D2D Communications over κ - μ Shadowed Fading Channels

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Summary
In this paper, performance of device-to-device (D2D) communication system over a κ-μ shadowed fading channel with spatial randomness, is analyzed. The D2D communication system is considered to be affected by various co-channel interferers in the system. The co-channel interference (CCI) is caused by the wireless devices in the system with which proper coordination is lost. The distribution for the CCI signals is assumed to be Nakagami. Expression for the probability density function (PDF) of the signal-to-interference ratio (SIR) of the D2D communication system is presented. Based on this PDF expression, effects of fading channels parameters, path-loss and interference conditions on the outage probability, success probability, outage capacity and symbol error rate (SER) are numerically analyzed.

Key words:
Co-channel interference, device-to-device, κ-μ shadowed fading, signal-to-interference ratio.

1. Introduction

Device-to-Device (D2D) communication system is characterized as a promising solution for the ever-increasing demand of high data rate applications. D2D communication system, a standard of 5th generation (5G) cellular communication system, is defined as the direct routing of information between active devices in a proximity without using the conventional cellular infrastructure. D2D communication system not only solves the problem of high data rate but also reduces load on base station (BS) and conserves battery power of the communicating devices [1-3]. In a network the D2D receiver can be at any distance from the D2D transmitter device, therefore spatial randomness of D2D channel is a matter of concern [4-5]. The frequency band for the wireless cellular communication is limited and a large number of bandwidth hungry devices compete for these resources. Lack of coordination between these wireless devices can cause co-channel interference (CCI), which degrades the performance of communication systems [6-8]. Therefore, effects of CCI should be considered while analyzing the performance of D2D communication systems. Outage probability, success probability, outage capacity, and symbol error rate (SER) performances are effective tools for analyzing CCI effects on the performance of D2D communication systems. Authors in [9], analyzed the outage probability of D2D system in a finite cellular network region over Nakagami fading channel with Rayleigh faded interference. In [10], authors examined the outage probability performance of D2D communication system with shortest path routing over Rayleigh fading channel. Performance of D2D communication system over Rician fading channel is studied by authors in [11].
The aim of this paper is to analyze outage probability, success probability, outage capacity and symbol error rate (SER) performances of spatially random D2D communication system in an interference limited scenario. The interference signals are assumed to originate from any wireless device in the system with which proper coordination is either lost or temporarily interrupted. The channel for the D2D communication is considered to be κ-μ shadowed distributed. The κ-μ shadowed distribution is a generalized distribution as it includes Rayleigh, Nakagami, Rician, κ-μ, one-side Gaussian and Rician shadowed fading distributions as special cases [12]. The channel for the CCI is assumed to be Nakagami distributed. The Nakagami is another versatile distribution frequently used in the research works to model various channels. The rest of this paper is organized as follows. In Section 2, system model is discussed and expressions of the probability density function (PDF) of the signal-to-interference ratio (SIR) of the system, outage probability, success probability, outage capacity and SER are presented. In Section 3, numerical results of the D2D communication are discussed. Finally, Section 4 concludes this paper.

2. System Model

A pair of device-to-device (D2D) communication system is considered with N co-channel interferers. An interference limited system is considered. System model is shown in Fig. 1. The power of the channel gain for the D2D communication signal is assumed to be κ-μ shadowed distributed. The probability density function (PDF) of shadowed distribution is [13]

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$$f_W(w)=\frac{\mu^{\mu}\delta^{\delta}(1+\kappa)^{\mu}w^{\mu-1}e^{-\frac{\mu(1+\kappa)w}{\Omega}}}{\Gamma(\mu)(\Omega)^{\mu}(\mu\kappa+\delta)^{\delta}}\times {}_1F_1\left(\delta,\mu,\frac{\mu^2\kappa(1+\kappa)w}{(\mu\kappa+\delta)\Omega}\right)$$

where 1F1 is confluent hypergeometric function [14]. The signal considered for the κ-μ shadowed fading is comprised of clusters of multipath signals. A dominant component that exist in each cluster can randomly fluctuate due to the shadowing phenomena. μ represents number of clusters, κ is the ratio of the total power of the dominant components and the total power of the scattered components, δ is the shadowing parameter and Ω is related to the average power. The channel gains for the interferer signals are considered to be Nakagami distributed. To keep the analysis mathematically tractable, following assumptions are considered: 1) All co-channel interferers' distances from the D2D pair's receiver is approximately same; 2) All co-channel interferers are assumed to be independent and identically distributed (IID).

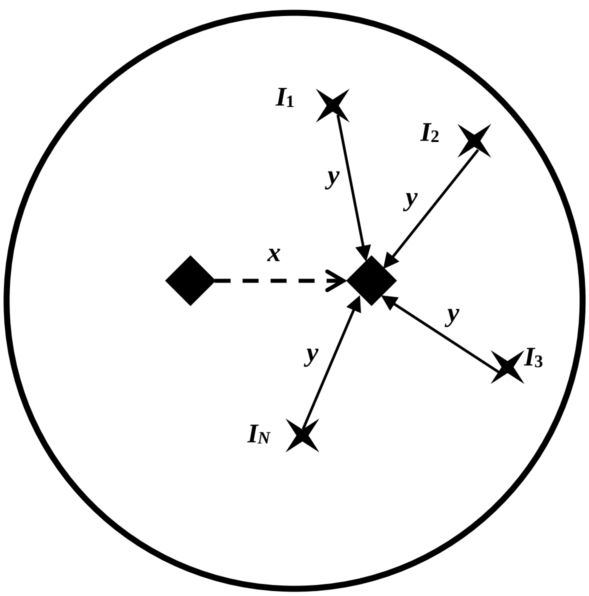

Fig. 1 D2D Communication System Model

A D2D device

Desired D2D Signal

Distance between D2D devices — *x*

i^{th} Co-channel Interferer

Co-channel Interference Signal

Distance between the i^{th} Co-channel Interferer and the D2D Receiver — *y*

The PDF of Nakagami distribution is [15]

$$f_L(l)=\frac{2m^m l^{2m-1}}{\varphi^m\,\Gamma(m)}e^{\left(-\frac{m\,l^2}{\varphi}\right)} \quad (1)$$

where m is the shape parameter which describes the severity of the fading channel and φ is the average power. In a network D2D with reference to transmitter, the receiver can be uniformly located within a circular region of radius xl. Therefore, the distribution of the channel distance between D2D pair x can be expressed as [16]

$$f_X(x)=\frac{2x}{x_l} \qquad 0 < x < x_l \quad (2)$$

The D2D communication system is affected by path-loss effects. A simplified path-loss model is considered here. The power of the received signal at the receiver of D2D pair is given as

$$S_d = P_D\left(\frac{\lambda}{4\pi x_0}\right)^2\left(\frac{x_0}{x}\right)^u \quad (3)$$

where PD is the power of D2D signal, x is the distance between D2D pair devices, λ is the wavelength and u is the path-loss exponent, x0 is the reference distance. The power of the i-th interferer at the receiver of D2D pair is

$$I = P_I\left(\frac{\lambda}{4\pi y_0}\right)^2\left(\frac{y_0}{y}\right)^v \quad (4)$$

where P_I is the power of interference signal, y is the distance between the i-th interferer and the receiver of the D2D pair, v is the path-loss exponent and y_0 is the reference distance. The SIR of the D2D system is

$$\gamma=\frac{\alpha}{g\sum_{i=1}^{N}\beta_i^2}, \qquad g=\frac{P_I}{P_D}\left(\frac{x^u}{y^v}\right)\frac{(x_0)^{2-u}}{(y_0)^{2-v}} \quad (5)$$

where α is the $\kappa-\mu$ shadowed fading variable for the D2D signal and β_i is the Nakagami fading variable of *i-th* interference signal. Using the identity, $f_\gamma(r)=\int_0^\infty x\, f_S(rx)\, f_I(x)\, dx$, the PDF expression of the SIR, γ, is given in Eq. 6. In Eq. 6, $\boldsymbol{\Delta}=\left(\frac{\mu(1+\kappa)}{\Omega}\right)^{\mu}\left(\frac{\delta}{\mu\kappa+\delta}\right)^{\delta}\left(\frac{\pi\sigma^{m_T}}{\Gamma(\delta)\Gamma(m_T)}\right)$,

$\Phi = \frac{\mu(1+\kappa)}{\Omega}$, $\Psi = \frac{\mu(\mu\kappa+\delta)}{\mu\kappa}$, $\varsigma = \frac{\sigma(\mu\kappa+\delta)}{\mu^2\kappa(1+\kappa)}$ and $m_T = Nm$. Moreover, $\sigma = \rho/g$ where $\rho = m/\varphi$. The outage probability is the probability that the SIR of system falls below a predefined threshold R.

$$f_\gamma(r) = \int_0^\infty \left[z \underbrace{\frac{\mu^\mu \delta^\delta (1+\kappa)^\mu (rz)^{\mu-1}}{\Gamma(\mu)(\Omega)^\mu (\mu\kappa+\delta)^\delta} e^{-\frac{\mu(1+\kappa)(rz)}{\Omega}} {}_1F_1\left(\delta, \mu, \frac{\mu^2\kappa(1+\kappa)(rz)}{(\mu\kappa+\delta)\Omega}\right)}_{f_S(rz)} \underbrace{\frac{\sigma^{m_T} z^{m_T-1}}{\Gamma(m_T)} \exp(-\sigma z)}_{f_I(z)} dz \right],$$

$$f_\gamma(r) = r^{\mu-1}\boldsymbol{\Delta}(\Phi\, r+\sigma)^{-(\mu+m_T)} G_{3,3}^{2,1}\left[\Psi + \frac{\varsigma}{r}\middle| \begin{matrix} 1, \mu, 0.5 \\ \mu+m_T, \delta, 0.5 \end{matrix}\right] \tag{6}$$

Hence, the outage probability of the D2D system is given as [17]

$$P_{out} = \int_0^{x_l}\left[\int_0^R f_\gamma(r)\ dr\right] dx \tag{7}$$

The success probability is also an important performance metric and is defined as the probability that the SIR of the system increases above a threshold R [18]. Success probability, i.e., PS of the D2D communication system is

$$P_s = 1 - \int_0^{x_l}\left[\int_0^R f_\gamma(r)\ dr\right] dx \tag{8}$$

Outage capacity is defined as the probability that instantaneous channel capacity C_γ, of a communication system drops down below a fixed channel capacity threshold Cth. To get an expression for outage capacity, at first the expression for PDF i.e. $f_{C_\gamma}(c_\gamma)$ is given as,

$$f_{C_\gamma}(c_\gamma) = 2^{c_\gamma}\ln(2)\left(2^{c_\gamma}-1\right)^{\mu-1}\boldsymbol{\Delta}\left(\Phi\left(2^{c_\gamma}-1\right)+\sigma\right)^{-(\mu+m_T)} \times G_{3,3}^{2,1}\left[\Psi + \frac{\varsigma}{2^{c_\gamma}-1}\middle| \begin{matrix} 1, \mu, 0.5 \\ \mu+m_T, \delta, 0.5 \end{matrix}\right] \tag{9}$$

Therefore, outage capacity of D2D communication system is

$$C_{out} = \int_0^{x_l}\left[\int_0^{C_{th}} f_{C_\gamma}(c_\gamma) dc_\gamma\right] \tag{10}$$

An analytical expression for the symbol error rate (SER) performance of M-ray Phase shift keying (M-PSK) modulated D2D communication system is given in Eq. 11.

$$P_{PSK} = \frac{1}{\pi}\int_0^{x_l}\left[\int_0^{\frac{(M-1)\pi}{M}}\left[\int_0^\infty f_\gamma(r)\exp\left(-\frac{\left(\sin\frac{\pi}{M}\right)^2 r}{(\sin\theta)^2}\right) dr\right] d\theta\right] dx \tag{11}$$

Where M is the order of modulation. The analytical expression for the SER performance D2D communication system incorporated square M-ray quadrature amplitude modulation (M-QAM) scheme is

$$P_{MQAM} = \frac{4\left(\sqrt{M}-1\right)}{\pi\sqrt{M}}\left[\int_0^{x_l}\left[\int_0^{\frac{\pi}{2}}\left[\int_0^\infty \exp\left(-\frac{\frac{3r}{\sin^2(\theta)}}{2(M-1)}\right) f_\gamma(r) dr\right] d\theta\right] dx\right] - \frac{\left(\sqrt{M}-1\right)}{\sqrt{M}}\left[\int_0^{x_l}\left[\int_0^{\frac{\pi}{4}}\left[\int_0^\infty \exp\left(-\frac{\frac{3r}{\sin^2(\theta)}}{2(M-1)}\right) f_\gamma(r) dr\right] d\theta\right] dx\right] \tag{12}$$

3. Numerical Results and Analysis

In this Section, numerical results are presented to analyze the effects of channel fading and interference on the outage, success probability, outage capacity and symbol error rate (SER) performances of D2D communication system. For the simplicity of numerical analysis, x_0 and y_0 are assumed to be 1 meters. The outage threshold R are assumed to be 10 dBm, respectively. The value of x_l is assumed to be 100 meters [16]. Outage performance of D2D system for various values of shadowing parameter and the distance between D2D receiver and co-channel interference (CCI) sources y is shown in Fig. 2. The values for D2D signal power P_D, path-loss exponent u, fading parameters κ and μ are considered to be 20 dBm, 2.7, 2.5 and 2, respectively. The values of power of the interferer P_I, interference path-loss exponent v, interference fading parameter m and number of interferers N are assumed to be 10 dBm, 3.3, 3 and 5, respectively. From the figure it can be seen that the outage performance of the system is worse for the lower values of the shadowing parameter δ. It is because shadowing effects are severe for the lower values of δ and as the values of δ are increased, the severity of shadowing decreases and hence, the outage performance of the system improves. Moreover, for the same values of δ, outage performance of D2D system improves as the values of the distance y increases. It is because of the path-loss effects of the CCI channels.

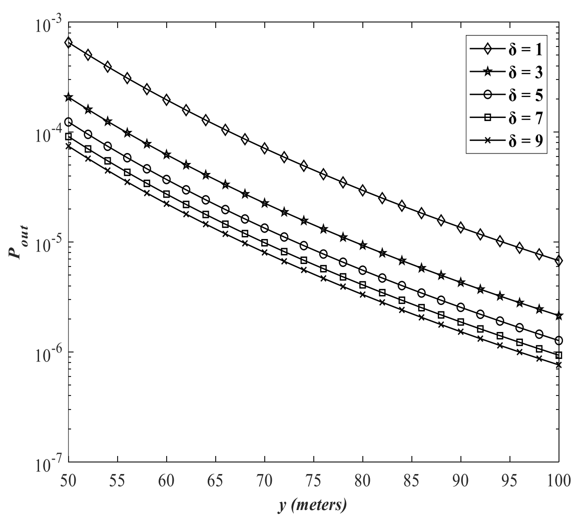

Fig. 2 Outage performance with varying values of the shadowing parameter

Fig. 3 shows outage performance with various values of δ and v. The values for PD, PI, κ, m, y, u and N are set to be 20 dBm, 10 dBm, 2.5, 3, 70 meters, 2.5 and 5, respectively. It can be observed from the figure that as the value of δ increases the outage performance of the D2D communication system improves. Increase in value of δ shows improvement in shadowing condition. An improvement in outage performance is also clear with an increase in the value of v. This is due to severe path-loss conditions of CCI channel. In Fig. 4 the success probability performance for various values of interference fading shape parameter m and the distance y is shown. The values of PD, PI, u, v, δ, μ, κ and N are assumed to be 20 dBm, 10 dBm, 3, 2.7, 1, 2, 2.5 and 5, respectively. From the figure it is observed that the success probability performance is worse for lower values of the m, i.e., fading shape parameter of CCI channel and is almost insensitive for the higher values of m. For the same values of m, success probability performance of the D2D communication system improves with increase in values of y. It is due to weakening of the interference signals at the receiver of the D2D receiver due to path-loss effects. Outage capacity performance with varying values of fading parameter of desired D2D signal μ and the shadowing parameter δ is shown in Fig. 5. The values of the parameters P_D, P_I, u, v, m, κ, N, C_{th} and y are 20 dBm, 10 dBm, 3, 3.5, 3, 2.7, 5, 0.1 bits/s/Hz and 70 meters, respectively. From the figure, is observed that the outage capacity performance of the system is better for the higher values of the D2D fading parameter μ. It is due to the improved fading conditions of the desired D2D channel. Moreover, for the same values of μ outage capacity of system decreases with increase in values of shadowing parameter δ.

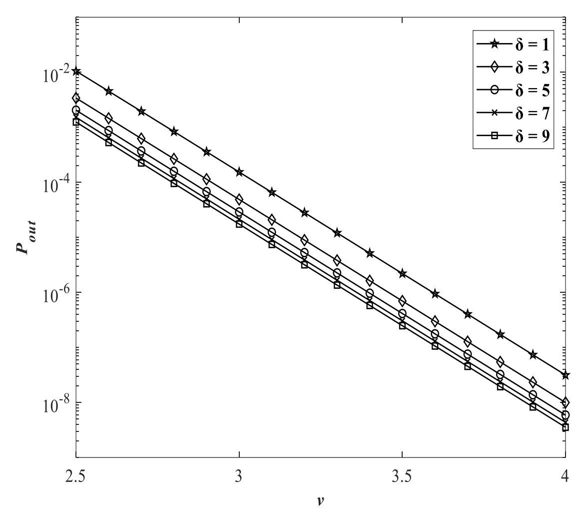

Fig. 3 Outage performance with varying values of the shadowing parameter

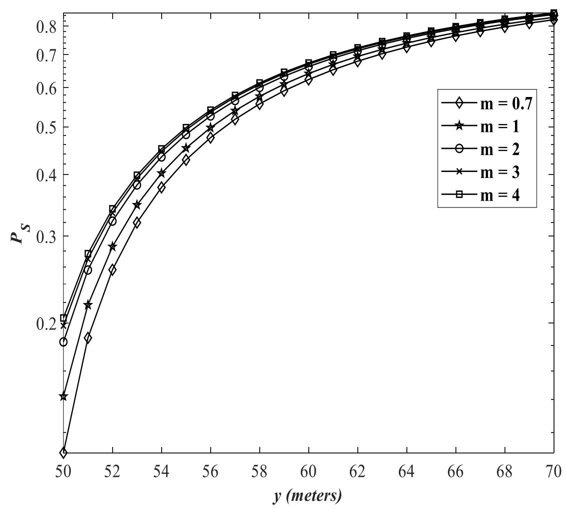

Fig. 4. Outage probability for various values of the interference shape parameter m

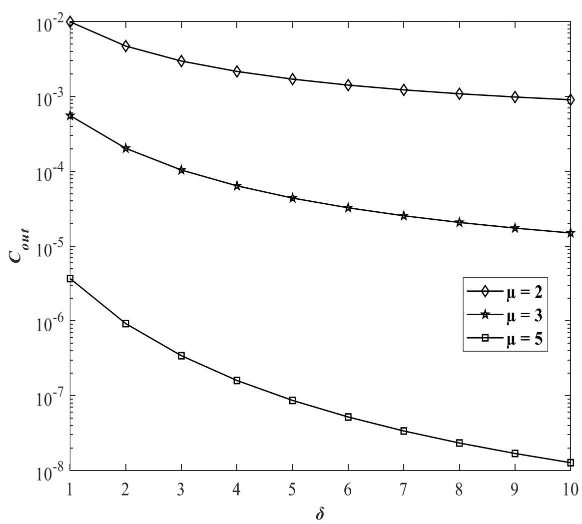

Fig. 5. Outage Capacity performance with varying fading parameter of D2D signal.

SER performance of 4-PSK modulated D2D system with varying values of desired signal path-loss exponent u is shown in Fig. 8. The values of PI, δ, μ, κ, v, m, N and y are assumed to be 10 dBm, 5, 3, 2.1, 4, 3, 5 and 80 meters, respectively. From the figure is seen that the SER performance of the system is worse for the higher values of u. It is due to deteriorated SIR condition of the system due to path-loss. Moreover, it can be observed from the figure that SER of the D2D system for the same value of path-loss exponent u, decreases with increase in transmit power of D2D signal PD.

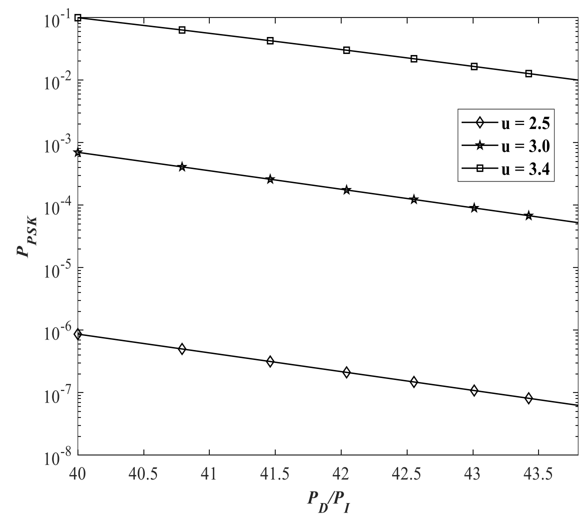

Fig. 6 SER performance for various values of path-loss exponent u of desired signal

4. Conclusion

Performance of a D2D communication system over a $\kappa-\mu$ shadowed fading channel is analyzed. The $\kappa-\mu$ shadowed distribution is a generalized distribution as it includes various distributions. Effects of co-channel interference due to various wireless devices are also considered. Expression of the PDF for the SIR is presented as a function of various interference, path-loss and channel parameters. Based on the PDF expression, numerical results of the outage probability, success probability, outage capacity and symbol error rate (SER) are discussed. It is observed that the presence of co-channel interference, shadowing and path-loss degrades the performance of the D2D communication system.

References

[1] 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," IEEE Journal on Selected Areas in Communications, vol. 36, no. 4, pp. 946-960, April 2018.

[2] P. Mach, Z. Becvar and T. Vanek, "In-Band Device-to-Device Communication in OFDMA Cellular Networks: A Survey and Challenges," IEEE Communications Surveys & Tutorials, vol. 17, no. 4, pp. 1885-1922, Fourthquarter 2015.

[3] O. Nait Hamoud, T. Kenaza and Y. Challal, "Security in device-to-device communications: a survey," IET Networks, vol. 7, no. 1, pp. 14-22, Jan. 2018.

[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] S. Kusaladharma, Z. Zhang and C. Tellambura, "Interference and Outage Analysis of Random D2D Networks Underlaying Millimeter-Wave Cellular Networks," IEEE Transactions on Communications, vol. 67, no. 1, pp. 778-790, Jan. 2019.

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

[7] X. Wang, X. J. Li, H. Y. Shwe, M. Yang and P. H. J. Chong, "Interference-aware resource allocation for device-to-device communications in cellular networks," 2015 10th International Conference on Information, Communications and Signal Processing (ICICS), Singapore, 2015, pp. 1-5.

[8] 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," IEEE Transactions on Wireless Communications, vol. 16, no. 7, pp. 4151-4165, July 2017.

[9] J. Guo, S. Durrani, X. Zhou and H. Yanikomeroglu, "Device-to-Device Communication Underlaying a Finite Cellular Network Region," IEEE Transactions on Wireless Communications, vol. 16, no. 1, pp. 332-347, Jan. 2017.

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

[11] Y. Li, J. Li, J. Jiang and M. Peng, "Performance analysis of device-to-device underlay communication in Rician fading channels," 2013 IEEE Global Communications Conference (GLOBECOM), Atlanta, GA, 2013, pp. 4465-4470.

[12] J. F. Paris, "Statistical Characterization of $\kappa-\mu$ Shadowed Fading," IEEE Transactions on Vehicular Technology, vol. 63, no. 2, pp. 518-526, Feb. 2014.

[13] Communications: Channel Modeling Using the Shadowed $\kappa-\mu$ Fading Model," IEEE Journal on Selected Areas in Communications, vol. 33, no. 1, pp. 111-119, Jan. 2015.

[14] I. S. Gradshteyn, I. M. Ryzhik. Table of Integrals, Series, and Products. 7th ed. San Diego, CA, USA: Academic Press; 2007.

[15] A. Mehbodniya and S. Aissa, "Outage and BER Analysis for Ultrawideband-Based WPAN in Nakagami-m Fading Channels," in IEEE Transactions on Vehicular Technology, vol. 60, no. 7, pp. 3515-3520, Sept. 2011.

[16] S. Kusaladharma and C. Tellambura, "Performance Characterization of Spatially Random Energy Harvesting Underlay D2D Networks With Transmit Power Control," IEEE Transactions on Green Communications and Networking, vol. 2, no. 1, pp. 87-99, March 2018.

[17] A. M. Mbah, J. G. Walker and A. J. Phillips, "Outage probability of WDM free-space optical systems affected by turbulence-accentuated interchannel crosstalk," IET Optoelectronics, vol. 11, no. 3, pp. 91-97, 6 2017.

[18] M. Peng, Y. Li, T. Q. S. Quek and C. Wang, "Device-to-Device Underlaid Cellular Networks under Rician Fading Channels," in IEEE Transactions on Wireless Communications, vol. 13, no. 8, pp. 4247-4259, Aug. 2014.

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