Performance Analysis of D2D Communication System over Fisher-Snedecor F Channels

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Summary
In this paper, the performance of Device-to-Device (D2D) communication system is investigated over a novel composite fading channel Fisher-Snedecor *F*. Multiple co-channel interference (CCI) signals are assumed to be affecting the D2D communication system. Nakagami fading channel is considered for the CCI signals. First, an expression for the probability density function (PDF) of the signal-to-interference ratio (SIR) of the D2D system is presented. The PDF is then employed for the analytical analysis of outage probability, success probability, outage capacity, channel capacity and symbol error rate (SER). Numerical results show the effects of shadowing and fading parameters of the D2D channel, CCI channel fading parameters and path-loss on the performance of the D2D system. Moreover, selection combining (SC) scheme is also considered to combat fading.

Key words:
Co-Channel Interference, Device-to-Device, Fisher-Snedecor F, Outage Capacity, Success Probability.

1. Introduction

Device-to-Device (D2D) communications is an emerging technology in 5th generation (5G) cellular communication systems. In this system mobile terminals are allowed to route information between them directly bypassing the base station (BS) [1-3]. Therefore, D2D communication has been categorized as a promising technology to off-load high data traffic in future cellular networks. D2D communications can be used for the applications like online gaming, multimedia file sharing and video calls that need high data rate [4-6]. Wireless channel bandwidth scarcity and absence of co-ordination between various wireless devices often cause co-channel interference (CCI) problem in the D2D system. Therefore, CCI effects should be considered while analyzing D2D communication system [7-8]. The metrics such as outage probability, success probability, outage capacity, channel capacity and symbol error rate (SER) are considered to analyze performance of communication systems. In [9], authors have designed resource allocation scheme for multiple D2D cluster multicast communications underlay cellular networks and analyzed outage over Rayleigh fading channels. Authors in [10], have analyzed the outage performance of D2D system over Gamma fading channel in presence of multiple co-channel interferers. Using stochastic geometry analysis, success probability of D2D systems over Rician fading channels is analyzed in [11]. Authors in [12], have proposed an algorithm to maximize channel capacity of D2D systems while minimizing power consumption. They also analyzed channel capacity over Rician faded channels. In [13], authors have proposed resource allocation scheme for multicarrier D2D video transmission system and analyzed SER performance.

The goal of this paper is to investigate outage probability, success probability, outage capacity, channel capacity and symbol-error-rate (SER) performances of D2D system. The desired D2D signals are affected by both fading and shadowing. A novel composite model Fisher-Snedecor *F* is considered for the desired D2D channel. This distribution can be used for line of sight (LOS) and non-LOS communication scenarios in indoor and outdoor. In addition, the Fisher-Snedecor *F* distribution is a generalized distribution. It can model Nakagami distribution, Rayleigh distribution and one-sided Gaussian distribution. This distribution can efficiently model various conditions of fading and shadowing [14-15]. The channel for the co-channel interference (CCI) is assumed to be Nakagami. Selection combining (SC) diversity scheme is also employed to mitigate the effects of fading. The organization of rest of the paper is as follows. The system model and expressions for the probability density function (PDF) of signal-to-interference ratio (SIR) of the D2D system is presented in Section 2. The expressions of outage probability, success probability, outage capacity, channel capacity and SER are also presented in Section 2. In Section 3, numerical analysis is presented. Finally, this paper is concluded in Section 4.

2. System Model

A pair of device-to-device (D2D) devices sharing information over a direct link is shown in Fig. 1. There are *N* co-channel interferers in the system. The co-channel interference (CCI) signals are generated by various wireless devices that has lost proper coordination with the desired D2D communication system. In this work, for the sake of keeping the mathematical expression easy-to-compute following assumptions are considered: 1) various co-channel interferers are present at approximately equal

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distance from the desired D2D pair's receiver; 2) all co-channel interferers are considered independent and identically distributed.

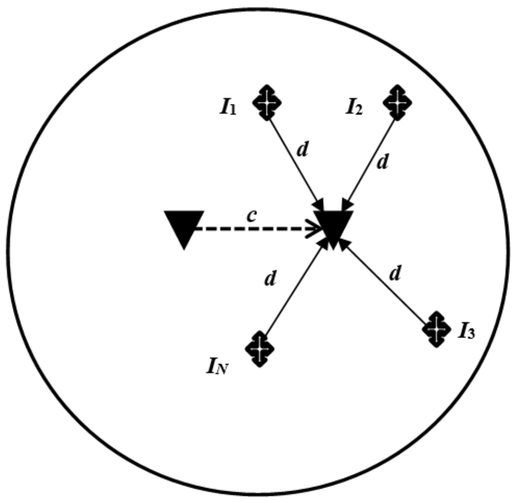

Fig. 1 System layout

Table 1: Nomenclature

D2D Device	▼
n-th Co-Channel Interferer	✣
Desired D2D Signal	- - - ->
Distance Between D2D Devices	***c***
Distance Between an i-th Co-Channel Interferer and the D2D Receiver	***d***
Co-channel Interference Signal	⟶

Nakagami channel is considered for the co-channel interference (CCI) signals. The probability density function (PDF) of Nakagami distribution is

$$f_X(x) = \frac{2}{\Gamma(\delta)}\left(\frac{\delta}{\Omega}\right)^{\delta} x^{2\delta-1}\exp\left(\frac{-\delta}{\Omega}x^2\right), \quad \delta \ge \frac{1}{2},\ x > 0$$

where δ is the fading parameter that controls the severity of the channel fading, Ω is the average power and $\Gamma(.)$ is the gamma function. The channel for the D2D communication signal is assumed to be Fisher-Snedecor F distributed. The PDF of Fisher-Snedecor F distribution is [16]

$$f_Y(y) = \frac{2m^m (m_s\phi)^{m_s} y^{2m-1}}{B(m,m_s)\left(my^2 + m_s\phi\right)^{m+m_s}}$$

where m_s is the shadowing parameter. As the value of m_s approaches zero severe shadowing is observed. As value of m_s increases the shadowing effects decreases. Moreover, m controls the fading severity and ϕ is the average power. Path-loss is also an important reason for the performance degradation in communication systems [17]. To consider the path-loss effects a simplified path-loss model is considered. The received power of the D2D 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 the D2D pair, λ is the wavelength, a is the path-loss exponent $(2 \le a \le 5)$ and c_0 is the reference distance (1 to 100 meters). The power of the i-th co-channel interferer at the D2D receiver is

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

In (2), P_2 is the CCI signal power, d is the distance between the receiver of D2D pair and the i-th co-channel interferer, b is the path-loss exponent of CCI signals and d_0 is the reference distance. With the help of expressions (1) and (2) the SIR of D2D system is

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

where h is the independent Fisher-Snedecor F fading variable of the D2D signal, α_i is an independent Nakagami fading variable of the i-th co-channel interferer and N is the number of co-channel interferers in the system. The PDF of the SIR of D2D communication system, i.e., $f_\gamma(r)$, is obtained by using the formula, $f_\gamma(r) = \int_0^\infty x\, f_S(rx)\, f_I(x)\, dx$, as

$$f_\gamma(r) = \int_0^\infty x \underbrace{\frac{m^m (m_s\phi)^{m_s}(xr)^{m-1}}{B(m,m_s)(mrx+m_s\phi)^{m+m_s}}}_{f_S(rx)} \times \underbrace{\frac{x^{\delta_T-1}\exp(\frac{-x}{\omega})}{\omega^{\delta_T}\Gamma(\delta_T)}}_{f_I(x)} dx,$$

$$f_\gamma(r) = \left(\frac{m_s\phi}{m\omega}\right)^{m_s}\frac{r^{-m_s-1}\Gamma(m+\delta_T)}{B(m,m_s)\Gamma(\delta_T)} \times U\left[m+m_s, 1+m_s-\delta_T, \frac{m_s\phi}{m\omega r}\right] \tag{4}$$

where m_s is the shadowing parameter and m is the fading parameter of the desired D2D signal, respectively. $U(.)$ is KummerU function [18] and $\delta_T = N \times \delta$. Also, $\omega = g/\delta$.

2.1 Outage Probability

The outage probability is the probability that the SIR of a communication system falls below a predefined SIR threshold R. The expression for outage probability of the D2D communication system is

$$P_{out} = \int_0^R \left(\frac{m_s\phi}{m\omega}\right)^{m_s} \frac{r^{-m_s-1}\Gamma(m+\delta_T)}{B(m,m_s)\Gamma(\delta_T)} \times U\left[m+m_s, 1+m_s-\delta_T, \frac{m_s\phi}{m\omega r}\right]dr \tag{5}$$

2.2 Success Probability

Success probability is the probability that the SIR of a system exceeds a predefined SIR threshold R. The expression for the success probability of the D2D communication system is

$$SP = \int_R^\infty \left(\frac{m_s\phi}{m\omega}\right)^{m_s} \frac{r^{-m_s-1}\Gamma(m+\delta_T)}{B(m,m_s)\Gamma(\delta_T)} \times U\left[m+m_s, 1+m_s-\delta_T, \frac{m_s\phi}{m\omega r}\right]dr \tag{6}$$

2.3 Outage Capacity

Outage capacity is described as the probability that the instantaneous channel capacity of a system falls below a predefined threshold C_{th}. The expression for the PDF of instantaneous channel capacity, i.e., C_γ is

$$f_{C_\gamma}(c_\gamma) = \left(\frac{m_s\phi}{m\omega}\right)^{m_s} \frac{2^{c_\gamma}\ln(2)\Gamma(m+\delta_T)}{\left(2^{c_\gamma}-1\right)^{m_s+1} B(m,m_s)\Gamma(\delta_T)} \times U\left[m+m_s, 1+m_s-\delta_T, \frac{m_s\phi}{m\omega\left(2^{c_\gamma}-1\right)}\right] \tag{7}$$

With the help of (7), the expression for the outage capacity is

$$f_{C_\gamma}(c_\gamma) = \int_0^{C_{th}} \left(\frac{m_s\phi}{m\omega}\right)^{m_s} \frac{2^{c_\gamma}\ln(2)\Gamma(m+\delta_T)}{\left(2^{c_\gamma}-1\right)^{m_s+1} B(m,m_s)\Gamma(\delta_T)} \times U\left[m+m_s, 1+m_s-\delta_T, \frac{m_s\phi}{m\omega\left(2^{c_\gamma}-1\right)}\right]dc_\gamma \tag{8}$$

2.4 Channel Capacity

The expression for the channel capacity of the D2D communication system is

$$C = \int_0^\infty \log_2(1+r) \left(\frac{m_s\phi}{m\omega}\right)^{m_s} \frac{r^{-m_s-1}\Gamma(m+\delta_T)}{B(m,m_s)\Gamma(\delta_T)} \times U\left[m+m_s, 1+m_s-\delta_T, \frac{m_s\phi}{m\omega r}\right]dr \tag{9}$$

2.5 Symbol Error Rate

The expression for the symbol error rate (SER) performance of M-ray phase shift keying (M-PSK) modulated D2D system is

$$P_{MPSK} = \int_0^{\frac{(M-1)\pi}{M}} \left[\int_0^\infty \exp\left(-\left[\frac{\sin\frac{\pi}{M}}{\sin\theta}\right]^2 r\right) \frac{r^{-m_s-1}\Gamma(m+\delta_T)}{B(m,m_s)\Gamma(\delta_T)} \times \left(\frac{m_s\phi}{m\omega}\right)^{m_s} U\left[m+m_s, 1+m_s-\delta_T, \frac{m_s\phi}{m\omega r}\right]dr\right]d\theta \tag{10}$$

The SER expression for D2D communication system incorporated square M-Ray quadrature amplitude modulation (M-QAM) scheme is shown in (11).

$$P_{MQAM} = \frac{4\left(\sqrt{M}-1\right)}{\pi\sqrt{M}}\left[\int_0^{\frac{\pi}{2}}\left[\int_0^\infty \exp\left(-\frac{3r}{2(M-1)\sin^2(\theta)}\right) f_\gamma(r)dr\right]d\theta - \frac{\left(\sqrt{M}-1\right)}{\sqrt{M}}\int_0^{\frac{\pi}{4}}\left[\int_0^\infty \exp\left(-\frac{3r}{2(M-1)\sin^2(\theta)}\right) f_\gamma(r)dr\right]d\theta\right] \tag{11}$$

2.6 Outage Probability with SC Technique

Diversity techniques are applied to improve the communication system performance in fading scenarios. Selection Combining (SC) is one of many diversity techniques [19]. In this paper SC diversity is considered in the D2D system to counter the effects of fading. The SIR of z-th branch of a Z branch SC is

$$\gamma_z = \frac{h_z^2}{g\sum_{i=1}^N \alpha_i^2}, \qquad g = \frac{P_2}{P_1}\left(\frac{c^a}{d^b}\right)\frac{(c_0)^{2-a}}{(d_0)^{2-b}}, \tag{12}$$

where h_z is the independent Fisher-Snedecor F fading variable of z-th diversity branch D2D signal. The outage probability expression for independent but non-identically distributed h_z is

$$P_{out,SC} = \Pr\left(\max[\gamma_1, \gamma_2, \cdots, \gamma_Z] \le R\right)$$

where Pr (.) is probability. The $P_{out,SC}$ can be written as

$$P_{out,SC} = \prod_{z=1}^{Z}\left[\int_0^R \left(\frac{m_{s_z}\phi_z}{m_z\omega}\right)^{m_{s_z}} \frac{r^{-m_{s_z}-1}\Gamma(m_z+\delta_T)}{B(m_z, m_{s_z})\Gamma(\delta_T)} \times U\left[m_z + m_{s_z}, 1+m_{s_z}-\delta_T, \frac{m_{s_z}\phi_z}{m_z\omega r}\right]dr\right] \tag{13}$$

Outage probability expression for IID h_z is

$$P_{out,SC} = \left[\int_0^R \left(\frac{m_{s_z}\phi_z}{m_z\omega}\right)^{m_{s_z}} \frac{r^{-m_{s_z}-1}\Gamma(m_z+\delta_T)}{B(m_z, m_{s_z})\Gamma(\delta_T)} \times U\left[m_z + m_{s_z}, 1+m_{s_z}-\delta_T, \frac{m_{s_z}\phi_z}{m_z\omega r}\right]dr\right]^Z \tag{14}$$

2.7 Success Probability with SC Technique

The expression for success probability for the case of independent but non-identically distributed h_z is

$$SP_{SC} = 1-\prod_{z=1}^{Z}\left[\int_0^R \left(\frac{m_{s_z}\phi_z}{m_z\omega}\right)^{m_{s_z}} \frac{r^{-m_{s_z}-1}\Gamma(m_z+\delta_T)}{B(m_z, m_{s_z})\Gamma(\delta_T)} \times U\left[m_z + m_{s_z}, 1+m_{s_z}-\delta_T, \frac{m_{s_z}\phi_z}{m_z\omega r}\right]dr\right] \tag{15}$$

Expression of success probability in case of IID h_z is

$$SP_{SC} = 1-\left[\int_0^R \left(\frac{m_{s_z}\phi_z}{m_z\omega}\right)^{m_{s_z}} \frac{r^{-m_{s_z}-1}\Gamma(m_z+\delta_T)}{B(m_z, m_{s_z})\Gamma(\delta_T)} \times U\left[m_z + m_{s_z}, 1+m_{s_z}-\delta_T, \frac{m_{s_z}\phi_z}{m_z\omega r}\right]dr\right]^Z \tag{16}$$

3. Numerical Analysis and Results

In this section, outage probability, success probability, outage capacity, channel capacity and symbol error rate (SER) performances of D2D communication system are with the help of numerical results. The reference distances c_0 and d_0 are assumed to be 1 meter, respectively. In Fig. 2, the outage performance with varying values of the desired D2D signal shadowing parameter m_s and the distance between D2D pair c is shown. The values of D2D signal power P_1, fading parameter m and path-loss exponent a are assumed to be 10 dBm, 2.5 and 2.7, respectively. The values of CCI signal power P_2, the fading parameter δ, the path-loss exponent b, distance between a co-channel interferer and the receiver of the D2D pair d, and the number of co-channel interferers N are assumed to be 14.77 dBm, 5, 3, 30 meters and 5, respectively. The outage threshold R is 10 dBm. It is observed that the outage performance is better for the higher values of shadowing parameter m_s. It is due to the fact that as the value of m_s increases channel shadowing conditions improve. It is further observed that as the distance c increases, the outage performance of D2D system degrades. It is due to path-loss.

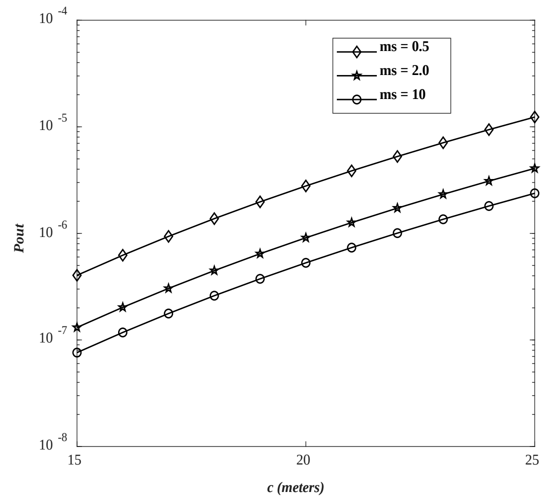

Fig. 2 Outage with varying values of shadowing parameter m_s

Fig. 3 shows the outage probability performance of the D2D communication system for the varying values of fading parameter of the desired D2D signal m. By setting the values of the shadowing parameter m_s to 0.5 and the rest of values same as that of the Fig. 2, it is seen that the outage performance of the system is better for the higher values of the fading parameter m. Moreover, by comparing results in Fig. 2 and Fig. 3, it is observed that the outage performance of the system is more variant to the changes in fading parameter m then that of the shadowing parameter m_s.

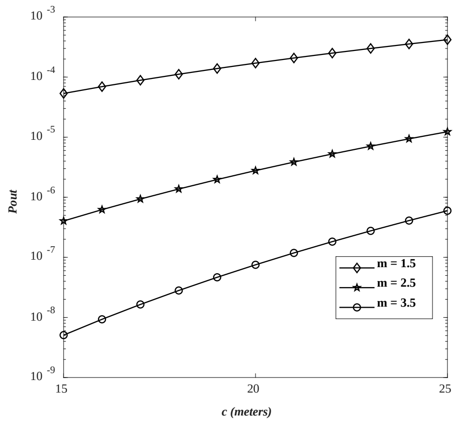

Fig. 3 Outage with varying values of fading parameter *m*

In Fig. 4, outage performance of D2D system with different values of *m* and the distance *d* is shown. The values of P_1, P_2, *a*, *b*, m_s, δ, *c*, *N* and *R* are set to be 20 dBm, 14.77 dBm, 2.7, 3, 1, 2, 25 meters, 5 and 10 dBm, respectively. It is observed that the outage performance is better for higher values of the fading parameter *m*. It is because at higher values of *m* fading conditions are better which improves SIR of the D2D system. Also, outage performance improves as the values of *d* are increased. It is because of the path-loss effects on the CCI signal, which improves SIR. Outage probability of D2D system with varying path-loss exponent of CCI signals *b* and desired signal path-loss exponent *a* is shown in Fig. 5. The values of P_1, P_2, m_s, *m*, δ, *c*, *d*, *N* and *R* are 20 dBm, 13 dBm, 4, 1.5, 4, 25 meters, 40 meters, 5 and 10 dBm, respectively. From the figure it is clear that the outage performance of the system improves as the values of path-loss exponent of the interferers in the system are increased. Moreover, an increase in outage probability is observed when the path-loss exponent of the D2D signal increases. Success probability of D2D system with varying number of *N* and P_1 is shown in Fig. 6. The values of P_2, *a*, *b*, m_s, *m*, δ, *c*, *d*, and *R* are 17 dBm, 3.5, 2.5, 1, 2.5, 2, 20 meters, 30 meters and 10 dBm, respectively. From the figure it is clear that the success probability decreases as the number of the interferers in the system are increased. However, an improvement in success probability is observed when the power of the D2D signal increases.

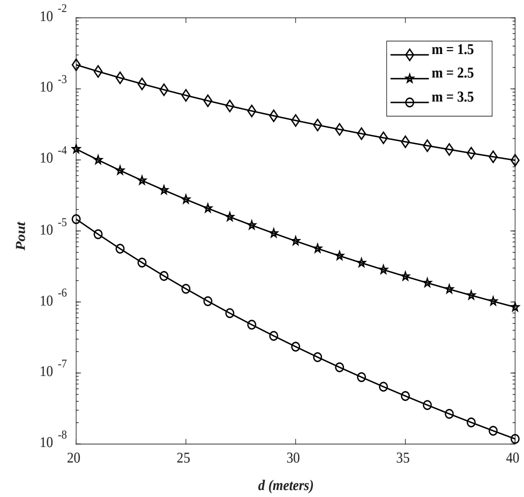

Fig. 4 Outage with varying values of fading parameter *m*

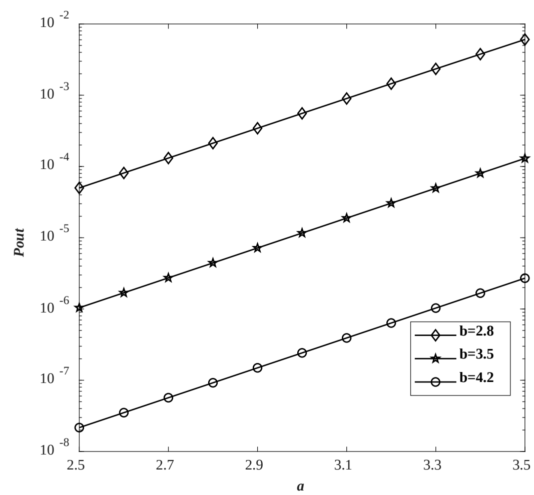

Fig. 5 Outage with varying values of CCI path-loss exponent *b*

Outage capacity of D2D system for various values of the path-loss exponent of D2D signal *a* and the distance *c* is given in Fig. 7. The values of P_1, P_2, *b*, m_s, *m*, δ, *d*, *N* and C_{th} are 20 dBm, 10 dBm, 3.5, 2, 2.5, 5, 35 meters, 5 and 0.1 bits/s/Hz, respectively. It is observed from the results that the outage capacity is better for the lesser values of path-loss *a*. Also, as D2D devices move away from each other outage capacity performance degrades. Outage capacity performance of D2D system for varying values of the CCI signals fading parameter δ and the D2D signal fading parameter *m* is given in Fig. 8. The values of P_1, P_2, *a*, *b*, m_s, *c*, *d*, *N* and C_{th} are 20 dBm, 10 dBm, 4, 3, 2, 15 meters, 35 meters, 5 and 0.1 bits/s/Hz, respectively. It is witnessed from the figure that the outage capacity is worse for the lesser values of CCI fading parameter δ and is almost insensitive to changes in fading conditions for higher values of δ. Also, as the values of D2D signals fading parameter increases outage capacity performance improves.

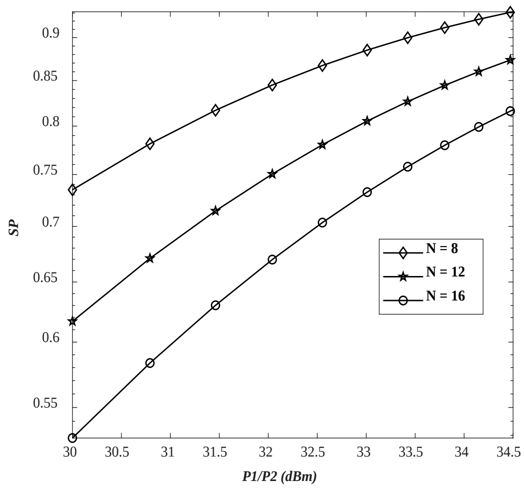

Fig. 6 Success probability for various number of CCI signals N

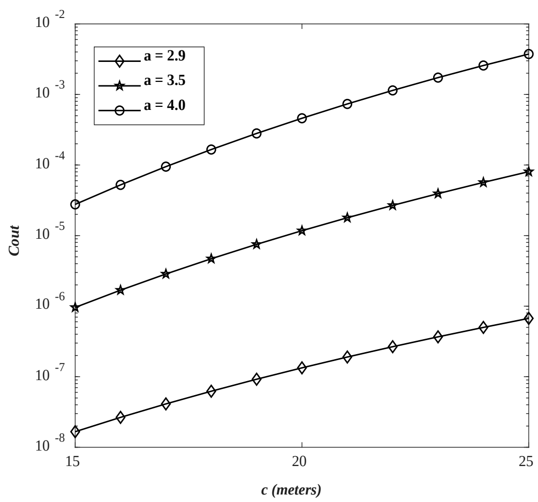

Fig. 7 Outage capacity with varying values of path-loss exponent a

In Fig. 9, channel capacity of D2D system for various values of CCI fading parameter δ and the distance d is shown. The values of P_1, P_2, a, b, m_s, m, c and N are assumed to be 20 dBm, 17 dBm, 2.7, 3, 1, 3.5, 15 meters and 5, respectively. From the figure, it is seen that the channel capacity performance of the system is worse for the lower values of fading parameter δ of CCI signals. However, for the higher values of fading parameter it is almost insensitive to the variations of the CCI fading conditions. Channel capacity with various values of CCI path-loss exponent b and N is shown in Fig. 10. The values of P_1, P_2, a, m_s, m, δ, c and d are 20 dBm, 17 dBm, 3, 1, 2.5, 20 meters and 30 meters, respectively. From the figure it is clear that channel capacity is high for higher values of CCI path-loss exponent. It is because CCI signals strength decrease with an increase in the path-loss exponent b values.

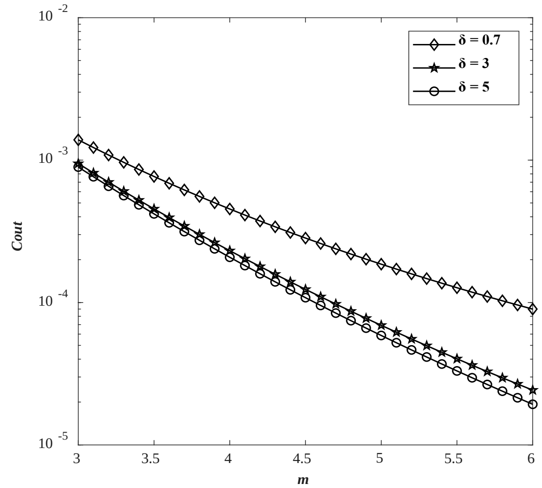

Fig. 8 Outage capacity with varying values of CCI fading parameter δ

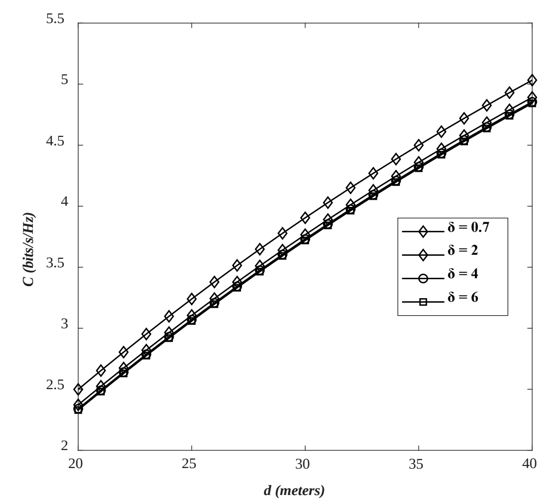

Fig. 9 Channel capacity with varying values of the CCI fading shape parameter δ

Channel capacity with various values of CCI fading parameter δ and D2D signal shadowing parameter m_s is shown in Fig. 11. The values of P_1, P_2, a, b, m, c, d and N are 20 dBm, 13 dBm, 2.5, 3, 1.5, 25 meters and 40 meters, respectively. From the figure it is seen that channel capacity is high for lower values of CCI path-loss fading parameter δ. But, for the higher values of CCI signals fading parameter it is nearly insensitive to the variations of the CCI fading conditions. Furthermore, a degradation in channel capacity performance of the system is observed as the values of D2D signal shadowing parameter m_s increases.

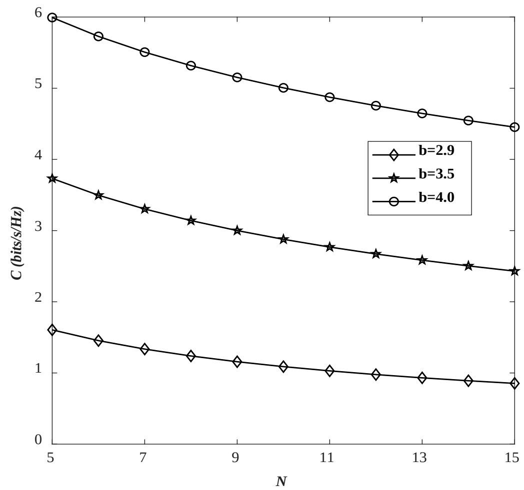

Fig. 10 Channel capacity with varying values of CCI path-loss exponent b

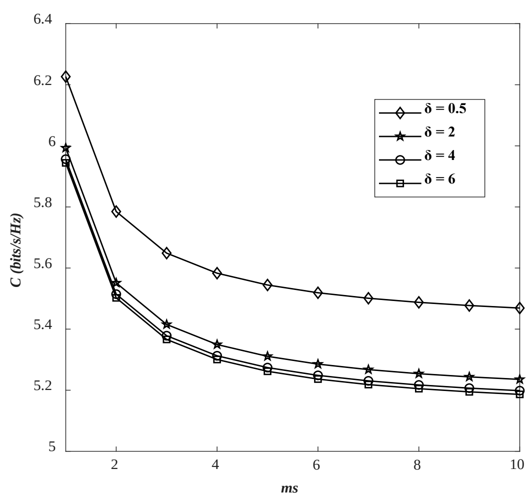

Fig. 11 Channel capacity with varying values of CCI fading parameter δ

Fig. 12 shows SER performance of M-PSK modulated D2D system with various fading and shadowing parameter values and the distance c. The values of P_1, P_2, a, b, δ, d and N are fixed to be 20 dBm, 10 dBm, 2.5, 3.5, 1, 40 meters and 5, respectively. The order of modulation M is 4. From the figure, it is observed that SER performance is better for higher values of the D2D system fading and shadowing parameters. It is because increasing m and m_s values improve fading and shadowing conditions. Moreover, SER performance degrades with an increase in distance c due to path-loss. Fig. 13 presents SER performance of square M-QAM modulated D2D communication system with varying values of power of CCI signals P_2 and the distance d. The values of P_1, m, m_s, a, b, δ, c and N are set to be 20 dBm, 3.5, 5, 2.5, 4, 1, 15 meters and 5, respectively. The order of modulation M is assumed to be 16. From the figure it is observed that the SER performance of D2D communication system is better for lower values of the power of the CCI signals. The increase in values of P_2 improves SIR conditions of the system and hence improves overall SER performance of the system. Moreover, the SER performance of system improves with increase in distance d due to path-loss effects on CCI signals.

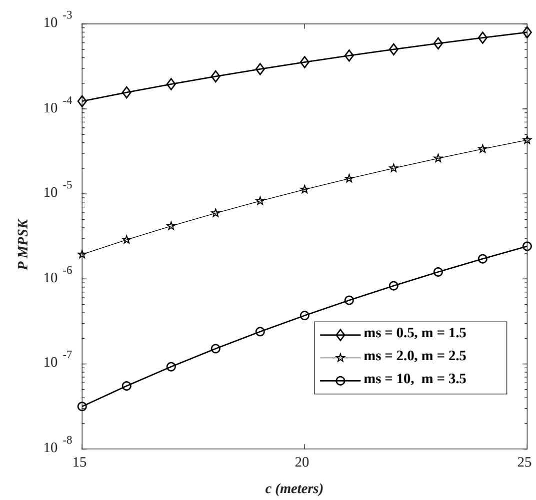

Fig. 12 SER performance with varying values of fading and shadowing parameter

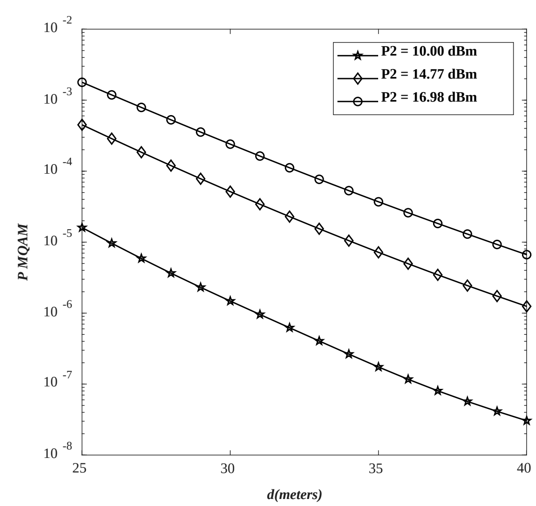

Fig. 13 SER performance of square M-QAM modulated system with varying values of P_2

In Fig. 14, outage probability with SC diversity scheme for various values of outage threshold R and the D2D signal power P_1 is shown. The values of P_2, a, b, m, m_s, δ, c, d and N are set to be 14.77 dBm, 3, 2.5, {20, 2, 0.5}, {2.5, 3.5, 4.5}, 3, 25 meters, 30 meters and 5, respectively. Number of diversity branches Z is fixed at 3. From the figure, it is observed that outage performance of D2D system is better for lower values of outage threshold R. Moreover, an improvement in outage performance is also noticed with an increase in power of D2D signal.

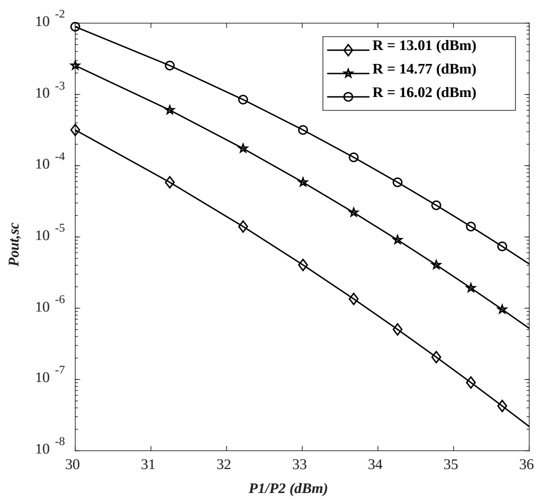

Fig. 14 Outage of D2D system with varying values outage threshold R

4. Conclusion

In this paper, the performance of D2D communication system over a composite model Fisher-Snedecor F is analyzed. The effects of co-channel interference (CCI) and path-loss are also considered. Probability density function (PDF) of signal-to-interference ratio (SIR) and PDF of instantaneous channel capacity of the D2D system are also presented. Using the PDFs the outage probability, success probability, outage capacity, channel capacity and symbol error rate (SER) performances of D2D communication system with various fading, shadowing, path-loss and CCI parameters are studied. It is observed that presence of path-loss, fading and shadowing worsen D2D system performance. But presence of path-loss also degrades CCI signals which improves performance. Performance of D2D system also deteriorates as the distance between the desired D2D devices increase. However, as the interferers move away from the D2D receiver performance improves.

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