2}}}{y_{\mathrm{sd}_2}}\right) p_{y_{\mathrm{sd}_2}}\left(y_{\mathrm{sd}_2}\right) dy_{\mathrm{sd}_2} \quad (12).$$

The CDF $F_{z_{\mathrm{sd}_2}}\left(z_{\mathrm{sd}_2}\right)$ can be expressed by [7]:

$$F_{z_{\mathrm{sd}_2}}\left(z_{\mathrm{sd}_2}\right) = \int_0^{z_{\mathrm{sd}_2}} p_{z_{\mathrm{sd}_2}}(r) dr \quad (13).$$

The LCR $N_{z_{\mathrm{sd}_2}}$ at the output of V2V AaF dual-hop relay system can be calculated using the formula [7]:

$$N_{z_{\mathrm{sd}_2}} = \int_0^{\infty} \dot{z}_{\mathrm{sd}_2} \, p_{z_{\mathrm{sd}_2} \dot{z}_{\mathrm{sd}_2}}\left(z_{\mathrm{sd}_2} \dot{z}_{\mathrm{sd}_2}\right) \mathrm{d}\dot{z}_{\mathrm{sd}_2} \quad (14).$$

We examine the V2V over i.i.d dual-branch SC in a scenario where dual-hop RSU relaying is assisted by direct V2V link as shown in Figure 2 (straight line).

The CDF $F_{z_{\mathrm{sd}}}{}^{(II)}(z_{\mathrm{sd}})$ for the proposed V2V communications scenario can be expressed as:

$$F_{z_{\mathrm{sd}}}{}^{(II)}(z_{\mathrm{sd}}) = F_{z_{\mathrm{sd}_1}}(z_{\mathrm{sd}}) F_{z_{\mathrm{sd}_2}}(z_{\mathrm{sd}}) \quad (15).$$

The LCR $N_{z_{\mathrm{sd}}}{}^{(II)}(z_{\mathrm{th}})$ can be obtained by the following expression [7] and expressed as a function of the variable (outage) threshold z_{th}:

$$N_{z_{\mathrm{sd}}}{}^{(II)}(z_{\mathrm{th}}) = N_{z_{\mathrm{sd}_1}}(z_{\mathrm{th}}) F_{z_{\mathrm{sd}_2}}(z_{\mathrm{th}}) + N_{z_{\mathrm{sd}_2}}(z_{\mathrm{th}}) F_{z_{\mathrm{sd}_1}}(z_{\mathrm{th}}) \quad (16).$$

Finally, the AFD $AFD^{(II)}(z_{th})$ is evaluated according to [7]:

$$AFD^{(II)}(z_{th}) = \frac{F_{z_{\mathrm{sd}}}{}^{(II)}(z_{th})}{N_{z_{\mathrm{sd}}}{}^{(II)}(z_{\mathrm{th}})} \quad (17).$$

Moreover, CDF, LCR and AFD of V2I communications with RSU relay assisted by AaF dual-hop vehicle-relay on one link and direct V2I on another link, shown in Figure 2 (dashed line) can be obtained by applying (15), (16) and (17), respectively.

4. Numerical Results

This section gives some numerical evaluation of the proposed vehicular model scenarios. Table I provides a summary of analytical expressions for CDF and LCR of the scenarios presented in Figure 1 (boxed) and in the Figure 2 (boxed), respectively, which enable us directly to apply equations (7), (8) and (9), as well as (15), (16) and (17), respectively. Exact integral-form solutions, presented in Table I are then approximated by Laplace approximation formula [3, eq. A.3], to obtain the closed form LCR expressions.

Due to motion of source and destination (Figure 2 - straight line scenario), the maximal Doppler frequency of the *i-th* path can be expressed as $f_{m_i} = \sqrt{f_{ms_i}{}^2 + f_{md_i}{}^2}, i = 1, N$, as given in [3, eq. 43], where f_{ms_i} and f_{md_i} are the *i-th* path maximal Doppler frequencies of source and destination, respectively. Further, we assume that $f_m = f_{m_i}$.

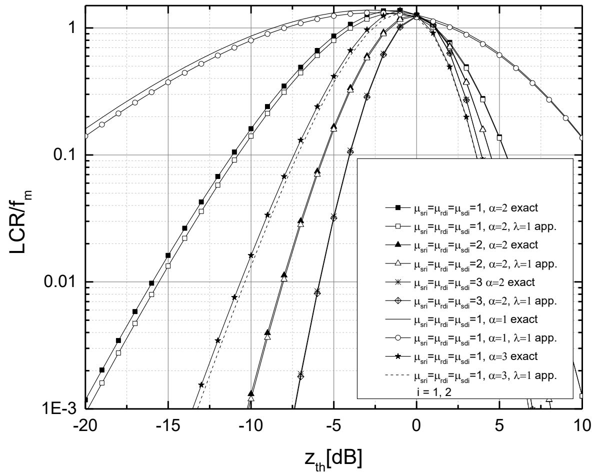

Figure 3. LCR of V2V communications over SC of dual-hop AaF RSU relay assisted by direct link.

Normalized LCR $N_{z_{\mathrm{sd}}}{}^{(II)}(z_{\mathrm{sd}})/f_m$ and AFD $AFD^{(II)}(Z_{sd}) \cdot f_m$ exact analytical expressions as well as closed form approximations for various values of fading severity parameters ($m_{\mathrm{sr}_1} = \mu_{\mathrm{sr}_1}, m_{\mathrm{sr}_2} = \mu_{\mathrm{sr}_2}, m_{\mathrm{rd}_1} = \mu_{\mathrm{rd}_1}, m_{\mathrm{rd}_2} = \mu_{\mathrm{rd}_2}$), normalized values ($\Omega_{\mathrm{sr}_1} = \Omega_{\mathrm{sr}_2} = \Omega_{\mathrm{rd}_1} = \Omega_{\mathrm{rd}_2} = 1$) as well as for various values of V2V direct link parameters ($m_{\mathrm{sd}_1} = \mu_{\mathrm{sd}_1}, m_{\mathrm{sd}_2} = \mu_{\mathrm{sd}_2}$), and normalized values ($\Omega_{\mathrm{sd}_1} = \Omega_{\mathrm{sd}_2} = 1$), are shown in Figure 3 and Figure 4, respectively. Moreover, the effect of the non-linearity parameter, α is investigated.

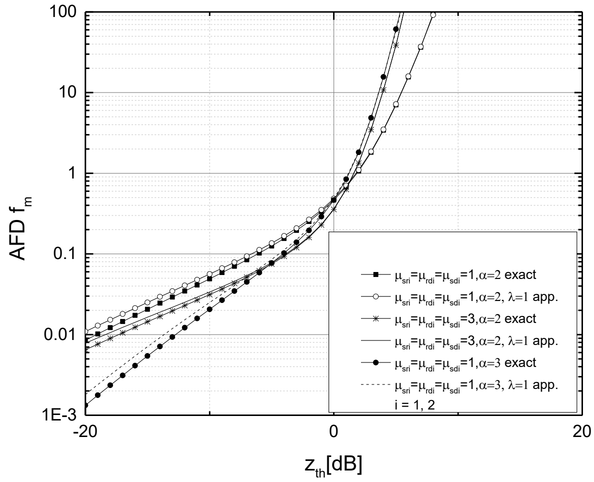

Figure 4. AFD of V2V communications over SC of dual-hop AaF RSU relay assisted by direct link.

Table I. CDF and LCR (derived using [8]) of V2V dual-hop relay link (Figure 1- boxed) and V2V direct link (Figure 2 - boxed).

CDF(I) Figure 1	$F_{z_{\mathrm{sd}_1}}(z_{\mathrm{sd}_1}) = \frac{8}{\Gamma(m_{sr_1})\Gamma(m_{sr_2})\Gamma(m_{rd_1})\Gamma(m_{rd_2})}\left(\frac{m_{sr_1}}{\Omega_{sr_1}}\right)^{m_{sr_1}}\left(\frac{m_{sr_2}}{\Omega_{sr_2}}\right)^{m_{sr_2}}\left(\frac{m_{rd_1}}{\Omega_{rd_1}}\right)^{m_{rd_1}}\left(\frac{m_{rd_2}}{\Omega_{rd_2}}\right)^{m_{rd_2}}$ $\times\int_0^\infty dy_{sr_2}\int_0^\infty dy_{rd_1}\int_0^\infty y_{sr_2}{}^{2m_{sr_2}-2m_{sr_1}-1}y_{rd_1}{}^{2m_{rd_1}-2m_{sr_1}-1}y_{rd_2}{}^{2m_{rd_2}-2m_{sr_1}-1}\,e^{-\left(\frac{m_{sr_2}}{\Omega_{sr_2}}y_{sr_2}{}^2+\frac{m_{rd_1}}{\Omega_{rd_1}}y_{rd_1}{}^2+\frac{m_{rd_2}}{\Omega_{rd_2}}y_{rd_2}{}^2\right)}$ $\times\left(\frac{\Omega_{sr_1}y_{sr_2}{}^2y_{rd_1}{}^2y_{rd_2}{}^2}{m_{sr_1}}\right)^{m_{sr_1}}\gamma\left(m_{sr_1},\frac{m_{sr_1}z_{\mathrm{sd}_1}{}^a}{\Omega_{sr_1}y_{sr_2}{}^2y_{rd_1}{}^2y_{rd_2}{}^2}\right)dy_{rd_2}$
CDF(II) Figure 2	$F_{z_{\mathrm{sd}_2}}(z_{\mathrm{sd}_2}) = \frac{(m_{\mathrm{sd}_1}-1)!}{\Gamma(m_{\mathrm{sd}_1})}$ $-\frac{2}{\Gamma(m_{\mathrm{sd}_1})\Gamma(m_{\mathrm{sd}_2})}\left(\frac{m_{\mathrm{sd}_2}}{\Omega_{\mathrm{sd}_2}}\right)^{m_{\mathrm{sd}_2}}(m_{\mathrm{sd}_1}-1)!\sum_{k=0}^{m_{\mathrm{sd}1}-1}\frac{\left(\frac{m_{\mathrm{sd}_1}z_{\mathrm{sd}_2}{}^a}{\Omega_{\mathrm{sd}_1}}\right)^k}{k!}\left(\frac{m_{\mathrm{sd}_1}\Omega_{\mathrm{sd}_2}z_{\mathrm{sd}_2}{}^a}{m_{\mathrm{sd}_2}\Omega_{\mathrm{sd}_1}}\right)^{\frac{m_{\mathrm{sd}_2}-k}{2}}K_{m_{\mathrm{sd}_2}-k}\left(2\sqrt{\frac{m_{\mathrm{sd}_1}m_{\mathrm{sd}_2}}{\Omega_{\mathrm{sd}_1}\Omega_{\mathrm{sd}_2}}z_{\mathrm{sd}_2}{}^a}\right)$
LCR(I) Figure 1	$N_{z_{\mathrm{sd}_1}}(z_{\mathrm{th}_1}) = f_m\frac{8\sqrt{2\pi}}{\Gamma(m_{sr_1})\Gamma(m_{sr_2})\Gamma(m_{rd_1})\Gamma(m_{rd_2})}\left(\frac{m_{sr_1}}{\Omega_{sr_1}}\right)^{m_{sr_1}-\frac{1}{2}}\left(\frac{m_{sr_2}}{\Omega_{sr_2}}\right)^{m_{sr_2}}\left(\frac{m_{rd_1}}{\Omega_{rd_1}}\right)^{m_{rd_1}}\left(\frac{m_{rd_2}}{\Omega_{rd_2}}\right)^{m_{rd_2}}z_{\mathrm{th}_1}{}^{\frac{\alpha}{2}(2m_{sr_1}-1)}$ $\times\int_0^\infty\int_0^\infty\int_0^\infty\sqrt{1+\frac{m_{sr_1}}{\Omega_{sr_1}}\frac{\Omega_{sr_2}}{m_{sr_2}}\frac{z_{\mathrm{th}_1}{}^\alpha}{y_{sr_2}{}^4y_{rd_1}{}^2y_{rd_2}{}^2}+\frac{m_{sr_1}}{\Omega_{sr_1}}\frac{\Omega_{rd_1}}{m_{rd_1}}\frac{z_{\mathrm{th}_1}{}^\alpha}{y_{sr_2}{}^2y_{rd_1}{}^4y_{rd_2}{}^2}+\frac{m_{sr_1}}{\Omega_{sr_1}}\frac{\Omega_{rd_2}}{m_{rd_2}}\frac{z_{\mathrm{th}_1}{}^\alpha}{y_{sr_2}{}^2y_{rd_1}{}^2y_{rd_2}{}^4}}$ $\times e^{\left(-\frac{m_{sr_1}}{\Omega_{sr_1}}\frac{z_{\mathrm{th}_1}{}^\alpha}{y_{sr_2}{}^2y_{rd_1}{}^2y_{rd_2}{}^2}-\frac{m_{sr_2}}{\Omega_{sr_2}}y_{sr_2}{}^2-\frac{m_{rd_1}}{\Omega_{rd_1}}y_{rd_1}{}^2-\frac{m_{rd_2}}{\Omega_{rd_2}}y_{rd_2}{}^2+ln y_{sr_2}{}^{2m_{sr_2}-2m_{sr_1}}+ln y_{rd_1}{}^{2m_{rd_1}-2m_{sr_1}}+ln y_{rd_2}{}^{2m_{rd_2}-2m_{sr_1}}\right)}dy_{sr_2}dy_{rd_1}dy_{rd_2}$
LCR(II) Figure 2	$N_{z_{\mathrm{sd}_2}}(z_{\mathrm{th}_2}) = f_m\frac{2\sqrt{2\pi}}{\Gamma(m_{\mathrm{sd}_1})\Gamma(m_{\mathrm{sd}_2})}\left(\frac{m_{\mathrm{sd}_1}}{\Omega_{\mathrm{sd}_1}}\right)^{m_{\mathrm{sd}_1}-\frac{1}{2}}\left(\frac{m_{\mathrm{sd}_2}}{\Omega_{\mathrm{sd}_2}}\right)^{m_{\mathrm{sd}_2}}z_{\mathrm{th}_2}{}^{\frac{\alpha}{2}(2m_{\mathrm{sd}_1}-1)}\int_0^\infty\sqrt{1+\frac{m_{\mathrm{sd}_1}}{\Omega_{\mathrm{sd}_1}}\frac{\Omega_{\mathrm{sd}_2}}{m_{\mathrm{sd}_2}}\frac{z_{\mathrm{th}_2}{}^\alpha}{y_{sd_2}{}^4}}\,e^{-\frac{m_{\mathrm{sd}_1}z_{\mathrm{th}_2}{}^\alpha}{\Omega_{\mathrm{sd}_1}y_{sd_2}{}^2}-\frac{m_{\mathrm{sd}_2}}{\Omega_{\mathrm{sd}_2}}y_{sd_2}{}^2+ln y_{sd_2}{}^{2m_{sd_2}-2m_{sd_1}}}\mathrm{d}y_{sd_2}$

5. Conclusions

This paper has proposed a model for performance evaluation of cooperative V2V dual-hop AaF vehicle-relaying over SC in NLOS general fading environments. The proposed model is extended to include V2I communications. Numerical examples are graphically presented to show that exact analytical expressions fits well with the approximations, especially in higher signal envelope dB regime. In theory, performance can be improved (in lower dB output regime) by designing the system with larger values for source-relay, relay-source and source-destination parameters.

6. Acknowledgements

The authors would like to acknowledge EUROWEB+, the IRACON COST Action 15104 and the EU ECSEL SAFECOP project.

7. References

1. P. S. Bithas, A. G. Kanatas, D. B. da Costa, P. K. Upadhyay, U. S. Dias, “On the double-generalized gamma statistics and their application to the performance analysis of V2V communications”, *IEEE Transactions on Communications*, vol. 66, no. 1, pp. 448-460, Jan. 2018.

2. E. Vinogradov, W. Joseph, C. Oestges, “Measurement-based modeling of time-variant fading statistics in indoor peer-to-peer scenarios”, *IEEE Transactions on Antennas and Propagation*, vol *63, no.* 5, pp. 2252-2263, May 2015.

3. Z. Hadzi-Velkov, N. Zlatanov, G. K. Karagiannidis, “On the second order statistics of the multihop rayleigh fading channel,” *IEEE Transactions on Communications*, vol. 57, no. 6, pp 1815 – 1823, June 2009.

4. B. Talha, M. Pätzold, “Channel models for mobile-to-mobile cooperative communication systems: A state of the art review”, *IEEE Vehicular Technology Magazine*, vol. *6, no.* 2, pp. 33-43, 2011.

5. M. Renzo, F. Graziosi, F. Santucci "A comprehensive framework for performance analysis of dual-hop cooperative wireless systems with fixed-gain relays over generalized fading channels." *IEEE Transactions on Wireless Communications,* vol. 8, no. 10, 2009.

6. M. D. Yacoub, “The α-μ distribution: A Physical Fading Model for the Stacy Distribution”, *IEEE Transactions on Vehicular Technology*, vol. 56, no. 1, pp. 27–34, Jan. 2007.

7. M. K. Simon and M.-S. Alouini, *Digital Communication over Fading Channels*, Wiley, New York, NY, USA, 1st edition, 2000.

8. I. S. Gradshteyn, I. M. Ryzhik, *Table of Integrals, Series, and Products*, 6th ed., New York: Academic, 2000.