

Analysis of D2D Communications over Gamma/Nakagami Fading Channels

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Abstract—In this paper, we investigate the outage probability, channel capacity and symbol error rate (SER) performance of device-to-device (D2D) communication systems. The D2D communication system is affected by several co-channel interferers. Gamma fading channel is considered for the D2D communication system. The channel for the co-channel interference is assumed to be Nakagami faded. An expression for the probability density function (PDF) of the signal-to-interference ratio (SIR) is presented. The PDF is a function of distances between various devices in the D2D system, path-loss, channel fading conditions and signal powers. Based on the PDF expression, we present the expressions for the outage, channel capacity and SER. With the help of numerical results the performance of D2D communication system is discussed under various conditions of interference, path-loss and channel fading.

Keywords—channel capacity; co-channel interference; D2D communication; outage; gamma fading; Nakagami fading

I. INTRODUCTION

The rapid growth of interconnected wireless devices needs efficient wireless networks to fulfill demands of high data rates [1-5]. For this purpose device-to-device (D2D) communication system is one of the promising technologies introduced [6-10]. D2D communication is a 5G cellular communication standard that facilitates nearby active devices to communicate directly without going through a base-station (BS) [11-15]. Services such as multimedia sharing, online gaming and cloud computing etc., have become vital part of daily communications. D2D communication is one of the communication systems which enable these services. D2D communication can also be used to encounter the excessive user density [16-20]. Due to the large number of wireless devices always competing for the limited wireless resources, any lack of coordination or management between them, may result in a scenario of unintentionally jamming of wireless signals due to co-channel interference (CCI). CCI causes degradation in the performance of the system. Therefore, effects of CCI should be taken into consideration while analyzing the performance of wireless communication systems [21-23]. D2D communication system also suffers from CCI [24]. Communication system performance can be analyzed using well known metrics like outage performance, channel capacity and symbol error rate (SER) [25, 28]. Outage

performance of multi-antenna D2D system is studied in [25] over a Rayleigh fading channel with CCI. In [26], authors investigate outage probability of D2D multichannel systems over Rayleigh fading channels in the presence of interference. The outage analysis of D2D systems with Suzuki fading channel and interference is presented in [27]. Channel capacity of D2D communication system is studied in [28] over a Rician fading channel and CCI. In [29], channel capacity of D2D system is presented over a Rician/Rayleigh channel and CCI. In [29], SER analysis of M-ary phase-shift keying (MPSK) for D2D systems over a Rician/Rayleigh channel is studied.

In this paper, we study outage probability, channel capacity and SER performance of D2D communication systems with multiple co-channel interferers. Based on the probability density function (PDF) expression of signal-to-interference (SIR) of the D2D system, expressions for the outage, channel capacity and SER are presented. Channel for D2D communication system is assumed to be Gamma distributed. The generality of Gamma distribution makes it feasible for the analysis of D2D communication system. It can be used to model severe channel fading conditions. In this work, we assume channel for the interferers to be Nakagami faded.

II. SYSTEM MODEL

We consider an interference limited system where an active pair of D2D communication devices is communicating [30]. System layout is shown in Figure 1. We consider several co-channel interferers in the system. These interferers are assumed to be equidistant from the D2D receiver. The channel for co-channel interferers is considered to be Nakagami faded. Channel gains for the co-channel interferers are assumed to be independent and identically distributed (IID) [31].

The PDF of Nakagami fading is given as [32]

$$f_x(x) = \frac{2}{\Gamma(m)} \left(\frac{m}{\Omega}\right)^m x^{2m-1} \exp\left(-\frac{m}{\Omega}x^2\right), \quad m \geq \frac{1}{2}, \Omega > 0, x > 0$$

where m is the fading parameter which describes the severity of the channel fading conditions, Ω is the average power of fading and $\Gamma(\cdot)$ is gamma function [32, 33]. The channel for

the D2D pair is assumed to be gamma distributed. The PDF of gamma distribution is [34]:

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

where k is the shape parameter, related to the intensity of the channel fading and θ is the scale parameter of gamma distribution [35]. Path-loss is another factor which affects the performance of communication systems. In this paper, we consider a simplified path-loss model. The received power of the D2D communication system is:

$$S_d = P_1 \left(\frac{\lambda}{4\pi c_0} \right)^2 \left(\frac{c_0}{c} \right)^a \tag{1}$$

where P_1 is the D2D signal power, c is the distance between sender and receiver of D2D pair, λ is the wavelength, a is the path-loss exponent ($2 \leq a \leq 5$) and c_0 is the reference distance (1 to 100 meters) [36]. Similarly, power of the i -th interferer at the D2D receiver is given as

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

In (2), P_2 is the interference signal power, d is the distance between the receiver of D2D pair and the i -th interferer, b is the path-loss exponent and d_0 is the reference distance. Using expressions (1) and (2) the SIR of considered D2D communication system is given as

$$\gamma = \frac{h^2}{g \sum_{i=1}^N \alpha_i^2}, \quad g = \frac{P_2}{P_1} \left(\frac{c^a}{d^b} \right) \left(\frac{c_0}{d_0} \right)^{2-a} \tag{3}$$

where h is the independent gamma fading variable of the desired D2D signal, α_i is an independent Nakagami fading variable of the i -th interferer and N is the number of co-channel interferers in the system. The PDF of the SIR of our system, i.e., $f_\gamma(r)$, is determined by using the formula

$$f_\gamma(r) = \int_0^\infty x f_S(rx) f_I(x) dx \tag{37}$$

$$f_\gamma(r) = \int_0^\infty x \underbrace{\frac{(rx)^{\delta-1} e^{-\frac{rx}{\rho}}}{2\rho^\delta \Gamma(\delta)}}_{f_S(rx)} \times \underbrace{\frac{\omega^{m_T} x^{m_T-1} \exp(-\omega x)}{\Gamma(m_T)}}_{f_I(x)} dx,$$

$$f_\gamma(r) = \frac{2^{-(\delta+2m_T)} \omega^{-\frac{\delta}{2}} \Gamma(\delta+2m_T)}{\rho^\delta \Gamma(\delta) \Gamma(m_T)} r^{\frac{\delta}{2}-1}$$

$$\times \psi\left(\frac{\delta+2m_T}{2}, \frac{1}{2}, \frac{r}{4\omega\rho^2}\right) \tag{4}$$

In (4), δ and ρ are the shape and the scale parameters of the desired signal, respectively, $\psi(\cdot)$ is KummerU function [33] and $m_T = Nm$, where m is the fading parameter for the interferer signals. Also, $\omega = \beta/g$, where $\beta = m/\Omega$ in which Ω is the average power of the interference fading channel. Based on (4), the expression of cumulative distribution function (CDF) of our system, after some mathematical manipulation, is given as

$$F_\gamma(r) = \frac{2^{-(\delta+2m_T)} \omega^{-\frac{\delta}{2}} \Gamma(\delta+2m_T) r^{\frac{\delta}{2}}}{\rho^\delta \Gamma(\delta) \Gamma(m_T) \Gamma\left(\frac{\delta+2m_T}{2}\right) \Gamma\left(\frac{\delta+2m_T}{2} + \frac{1}{2}\right)}$$

$$\times G_{2,3}^{2,2} \left(\frac{r}{4\omega\rho^2} \left| \begin{matrix} 1 - \frac{\delta}{2}, 1 - \frac{(\delta+2m_T)}{2} \\ 0, \frac{1}{2}, -\frac{\delta}{2} \end{matrix} \right. \right) \tag{6}$$

In (5), $G_{y,z}^{w,x}$ is the Meijer-G function [33]. The probability of drop-down of the SIR of a system below a predefined threshold R is termed as the outage probability. By using

$P_{out} = \int_0^R f_\gamma(r) dr$ [38] the expression for the outage probability of our D2D communication system is :

$$P_{out} = \frac{2^{-(\delta+2m_T)} \omega^{-\frac{\delta}{2}} \Gamma(\delta+2m_T) R^{\frac{\delta}{2}}}{\rho^\delta \Gamma(\delta) \Gamma(m_T) \Gamma\left(\frac{\delta+2m_T}{2}\right) \Gamma\left(\frac{\delta+2m_T}{2} + \frac{1}{2}\right)}$$

$$\times G_{2,3}^{2,2} \left(\frac{R}{4\omega\rho^2} \left| \begin{matrix} 1 - \frac{\delta}{2}, 1 - \frac{(\delta+2m_T)}{2} \\ 0, \frac{1}{2}, -\frac{\delta}{2} \end{matrix} \right. \right) \tag{6}$$

By using the channel capacity expression $C = \int_0^\infty \log_2(1+r) f_\gamma(r) dr$ [41], the expression for the channel capacity of our D2D communication system is:

$$C = \frac{2^{-(\delta+2m_T)} \omega^{-\frac{\delta}{2}} \Gamma(\delta+2m_T)}{\ln(2) \rho^\delta \Gamma(\delta) \Gamma(m_T) \Gamma\left(\frac{\delta+2m_T}{2}\right) \Gamma\left(\frac{\delta+2m_T}{2} + \frac{1}{2}\right)}$$

$$\times G_{3,4}^{4,2} \left(\frac{1}{4\omega\rho^2} \left| \begin{matrix} 1 - \frac{(\delta+2m_T)}{2}, -\frac{\delta}{2}, 1 - \frac{\delta}{2} \\ 0, \frac{1}{2}, -\frac{\delta}{2}, -\frac{\delta}{2} \end{matrix} \right. \right) \tag{7}$$

The SER performance expression for the D2D system incorporating M -ary phase-shift keying (M -PSK) modulation, after some mathematical manipulations, is [33]:

$$P_e = \frac{2^{-(\delta+2m_r)} \omega^{-\frac{\delta}{2}} \Gamma(\delta+2m_r) \Gamma\left(\frac{\delta}{2}\right) \Gamma\left(\frac{\delta+1}{2}\right)}{\pi \rho^\delta \Gamma(\delta) \Gamma(m_r) \Gamma\left(\delta+m_r+\frac{1}{2}\right) \left(\sin\frac{\pi}{M}\right)^\delta} \times \int_0^{\frac{(M-1)\pi}{M}} (\sin\theta)^\delta {}_2F_1\left(\frac{\delta}{2}, \frac{\delta+2m_r}{2}; \delta+m_r+\frac{1}{2}; 1 - \frac{\left(\frac{\sin\theta}{\sin\frac{\pi}{M}}\right)^2}{4\omega\rho^2}\right) d\theta \quad (8)$$

where M is the order of modulation and ${}_2F_1$ is hypergeometric function [33].

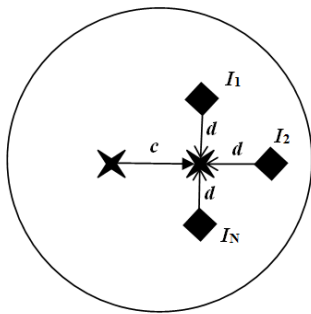


Fig. 1. D2D communication system layout

where

- Device-to-Device Pair
- N Interferers (I_N)
- Desired signal communication between D2D pair
- Distance Between D2D pair (c)
- Interference signal
- Distance Between an Interferer and D2D Receiver (d)

III. NUMERICAL RESULTS

In this section, numerical results are presented and discussed based on the expressions in Section II. Our expressions are valid for arbitrary values of the channel and interference parameters. For the analysis the reference distances c_0 and d_0 are assumed to be 1m. For the outage probability analysis, the SIR threshold is assumed to be 10dBm. The outage performance of our D2D communication system is shown in Figure 2. The values of P_1 , δ and a , are assumed to be 20dBm, 3 and 3, respectively. The values of P_2 , b and m are considered to be 13dBm, 2.8 and 2, respectively. We consider 5 interferers in the system. From the figure, we observe that as the distance between D2D devices increases the outage performance degrades due to worsening of SIR performance. We also observe that as interferers move away from the receiver the outage performance improves.

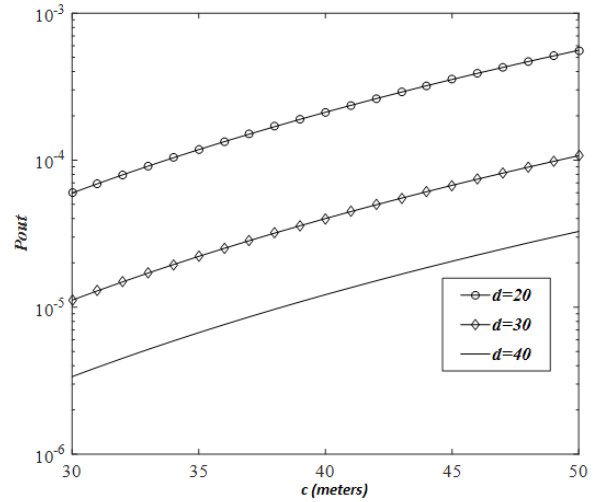


Fig. 2. Outage probability comparison with varying distance between the receiver and the interferers

Figure 3 shows the outage performance with varying fading conditions for the interference. The values of P_1 , δ , P_2 , a , b and d are considered to be 20dBm, 3, 13dBm, 3.5, 2.7 and 50m, respectively. We consider 5 interferers in the system. From the figure, we observe negligible change in the outage performance of our system when the interference channel fading conditions are varied. Hence, our system is mostly insensitive to the variations in the fading conditions of the interferers. Figure 4 shows the outage performance with varying path-loss exponent values of the interfering signals, b . The values for P_1 , δ , P_2 , m , a and d are fixed at 20dBm, 3, 13dBm, 2, 3.5 and 50m, respectively. We consider 5 interferers in the system. From the figure, it can be observed that by increasing the path-loss exponent value of the interference signal, the outage performance improves. It is due to the weakening effect of the interference signal strength at the receiver when path-loss exponent value is increased. There is an inverse relation between the received signal strength and the path-loss exponent value. Channel capacity performance of our system with varying numbers of co-channel interferers and D2D signal power is shown in Figure 5. The values for δ , a , m , b , c , d and P_2 are considered to be 3, 2.7, 2, 3, 60ms, 30m and 16dBm, respectively. From the Figure, it can be seen that when the strength of the D2D signal is increased, capacity performance improves due to the improved SIR conditions of the system. However, when the number of interferers in the system is increased, capacity performance deteriorates due to degraded SIR conditions. Channel capacity performance comparison with varying path-loss exponent values of co-channel interferers is shown in Figure 6. We also vary the number of interferers in the system. The values for P_1 , δ , a , m , b , c , d and P_2 are considered to be 20dBm, 3, 2.8, 2, 3.5, 60m, 30m and 16dBm, respectively. It can be observed that by increasing the path-loss exponent values of co-channel interferers the capacity performance improves. It is due to the weakening of the interference signals when path-loss exponent value increases.

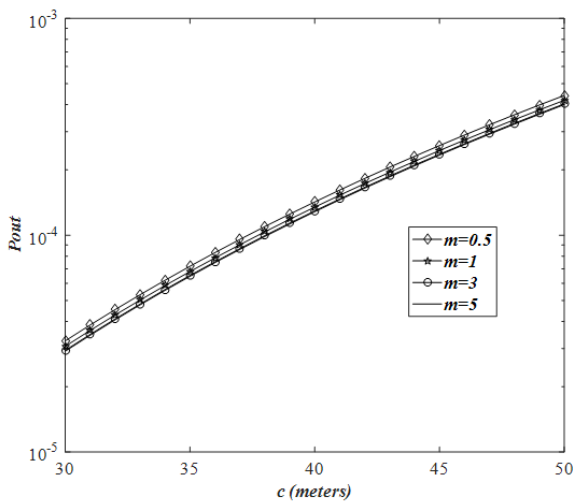


Fig. 3. Outage performance comparison with varying fading parameters of the interferers.

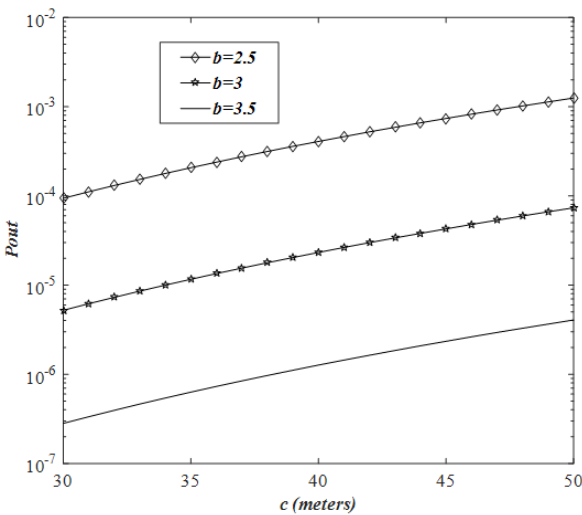


Fig. 4. Outage probability comparison with varying path-loss exponent values of the interferers.

Performance analysis of 8-PSK modulated D2D system with varying values of shape parameter and path-loss exponents of desired signal is shown in Figure 7. The values of P_1 , P_2 , m , b , c and d are assumed to be 20dBm, 13dBm, 2, 4, 30 m and 70 m, respectively. We consider 5 interferers in the system. From the figure, we observe that the SER performance degrades as the path-loss exponent value is increased. [This is due to the weakening of the received D2D signal. We also observe that under better channel fading conditions SER performance of our system is improved. Performance analysis of 8-PSK system with varying D2D signal power and D2D signal path-loss exponent values is shown in Figure. 8. The values for P_2 , m , b , c and d are assumed to be 13dBm, 2, 3.5, 30m and 70 m, respectively. We consider 5 interferers in the system. It can be seen from the figure that when the D2D signal strength is increased, improved SER performance is observed due to better SIR conditions.

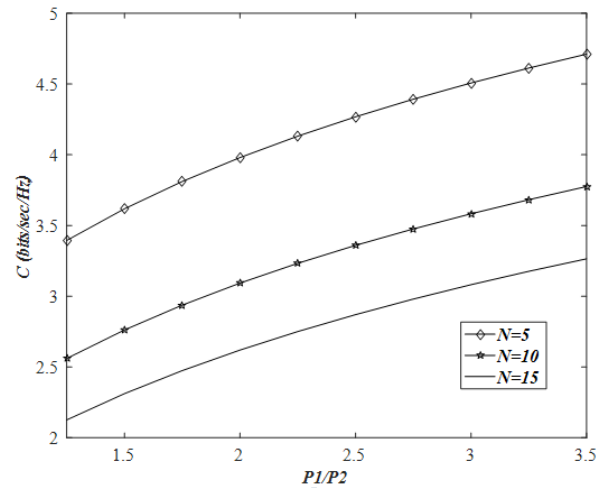


Fig. 5. Capacity performance comparison with varying number of co-channel interferers

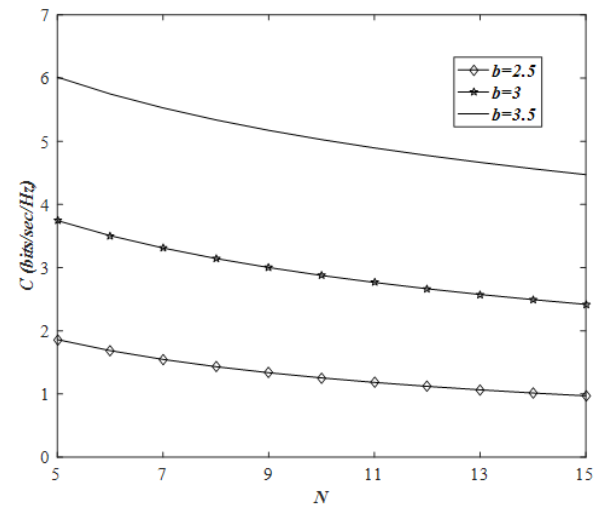


Fig. 6. Capacity performance with varying number of path-loss exponent values of interferers

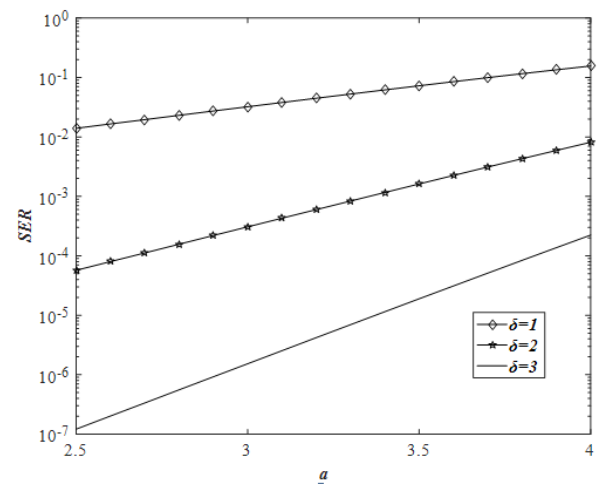


Fig. 7. SER performance of 8-PSK system with varying shape parameters of D2D signal

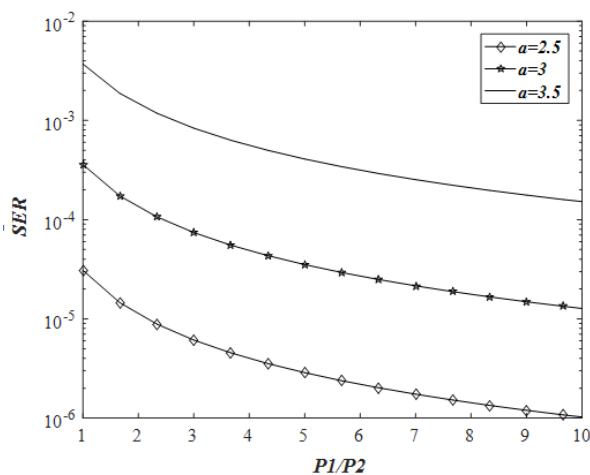


Fig. 8. SER performance of 8-PSK system with varying path-loss exponents of D2D signal

IV. CONCLUSION

We studied and analyzed the outage probability, channel capacity and SER performances of D2D communication systems over gamma fading channels in the presence of multiple Nakagami faded co-channel interferers. We also considered path-loss effects in our system. We presented a PDF of the SIR of our system. Based on this PDF, expressions for the outage probability, channel capacity and SER are presented. With the help of numerical results based on our expressions, we discussed the effects of various channel parameters, like fading and path-loss, on the outage, channel capacity and SER performances of our D2D communication system. We also observed that our D2D communication system performance is largely insensitive to the variations in the channel fading conditions of the interferers. However, variation in the path-loss exponent values of the interference signal show variation in the overall D2D system performance.

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