Performance Analysis of D2D Communication System Over η-μ Fading Channel

Zakir Hussain*, Asim ur Rehman Khan, Haider Mehdi and Aamir Ali

National University of Computer and Emerging Sciences, Karachi, Pakistan

Summary
In this paper, performance of a device-to-device (D2D) communication system in an interference limited scenario is analyzed. Channel for the D2D communication is assumed to be η-μ distributed. Co-channel interference (CCI) in the system is caused by the devices that have lost proper co-ordination with the D2D system. Nakagami distribution is considered for the CCI signals. Expression for probability density function (PDF) of signal-to-interference (SIR) of the D2D system is presented. Using this PDF expression, outage probability and success probability performances under various conditions of channel fading, path-loss and interference with selection combining (SC) diversity scheme are numerically analyzed.

Key words:
Co-channel interference, device-to-device communication, η-μ distribution, signal-to-interference ratio, outage probability.

1. Introduction

Device-to-device (D2D) communication, enable communication over direct links between users in proximity, is envisioned as a promising technology to improve performance of cellular communication networks. D2D communication offloads the base-station (BS) [1-3]. In D2D communication system, the communicating devices can be at any distance. Therefore, it is important to consider the spatial randomness of the D2D communication [4]. In the absence of proper co-ordination between various wireless communication devices, co-channel interference (CCI) can cause problems in the D2D system. Hence, CCI effects should also be taken into consideration while analysing D2D communication system [5-6]. Outage probability and success probability are important performance metrics for the analysis of D2D systems. Authors in [7], have studied outage probability of D2D communication system using the shortest path routing algorithm. A Rayleigh faded D2D and CCI channel is considered for the analysis. A resource allocation scheme is proposed and studied by authors in [8] for D2D cluster multicast communication systems. Success probability performance of D2D systems using statistical-feature-based power control algorithm over a Rayleigh faded channel is studied in [9].

The aim of this paper is to study and investigate outage probability and success probability performance of a D2D communication system under selection combining (SC) diversity scheme. The system considered for analysis in this paper is interference limited. The sources of co-channel interference (CCI) signals are assumed to be wireless devices which have lost co-ordination with the D2D system. The D2D devices are considered to be at random distance. The fading model for D2D communication signal is assumed to be η-μ distributed. The η-μ distribution is a flexible and generalized fading model that includes fading distribution like, Nakagami and Hoyt as special cases [10]. Nakagami distribution is used for the modelling of CCI channels. Nakagami is a well-known distribution often used for modelling fading channels. Selection combining (SC) based diversity scheme is incorporated to mitigate the effects of fading. The rest of paper is organized as follows. Section 2 presents the system model and the expressions. In Section 3, numerical analysis is presented. Finally, this paper is concluded in Section 4.

2. System Model

A device-to-device (D2D) communication pair in an interference limited scenario is considered. Spatial randomness is considered for the D2D channel. Fig. 1 shows the layout of the D2D system. As shown in the figure, there are N number of co-channel interferers in the system. The channel for D2D communication system is assumed to be η-μ distributed. The probability density function (PDF) of the η-μ distribution [11]

$$f_Z(z) = \frac{4\sqrt{\pi}\mu^{\mu+\frac{1}{2}}h^{\mu}}{\Gamma(\mu)H^{\mu-\frac{1}{2}}}\left(\frac{z}{\phi}\right)^{2\mu}\exp\left(\frac{-2\mu h z^2}{\phi^2}\right)\times I_{\mu-\frac{1}{2}}\left(\frac{2\mu H z^2}{\phi^2}\right) \quad (1)$$

where $0<\eta<\infty$ is the ratio of powers of in-phase and quadrature components of scattered signal in each multipath cluster and μ describes the number of multipath clusters [11]. η and μ jointly controls the fading. ϕ is the average power. The parameters $H=\frac{\eta^{-1}-\eta}{4}$ and $h=\frac{2+\eta^{-1}+\eta}{4}$. $I(.)$ is the modified Bessel function of first kind [12]. To

Manuscript received October 5, 2019
Manuscript revised October 20, 2019

include the effects of path-loss, a simplified path-loss model is considered [13]. For mathematical tractability, the co-channel interferers are assumed to have equal powers and are assumed to be equidistant from the receiver of the D2D pair. The co-channel interferers are considered to be independent and identically distributed. The interference channel is assumed to be Nakagami distributed. The PDF of the Nakagami distribution is [14]

$$f_w(w) = \frac{2m^m w^{2m-1}}{\Omega^m \, \Gamma(m)} e^{\left(-\frac{m w^2}{\Omega}\right)} \tag{2}$$

In above expression, m is the shape parameter of the fading distribution. Shape parameter m describes the severity of the fading channel. Ω is the average power. Selection combining (SC) diversity is incorporated in the D2D system to mitigate the effects of fading channel. In a D2D communication system, the receiver device can be uniformly positioned within a circular region of radius X_D with reference to the transmitter device. Therefore, the distribution of the channel distance between D2D pair can be expressed as

$$f_X(x) = \frac{2x}{X_D} \qquad 0 < x < X_D \tag{3}$$

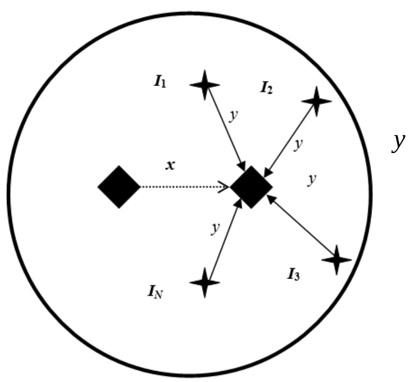
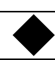
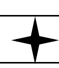
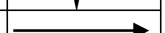


Fig. 1 System Layout

Table 1: Nomenclature

A D2D device	
Desired D2D Signal	
The random distance between D2D devices	***x***
i-th Co-channel Interferer	
Co-channel Interference Signal	
Distance between i-th Co-channel Interferer and the D2D Receiver	***y***

The expression for the SIR at the output of L branches SC diversity scheme is

$$\gamma_\ell = \frac{\alpha_\ell^{\,2}}{g \sum_{i=1}^{N} \beta_i^2}, \qquad g = \frac{P_2}{P_1}\left(\frac{x^u}{y^v}\right)\frac{(x_0)^{2-u}}{(y_0)^{2-v}} \tag{4}$$

In (3), α_ℓ is the independent η-μ fading variable of $\ell-th$ diversity branch signal, P_1 is the power of the $\ell-th$ diversity branch of D2D signal, u $(2 \le u \le 5)$ is the path-loss exponent of the $\ell-th$ diversity branch of D2D signal. The random spatial distance between D2D pair is denoted by x and x_0 $(1 \le x_0 \le 100 \text{ meters})$ is the reference distance. β_i is the independent Nakagami random variable for i-th interferer, P_2 is the power of the i-th interferer signal, v is the path-loss exponent, y is the distance between i-th interferer and the receiver of the D2D pair and y_0 is the reference distance. The PDF expression of SIR, i.e., γ_ℓ of the $\ell-th$ diversity branch D2D communication system is

$$f_{\gamma_\ell}(r) = \int_0^\infty \left[k \, \frac{2(\pi)^{\frac{1}{2}} \mu_\ell^{\mu_\ell+\frac{1}{2}} h_\ell^{\mu_\ell} (rk)^{\mu_\ell-\frac{1}{2}}}{\Gamma(\mu_\ell)\phi_\ell^{3\mu_\ell}} e^{-\frac{2\mu_\ell h_\ell}{\phi_\ell^2}(rk)} \right.$$
$$\left. I_{\mu_\ell-\frac{1}{2}}\left(\frac{2\mu_\ell H_\ell}{\phi_\ell^2}\,(rk)\right) \frac{\varphi^{m_T} k^{m_T-1}}{\Gamma(m_T)} \exp(-\varphi\, k)dk \right],$$

$$f_{\gamma_\ell}(r) = \rho_\ell r^{2\mu_\ell-1}\left(\frac{2\mu_\ell h_\ell r}{\phi_\ell^{\,2}} + \varphi\right)^{-2\mu_\ell-m_T} \times$$
$$G_{3,3}^{1,2}\left[\left(\frac{2\mu_\ell H_\ell r}{\phi_\ell^{\,2}(2\mu_\ell h_\ell r + \varphi)}\right)^2 \middle| \begin{matrix} \mathbf{\Delta}_\ell \\ \Psi_\ell \end{matrix}\right] \tag{5}$$

where $\rho_\ell = \frac{\pi \, 2^{2\mu_\ell+m_T} \mu_\ell^{\,2\mu_\ell} h_\ell^{\,\mu_\ell} \varphi^{m_T}}{\Gamma(\mu_\ell)\Gamma(m_T)\phi^{3\mu_\ell}}$, $\Psi_\ell = 0, -\mu_\ell + \frac{1}{2}, \frac{1}{2}$ and $\mathbf{\Delta}_\ell = \frac{1-m_T-2\mu_\ell}{2}, \frac{2-m_T-2\mu_\ell}{2}, \frac{1}{2}$. Also, $m_T = Nm$ and $\varphi = \sigma/g$ where $\sigma = m/\Omega$. The outage probability for independent but non-identically distributed α_ℓ is

$$P_{out,SC} = \Pr\left(\max[\gamma_1, \gamma_2, \cdots, \gamma_L] \le R\right) \tag{6}$$

where Pr (.) means probability and R is the outage threshold. Hence, the $P_{out,SC}$ can be written as

$$P_{out,SC} = \prod_{\ell=1}^{L}\left[\int_0^{X_D}\left[\rho_\ell \int_0^R r^{2\mu_\ell-1}\left(\frac{2\mu_\ell h_\ell r}{\phi_\ell^{\,2}} + \varphi\right)^{-2\mu_\ell-m_T}\right.\right.$$
$$\left.\left. \times G_{3,3}^{1,2}\left[\left(\frac{2\mu_\ell H_\ell r}{\phi_\ell^{\,2}(2\mu_\ell h_\ell r + \varphi)}\right)^2 \middle| \begin{matrix} \mathbf{\Delta}_\ell \\ \Psi_\ell \end{matrix}\right] dr\right] dx\right] \tag{7}$$

Success probability expression for SC diversity based D2D communication system for independent but non-identically distributed α_ℓ is

$$P_{S,SC} = 1 - \prod_{\ell=1}^{L}\left[\int_0^{X_D}\left[\rho_\ell \int_0^{R} r^{2\mu_\ell - 1}\left(\frac{2\mu_\ell h_\ell r}{\phi_\ell^2} + \varphi\right)^{-2\mu_\ell - m_T}\right.\right. \tag{8}$$

$$\left.\left.\times G_{3,3}^{1,2}\left[\left(\frac{2\mu_\ell H_\ell r}{\phi_\ell^2\left(2\mu_\ell h_\ell r + \varphi\right)}\right)^2 \middle| \begin{matrix}\Delta_\ell \\ \Psi_\ell\end{matrix}\right] dr\right] dx\right]$$

3. Numerical Results and Analysis

In this section, numerical results obtained from the expressions in Section 2 are discussed for various parameters of D2D and co-channel interference (CCI) signals. For the purpose of analysis, the reference distances of D2D signal x_0 and CCI signal y_0 are considered to be 1 meter. The value of X_D is assumed to be 100 meters [4]. Outage probability performance of D2D system for various number of diversity branches L and the outage threshold R is shown in Fig. 2. The values of D2D signal power P_1, the path-loss exponent u, the fading parameters η_ℓ and μ_ℓ are assumed to have same values for all number of branches. The values P_1, u, η_ℓ and μ_ℓ are 20 dBm, 3, 2 and 1 respectively. The values of CCI signal power P_2, the path-loss exponent of the CCI channel v, the fading parameter of the CCI m, number of CCI signals N and the distance between the receiver of the D2D pair and each co-channel interferer y are set to be 10 dBm, 2.8, 2, 5 and 60 meters, respectively. From the figure, it is observed that the outage performance is better for the higher number of diversity branches of the desired D2D signal. Moreover, from the figure it is also observed that the diversity gain is 6.83 dBm for the outage probability of 10^{-3}.

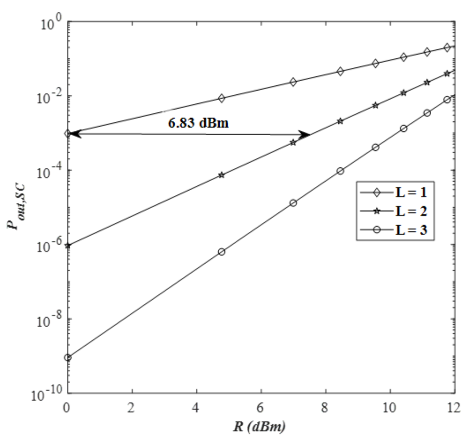


Fig. 2 Outage performance with varying values of R

In Fig. 3, outage probability performance of D2D communication for the various values of distance X_D is shown. The values of P_1, P_2, η_ℓ, μ_ℓ, u, m, y, N and R are considered to 20 dBm, 10 dBm, 3, 1, 3, 2, 40 meters, 5 and 10 dBm, respectively. From the figure, it is observed that the outage performance is better for the lower values of distance X_D. Moreover, from the figure it is seen that the outage performance of the system improves as the path-loss exponent of CCI signal is increased. It is because of the improved SIR condition of the system due to weakening of CCI signals. In Fig. 4, outage probability performance of D2D communication for the various values of CCI shape parameter m is shown. The values of P_2, η_ℓ, μ_ℓ, u, v, y, N and R are considered to 10 dBm, {1, 1.5, 2}, {1, 2, 3}, 3, 2.8, 55 meters, 5 and 10 dBm, respectively. From the figure, it is observed that the outage performance is worse for the lower values of CCI fading parameter m. However, for the higher values of m outage performance is almost insensitive to the variations of m. Moreover, from the figure it is seen that the outage performance of the system improves as the power of the D2D signal P_1 is increased. It is because of the improved SIR condition of the system.

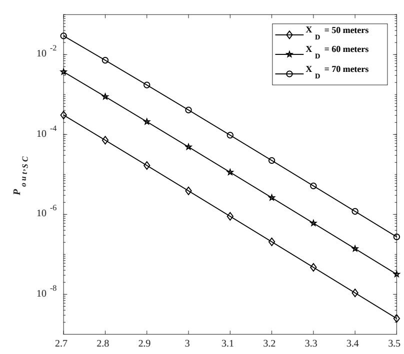


Fig. 3 Outage performance with varying values of X_D

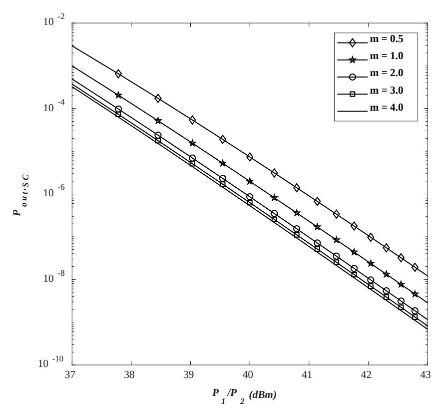


Fig. 4. Outage performance for the various values of m

Fig. 5 shows the outage performance with varying values D2D signal fading parameter μ_ℓ. The values for parameters P_1, P_2, η_ℓ, m, u, v, N and R are considered to be 20 dBm, 10 dBm, {1, 1.5, 2}, 4, 3, 2.8, 5 and 10 dBm, respectively. From the figure, it is can be observed that the outage performance is better for higher values of μ_ℓ. It is due to the improved fading conditions of the D2D signal. Furthermore, an improvement in outage performance is also observed with increasing values of y. It is because of the path-loss effects. Outage performance of D2D system with varying values CCI path-loss exponent v is shown in Fig. 6. The values for parameters P_1, P_2, η_ℓ, μ_ℓ, m, u, y and R are assumed to be 20 dBm, 10 dBm, 1, 1, 2, 3, 90 meters and 10 dBm, respectively. From the figure, it is observed that the outage performance is better for higher values of v. It is because of weakening of CCI signals due to path-loss effects which improves the overall outage performance of the system. Also, deterioration in the outage performance is observed with an increase in the number of CCI interferers.

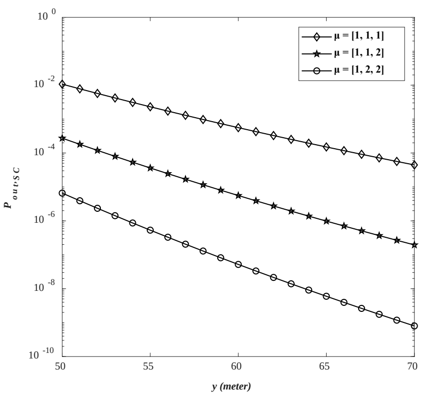


Fig. 5. Outage performance with various values of μ_ℓ

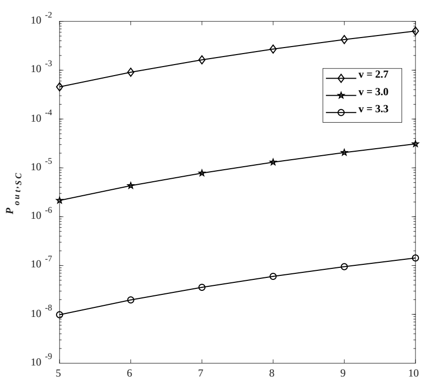


Fig. 6. Outage performance for various values of v

Success probability performance of D2D communication system with varying values D2D signal fading parameter η_ℓ is shown in Fig. 7. The values of parameters P_2, μ_ℓ, m, u, v, N, y and R are assumed to be 10 dBm, {1, 2}, 2, 3, 2.5, 5, 70 meters and 10 dBm, respectively. From the figure, it is observed that the success probability performance is better for lower values of D2D signal fading parameter η_ℓ. Moreover, improved success probability performance is witnessed with the increase in power of desired D2D signal P_1.

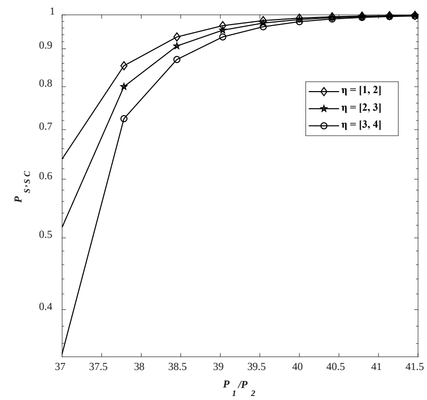


Fig. 7. Success probability performance with varying values of η_ℓ

4. Conclusion

D2D communication system performance over a η-μ faded channel with spatial randomness is analyzed. Effects of co-channel interference (CCI) on performance of D2D system are also considered. PDF expression of the SIR of D2D system is presented in terms of various channel fading parameters, path-loss and interference conditions. Based on the expression of PDF, outage probability and success probability performances are presented and numerically analyzed. From the analysis, it is observed that various fading conditions of the interference have insignificant effect on the performance of D2D system. Moreover, it is noticed that the increase in value of path-loss exponent of CCI signal improves the performance of the D2D system. Furthermore, it is also observed that the selection combining (SC) diversity technique improves performance of the D2D system.

References

[1] H. H. Esmat, M. M. Elmesalawy and I. I. Ibrahim, "Adaptive Resource Sharing Algorithm for Device-to-Device Communications Underlaying Cellular Networks," in IEEE Communications Letters, vol. 20, no. 3, pp. 530-533, March 2016.

[2] J. Wang, Y. Huang, S. Jin, R. Schober, X. You and C. Zhao, "Resource Management for Device-to-Device Communication: A Physical Layer Security Perspective," in IEEE Journal on Selected Areas in Communications, vol. 36, no. 4, pp. 946-960, April 2018.

[3] M. Haus, M. Waqas, A. Y. Ding, Y. Li, S. Tarkoma and J. Ott, "Security and Privacy in Device-to-Device (D2D) Communication: A Review," in IEEE Communications Surveys & Tutorials, vol. 19, no. 2, pp. 1054-1079, Secondquarter 2017.

[4] S. Kusaladharma and C. Tellambura, "Performance characterization of spatially random energy harvesting underlay D2D networks with primary user power control," 2017 IEEE International Conference on Communications (ICC), Paris, 2017, pp. 1-7.

[5] Y. J. Chun, S. L. Cotton, H. S. Dhillon, A. Ghrayeb and M. O. Hasna, "A Stochastic Geometric Analysis of Device-to-Device Communications Operating Over Generalized Fading Channels," in IEEE Transactions on Wireless Communications, vol. 16, no. 7, pp. 4151-4165, July 2017.

[6] K. Yang, S. Martin, C. Xing, J. Wu and R. Fan, "Energy-Efficient Power Control for Device-to-Device Communications," in IEEE Journal on Selected Areas in Communications, vol. 34, no. 12, pp. 3208-3220, Dec. 2016.

[7] S. Wang, W. Guo, Z. Zhou, Y. Wu and X. Chu, "Outage Probability for Multi-Hop D2D Communications With Shortest Path Routing," in IEEE Communications Letters, vol. 19, no. 11, pp. 1997-2000, Nov. 2015.

[8] J. Kim, J. Joung and J. W. Lee, "Resource Allocation for Multiple Device-to-Device Cluster Multicast Communications Underlay Cellular Networks," in IEEE Communications Letters, vol. 22, no. 2, pp. 412-415, Feb. 2018.

[9] P. Sun, K. G. Shin, H. Zhang and L. He, "Transmit Power Control for D2D-Underlaid Cellular Networks Based on Statistical Features," in IEEE Transactions on Vehicular Technology, vol. 66, no. 5, pp. 4110-4119, May 2017.

[10] D. B. Da Costa, J. C. Silveira Santos Filho, M. D. Yacoub and G. Fraidenraich, "Second-Order Statistics of η-μ Fading Channels: Theory and Applications," in IEEE Transactions on Wireless Communications, vol. 7, no. 3, pp. 819-824, March 2008.

[11] M. D. Yacoub, "The κ-μ distribution and the η-μ distribution," in IEEE Antennas and Propagation Magazine, vol. 49, no. 1, pp. 68-81, Feb. 2007.

[12] I.S. Gradshteyn and I.M. Ryzhik, Table of integrals, series, and products, Academic press, 2014.

[13] S. T. Rappaport, Wireless communications: principles and practice, Vol. 2. New Jersey: prentice hall PTR, 1996.

[14] Z. Hussain , A. R. Khan, H. Mehdi ,and S. M. A. Saleem, "Analysis of Device-to-Device Communication over Double-Generalized Gamma Channels ", Engineering, Technology & Applied Science Research, vol. 8, no. 4, pp. 3265-3269, 2018.

Zakir Hussain received M.S. degree in Electrical Engineering from National University of Computer and Emerging Sciences (NUCES), Karachi Campus in 2017. Research areas includes Device-to-Device communication, interference analysis in wireless communication systems, digital communication systems, signal processing.

Asim ur Rehman Khan received BSc degree in Electrical Engineering (EE) from UET Lahore, Pakistan in 1981, MS EE from South Dakota State University, South Dakota, USA in 1987, and PhD EE from Polytechnic University (now NYU) in Brooklyn, New York, USA in 1993. His main area of research is AI, Computer Vision, and Pattern Recognition. He has worked in various telecom projects in Pakistan. Since 2002, he is Professor of Electrical Engineering at the Karachi campus of National University of Computer & Emerging Sciences (NUCES), Pakistan.

Haider Mehdi research interests include Device-to-Device communication, interference analysis in wireless communication systems, digital communication systems, digital signal processing, and signal-processing techniques for the communication systems.

Aamir Ali received the B.S. and M.S. degrees in Electrical Engineering from National University of Computer and Emerging Sciences in 2015 and 2019, respectively. He has been associated with the faculty of Electrical Engineering Department at National University of Computer and Emerging Sciences since Jan 2016. He has been author of many research papers. His research interest include Robotics and Telecommunication.