Analysis of D2D Communication System Over κ-μ Shadowed Fading Channel

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Abstract—**Outage performance of a device-to-device (D2D) communication system in the presence of co-channel interference (CCI) is analyzed in this paper. Channels for the D2D and CCI signals are assumed to be κ-μ shadowed faded. Maximal ratio combining (MRC) and selection combining (SC) techniques are considered to combat fading conditions. Characteristic function (CF) expression of the D2D system in the presence of CCI is presented. Outage probability and success probability expressions are presented for the MRC and SC schemes. These outage probability and success probability expressions are functions of various CCI, path-loss and channel fading parameters. With the help of numerical results, effects of CCI on the performance of D2D communication system under different channel fading and path-loss conditions are discussed.**

Keywords-co-channel interference; D2D communication; κ-μ shadowed distribution; maximal ratio combining; selection combining; outage probability

I. INTRODUCTION

The continuous development of technology and ever increasing number of connected devices has boosted the requirement of high data rates for efficient communication. Device-to-device (D2D) communication system has emerged as a promising solution for this problem. D2D communication system is one of the most important standards of the 5th generation (5G) cellular communication system that permits the communication of nearby devices directly bypassing the base station (BS) [1]. D2D communication system can improve data rate and bandwidth efficiency. It can also offload the base station, and it is power efficient communication for the user equipment [2-3]. Many D2D communication devices coexisting with other wireless devices are competing for limited bandwidth recourses, which may lead to the co-channel interference (CCI) problem. Therefore, the effects of CCI must be taken into account while analyzing the performance of D2D communication systems [4-5]. The aim of this paper is to analyze the outage and success probabilities of a D2D communication system in an interference limited scenario. Outage performance of a full duplex D2D system over a Rayleigh fading channel is studied in [6]. Authors in [7], studied outage performance of D2D communication system over a Rayleigh fading channel in the presence of interference. Success probability performance of D2D communication system over Rician fading channel is studied and analyzed in [8]. In [9], authors analyzed the success probability performance of D2D communication system over a Rayleigh fading channel.

The main objective of this work is to analyze the outage and success probabilities of a D2D communication system affected by several co-channel interferers over a κ-μ shadowed fading channel. The interference signals are assumed to originate from any wireless device in the system with which proper coordination is either lost or interrupted. The κ-μ shadowed fading channel is considered for both desired D2D and CCI signals. The κ-μ shadowed fading distribution is a versatile model with a mathematically tractable form [10]. The κ-μ shadowed fading distribution can model Rayleigh, Rician, one-side Gaussian, and Rician shadowed fading distributions. Maximal ratio combining (MRC) and selection combining (SC) techniques are incorporated to tackle the fading conditions. Outage probability and success probability expressions based on the characteristic function (CF) expressions for the MRC and SC cases are presented. These outage probability and success probability expressions are functions of various channel fading, shadowing, path-loss and interference conditions.

II. SYSTEM MODEL

The D2D communication model consists of a pair of D2D enabled devices communicating with each other directly. The system model is shown in Figure 1. There are N co-channel interferers in the system. The D2D and CCI signals are assumed to be independent and non-identically distributed. The CCI sources are considered to be situated at different distances from the receiver of the D2D pair. The κ-μ shadowed fading channel is assumed for both desired D2D and CCI signals. The probability density function (PDF) of κ-μ shadowed fading distribution is [11]:

$$f_Z(z)=\frac{\mu^\mu m^m(1+\kappa)^\mu z^{\mu-1}e^{-\frac{\mu(1+\kappa)z}{\Omega}}}{\Gamma(\mu)(\Omega)^\mu(\mu\kappa+m)^m}\times {}_1F_1\left(m,\mu,\frac{\mu^2\kappa(1+\kappa)z}{(\mu\kappa+m)\Omega}\right)$$

where ${}_1F_1(.)$ is the confluent hypergeometric function of first kind [12]. The signal modeled by κ-μ shadowed fading distribution is considered to contain clusters of multipath signals. Each cluster has a dominant component and that component can fluctuate randomly due to shadowing. μ denotes the number of clusters, κ is the ratio of sum of powers of dominant components to the sum of powers of all the scattered components, m is the shadowing parameter and Ω is related to the average power. A simplified path-loss model is also considered [13]. MRC and SC based diversity techniques with M branches are incorporated to combat fading conditions.

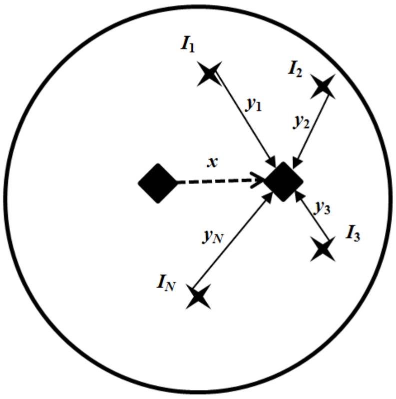

Fig. 1. D2D system layout

Considered D2D device	◆
n^{th} interference	✖
Distance between desired D2D devices	x
Distance between n^{th} interference and the desired D2D pair's receiver	y_n
Desired D2D communication signal	- - - →
n^{th} Interference signal	⟶

A. MRC Scheme

The signal-to-interference power ratio (SIR) at the output of M branches MRC combiner is:

$$\frac{S_{d,MRC}}{S_I}=\frac{P_d\left(\frac{x_0^{\,u-2}}{x^u}\right)\sum_{l=1}^{M}h_l}{\sum_{n=1}^{N}P_{I,n}\left(\frac{y_{0,n}^{\;v_n-2}}{y_n^{\;v_n}}\right)\beta_n} \tag{1}$$

In (1), P_d is the power of the D2D signal, x is the distance between D2D devices, u is the path-loss exponent $\left(2\le u\le 5\right)$ for the D2D signal, x_0 is the reference distance and h_l is an independent κ-μ shadowed fading variable in the l^{th} diversity branch. Similarly, the power of the n^{th} co-channel interferer is $P_{I,n}$ which is located at a distance y_n from the D2D receiver, $y_{0,n}$ is the reference distance, v_n is the path-loss exponent of the n^{th} co-channel interferer and β_n is an independent κ-μ shadowed fading variable of the n^{th} co-channel interferer. The performance of a wireless communication system is assessed by computing the outage probability. The outage probability P_{out} is defined as the probability that the instantaneous SIR of the system drops below threshold R. The outage probability is:

$$P_{out,MRC}=\Pr\left(RS_I>S_{d,MRC}\right) \tag{2}$$

where Pr(.) denotes the probability. Using the expression given in (2), a decision variable φ is defined as:

$$\varphi=RS_I-S_{d,MRC} \tag{3}$$

For an acceptable quality of a desired D2D received signal, the value of φ has to be negative. Otherwise, outage will occur. Mathematically,

$$\varphi\begin{cases}>0 & \text{Outage}\\ \le 0 & \text{Acceptable transmission}\end{cases} \tag{4}$$

To get the expression of the outage probability, a characteristic function (CF) based approach is considered here. With the help of [11], the CF of the decision variable φ is:

$$\phi_\varphi(\omega)=\prod_{n=1}^{N}\left(\frac{A_n}{\left(-C_n\right)^{\mu_n}}\frac{\left(W_n-j\omega\right)^{m_n-\mu_n}}{\left(X_n-j\omega\right)^{m_n}}\right)\times\prod_{l=1}^{M}\left(\frac{A_l}{\left(-B_l\right)^{\mu_l}}\frac{\left(T_l+j\omega\right)^{m_l-\mu_l}}{\left(Z_l+j\omega\right)^{m_l}}\right) \tag{5}$$

where:

$A_n=\left(\frac{-\mu_n\left(1+\kappa_n\right)}{\Omega_n}\right)^{\mu_n}\left(\frac{m_n}{\mu_n\kappa_n+m_n}\right)^{m_n}$, $W_n=\frac{\mu_n\left(1+\kappa_n\right)}{\Omega_n C_n}$,

$X_n=W_n\left(\frac{m_n}{\mu_n\kappa_n+m_n}\right)$, $C_n=RP_{I,n}\frac{\left(y_{0,n}\right)^{v_n-2}}{\left(y_n\right)^{v_n}}$,

$A_l=\left(\frac{-\mu_l\left(1+\kappa_l\right)}{\Omega_l}\right)^{\mu_l}\left(\frac{m_l}{\mu_l\kappa_l+m_l}\right)^{m_l}$,

$T_l=\frac{\mu_l\left(1+\kappa_l\right)}{\Omega_l\,B_l}$, $Z_l=T_l\left(\frac{m_l}{\mu_l\kappa_l+m_l}\right)$, $B_l=P_d\frac{x_0^{\,u-2}}{x^u}$,

$\Omega_n=E\left[\beta_n\right]$ and $\Omega_l=E\left[h_l\right]$.

Based on (4) and (5), the outage probability of the D2D communication system can be obtained by using the formula:

$$P_{out}=\frac{1}{2}+\frac{1}{\pi}\int_0^\infty\frac{Im(\varphi_\varphi(\omega))}{\omega}d\omega$$

where Im(.) is the imaginary part of the CF of the decision variable φ. The outage probability of MRC based D2D communication system is given in (6). In (6), $\theta_n=m_n\tan^{-1}\left(\frac{\omega}{X_n}\right)-\left(m_n-\mu_n\right)\tan^{-1}\left(\frac{\omega}{W_n}\right)$ and $\psi_l=\left(m_l-\mu_l\right)\tan^{-1}\left(\frac{\omega}{T_l}\right)-m_l\tan^{-1}\left(\frac{\omega}{Z_l}\right)$. The success probability is defined as the probability for which the SIR of a system excides a fixed threshold R. P_S of MRC based D2D communication system is given in (7).

$$P_{S,SC}=1-\prod_{l=1}^{M}\left[\frac{1}{2}+\frac{1}{\pi}\int_{0}^{\infty}\left[\prod_{n=1}^{N}\left(\frac{A_n}{(-C_n)^{\mu_n}}\frac{\left(W_n^{2}+\omega^2\right)^{\frac{m_n-\mu_n}{2}}}{\left(X_n^{2}+\omega^2\right)^{\frac{m_n}{2}}}\right)\times\left(\frac{A_l}{(-B_l)^{\mu_l}}\frac{\left(T_l^{2}+\omega^2\right)^{\frac{m_l-\mu_l}{2}}}{\left(Z_l^{2}+\omega^2\right)^{\frac{m_l}{2}}}\right)\frac{\sin\left(\sum_{n=1}^{N}\theta_n+\psi_l\right)}{\omega}\right]d\omega\right] \tag{6}$$

$$P_{S,MRC}=\frac{1}{2}-\frac{1}{\pi}\int_{0}^{\infty}\left[\prod_{n=1}^{N}\left(\frac{A_n}{(-C_n)^{\mu_n}}\frac{\left(W_n^{2}+\omega^2\right)^{\frac{m_n-\mu_n}{2}}}{\left(X_n^{2}+\omega^2\right)^{\frac{m_n}{2}}}\right)\prod_{l=1}^{M}\left(\frac{A_l}{(-B_l)^{\mu_l}}\frac{\left(T_l^{2}+\omega^2\right)^{\frac{m_l-\mu_l}{2}}}{\left(Z_l^{2}+\omega^2\right)^{\frac{m_l}{2}}}\right)\frac{\sin\left(\sum_{n=1}^{N}\theta_n+\sum_{l=1}^{M}\psi_l\right)}{\omega}\right]d\omega \tag{7}$$

B. Selection Combining

For the D2D communication system with SC diversity technique, the SIR of the l^{th} diversity branch is:

$$\frac{S_{d-SC,l}}{S_I}=\frac{P_d\left(\frac{x_0^{\,u-2}}{x^u}\right)h_l}{\sum_{n=1}^{N}P_{I,n}\left(\frac{y_{0,n}^{\,v_n-2}}{y_n^{\,v_n}}\right)\beta_n} \tag{8}$$

The outage probability for a SC diversity based D2D communication system is:

$$P_{out,SC}=\Pr\left(RS_I>S_{d-SC,MAX}\right) \tag{9}$$

where $S_{d-SC,MAX}=\max_{l=1,\ldots,M}\left(S_{d-SC,l}\right)$. A decision variable Θ is defined as:

$$\Theta\begin{cases}>0 & \text{Outage}\\ \le 0 & \text{Acceptable Transmission}\end{cases} \tag{10}$$

Based on (9) and (10), the outage probability and success probability expressions of SC diversity based D2D communication system are given in (11) and (12) respectively.

$$P_{out,SC}=\prod_{l=1}^{M}\left[\frac{1}{2}+\frac{1}{\pi}\int_{0}^{\infty}\left[\prod_{n=1}^{N}\left(\frac{A_n}{(-C_n)^{\mu_n}}\frac{\left(W_n^{2}+\omega^2\right)^{\frac{m_n-\mu_n}{2}}}{\left(X_n^{2}+\omega^2\right)^{\frac{m_n}{2}}}\right)\times\left(\frac{A_l}{(-B_l)^{\mu_l}}\frac{\left(T_l^{2}+\omega^2\right)^{\frac{m_l-\mu_l}{2}}}{\left(Z_l^{2}+\omega^2\right)^{\frac{m_l}{2}}}\right)\frac{\sin\left(\sum_{n=1}^{N}\theta_n+\psi_l\right)}{\omega}\right]d\omega\right] \tag{11}$$

$$P_{S,SC}=1-\prod_{l=1}^{M}\left[\frac{1}{2}+\frac{1}{\pi}\int_{0}^{\infty}\left[\prod_{n=1}^{N}\left(\frac{A_n}{(-C_n)^{\mu_n}}\frac{\left(W_n^{2}+\omega^2\right)^{\frac{m_n-\mu_n}{2}}}{\left(X_n^{2}+\omega^2\right)^{\frac{m_n}{2}}}\right)\times\left(\frac{A_l}{(-B_l)^{\mu_l}}\frac{\left(T_l^{2}+\omega^2\right)^{\frac{m_l-\mu_l}{2}}}{\left(Z_l^{2}+\omega^2\right)^{\frac{m_l}{2}}}\right)\frac{\sin\left(\sum_{n=1}^{N}\theta_n+\psi_l\right)}{\omega}\right]d\omega\right] \tag{12}$$

III. NUMERICAL RESULTS

In this section, numerical results are discussed based on the expressions presented above. The reference distances x_0, $y_{n,0}$ are considered to be 1m. Outage threshold R is fixed at 10dBm. In Figure 2, the number of diversity branches M is considered to be 3 for both SC and MRC. The values of signal power of the desired D2D signal P_d, path-loss exponent u, shadowing parameter m_l, parameters μ_l and κ_l are assumed to be 20dBm, 3.2, {4, 1, 2}, {1, 2, 3} and {2.7, 3.7, 1.7}, respectively. For CCI signals, the values of signal power $P_{I,n}$, path-loss exponents v_n, distances between interferers and the receiver of D2D pair y_n, shadowing parameters m_n, parameters μ_n, and κ_n, and number of interferers N are considered to be {19.59, 19.03, 18.14, 19.35, 19.3}, {3, 3.2, 3.4, 3, 2.5}, {20, 30, 25, 15, 30} meters, {3, 2, 1, 4, 4}, {1, 2, 2, 1, 3}, {2.7, 3.7, 2.7, 2.7, 2.7} and 5, respectively. It can be observed that MRC outperforms SC. Furthermore, as the desired D2D devices move away from each other outage performance degrades. It is due to increase in path-loss effects.

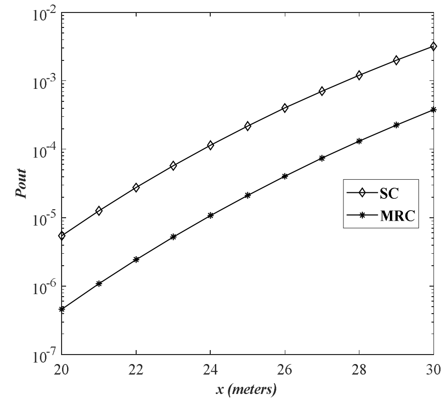

Fig. 2. Outage performance comparison of MRC and SC scheme

Figure 3 shows the outage performance with MRC diversity based D2D communication system for various M. The values of P_d and u are assumed to be 20dBm and 3.3, respectively. The values of m_l, μ_l and κ_l for M=2 are set to be {4, 1}, {1, 2}, {2.7, 3.7}, for M=3 the values of m_l, μ_l and κ_l are {4, 1, 2}, {1, 2, 3}, {2.7, 3.7, 1.7} and for M=4 the values of m_l, μ_l and κ_l are {4, 1, 2, 2}, {1, 2, 3, 2}, {2.7, 3.7, 1.7, 1}, respectively. For the interference signals, parameters $P_{I,n}$, v_n, y_n, N, m_n, μ_n and κ_n are fixed at {19.59, 19.03, 18.14, 19.35, 19.3}, {3, 3.2, 3.4, 3, 2.5}, {20, 30, 25, 15, 30} meters, 5, {3, 2, 1, 4, 4}, {1, 2, 2, 1, 3}, {2.7, 3.7, 2.7, 2.7, 2.7}, respectively. From the figure, it can be observed that by increasing the number of diversity branches, the outage performance of the system improves.

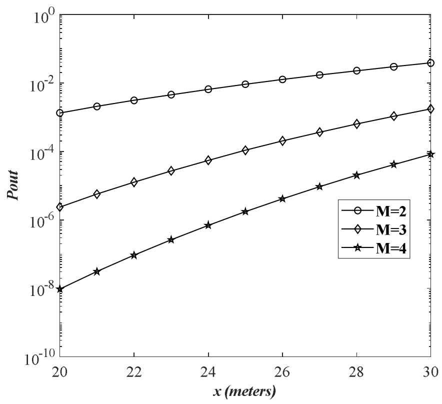

Fig. 3. Outage performance with varying number of diversity branches

Outage performance with varying fading parameter values of the D2D signal μ_l is shown in Figure 4. MRC diversity scheme is considered. The values of P_d, u, M, m_l and κ_l are fixed at 20dBm, 3.4, 3, {3, 1, 2} and {2.7, 3.7, 1.7}, respectively. For the interference signals, parameters $P_{I,n}$, v_n, y_n, N, m_n, μ_n and κ_n are considered to be {19.59, 19.03, 18.14, 19.35, 19.3}, {3, 3.2, 3.4, 3, 2.5}, {20, 30, 25, 15, 30} meters, 5, {3, 2, 1, 4, 4}, {1, 2, 2, 1, 3}, {2.7, 3.7, 2.7, 2.7, 2.7}, respectively. It can be observed that as the values of fading parameter μ_l are increased, the outage performance of D2D system is improved.

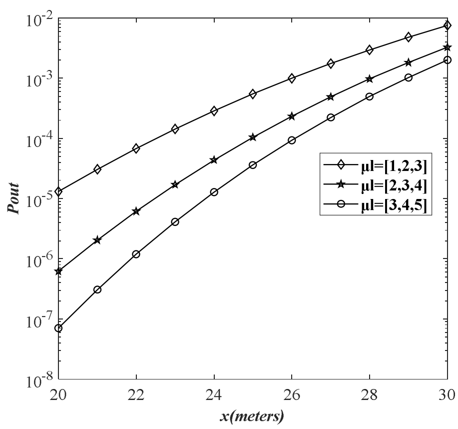

Fig. 4. Outage performance with various values of μl of the D2D signal

Outage performance with varying shadowing parameter values of the interference signal m_n is shown in Figure 5. MRC diversity scheme is considered. The values of P_d, u, M, m_l, μ_l and κ_l are fixed at 20dBm, 3.4, 3, {3, 1, 2}, {3, 4, 5} and {2.7, 3.7, 1.7}, respectively. For CCI signals, values of $P_{I,n}$, v_n, y_n, N, μ_n and κ_n are assumed to be {19.59, 19.03, 18.14, 19.35, 19.3}, {3, 3.2, 3.4, 3, 2.5}, {20, 30, 25, 15, 30} meters, 5, {1, 2, 2, 1, 3}, {2.7, 3.7, 2.7, 2.7, 2.7}, respectively. It is observed that slight change in the outage performance of the system occurs when the interference shadowing conditions are changed. Therefore, outage performance is mostly insensitive to the variations of CCI shadowing conditions.

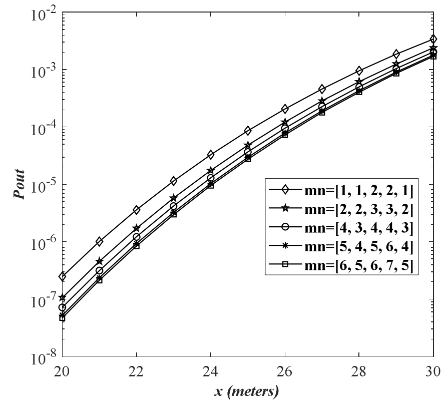

Fig. 5. Outage performance with various values of interference shadowing parameters.

Outage performance with varying values of interference signal μ_n is shown in Figure 6. MRC diversity scheme is incorporated. The values of x, u, M, m_l, μ_l and κ_l are fixed at 20m, 3.3, 3, {4, 1, 2}, {1, 2, 3} and {2.7, 3.7, 1.7}, respectively. For the interference signals, parameters $P_{I,n}$, v_n, y_n, N, m_n and κ_n the values are fixed at {19.59, 19.03, 18.14, 19.35, 19.3}, {3, 3.2, 3.4, 3, 2.5}, {20, 30, 25, 15, 30} meters, 5, {3, 2, 1, 4, 4}, {2.7, 3.7, 2.7, 2.7, 2.7}, respectively. The value of R is 10dBm. From the figure, it is observed that the outage performance of the D2D system is largely insensitive to the varying values of interference parameter μ_n.

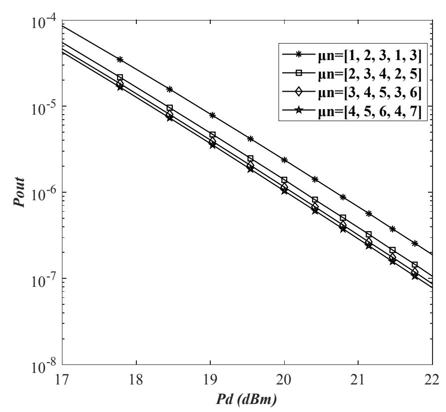

Fig. 6. Outage performance with various values of μn of CCI

Outage performance with varying path-loss exponent values of D2D signal u is shown in Figure 7. SC diversity scheme is incorporated. The values of x, M, m_l, μ_l and κ_l are fixed at 25m, 3, {4, 1, 2}, {1, 2, 3} and {2.7, 3.7, 1.7}, respectively. For CCI signals, parameters $P_{I,n}$, v_n, y_n, N, m_n, μ_n and κ_n the are assumed to be {19.59, 19.03, 18.14, 19.35, 19.3}, {3, 3.2, 3.4, 3, 2.5}, {20, 30, 25, 15, 30} meters, 5, {3, 2, 1, 4, 4}, {1, 2, 2, 1, 3}, {2.7, 3.7, 2.7, 2.7, 2.7}, respectively. It is clear from the figure that outage performance degrades as the path-loss exponent values of the D2D signal is increased. It is due to degradation of the SIR due to path-loss effects. Outage performance with varying shadowing parameter values of the D2D signal m_l is shown in Figure 8. MRC diversity scheme is considered. The values of P_d, u, M, μ_l and κ_l are fixed at 20dBm, 3.2, 3, {1, 2, 3} and {2.7, 3.7, 1.7}, respectively. For CCI signals, values of $P_{I,n}$, v_n, y_n, N, μ_n and κ_n are assumed to be {19.59, 19.03, 18.14, 19.35, 19.3}, {3, 3.2, 3.4, 3, 2.5}, {20, 30, 25, 15, 30} meters, 5, {1, 2, 2, 1, 3}, {2.7, 3.7, 2.7, 2.7, 2.7}, respectively. It is observed that the outage performance of D2D communication system improves with increasing values of the shadowing parameter of D2D signal m_l. It is because of improved shadowing conditions of D2D signal's channel with increase in values of shadowing parameter m_l.

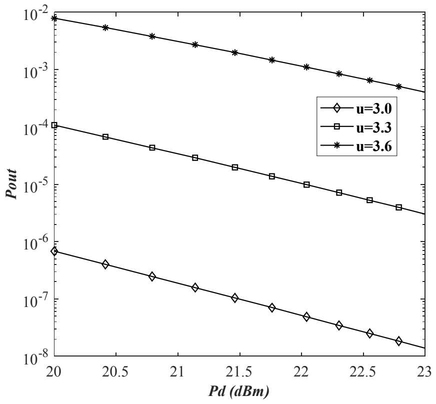

Fig. 7. Outage performance with various path-loss exponent values of D2D signal

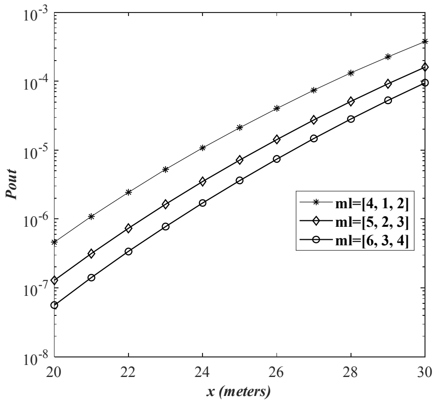

Fig. 8. Outage performance with varying values of shadowing parameter of D2D signal.

Success probability performance of D2D communication system varying path-loss exponent values of interference signal v_n is shown in Figure 9. SC diversity scheme is considered. The values of P_d, u, M, m_l, μ_l and κ_l are fixed at 20dBm, 3.9, 3, {1, 2, 3}, {1, 2, 3} and {2.7, 3.7, 1.7}, respectively. For the interference signals, parameters $P_{I,n}$, yn, N, m_n, μ_n and κ_n are fixed at {19.59, 19.03, 18.14, 19.35, 19.3}, {3, 3.2, 3.4, 3, 2.5}, {20, 30, 25, 15, 30} meters, 5, {3, 2, 1, 4, 4}, {1, 2, 2, 1, 3}, {2.7, 3.7, 2.7, 2.7, 2.7}, respectively. It is observed that for higher path-loss exponent values of interference signals success the probability of the D2D system is high. It is due to weakening of the CCI signals at the receiver of the desired D2D pair. This is because of path-loss effects. The success probability performance with varying distances y_n is shown in Figure 10. MRC diversity scheme is assumed. The values of x, u, M, m_l, μ_l and κ_l are fixed at 30m, 3.3, 3, {4, 1, 2}, {1, 2, 3} and {2.7, 3.7, 1.7}, respectively. For interference signals, parameters $P_{I,n}$, v_n, N, m_n, μ_n and κ_n are fixed at {19.59, 19.03, 18.14, 19.35, 19.3}, {2.5, 2.7, 3, 3.3, 2.8}, 5, {3, 2, 1, 4, 4}, {1, 2, 2, 1, 3}, {2.7, 3.5, 4.1, 3.2, 3.6}, respectively. It is clear that as the interferers move away from the desired D2D receiver, success probability performance of the system improves. It is because as the interferers move away from the D2D receiver, interference signals weaken at the D2D receiver side. It is due to path-loss effects.

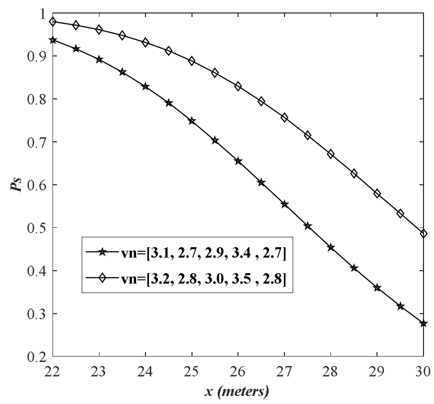

Fig. 9. Success probability performance with various path-loss exponent values of interference signal

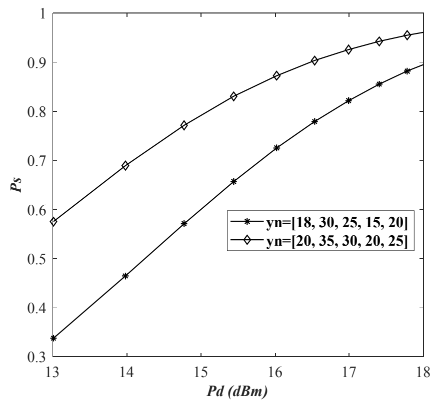

Fig. 10. Success probability performance with varying distances yn

IV. Conclusions

Outage and success probabilities of a D2D communication system over κ-μ shadowed faded channels have been analyzed. Effects of CCI on the performances were also considered. MRC and SC based diversity techniques are considered to mitigate fading conditions. The D2D and CCI signals are assumed to be independent and non-identically distributed. The interferers are assumed to be present at different distances from the receiver of the considered D2D pair. Outage probability and success probability expressions are presented based on a CF based approach. These outage probability and success probability expressions are functions of interference, channel fading and shadowing, and path-loss parameters. From the numerical results, it was observed that the fading, shadowing, path-loss and CCI affect the performance of the D2D system. It was also observed that D2D communication system performance is largely insensitive to the channel conditions of the interferers.

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