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Performance Analysis of Relay-Assisted Device-to-Device Communication

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***Abstract*—Outage and Success performances of an amplify-and-forward relay-assisted D2D communication system over a *κ-μ* shadowed fading wireless link are presented here. Co-channel interference (CCI) is assumed to affect the D2D signals at relay and destination nodes. The system is analyzed with two scenarios, namely, with diversity combining and without diversity combining. Selection combining (SC) based diversity scheme is incorporated at the D2D receiver to combat fading conditions. The expressions for success and outage probabilities are presented by using the characteristic function approach. The expressions are functions of path-loss exponents, wireless link length between relay and D2D source node, wireless link length between the receiver node and relay, distances between interferers and the relay node, CCI distances from various devices of the system, fading channel. The numerical analysis for various scenarios is presented and analyzed.**

***Keywords*—CCI signals; D2D Communication; *κ-μ* shadowed fading; Outage Probability; Relay**

I. Introduction

THE required data rate for multimedia services is a challenge for present cellular communications. New technologies, like, device-to-device (D2D) communication are required to cope such challenges [1-2]. In D2D communication, nearby devices can communicate directly bypassing the base station. D2D networks offload base stations and provide high data rate. Sometimes a D2D network may not perform as expected due to long separation distances of communicating nodes. In this case, a relay assisted D2D system can improve overall D2D system behaviour. Here, an amplify-and-forward (AF) based relay based D2D system is analysed. However, D2D can create a high density of devices in a cellular system. These devices often compete for limited available bandwidth. This competition may cause co-channel interference (CCI) problem in the system. Therefore, the effects of CCI are also included in this work. In [3], authors analysed outage of D2D networks based on the perspective of threshold. Framework to study the outage performance over multichannel conditions and Rayleigh faded links was considered. Authors in [4] proposed outage expressions over Suzuki channels and additive white Gaussian noise. The expressions are solved numerically with the help of Gauss–Legendre and Gauss–Laguerre techniques. In [5], authors discussed outage analysis of D2D for Internet-of-Things (IoTs).

Different from previously mentioned work, our aim here is to present success as well as relay assisted D2D system's outage behaviour with CCI over κ-μ shadowed fading channels [6]. Various rogue wireless devices in the system act as CCI source. D2D and CCI signals' channels are *κ-μ* shadowed faded. It is a versatile distribution with good mathematical characteristics [6]. It can model Rician, Rayleigh and Rician shadowed fading conditions. In order to mitigate the effects of channel fading selection combining (SC) based diversity scheme is also incorporated in the system. Two types of conditions will be presented here, (1) when there is no diversity, (2) when the diversity is used at the receiver side. Success and outage expressions based on the characteristic function technique are derived under different conditions. D2D system model and expressions are given in Section II. In Section III, numerical analysis is given. Section IV concludes this work.

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II. System Model

Relay assisted amplify-and-forward based D2D system is presented in Fig. 1. In the system, *N* co-channel interference (CCI) sources near relay and *L* co-cannel interferers are at the D2D receiver. Independent and non-identically distributed CCI signals are considered. D2D and CCI signals' channels are *κ-μ* shadowed [6] distributed. Probability density function (PDF) of *κ-μ* shadowed link is:

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

where ${}_1F_1(.)$ is confluent hypergeometric function of first kind [7]. *κ-μ* shadowed wireless link has clusters of multipath with a dominant component that can fluctuate randomly due to shadowing. *μ* gives clusters' number, ratio of dominant components' power to the scattered components' power is given by *κ*, shadowing effects are controlled by *m* and average power is presented by Ω. The D2D signal from the D2D source is received by the relay over a *κ-μ* shadowed fading channel. The relay then amplifies and forwards the received D2D signal and CCI signals to the D2D receiver. In this paper, the communication channel from relay to D2D receiver is assumed to be affected by negligible fading effects. Only the effects of path loss are considered on this link. What follows is the analysis of the relay-assisted D2D system without any diversity combining scheme. The overall signal-to-interference power ratio (SIR) is:

$$\frac{S_d}{S_I}=\frac{GP_1x^{-u}y^{-q}h}{Gy^{-q}\sum_{n=1}^{N}P_{I,n}z_n^{-v_n}\beta_n+\sum_{l=1}^{L}P_{I,l}g_l^{-c_l}\alpha_l} \tag{2}$$

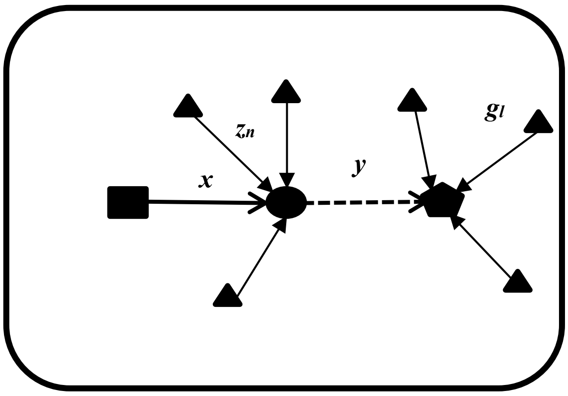

Fig. 1. System Model

D2D source	■
D2D receiver	⬟
Relay	●
Desired D2D signal from D2D source to relay	⟶
Desired D2D signal from relay to D2D receiver	- - ➔
Distance from D2D source to relay	x
Distance from relay to D2D receiver	y
Co-channel Interferer	▲
Signal of CCI	⟶
n-th CCI to relay link length	zn
l-th CCI to receiver link length	gl

In (2), S_d is desired D2D signal's power from relay, total power of CCI S_I, D2D signal power is P_1, D2D path-loss exponent is u and κ-μ shadowed variable is h. n-th CCI power at relay is $P_{I,n}$, distance between the n-th CCI and the relay is z_n, n-th CCI path-loss exponent is v_n and n-th CCI κ-μ shadowed variable is β_n and path-loss exponent for relay to D2D receiver link is q. At the receiver node, l-th CCI path-loss exponent is c_l and α_l is an independent κ-μ shadowed fading variable of the l-th CCI. G is the relay's amplification factor is given in (3). In (3), P_R is the relay amplifying power, $\Omega_d=E[h]$ and $\Omega_n=E[\beta_n]$ are average powers of D2D and n-th CCI signals, respectively.

$$G=\frac{P_R}{P_1x^{-u}\,\Omega_d+\sum_{n=1}^{N}P_{I,n}z_n^{-v_n}\,\Omega_n} \tag{3}$$

Outage probability P_{out} of our system with threshold value R is:

$$P_{out}=\Pr\left(RS_I>S_d\right) \tag{4}$$

where Pr(.) denotes the probability. Based on (4), consider $\theta=RS_I-S_d$. Such that:

$$\theta\begin{cases}>0 & \text{Outage}\\ \le 0 & \text{Acceptable Transmission}\end{cases} \tag{5}$$

P_{out} is derived based on characteristics function (CF) based technique. CF of θ is:

$$\phi_\theta(\omega)=\left(\frac{A_d}{(-C_d)^{\mu_d}}\frac{(W_d-j\omega)^{m_d-\mu_d}}{(X_d-j\omega)^{m_d}}\right)\prod_{n=1}^{N}\left(\frac{A_n}{(-C_n)^{\mu_n}}\frac{(W_n+j\omega)^{m_n-\mu_n}}{(X_n+j\omega)^{m_n}}\right)$$

$$\prod_{l=1}^{L}\left(\frac{A_l}{(-B_l)^{\mu_l}}\frac{(T_l+j\omega)^{m_l-\mu_l}}{(Z_l+j\omega)^{m_l}}\right)$$

Where,

$$A_d=\left(\frac{-\mu_d(1+\kappa_d)}{\Omega_d}\right)^{\mu_d}\left(\frac{m_d}{\mu_d\kappa_d+m_d}\right)^{m_d},\ W_d=\frac{\mu_d(1+\kappa_d)}{\Omega_dC_d},$$

$$X_d=W_d\left(\frac{m_d}{\mu_d\kappa_d+m_d}\right),\ C_d=GP_1x^{-u}y^{-q}$$

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

$$X_n=W_n\left(\frac{m_n}{\mu_n\kappa_n+m_n}\right),C_n=RGP_{I,n}z_n^{-v_n}y^{-q}$$

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

$$Z_l=T_l\left(\frac{m_l}{\mu_l\kappa_l+m_l}\right),B_l=RP_{I,l}g_l^{-c_l}\ \text{and}\ \Omega_l=E[\alpha_l].$$

Also, m_d, μ_d and κ_d are independent κ-μ shadowed parameters of the D2D signal at the receiver. And m_n, μ_n and κ_n are independent κ-μ shadowed parameters of the n-th CCI signal at the relay. Similarly, m_l, μ_l and κ_l are independent κ-μ shadowed parameters of the l-th CCI signal at the relay. Using the CF of θ P_{out} can be found with the help of,

$P_{out} = \frac{1}{2} + \frac{1}{\pi}\int_0^\infty \frac{\mathrm{Im}\left(\phi_\theta(\omega)\right)}{\omega} d\omega$, in the formula imaginary part is Im(.). The P_{out} is

$$P_{out} = \frac{1}{2} + \frac{1}{\pi}\int_0^\infty \left[\begin{array}{l} \left(\frac{A_d}{(-C_d)^{\mu_d}} \frac{\left(W_d^2+\omega^2\right)^{\frac{m_d-\mu_d}{2}}}{\left(X_d^2+\omega^2\right)^{\frac{m_d}{2}}} \right) \prod_{n=1}^{N} \left(\frac{A_n}{(-C_n)^{\mu_n}} \frac{\left(W_n^2+\omega^2\right)^{\frac{m_n-\mu_n}{2}}}{\left(X_n^2+\omega^2\right)^{\frac{m_n}{2}}} \right) \\ \prod_{l=1}^{L} \left(\frac{A_l}{(-B_l)^{\mu_l}} \frac{\left(T_l^2+\omega^2\right)^{\frac{m_l-\mu_l}{2}}}{\left(Z_l^2+\omega^2\right)^{\frac{m_l}{2}}} \right) \frac{\sin\left(\rho_d + \sum_{n=1}^{N}\lambda_n + \sum_{l=1}^{L}\psi_l\right)}{\omega} \end{array} \right] d\omega$$

Where,

$$\rho_d = m_d \tan^{-1}\left(\frac{\omega}{X_d}\right) - (m_d - \mu_d)\tan^{-1}\left(\frac{\omega}{W_d}\right),$$

$$\lambda_n = (m_n - \mu_n)\tan^{-1}\left(\frac{\omega}{W_n}\right) - m_n \tan^{-1}\left(\frac{\omega}{X_n}\right)$$

and $\psi_l = (m_l - \mu_l)\tan^{-1}\left(\frac{\omega}{T_l}\right) - m_l \tan^{-1}\left(\frac{\omega}{Z_l}\right)$.

The success probability P_S is the probability for which SIR exceeds a threshold value R is given as

$$P_S = \frac{1}{2} - \frac{1}{\pi}\int_0^\infty \left[\begin{array}{l} \left(\frac{A_d}{(-C_d)^{\mu_d}} \frac{\left(W_d^2+\omega^2\right)^{\frac{m_d-\mu_d}{2}}}{\left(X_d^2+\omega^2\right)^{\frac{m_d}{2}}} \right) \prod_{n=1}^{N} \left(\frac{A_n}{(-C_n)^{\mu_n}} \frac{\left(W_n^2+\omega^2\right)^{\frac{m_n-\mu_n}{2}}}{\left(X_n^2+\omega^2\right)^{\frac{m_n}{2}}} \right) \\ \prod_{l=1}^{L} \left(\frac{A_l}{(-B_l)^{\mu_l}} \frac{\left(T_l^2+\omega^2\right)^{\frac{m_l-\mu_l}{2}}}{\left(Z_l^2+\omega^2\right)^{\frac{m_l}{2}}} \right) \frac{\sin\left(\rho_d + \sum_{n=1}^{N}\lambda_n + \sum_{l=1}^{L}\psi_l\right)}{\omega} \end{array} \right] d\omega$$

Now, the analysis will be presented when a selection combining (SC) based diversity scheme is considered at the receiver. A B diversity SC receiver is considered. The SIR of the b-th branch will be

$$\frac{S_{SC,b}}{S_I} = \frac{G P_1 x^{-u} y^{-q} h_b}{G y^{-q} \sum_{n=1}^{N} P_{I,n} z_n^{-v_n} \beta_n + \sum_{l=1}^{L} P_{I,l} g_l^{-c_l} \alpha_l} \tag{6}$$

where $S_{SC,b}$ is the received power in the b-th diversity branch, h_b is the independent κ-μ shadowed variable in the b-th branch. Outage probability P_{out} will be

$$P_{out} = \Pr\left(R S_I > S_{SC,MAX}\right) \tag{7}$$

where

$S_{SC,MAX} = \max_{b=1,2,\dots,B}\left(S_{SC,b}\right)$ Consider, $\theta = R S_I - S_{SC,b}$. The CF of θ is

$$\sigma_\theta(\omega) = \left(\frac{A_{d,b}}{(-C_d)^{\mu_{d,b}}} \frac{\left(W_{d,b} - j\omega\right)^{m_{d,b}-\mu_{d,b}}}{\left(X_{d,b} - j\omega\right)^{m_{d,b}}} \right) \prod_{n=1}^{N} \left(\frac{A_n}{(-C_n)^{\mu_n}} \frac{\left(W_n + j\omega\right)^{m_n-\mu_n}}{\left(X_n + j\omega\right)^{m_n}} \right) \times \prod_{l=1}^{L} \left(\frac{A_l}{(-B_l)^{\mu_l}} \frac{\left(T_l + j\omega\right)^{m_l-\mu_l}}{\left(Z_l + j\omega\right)^{m_l}} \right)$$

Where

$$A_{d,b} = \left(\frac{-\mu_{d,b}\left(1+\kappa_{d,b}\right)}{\Omega_{d,b}} \right)^{\mu_{d,b}} \left(\frac{m_{d,b}}{\mu_{d,b}\kappa_{d,b} + m_{d,b}} \right)^{m_{d,b}}, \quad W_{d,b} = \frac{\mu_{d,b}\left(1+\kappa_{d,b}\right)}{\Omega_{d,b} C_{d,b}},$$

$X_{d,b} = W_{d,b}\left(\frac{m_{d,b}}{\mu_{d,b}\kappa_{d,b} + m_{d,b}} \right)$ and $\Omega_{d,b} = E\left[h_b\right]$

Also, $m_{d,b}$, $\mu_{d,b}$ and $\kappa_{d,b}$ are independent κ-μ shadowed parameters of the D2D signal in the b-th diversity branch of the receiver. With the help of the CF of θ, the overall outage probability of a SC based relay-assisted D2D system is given as

$$P_{out} = \prod_{b=1}^{B} \left(\frac{1}{2} + \frac{1}{\pi}\int_0^\infty \left[\begin{array}{l} \left(\frac{A_{d,b}}{(-C_d)^{\mu_{d,b}}} \frac{\left(W_{d,b}^2+\omega^2\right)^{\frac{m_{d,b}-\mu_{d,b}}{2}}}{\left(X_{d,b}^2+\omega^2\right)^{\frac{m_{d,b}}{2}}} \right) \prod_{n=1}^{N} \left(\frac{A_n}{(-C_n)^{\mu_n}} \frac{\left(W_n^2+\omega^2\right)^{\frac{m_n-\mu_n}{2}}}{\left(X_n^2+\omega^2\right)^{\frac{m_n}{2}}} \right) \\ \prod_{l=1}^{L} \left(\frac{A_l}{(-B_l)^{\mu_l}} \frac{\left(T_l^2+\omega^2\right)^{\frac{m_l-\mu_l}{2}}}{\left(Z_l^2+\omega^2\right)^{\frac{m_l}{2}}} \right) \frac{\sin\left(\rho_{d,b} + \sum_{n=1}^{N}\lambda_n + \sum_{l=1}^{L}\psi_l\right)}{\omega} \end{array} \right] d\omega \right)$$

Where

$$\rho_{d,b} = m_{d,b} \tan^{-1}\left(\frac{\omega}{X_{d,b}}\right) - \left(m_{d,b} - \mu_{d,b}\right)\tan^{-1}\left(\frac{\omega}{W_{d,b}}\right)$$

Similarly, the success probability is given as

$$P_S = 1 - \prod_{b=1}^{B} \left(\frac{1}{2} + \frac{1}{\pi}\int_0^\infty \left[\begin{array}{l} \left(\frac{A_{d,b}}{(-C_d)^{\mu_{d,b}}} \frac{\left(W_{d,b}^2+\omega^2\right)^{\frac{m_{d,b}-\mu_{d,b}}{2}}}{\left(X_{d,b}^2+\omega^2\right)^{\frac{m_{d,b}}{2}}} \right) \prod_{n=1}^{N} \left(\frac{A_n}{(-C_n)^{\mu_n}} \frac{\left(W_n^2+\omega^2\right)^{\frac{m_n-\mu_n}{2}}}{\left(X_n^2+\omega^2\right)^{\frac{m_n}{2}}} \right) \\ \prod_{l=1}^{L} \left(\frac{A_l}{(-B_l)^{\mu_l}} \frac{\left(T_l^2+\omega^2\right)^{\frac{m_l-\mu_l}{2}}}{\left(Z_l^2+\omega^2\right)^{\frac{m_l}{2}}} \right) \frac{\sin\left(\rho_{d,b} + \sum_{n=1}^{N}\lambda_n + \sum_{l=1}^{L}\psi_l\right)}{\omega} \end{array} \right] d\omega \right)$$

III. Numerical Analysis

Numerical analysis of relay assisted κ-μ shadowed faded D2D system is presented. Table I shows the parameters whose values are fixed for the numerical analysis.

TABLE I
PARAMETERS AND NUMERIC VALUES

Parameters	Values
N	3
L	3
P_R	20.8 dBm
u	3 (for Figs. 2 to 12)
P_1	20.8 dBm
R	10 dBm
$P_{I,n}$	16.99 dBm, 19.031 dBm, 18.136 dBm
v_n	3.5, 2.7, 2.9
z_n	25 m, 30 m, 35 m
$P_{I,l}$	19.35 dBm, 19.3 dBm, 19.782 dBm
c_l	3.2, 3.0, 3.3
g_l	30 m, 35 m, 30 m

In Fig. 2 outage variations with different source and relay distance is given. Also, $m_d = 3$, $\kappa_d = 0.1$, $q = 3.5$, $y = 15$ m, $\mu_n = [1, 2, 4]$, $\mu_l = [2, 3, 3]$, $\kappa_n = [2.7, 3.7, 3]$, $\kappa_l = [2, 4.1, 2]$, $m_n = [3, 2, 1]$, and $m_l = [4, 4, 4]$. From the figure, it is clear that as the D2D source moves away from the relay the outage performance degrades. Furthermore, by increasing clusters' number the outage is improved

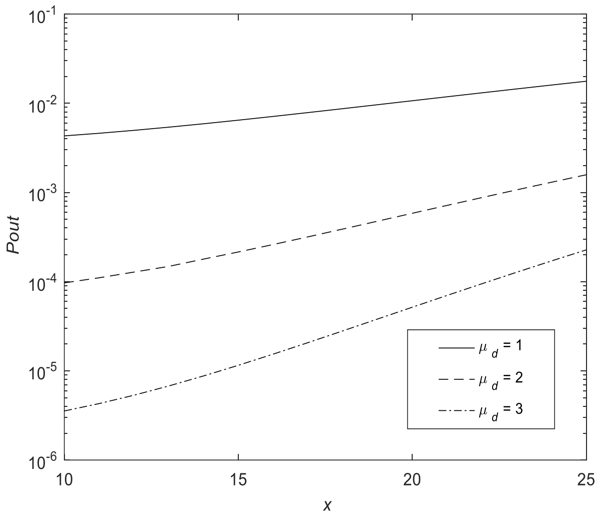

Fig. 2. Outage with different cluster numbers

Fig. 3 shows the performance with various shadowing conditions of the D2D signal. It is assumed that $\mu_d = 2$, $\kappa_d = 3$, $q = 3.5$, $y = 15$ m, $\mu_n = [1, 2, 4]$, $\mu_l = [2, 3, 3]$, $\kappa_n = [2.7, 3.7, 3]$, $\kappa_l = [2, 4.1, 2]$, $m_n = [3, 2, 1]$, and $m_l = [4, 2, 1]$. Outage is improved when the values of m_d are increased.

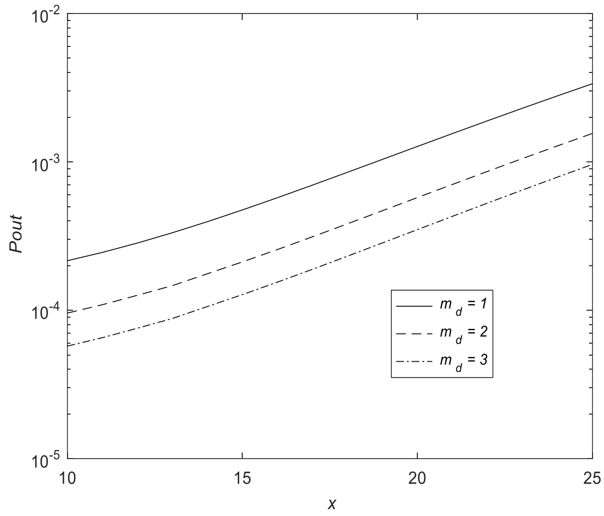

Fig. 3. Outage variations under different shadowing conditions

Fig. 4 shows the performance with varying κ_d of D2D signal. With $\mu_d = 2$, $m_d = 3$, $q = 3.5$, $y = 15$ m, $\mu_n = [1, 2, 4]$, $\mu_l = [2, 3, 3]$, $\kappa_n = [2.7, 3.7, 3]$, $\kappa_l = [2, 4.1, 2]$, $m_n = [3, 2, 1]$, and $m_l = [4, 2, 1]$. From the figure, it is clear that as the value of κ_d increases, P_{out} is improved because of better system SIR.

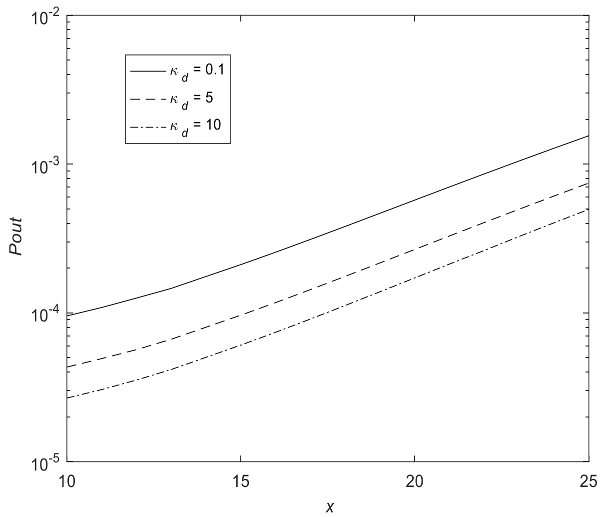

Fig. 4. Outage performance with various κ_d values of the D2D signal

Fig. 5 shows the performance with varying number of clusters of CCI at the relay. Also, $\mu_d = 2$, $m_d = 3$, $\kappa_d = 3$, $q = 3.5$, $y = 15$ m, $\mu_l = [2, 3, 3]$, $\kappa_n = [2.7, 3.7, 3]$, $\kappa_l = [2, 4.1, 2]$, $m_n = [3, 2, 1]$ and $m_l = [4, 2, 1]$. D2D outage is almost unaffected by varying the number of clusters of CCI signals at the relay.

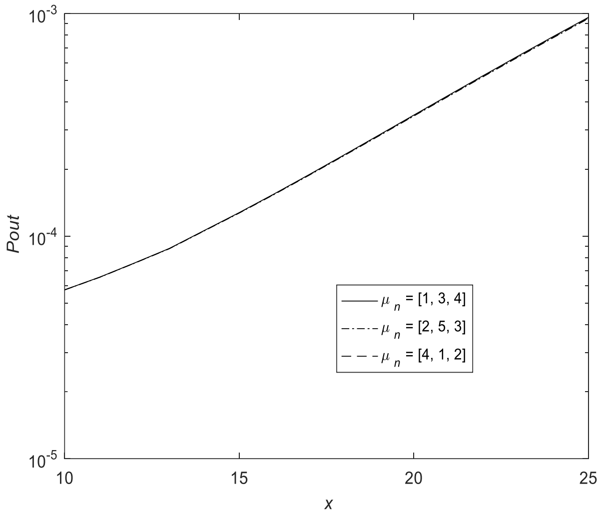

Fig. 5. Performance with varying number of clusters of CCI signals at the relay

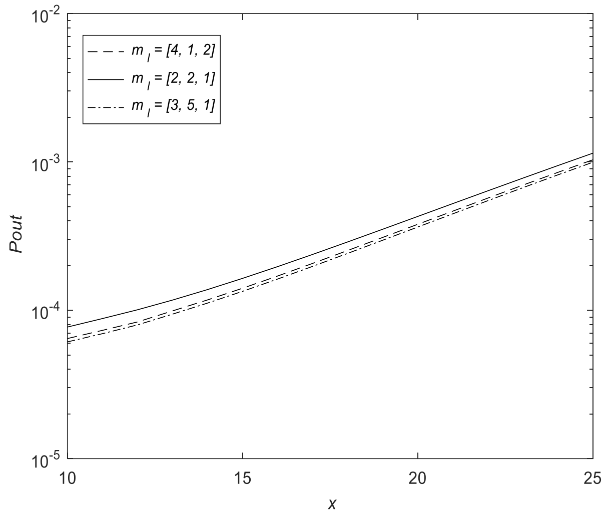

Fig. 7. Performance with varying CCI shadowing conditions at the D2D receiver

Fig. 6 shows the performance with various κ_l of CCI signals at the D2D receiver. With $y = 15$ m, $\mu_d = 2$, $m_d = 3$, $\kappa_d = 3$, $q = 3.5$, $\mu_n = [4, 2, 1]$, $\mu_l = [2, 3, 4]$, $\kappa_n = [2.7, 3.7, 3]$, $m_n = [3, 2, 1]$, and $m_l = [4, 2, 1]$. It is observed that various values of κ_l of CCI signals at the relay have negligible effect on the D2D P_{out}. Fig. 7 shows the performance with various shadowing conditions of the CCI signals at the D2D receiver. With $\mu_d = 2$, $m_d = 3$, $\kappa_d = 3$, $q = 3.5$, $y = 15$ m, $\mu_n = [4, 2, 1]$, $\mu_l = [2, 3, 4]$, $\kappa_n = [2.7, 3.7, 3]$, $\kappa_l = [2, 3, 0.1]$, and $m_n = [3, 2, 1]$. It is observed that the various shadowing conditions of the CCI at the D2D receiver have negligible effect on the performance. Fig. 8 gives success analysis under varying channel path-loss conditions from relay to the D2D receiver. With $\mu_d = 2$, $m_d = 3$, $\kappa_d = 3$, $y = 40$ m, $\mu_n = [4, 2, 1]$, $\mu_l = [2, 3, 4]$, $\kappa_n = [2.7, 3.7, 3]$, $\kappa_l = [2, 3, 0.1]$, $m_n = [3, 2, 1]$, and $m_l = [2, 1, 5]$. P_S is improved when the severity of the path-loss is reduced.

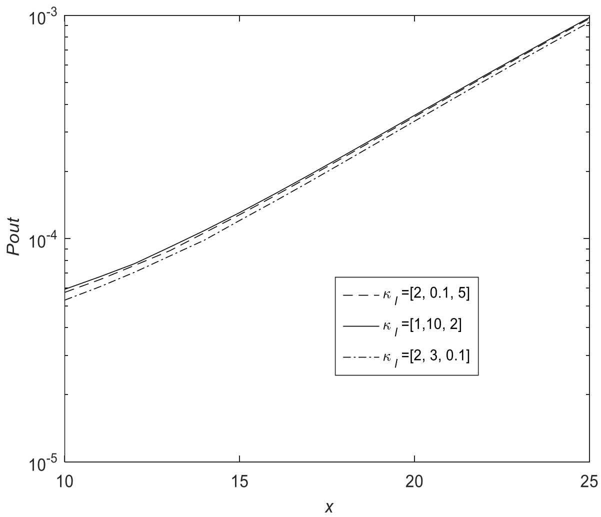

Fig. 6. Outage with various CCI κ_l values at the D2D receiver

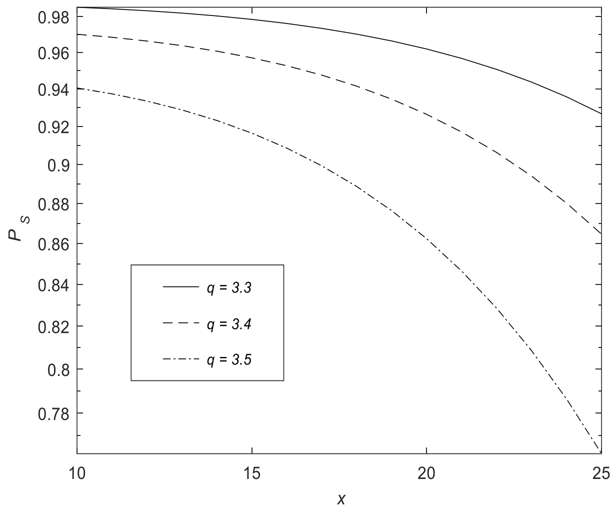

Fig. 8. Success performance with various path-loss conditions

Fig. 9 gives outage analysis with SC diversity scheme. The values of various system parameters are $q = 3.5$, $y = 30$ m, $\mu_n = [4, 2, 1]$, $\mu_l = [2, 3, 1]$, $\kappa_n = [2, 3, 4]$, $\kappa_l = [2, 3, 1]$, $m_n = [3, 2, 1]$, and $m_l = [2, 1, 5]$. For $B = 2$, $\mu_d = [2, 3]$, $m_d = [3, 1]$, and $\kappa_d = [1, 2]$. For $B = 3$, $\mu_d = [2, 3, 2]$, $m_d = [3, 1, 3]$, and $\kappa_d = [1, 2, 2]$. Outage performance is improved when the number of diversity branches are increased.

Fig. 10, gives the outage performance with SC diversity when the number of clusters in each diversity branch is increased. The values of different parameters are $q = 3.5$, $y = 30$ m, $\mu_n = [4, 2, 1]$, $\mu_l = [2, 3, 1]$, $\kappa_n = [2, 3, 4]$, $\kappa_l = [2, 3, 1]$, $m_n = [3, 2, 1]$, and $m_l = [2, 1, 5]$. For $B = 2$, $m_d = [3, 1]$, and $\kappa_d = [1, 2]$. It is obvious from the figure that as the number of clusters is increased the outage performance is also improved.

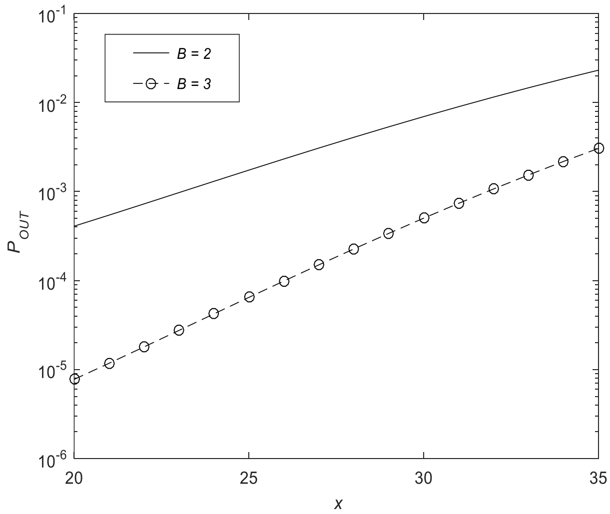

Fig. 9. Outage performance with varying diversity conditions at the D2D receiver

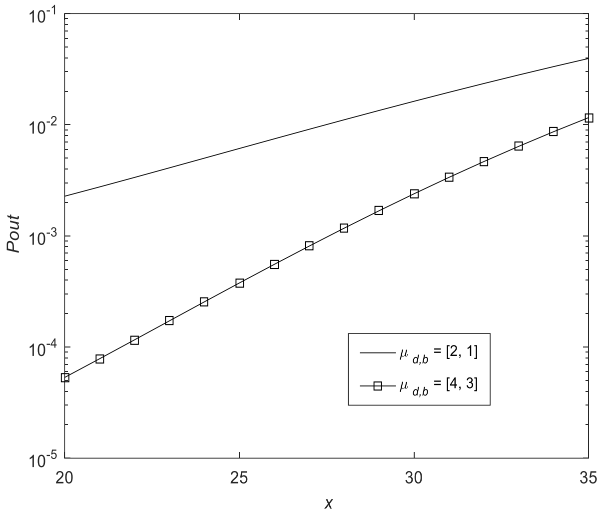

Fig. 10. Outage performance with varying number of clusters in each diversity branch

Fig. 11, shows the performance when the value $\kappa_{d,b}$ is changed in each diversity branch. With q = 3.5, y = 30 m, μ_n = [4, 2, 1], μ_l = [2, 3, 1], κ_n = [2, 3, 4], κ_l = [2, 3, 1], m_n = [3, 2, 1], and m_l = [2, 1, 5]. For B = 2, m_d = [3, 1], and μ_d = [2, 3]. Figure shows improvement in outage performance as the value of $\kappa_{d,b}$ is increased in each branch. Fig. 12, shows comparison of performance when the value of number of clusters is changed in each diversity branch for the cases B = 2 and B = 3. With q = 3.5, y = 30 m, μ_n = [4, 2, 1], μ_l = [2, 3, 1], κ_n = [2, 3, 4], κ_l = [2, 3, 1], m_n = [3, 2, 1], and m_l = [2, 1, 5]. For B = 2, m_d = [3, 2], and κ_d = [2, 3]. For B = 3, m_d = [3, 2, 3], and κ_d = [2, 3, 2]. From the figure it is clear that when the number of clusters for the diversity branch case B = 3 is decreased the overall outage performance is degraded as compared to B = 2 case.

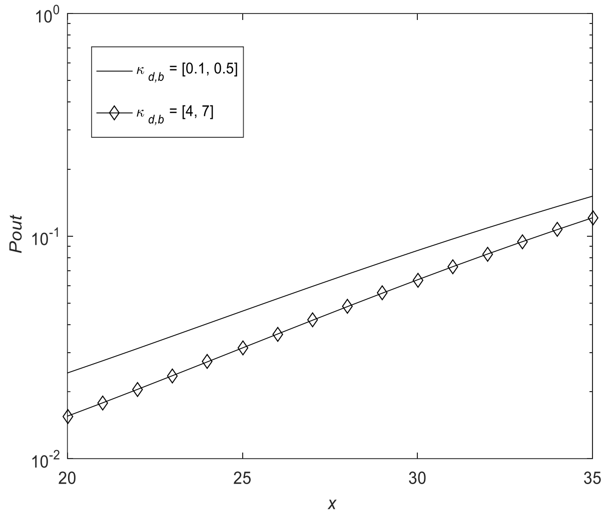

Fig. 11. Outage performance with varying $\kappa_{d,b}$ in diversity branches

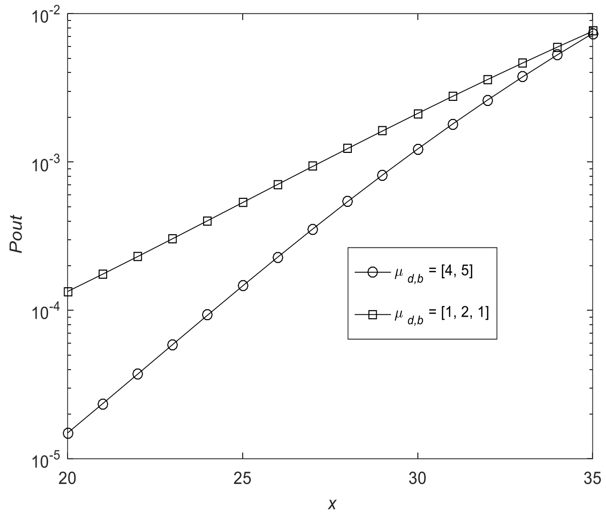

Fig. 12. Outage performance comparison with various number of clusters in each diversity branch for B = 2 and B = 3 cases

Fig. 13, shows comparison of performance when the values of path-loss exponents are changed for both paths for the cases B = 2 and B = 3. With y = 30 m, μ_n = [4, 2, 1], μ_l = [2, 3, 1], κ_n = [2, 3, 4], κ_l = [2, 3, 1], m_n = [3, 2, 1], and m_l = [2, 1, 5]. For B = 2, m_d = [3, 2], μ_d = [4, 3] and κ_d = [2, 3]. For B = 3, m_d = [3, 2, 3], μ_d = [4, 3, 2] and κ_d = [2, 3, 2]. From the figure it is obvious that when the values of path-loss exponents are increased for the B = 3 case as compared to B = 2 outage performance is degraded. Fig. 14, shows comparison of outages when the values of distance between relay to D2D receiver is varied for the cases B = 2 and B = 3. With u = 3, q = 3.3, μ_n = [4, 2, 1], μ_l = [2, 3, 1], κ_n = [2, 3, 4], κ_l = [2, 3, 1], m_n = [3, 2, 1], and m_l = [2, 1, 5]. For B = 2, m_d = [3, 2], μ_d = [4, 3] and κ_d = [2, 3]. For B = 3, m_d = [3, 2, 3], μ_d = [4, 3, 2] and κ_d = [2, 3, 2]. Figure shows that when the distance between relay to D2D relay is increased for the B = 3 case as compared to B = 2 outage performance of the system is degraded.

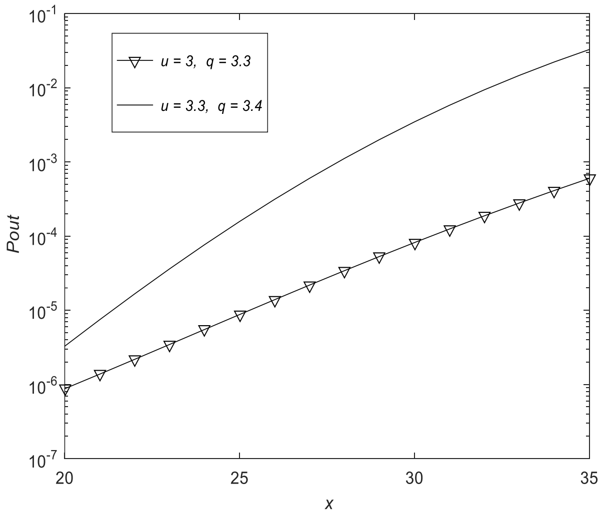

Fig. 13. Outage performance comparison with increased path-loss exponents for $B = 3$ case as compared to $B = 2$ case

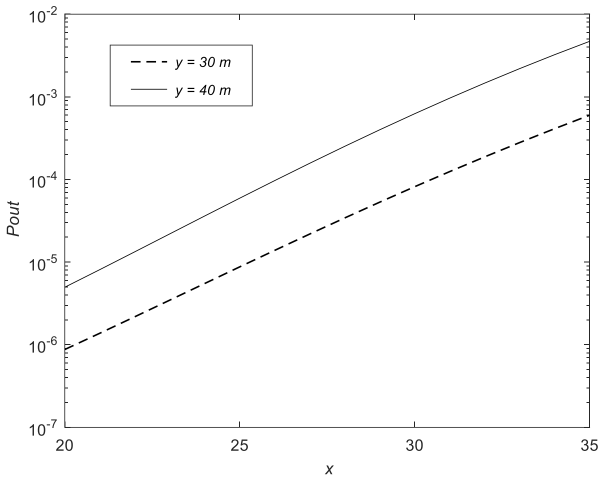

Fig. 14. Outage performance comparison with increased distance from relay to D2D receiver for $B = 3$ case as compared to $B = 2$ case

IV CONCLUSION

Success and outage analysis of relay-assisted D2D systems with κ-μ shadowed faded channels are studied. Effects of CCI at the replay and D2D receiver on the performances are also presented. Outage and success probabilities expressions are derived based on a characteristic function (CF) based technique. Selection combining based diversity scheme is also considered. These outage and success probabilities expressions are functions of various interference conditions, channel fading and shadowing conditions, and various path-loss parameters of the system. It was observed from the numerical analysis that the fading and shadowing, and path-loss affect the D2D performance. Also, variations in the fading and shadowing conditions of the CCI showed negligible impact on the D2D system. It was also observed that by decreasing the number of clusters, the receiver with higher number of diversity branches showed degraded performance as compare to one with lesser number of diversity branches.

REFERENCES

[1] L. Ma, X. Deng, J. Wang, Y. Huang and F. Shi, "Downlink Resource Sharing in Multichannel Device-to-Device Communication," in *IEEE Wireless Communications Letters*, vol. 8, no. 3, pp. 741-744, June 2019. http://doi.org/10.1109/LWC.2018.2890599

[2] Y. Chen, B. Ai, Y. Niu, R. He, Z. Zhong and Z. Han, "Resource Allocation for Device-to-Device Communications in Multi-Cell Multi-Band Heterogeneous Cellular Networks," in *IEEE Transactions on Vehicular Technology*, vol. 68, no. 5, pp. 4760-4773, May 2019. DOI: http://doi.org/10.1109/TVT.2019.2903858

[3] Liu, H. Nishiyama, N. Kato and J. Guo, "On the Outage Probability of Device-to-Device-Communication-Enabled Multichannel Cellular Networks: An RSS-Threshold-Based Perspective," in *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 1, pp. 163-175, Jan. 2016. http://doi.org/10.1109/JSAC.2015.2452492

[4] H. Ghavami and S. Shirvani Moghaddam, "Outage Probability of Device to Device Communications Underlaying Cellular Network in Suzuki Fading Channel," in *IEEE Communications Letters*, vol. 21, no. 5, pp. 1203-1206, May 2017. http://doi.org/10.1109/LCOMM.2017.2655042

[5] B. M. El Halawany, R. Ruby and K. Wu, "D2D Communication for Enabling Internet-of-Things: Outage Probability Analysis," in *IEEE Transactions on Vehicular Technology*, vol. 68, no. 3, pp. 2332-2345, March 2019. http://doi.org/10.1109/TVT.2019.2891648

[6] J. F. Paris, "Statistical Characterization of κ-μ Shadowed Fading," in *IEEE Transactions on Vehicular Technology*, vol. 63, no. 2, pp. 518-526, Feb. 2014. http://doi.org/10.1109/TVT.2013.2281213

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

[8] Y. Ni, X. Wang, S. Jin, K. Wong, H. Zhu and N. Zhang, "Outage probability of device-to-device communication assisted by one-way amplify-and-forward relaying," in *IET Communications*, vol. 9, no. 2, pp. 271-282, 22 1 2015. http://doi.org/10.1049/iet-com.2014.0686