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Analysis of Device-to-Device Communication System in the Presence of Multiple Co-Channel Interference

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Abstract: In this paper, analysis of outage, channel capacity and symbol error rate (SER) analysis of Device-to-Device (D2D) communication systems is presented. The received signals of D2D communication system are affected by multiple co-channel interferers. The channel gain powers are considered to follow Gamma distribution. An expression for probability density function (PDF) expression of the signal-to-interference ratio (SIR) is presented. Based on expression of the PDF, the expressions for the outage, channel capacity and symbol error rate (SER) are presented. The performance of D2D communication system is then numerically analyzed and discussed under various conditions of channel fading and interference.

Keywords: D2D communication; co-channel interference; signal-to-interference ratio;

I. INTRODUCTION

With technological progression, the number of active cellular devices has increased rapidly. Due to bandwidth hungry applications, the amount of data rate is excessive. This excessive data rate is mainly due to file sharing, video streaming, social networking, and so on. This trend is expected to increase exponentially in the next decade. The current cellular communication system is incapable to satisfy the increasing demand of high data rates. Device-to-Device (D2D) communication system is one of the solutions to this problem. The D2D communication is a promising technology which allows direct communication among close proximity users without involvement of the base station (BS). In the published work, various D2D communication scenarios are discussed. In [1], authors have proposed a network assisted signaling algorithm for Device-to-Device (D2D) devices discovery. Authors have proposed a time-varying graph model to characterize the impacts of both social selfishness and individual on the D2D communications in [2]. In [3], authors study the D2D communications over $\kappa-\mu$ and $\eta-\mu$ fading channels. A framework based on the stochastic geometry to assess the coverage probability for cellular as well as D2D networks is presented in [4]. In [5], authors study the joint resource block assignment and transmit power allocation issues, for the optimization of the network performance. To maximize the D2D offloading utility an optimal content pushing technique based on the user interests and sharing is proposed in [6]. In [7], various resource allocation techniques for the full-duplex D2D communication are discussed. A probabilistic distance and path-loss model is presented in [8] to analyze the performance of D2D communication systems. Effects of D2D communication on the cellular communication performance is studied in [9] with the help of a frame work proposed by the authors. Authors in [10], studied the resource allocation and interference management for the D2D heterogeneous networks.

As the frequency band is limited and many wireless devices try to communicate simultaneously, in the absence of proper coordination between these devices, co-channel interference (CCI) occurs. Therefore, it is necessary to consider CCI when analyzing performance of such wireless systems. A D2D communication system is no exception [11, 12]. Outage performance, channel capacity and symbol error rate (SER) are important metrics to analyze the performance of a communication system [13], [14], [15]. Outage analysis for the D2D system in finite cellular networks has been presented by authors in [13] with Nakagami fading and Rayleigh distributed multiple interferers. In [11], authors have studied the outage performance of D2D systems over Weibull-lognormal and Weibull-gamma channels with gamma shadowed Nakagami co-channel interference. The channel capacity is analyzed by authors in [14] over Rician fading channel affected by multiple Rician faded CCI. In [15], authors have analyzed channel capacity by considering Rician channel and Rayleigh distributed interferers. In [16], SER performance of M-PSK is studied for the Rayleigh and Rician channels.

In this work, different from the published work, our objective is to analyze outage, channel capacity and SER performances of D2D systems with multiple co-channel interferers. Channel fading conditions are also considered for the desired D2D communication signals and the interferers. The effects of the path-loss are also considered. The wireless channel gain powers are assumed to be Gamma distributed. Gamma distribution is considered here because it is a mathematically tractable generalized distribution. It also models severely faded channel conditions [17]. The expressions of outage, channel capacity and SER metrics, based on the probability density function (PDF) expression of the signal-to-interference ratio (SIR) are presented. The rest of the paper is presented as follows. In Section II, expressions of outage, channel capacity and SER are presented. Based on these expressions, numerical results are presented in Section III. Finally, this paper is concluded in Section IV.

II. SYSTEM MODEL

A scenario is considered in which a pair of D2D communication devices is communicating in interference limited environment [18]. In Fig. 1, the system layout is shown. Multiple co-channel interferers in the system are assumed to be equidistant from the D2D receiver, and independent and identically distributed (i.i.d) [19]. A flat fading channel is assumed. The channel gain powers are considered to be Gamma distributed for the D2D pair and co-channel interferers.

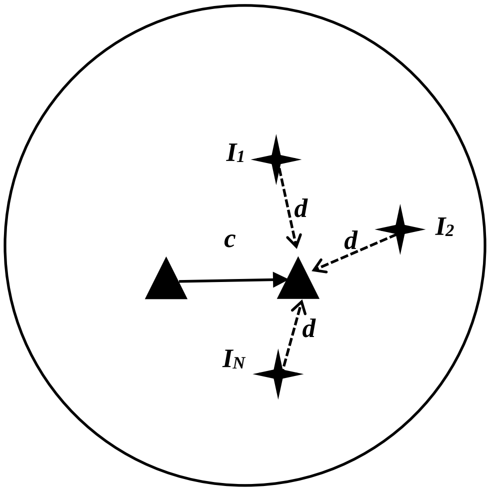

Figure 1. Layout of a D2D communication system in the presence of multiple CCI

Device-to-Device pair	▲
N Interferers (***I$_N$***)	✦
Desired communication signal between D2D Pair	⟶
c is D2D pair distance	
Interference signal from an interferer at distance ***d***	- - - - - - - - ->
The distance between an interferer and the D2D receiver is ***d***	

PDF of the Gamma distribution is as follows [20]

$$f(x) = \frac{e^{-\frac{x}{\theta}} x^{k-1}}{\theta^k \Gamma(k)}, \qquad x \geq 0, \theta > 0, k > 0. \tag{1}$$

In (1), shape parameter is k, scale parameter is θ and gamma function is given by $\Gamma(.)$ [23]. The fading power of the Gamma variable is related to the scale parameter θ whereas the severity of fading is determined by the shape parameter k [21]. In this paper, a simplified version of the path-loss model is also considered to include the effects of path-loss on the overall performance of D2D communication [22]. Power of the received desired signal is given as

$$S_d = P_1 \left(\frac{\lambda}{4\pi c_0} \right)^2 \left(\frac{c_0}{c} \right)^a \tag{2}$$

where S_d is the power of the D2D signal, P_1 is the transmitted signal power, c is the distance between the D2D pair, a is path-loss exponent $\left(2 \leq a \leq 5\right)$, λ is wavelength and c_0 is the reference distance (1 to 100 meters). Similarly, the i-th interferer power is

$$I = P_2 \left(\frac{\lambda}{4\pi d_0} \right)^2 \left(\frac{d_0}{d} \right)^b \tag{3}$$

where I is the power of the i-th interferer, P_2 is the transmitted power of i-th interferer, distance between an i-th interference source and D2D receiver is d, b is path-loss exponent and d_0 is the reference distance. Based on (2) and (3), D2D system signal-to-interference ratio (SIR) i.e. γ, is

$$\gamma = \frac{h}{\sum_{i=1}^{N} \varphi \, \alpha_i}, \qquad \varphi = \frac{P_2}{P_1} \left(\frac{c^a}{d^b} \right) \frac{\left(c_0\right)^{2-a}}{\left(d_0\right)^{2-b}} \tag{4}$$

where h and α_i are independent and Gamma distributed channel-gain powers of D2D signal and the i-th interferer, respectively, and number of co-channel interferers is N. The SIR PDF expression of our system, i.e., $f_\gamma(r)$, will now be presented with the help of the formula $f_\gamma(r) = \int_0^\infty u \, f_S(ru) \, f_I(u) \, du$ [24] as

$$f_\gamma(r) = \int_0^\infty u \; \underbrace{\frac{(ru)^{\delta-1} e^{-\frac{(ru)}{\rho}}}{\rho^\delta \, \Gamma(\delta)}}_{f_S(ru)} \times \underbrace{\frac{e^{\left(-\frac{u}{\varphi\sigma}\right)} u^{m_T-1}}{\sigma^{m_T} \, \Gamma(m_T) \, \varphi^{m_T}}}_{f_I(u)} \, du,$$

$$f_\gamma(r) = \frac{r^{\delta-1}}{B(\delta,m_T)}\left(\frac{\rho}{\sigma\ \varphi}\right)^{m_T} \times \left(r+\frac{\rho}{\sigma\ \varphi}\right)^{-(\delta+m_T)} \qquad (5)$$

In (5), δ and m are the shape parameters of D2D and interference signals, respectively, $B(.)$ is the beta function [23], ρ and σ are the scale parameters of the desired and the interference signals, respectively, and $m_T = N\,m$. Based on (5), the cumulative distribution function (CDF) is

$$F_\gamma(r) = \left(\frac{\sigma}{\rho}\varphi\, r\right)^{\delta}\left(1+\frac{\sigma}{\rho}\varphi\, r\right)^{1-(\delta+m_T)} \times {}_2F_1\left(1-m_T,1;1+\delta;-\varphi\, r\right) \qquad (6)$$

In (6), ${}_2F_1(.)$ is the hypergeometric function [23]. The outage probability of a communication system is the probability that the SIR of a system drops down a predefined threshold R, i.e. $P_{out} = \int_0^R f_\gamma(r)\,dr$ [17]. Hence, D2D communication system outage probability is [23]

$$P_{out} = \frac{\left(\left(\frac{\sigma}{\rho}\varphi\right)R\right)^{\delta}\left(1+\left(\frac{\sigma}{\rho}\varphi\right)R\right)^{1-(\delta+m_T)}}{\delta\ B(\delta,m_T)} \times {}_2F_1\left(1-m_T,1;1+\delta;-\frac{\sigma}{\rho}\varphi R\right) \qquad (7)$$

Now, by using the channel capacity expression $C = \int_0^\infty \log_2(1+r)\,f_\gamma(r)\,dr$ [25], after some algebraic manipulations the capacity expression is [23]

$$C = \frac{G^{2,3}_{3,3}\left(\frac{\rho}{\sigma}\frac{1}{\varphi}\middle|\begin{matrix}1-\delta,1,1\\ m_T,1,0\end{matrix}\right)}{\ln(2)B(\delta,m_T)\Gamma(\delta+m_T)} \qquad (8)$$

where $G^{w,x}_{y,z}$ is the Meijer-G function [23]. Next, SER expression of the D2D communication system is shown by considering M-ary phase-shift keying (M-PSK) [26]. SER of M-PSK scheme is given as [23] and [26]

$$P_{MPSK} = \frac{\Gamma(\delta)\displaystyle\int_0^{(M-1)\frac{\pi}{M}} \psi\left(\delta;1-m_T;\frac{\left(\sin\frac{\pi}{M}\right)^2\left(\frac{\rho}{\sigma}\frac{1}{\varphi}\right)}{(\sin\theta)^2}\right)d\theta}{\pi B(\delta,m_T)} \qquad (9)$$

where M is the order of the modulation. In (9), $\psi(.)$ is confluent hypergeometric function of second kind [23].

III. NUMERICAL RESULTS

Numerical results based on our mathematical expressions of Section II are discussed in this section. Expressions are valid for arbitrary values of channel and interference parameters. The reference distance for D2D pair c_0 and co-channel interferer d_0 are assumed to be 1 meter. The number of interferers is assumed to be 5. For the outage performance analysis, the SIR threshold is set to be 10 dBm. In Fig. 2, outage of D2D system is shown. For D2D pair transmitted power P_1 and path-loss exponent a are considered to be 31.8 dBm and 3, respectively. The transmitted interference power P_2, path-loss exponent b, fading channel shape parameter m, and distance between the co-channel interference and the receiving D2D device are considered to be 27 dBm, 2.8, 2 and 40 meters, respectively. The distance between D2D pair, i.e., c and the shape parameter δ of the desired signal are varied. From the figure, it can be observed that the outage performance of the system for the higher values of δ is better than that of the lower values. The reason is that as the value of δ is increased, the fading conditions of the channel improves which results in improved outage performance of the system. It is also observed that as the distance between the D2D pair increases, i.e., the value of c is increased, the outage performance degrades. It is due to the reason that the transmitted signal strength decreases with distance due to path-loss effects, i.e., the inverse relation between received power and the distance. Outage with varying c and path-loss exponent of the desired D2D signal is shown in Fig. 3. The values of P_1, δ, P_2, m and b are fixed at 31.8 dBm, 2, 27 dBm, 4 and 3, respectively. From the figure, it can be observed that outage probability is low for lower values of a and high for higher values of a at same values of c. It is because as the value of a increases, loss in desired signal strength increases with the increase in path-loss severity. Hence, outage of D2D system degrades.

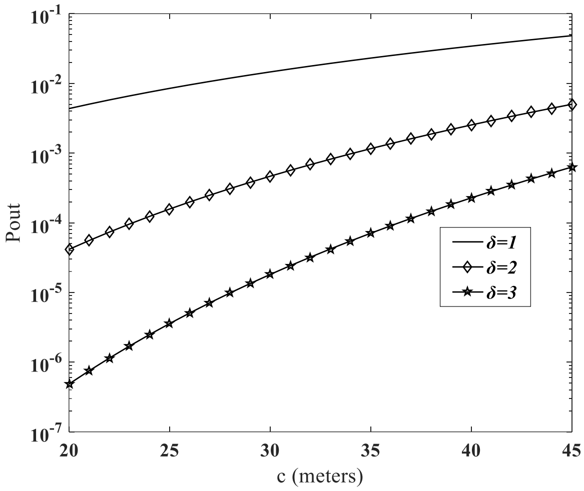

Figure 2. Outage performance with varying desired signal shape parameter

In Fig. 4, outage analysis with varying path-loss exponent of the interfering signals b and the distance c is shown. The values for P_1, δ, P_2, m and a are considered to be 31.8 dBm, 2, 27 dBm, 4 and 3, respectively. The distance d is considered to be 25 meters. From the figure, it is observed that outage performance is better for higher values of b as compared to lower values. Because as the value of path-loss exponent is increased, the power level of the interfering signal reduces because of path-loss effects. Therefore, overall SIR of the system increases resulting in an improved outage performance of the system. In Fig. 5, outage performance is shown with varying path-loss exponents of the desired and the interfering signals. The path-loss exponent values a and b are considered to be equal. The values of the parameters P_1, P_2, δ, m and d are fixed at 31.8 dBm, 27 dBm, 2, 2, 35 meters, respectively. It is evident from the figure that the performance of the system is better for higher values of a and b for $c < d$ where $d = 35$ meters. It is because the transmitted powers of D2D and interferer are affected by similar channel conditions, therefore, when $c < d$ where $d = 35$ meters, desired signal source being nearer to the receiver than interferers causes overall improved SIR conditions and better outage performance for higher path-loss exponent values. However, for $c > d$ where $d = 35$ meters, the outage performance is better for the lower values of a and b. It is because the system with the desired signal under less severe path-loss conditions show better SIR conditions. In Fig. 6, outage performance with varying number of co-channel interferes, i.e., N is shown. The values for P_2, δ, m, a, b, c and d are considered to be 27 dBm, 3, 2, 3, 2.7, 26 meters and 45 meters, respectively. It is clear from the figure that the outage worsens when the number of interferers are increased. It is because as the number of interferers increases, system suffers from degraded SIR performance, resulting in deteriorated outage performance.

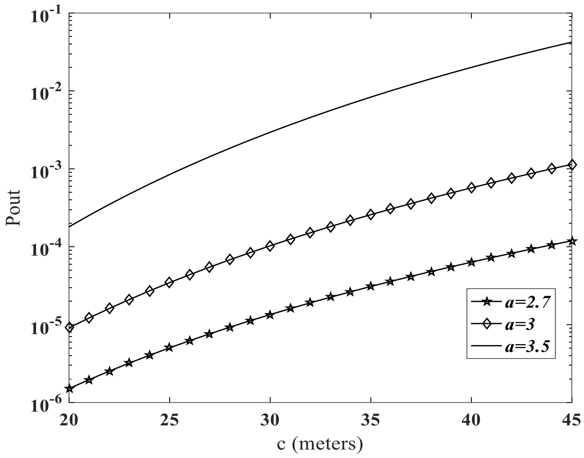

Figure 3. Outage performance with various path-loss exponents of the desired signal

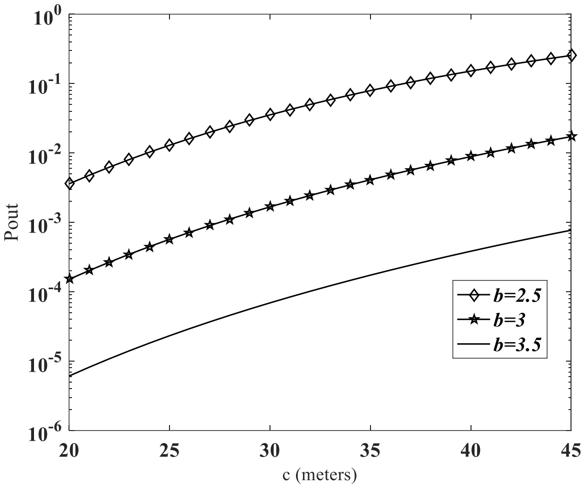

Figure 4. Outage performance with various path-loss exponents of the interference

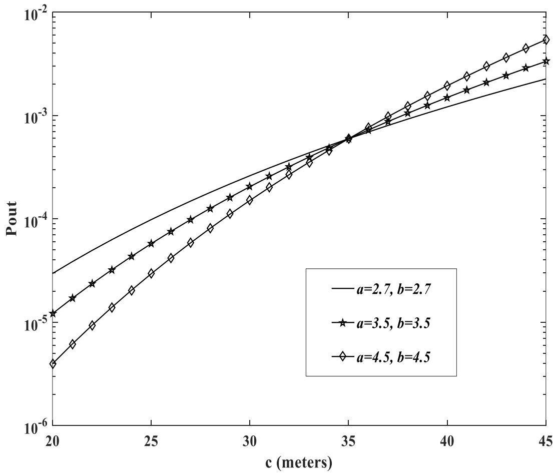

Figure 5. Outage performance with equal path-loss exponents of the desired and interference signals

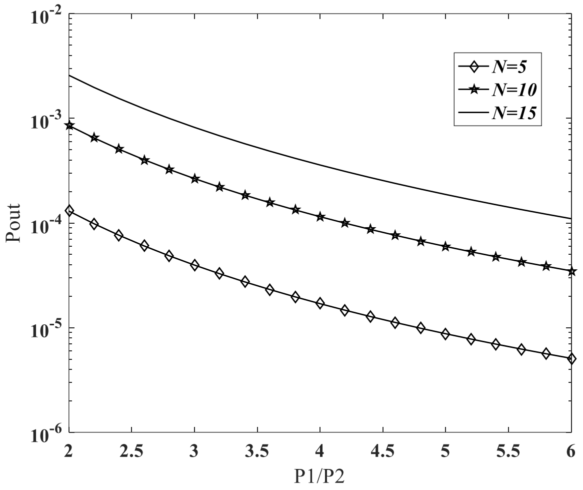

Figure 6. Outage performance with various co-channel interferers

Channel capacity performance of the system with varying values of m and d is shown in Fig.7. Values of P_1, δ, c, and P_2 are fixed at 34 dBm, 3, 40 meters and 26 dBm, respectively. From the figure, it can be seen that capacity performance is better for small values of m, i.e., under severe interference fading conditions. However, for the higher values of m, i.e., under better fading conditions, the channel capacity is almost insensitive to the variations in the interference fading conditions. In Fig. 8, channel capacity performances are shown with varying path-loss exponent of the interfering signal and d. The values of P_1, δ, P_2, m and a are considered to be 34 dBm, 2, 27 dBm, 5 and 2.8, respectively. As shown in the figure, the channel capacity performance is improved for the higher values of b and d. The reason is that for the higher values of b and d interference signals strengths deteriorate.

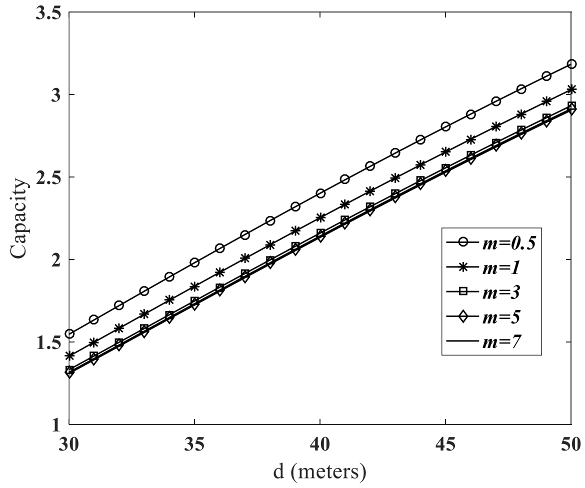

Figure 7. Channel Capacity (bits/s/Hz) with various interference shape parameter values

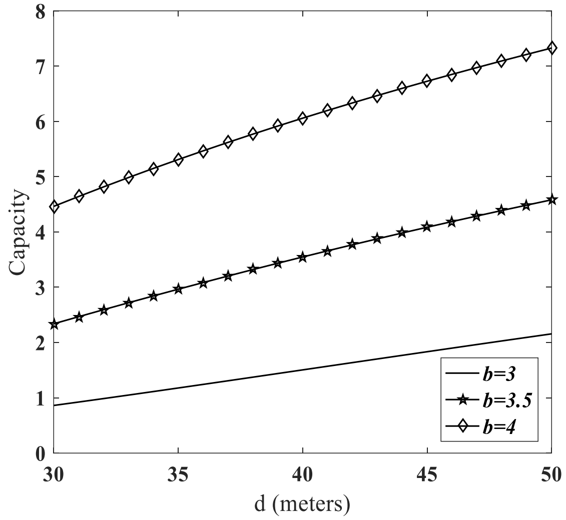

Figure 8. Channel Capacity (bits/s/Hz) with various path-loss exponents of the interference

In Fig. 9, channel capacity performances are shown with varying values of the path-loss exponents a and b. The path-loss exponent values are considered to be equal. Values for P_1, P_2, δ, d and m are 34 dBm, 27 dBm, 3, 35 meters and 2, respectively. The figure clearly shows that capacity of D2D system is better for the higher values of path-loss exponents when $c < d$ where $d = 35$ meters. However, when $c > d$ where $d = 35$ meters, the capacity is better for the lower values of a and b. SER performance of 8-PSK system with various values of the interference shape parameters is shown in Fig. 10. The values of P_1, P_2, δ, a and b are fixed at 34 dBm, 24.77 dBm, 5, 2.5 and 3, respectively. From the figure, it can be observed that as the values of m are increased, SER improves. However, for higher values of m, i.e., better interference fading conditions, the system SER performance is insensitive to change of interference fading conditions. Also, when the distance between the D2D pair increases, i.e., c, the SER performances converge for all interference fading conditions. It is because when the distance between D2D pair increases, path-loss becomes a dominant factor affecting the SER performance of the system. SER performance analysis of 8-PSK modulated system with varying N and P_1/P_2 is shown in Fig.11. The values for P_2, δ, m, a, b, c and d are assumed to be 24.77 dBm, 5, 2, 2.7, 3.5, 30 meters and 70 meters, respectively. From the figure, it is observed that SER performance of the system deteriorates as the number of co-channel interferers are increased. Moreover, it is observed from the figure that SER of the system improves with increase in power P_1.

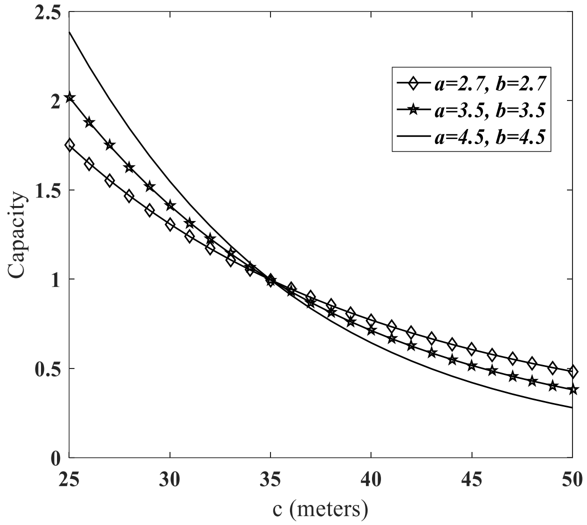

Figure 9. Channel Capacity (bits/s/Hz) with equal path-loss exponents

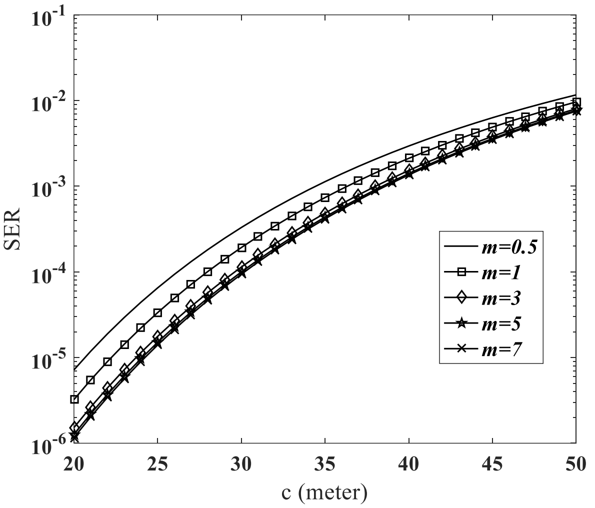

Figure 10. 8-PSK SER with varying interference shape parameters

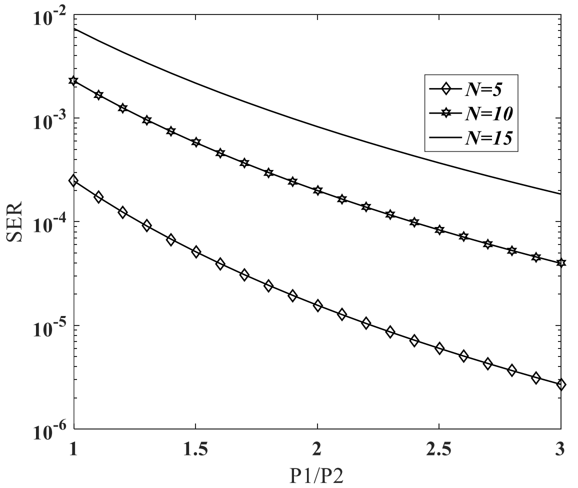

Figure 11. 8-PSK SER with various co-channel interferers

IV. CONCLUSIONS

In this work, outage, channel capacity and SER performances of D2D communication systems is studied and analyzed with multiple co-channel interference. Path-loss effects are also considered. The power of the channel gain is assumed to be Gamma distributed for both desired and interference signals. Based on the PDF of the SIR, the expressions for the outage performance, channel capacity and SER are presented. It is observed that various D2D communication system factors, like, fading and path-loss, affects the overall outage, channel capacity and SER performances. It is also observed that co-channel interference despite being affected by various hostile conditions, like, fading and path-loss, degrades the performance of D2D communication system.

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