Outage Analysis of Device-to-Device Communication System

Hussain Z., Khan A. U. R., Mehdi H., Saleem S. M. A.

National University of Computer and Emerging Sciences, Pakistan

E-mail: *zakir.hussain@nu.edu.pk*

In this paper, we analyze the outage performance of Device-to-Device (D2D) communication system in the presence of co-channel interference (CCI). Gamma distribution is considered here to model the random channel gain powers of D2D communication system and co-channel interferers. A characteristic function (CF) expression of the D2D communication system in the presence of CCI is presented as a function of various parameters of the system. Based on this CF expression an outage probability expression is presented as a function of arbitrary parameters of channel fading, CCI and path-loss. Effects of the CCI on the outage performance are then discussed with the help of numerical results under various channel and interference conditions.

Key words: co-channel Interference; D2D communication; gamma distribution; outage probability

1 Introduction

The inevitably increasing demand of communicating smart devices increases demand of high data rate and hence causing shortage of wireless bandwidth [1–3]. Device-to-device (D2D) communication system is one of the emerging technologies to fulfill the demand of high data rate and to enhance the performance of cellular communication system. D2D communication system is a fifth generation (5G) cellular communication system standard that allows direct communication between user devices without routing of data through cellular infrastructure which results in an improved data rate [4–7]. However, due to the presence of large number of wireless communication devices, coexistence issues arise. In the absence of suitable coordination between various wireless communication devices in the network co-channel interference (CCI) may take place [8–11]. Therefore, effects of CCI should be considered in the performance analysis of D2D communication systems. In this work, our aim is to analyze the effects of CCI on the performance of D2D communication systems. Outage probability is a useful tool to analyze the quality of the received signal at the receiving node in the presence of CCI and various channel conditions. Outage probability of multi-hop D2D communication system is studied by authors in [12] over Rayleigh fading channel. In [13], authors studied the outage probability of D2D communication system over Suzuki fading channel. Authors in [14] has studied the outage performance of D2D communication system in presence of interference and noise in Rayleigh fading. Authors in [15], studied outage

probability of D2D communication system over Rayleigh fading channel. In [16], authors have considered the Gamma faded channel for the desired D2D signal and Nakagami faded channel for the CCI signals. Moreover, authors have considered identically distributed co-channel interferers. No diversity is considered in the paper.

In this paper, outage performance of D2D communication system in the presence of CCI is discussed. Outage probability expression as a function of various channel and interference parameters is presented. Also, the random channel gain powers are assumed to be gamma distributed for both desired and interference signals. The generality of the Gamma distribution and its ability to model severe fading conditions makes it an attractive choice for the analysis of different fading conditions [17]. Furthermore, to combat the fading conditions maximal ratio-combining (MRC) and selection combining (SC) schemes are incorporated in our system. The rest of the paper is organized as follows. In Section 2, system model and outage probability expressions are presented. Numerical results are discussed in Section 3. Finally, this paper is concluded in Section 4.

2 System model

As shown in fig. 1, a pair of D2D devices is communicating. There are also N co-channel interferers with variable power levels. These interferers are located at various distances from the D2D receiver. Our system is assumed to be interference limited [18]. Random channel gain powers of the communication

link and interference are assumed to be independent and gamma distributed. To combat the fading conditions maximum-ratio-combining (MRC) and Selection Combining (SC) schemes with M diversity branches are considered. The PDF of the gamma distribution is [19]

$$f(z) = \frac{e^{-\frac{z}{d}} z^{c-1}}{d^c \Gamma(c)}, z \geqslant 0, d > 0, c > 0, \quad (1)$$

where c is the shape parameter and d is the scale parameter of gamma distribution. The shape parameter c measures the severity of fading and scale parameter d is related to the average power of distribution. Path-loss also affects the performance of communication systems. Therefore, a simplified path-loss model [20] is considered in this work.

D2D receiver node

D2D sender node

N co-channel interferers (I_N)

Desired signal
Distance between D2D pair $\qquad\qquad x$

Co-channel interference signals
Distance between the n-th co-channel
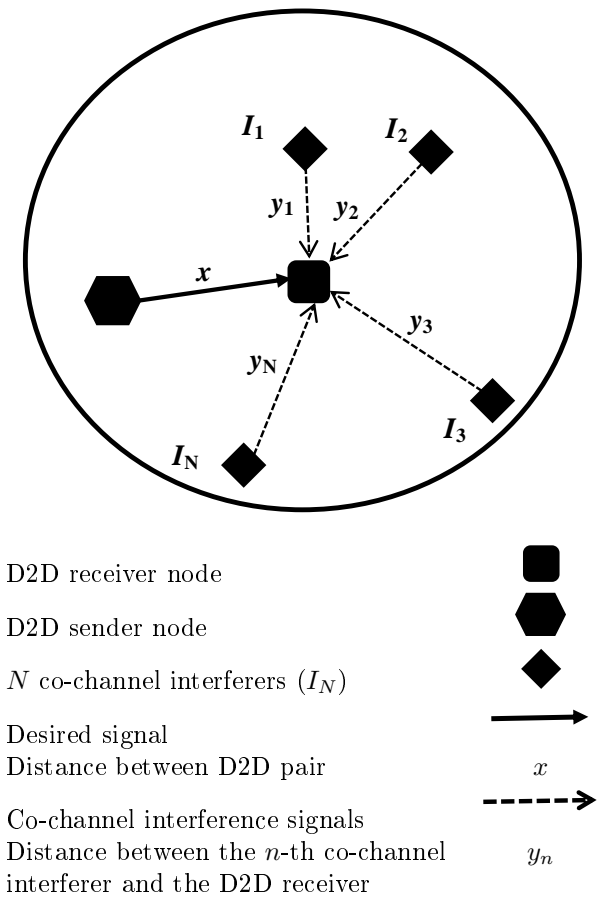interferer and the D2D receiver $\qquad y_n$

Fig. 1. System model of D2D communication system

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

$$\frac{S_{S,MRC}}{S_I} = \frac{P_s \left(\frac{\lambda}{4\pi x_0}\right)^2 \left(\frac{x_0}{x}\right)^u \sum_{k=1}^{M} h_k}{\sum_{n=1}^{N} P_{I,n} \left(\frac{\lambda}{4\pi y_{0,n}}\right)^2 \left(\frac{y_{0,n}}{y_n}\right)^{v_n} \beta_n},$$

$$\frac{S_{S,MRC}}{S_I} = \frac{P_s \left(\frac{x_0^{u-2}}{x^u}\right) \sum_{k=1}^{M} h_k}{\sum_{n=1}^{N} P_{I,n} \left(\frac{y_{0,n}^{v_n-2}}{y_n^{v_n}}\right) \beta_n}.$$

$$(2)$$

In (2), the power of the D2D signal is P_S, x is the distance between D2D pair, λ is the wavelength, u is path-loss exponent ($2 \leqslant u \leqslant 5$) for the D2D signal, x_0 is the reference distance and h_k is an independent gamma variable in the k-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 ($2 \leqslant u \leqslant 5$) and β_n is an independent gamma variable of the n-th co-channel interferer. To study the quality of the received D2D signal over a hostile channel, due to its effectiveness outage probability is considered here [21]. Outage probability is defined as the probability that the SIR of a received signal is below a predefined threshold R. The outage probability for our MRC based system is

$$P_{out} = P(RS_I > S_{S,MRC}). \quad (3)$$

Based on the expression (3), we define a decision variable θ as

$$\theta = RS_I - S_{S,MRC}. \quad (4)$$

For a satisfactory reception quality, the value of θ must be negative. Otherwise outage will take place. Mathematically,

$$\theta \begin{cases} > 0 & \text{Outage} \\ \leqslant 0 & \text{Satisfactory Reception} \end{cases}. \quad (5)$$

To obtain an expression for the outage probability a characteristic function (CF) based approach is considered here. The CF of the decision variable θ is

$$\phi_\theta(\omega) = \prod_{n=1}^{N} (1 - jA_n\omega)^{-\eta_n} \prod_{k=1}^{M} (1 + jB_k\omega)^{-\delta_k}, \quad (6)$$

where δ_k is the shape parameter and σ_k is the scale parameter of the desired received signal in the k-th diversity branch. In (6), η_n and ε_n are the shape and scale parameters of the n-th co-channel interferer, respectively. Moreover, in (6)

$$A_n = RP_{I,n} \frac{y_{0,n}^{v_n-2}}{y_n^{v_n}} \varepsilon_n; \quad (7)$$

$$B_k = P_s \frac{x_0^{u-2}}{x^u} \sigma_k. \quad (8)$$

The characteristic function expression in (6) is a function of various parameters of the desired D2D and CCI signals, and fading channels. Hence, based on this characteristic function expression the outage performance is analyzed. Based on (5) and (6), the outage probability of our systems can be determined by using the following formula,

$$P_{out} = \frac{1}{2} + \frac{1}{\pi} \int_0^\infty \frac{\text{Im}(\phi_\theta(\omega))}{\omega} \, d\omega,$$

where Im (.) is imaginary part of the CF expression in (6).

The outage probability expression of our MRC based D2D communication system is

$$P_{out,MRC} = \frac{1}{2} + \frac{1}{\pi} \int_0^\infty \left(\frac{sin\left[\sum\limits_{n=1}^{N} \eta_n tan^{-1}\left(A_n\omega\right) - \sum\limits_{k=1}^{M} \delta_k tan^{-1}\left(B_k\omega\right) \right]}{\omega \times \prod\limits_{n=1}^{N} \left[1 + \left(A_n\omega\right)^2\right]^{\frac{\eta_n}{2}} \prod\limits_{k=1}^{M} \left[1 + \left(B_k\omega\right)^2\right]^{\frac{\delta_k}{2}}} \right) d\omega. \tag{9}$$

Now for the selection combining (SC) based diversity scheme, the SIR of the k-th diversity branch is

$$\frac{S_{S-SC,k}}{S_I} = \frac{P_s \left(\frac{\lambda}{4\pi x_0}\right)^2 \left(\frac{x_0}{x}\right)^u h_k}{\sum\limits_{n=1}^{N} P_{I,n} \left(\frac{\lambda}{4\pi y_{0,n}}\right)^2 \left(\frac{y_{0,n}}{y_n}\right)^{v_n} \beta_n};$$

$$\frac{S_{S-SC,k}}{S_I} = \frac{P_s \left(\frac{x_0^{u-2}}{x^u}\right) h_k}{\sum\limits_{n=1}^{N} P_{I,n} \left(\frac{y_{0,n}^{v_n-2}}{y_n^{v_n}}\right) \beta_n}. \tag{10}$$

The outage probability of our SC diversity based D2D communication system is

$$P_{out} = P(RS_I > S_{S-SC,MAX}). \tag{11}$$

Based on (11), we define decision a variable ψ as

$$\psi = RS_I - S_{S-SC,MAX}. \tag{12}$$

For a satisfactory reception, the value of ψ must be negative. Otherwise outage will result. Mathematically,

$$\psi \left\{ \begin{array}{ll} > 0 & \text{Outage} \\ \leqslant 0 & \text{Satisfactory Reception} \end{array} \right., \tag{13}$$

where $S_{S-SC,MAX} = \max\limits_{k=1,...,M} (S_{S-SC,k})$ is the branch selected by the SC scheme. Now, based on (11) to (13), the outage probability expression of our SC diversity based D2D communication system is

$$P_{out,SC} = \prod_{k=1}^{M} \left[\frac{1}{2} + \frac{1}{\pi} \int_0^\infty \left(\frac{sin\left[\sum\limits_{n=1}^{N} \eta_n tan^{-1}\left(A_n\omega\right) - \delta_k tan^{-1}\left(B_k\omega\right) \right]}{\omega \prod\limits_{n=1}^{N} \left[1 + \left(A_n\omega\right)^2\right]^{\frac{\eta_n}{2}} \left[1 + \left(B_k\omega\right)^2\right]^{\frac{\delta_k}{2}}} \right) d\omega \right]. \tag{14}$$

3   Numerical analysis

Numerical results are presented based on the outage expression presented in Section 2. Our expression is valid for arbitrary values of channel conditions. In the following numerical results, the reference distances x_0 and $y_{0,n}$ are assumed to be 1 meters. In fig. 2, outage performance of D2D communication system with selection combining (SC) and maximum ratio combining (MRC) diversity techniques are shown. Shape parameters of D2D signal δ_k for $M = 3$ branches are considered to be {2, 4, 1}, path-loss exponent of the D2D signal, u is considered to be 3.5 and the power P_S is fixed at 20 dBm. There are $N = 5$ co-channel interferers in the system. Powers of the interferers $P_{I,n}$, distances between the n-th interferer y_n and the D2D receiver, path-loss exponents of co-channel interferers and the shape parameters of interferers are assumed to be {13, 10.79, 11.76, 13, 10.41} dBm, {30, 35, 50, 70, 75} meters, {4.7, 2.5, 3, 4.7, 2.5} and {1, 5, 2, 3, 5}, respectively. Outage threshold R is set to be 16 dBm. From the figure it is observed that the outage performance of the D2D communication system is better with MRC diversity than the SC diversity. Moreover degradation in performance is observed with increase in distance x due to path-loss effects. In fig. 3, outage performance of MRC based D2D communication with varying number of diversity branches is shown.

Here, $M = 2$, 3 and 5 diversity branches are considered. Values of δ_k of D2D signal for $M = 2$, 3 and 5 branches are considered to be {3, 1}, {3, 1, 0.5} and {3, 1, 0.5, 0.7, 0.5}, respectively. Values of u for the D2D signal is considered to be 3.5 and the P_S is fixed at 20 dBm. Number of co-channel interferers N is considered to be 7. Values of $P_{I,n}$, y_n, v_n and η_n are assumed to be {13, 10, 10.8, 11.76, 13, 10.8, 10} dBm, {30, 35, 40, 55, 70, 75, 80} meters, {4.7, 3.5, 2.5, 3, 4.7, 3.5, 2.5} and {1, 2, 5, 3, 1, 2, 5}, respectively. R is set to be 17 dBm. It can be seen from the figure that when diversity branches are increased outage performance of the system is improved. It is also observed that as the D2D devices moves away from each other, outage performance degrades. It is due to the decrease in the received power of the desired signal at the D2D receiver due to path-loss effects. Outage performance of MRC diversity D2D communication system with varying shape parameters of D2D signal is shown in fig. 4. P_S, M and u are assumed to be 20 dBm, 3 and 3.5, respectively. For $N = 5$ co-channel interferers, $P_{I,n}$, η_n, v_n, and y_n are assumed to be {13, 10.79, 11.76, 13, 10.41} dBm, {1, 5, 3, 1, 5}, {4.7, 2.5, 3, 4.7, 2.5}, and {30, 35, 50, 70, 75} meters, respectively. Threshold is set at 17 dBm. It is clear from the figure that under less severe fading conditions for the desired signal, outage performance of the system is improved.
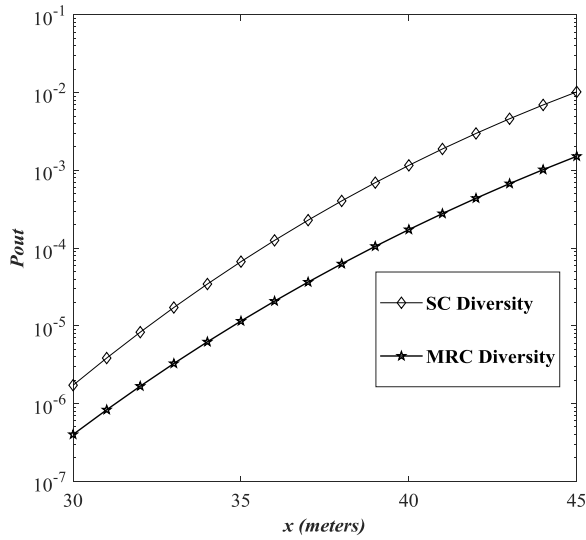
Fig. 2. Outage performance of D2D communication system with SC and MRC diversity
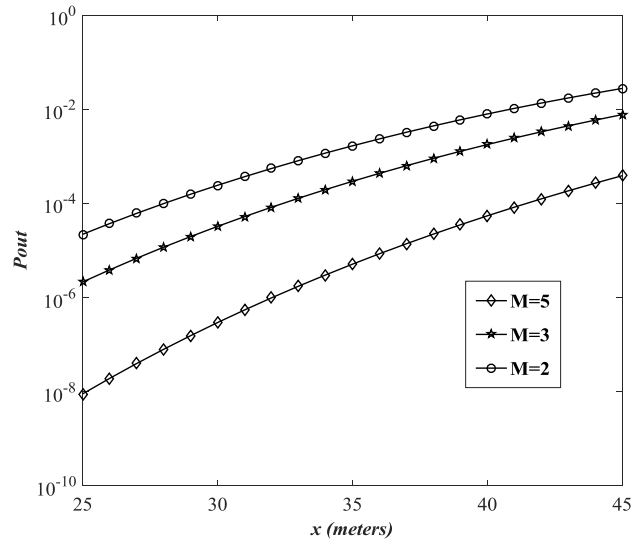

Fig. 3. Outage performance MRC diversity with varying number of diversity branches M
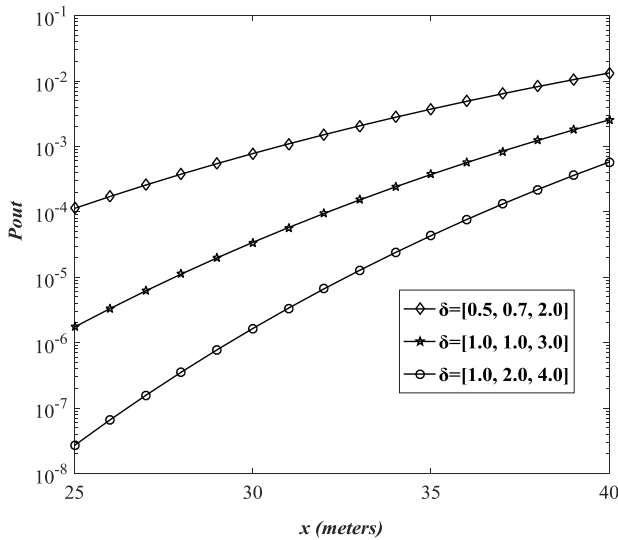

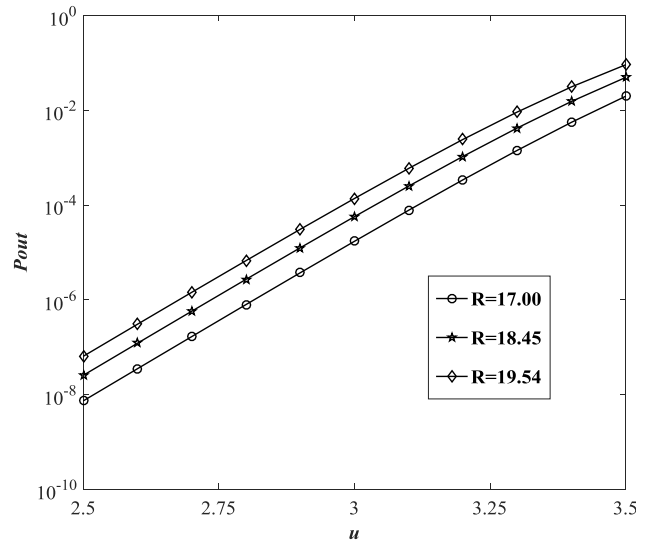Fig. 4. Outage performance with varying shape parameters of the desired signal

Fig. 5. Outage performance with varying values of threshold R (dBm)

Performance of MRC diversity D2D communication system with various path-loss exponents of D2D signals and the threshold values is shown in fig. 5. P_S, x, M and δ_k are assumed to be 20 dBm, 70 meters, 3 and {1, 0.7, 2}, respectively. For $N = 5$ interferers, $P_{I,n}$, v_n, η_n and y_n are assumed to be {7, 8.45, 10, 9.54, 7.78} dBm, {3, 3.1, 3, 2.5, 3.2}, {5, 3, 4, 3, 5} and {40, 45, 555, 70, 75} meters, respectively. From the figure, it is observed that by increasing the path-loss exponent for the desired signal, the outage performance degrades due to increase in path-loss and hence, reduction in

the received signal strength at the D2D receiver. We also observe degradation in the outage performance at every path-loss exponent value as the threshold value is increased.

Outage performance of MRC based D2D communication system with various values of path-loss exponents of the co-channel interferers is shown in fig. 6. P_S, u, M and δ_k are assumed to be 20 dBm, 3.4, 3 and {1, 2, 1}, respectively. For $N = 5$ co-channel interferers, $P_{I,n}$, η_n and y_n are assumed to be {13, 10, 11.76, 13, 10} dBm, {1, 2, 3, 1, 2} and {25, 30,

50, 70, 75} meters, respectively. Outage threshold is fixed at 17 dBm. From the figure, it is observed that the outage performance is improved as the path-loss exponents of the interferers are increased. This is due to the weakening of the interference signals at the receiver node.

In fig. 7, numerical analysis of a scenario of D2D communication system with MRC diversity technique is shown. In this scenario, 20 equal power and equal path-loss exponent co-channel interferers are considered. 10 of the interferers are placed at a distance 30 meters and the rest are placed at 70 meters from the receiver node. The powers and path-loss exponent

of the interferers are assumed to be 8.75 dBm and 3.7, respectively. For our desired signal, the values of P_S, u, M and δ_k are assumed to be 20 dBm, 4.3, 3 and 5, respectively. Threshold is fixed at 18.13 dBm. Firstly, the fading condition for the interferers near the receiver is considered to be better than the ones away from the receiver. Then, the fading conditions are considered to be reversed for the interferers. From the figure, it is clear that when the interferers near the receiver are under severe fading conditions than the ones away from the receiver node, outage performance of our system suffers despite the fact that all the interferers have same path-loss exponents and transmit powers.
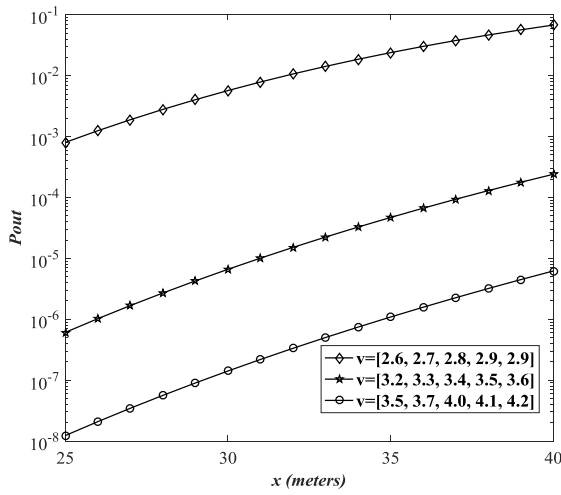

Fig. 6. Outage performance with varying path-loss exponents of co-channel interferer signals
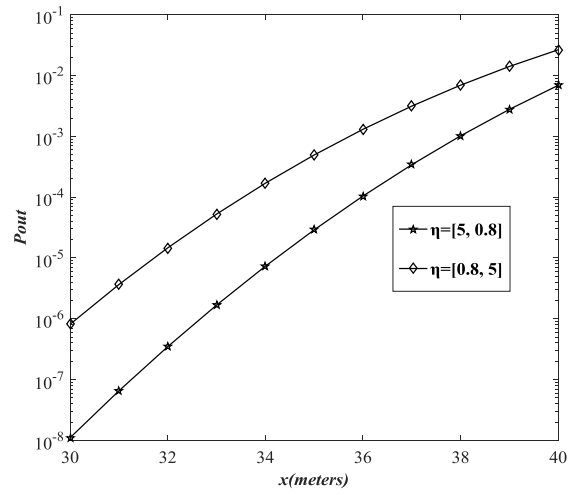

Fig. 7. Outage analysis with varying fading conditions for the co-channel interference
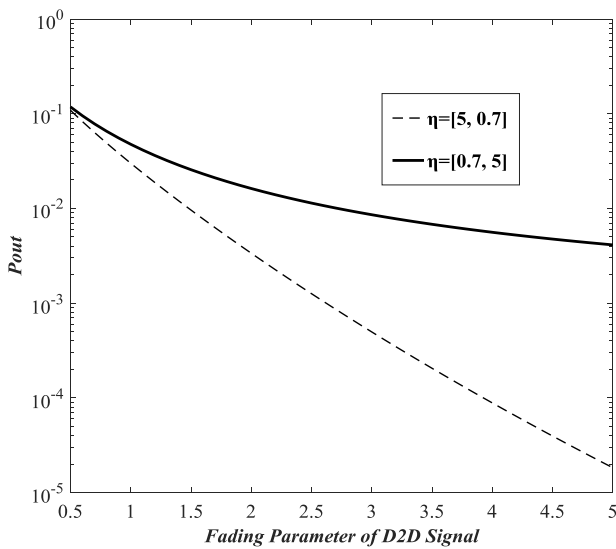

Fig. 8. Analysis with various fading conditions for the interference and desired signals
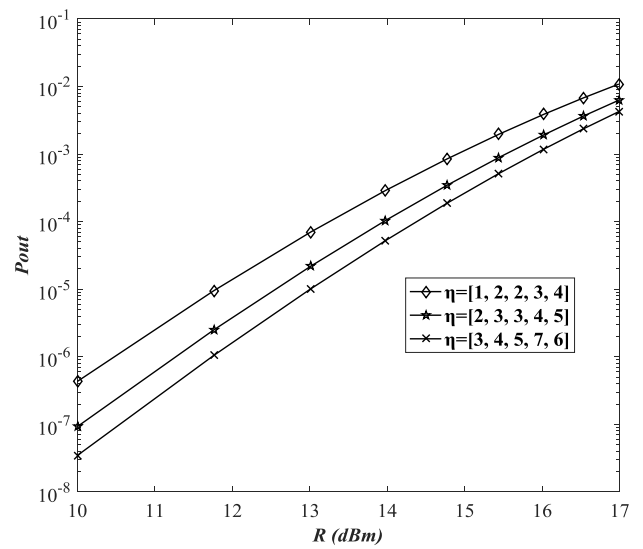

Fig. 9. Analysis with various fading conditions for the interference and threshold
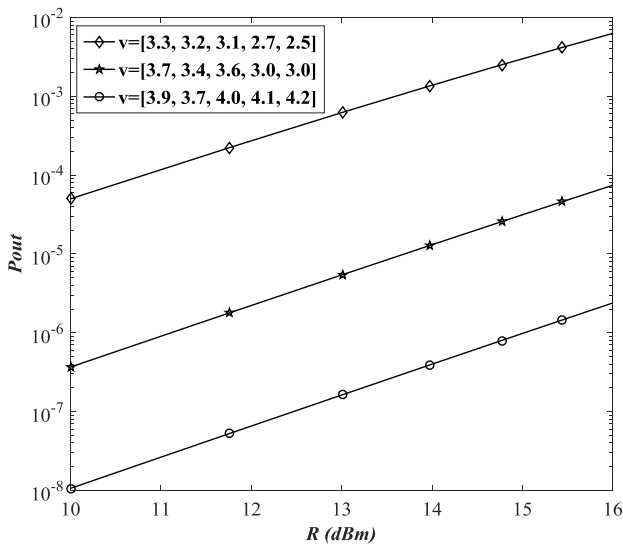
Fig. 10. Outage with various path-loss exponents for the interference

Fig. 11. Outage performance with varying number of interferers

Similar to our previous scenario shown in fig. 7, 20 equal power and equal path-loss exponent co-channel interferers are again considered in fig. 8. However, this time the fading conditions of the desired signal are also varying. 10 of the interferers are at a distance of 30 meters and the rest are at 70 meters from the D2D receiver. The powers and path-loss exponent of the interferers are assumed to be 8.75 dBm and 3.6, respectively. Threshold value is set at 10 dBm. The values of P_S, x, M and u are assumed to be 20 dBm, 50 meters, 5 and 4.5, respectively. Similar process of swapping the fading conditions of the near and far placed interferers is adopted once again. From the figure, once again it is observed that the outage performance suffers when the interferers near the receiver are under severe fading conditions as compared to the case when the nearer interferers are under better fading conditions. However, the gap between the two cases increases with the improvement in the fading conditions of the desired signal.

Outage performance of MRC diversity based D2D communication system with varying shape parameter values of co-channel interferers is shown in fig. 9. Values of P_S, δ_k, M, x and u are assumed to be 20 dBm, {2, 3, 5}, 3, 50 meters and 3.5, respectively. For $N = 5$ interferers, $P_{I,n}$, v_n, and y_n are assumed to be {13, 10, 11.76, 13, 10} dBm, {4.7, 2.5, 3, 4.7, 2.5} and {30, 35, 50, 70, 75} meters, respectively. It is clear from the figure that outage performance suffers under worse fading conditions for the interferers. Also, when the threshold value is increased performance degrades. Effects of varying path-loss exponents of co-channel interferers on the outage performance of MRC based D2D communication system are shown in fig. 10.
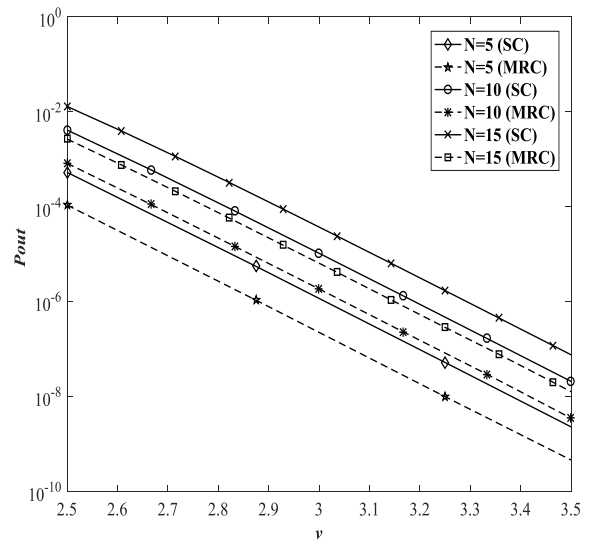
Values of P_S, u, x, M and δ_k are assumed to be 20 dBm, 3.5, 50 meters, 3 and {1, 2, 1}, respectively. For $N = 5$ co-channel interferers, $P_{I,n}$, η_n, and y_n are assumed to be {13, 10, 11.76, 13, 10} dBm, {1, 2, 3, 1, 2} and {25, 30, 50, 70, 75} meters, respectively. From the figure, it is observed that outage performance improves as the path-loss conditions for the interference signals get worse. It is due to the weakening of the received interference signals.

Outage performance of SC and MRC based D2D systems with various numbers of CCIs are shown in fig. 11. Values of P_S, u, x, M and δ_k are assumed to be 23.01 dBm, 3.5, 30 meters, 3 and {1.5, 1, 0.7}, respectively. The interferers are assumed to be independent and identically distributed. The values for interferers parameters $P_{I,n}$, and y_n are assumed to be 11.76 dBm and 50 meters, respectively. Threshold R is set to be 14.77 dBm. From the figure, it is observed that outage performance of the system worsens as the number of interferers are increased. Moreover, for the same number of interferers system with MRC shows better performance than the system with SC. It is also observed that increase in the path-loss exponent of CCI improves outage performance. It is due to the weakening of the CCI signals with the increase of the path-loss exponent values.

Conclusion

The D2D system is studied in the presence of multiple co-channel interferers. The effects of path-loss are also considered. Gamma distribution is considered to model the random channel gain powers

of the desired and interference signals. To analyse the system, an expression for the outage probability is presented as a function of diversity branches, path-loss parameters, channel fading and interference parameters. It is observed that diversity schemes improves the outage performance of the D2D communication system. Furthermore, it is observed that the performance of the MRC diversity based D2D communication system is better than that of SC diversity based system. It is observed that the presence of fading and path-loss degrades system performance. Also, co-channel interference in spite of being affected by the fading and path-loss conditions degrades outage performance of the system. It is observed that when the path-loss exponent of the CCI is decreased, the outage performance of the D2D system is degraded. For the distance between the D2D devices, $x = 30$ meters , and the path-loss exponent values of the $N = 5$ interferers are $v = \{3.5, 3.7, 4, 4.1, 4.2\}$, the outage probability is $P_{out} = 1.414 \times 10^{-7}$. When the path-loss exponent values of CCI are decreased to $v = \{3.2, 3.3, 3.4, 3.5, 3.6\}$, the outage perfromance degrades, i.e., $P_{out} = 6.614 \times 10^{-6}$. When the path-loss exponent values of CCI are further decreased to $v = \{2.6, 2.7, 2.8, 2.9, 2.9\}$, the ouage perfromance further degrades to $P_{out} = 0.0057$.

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Аналіз збоїв систем зв'язку різновиду пристрій-пристрій

Хусейн З., Хан А. Р., Мехді Х., Салем С.М. А.

У цій статті аналізується продуктивність систем зв'язку "пристрій-пристрій" (D2D) при наявності міжканальних перешкод (CCI). Для моделювання коефіцієнтів посилення випадкового каналу системи зв'язку D2D і міжканальних перешкод використовується гамма-розподіл. Вираз характеристичної функції системи зв'язку D2D в присутності міжканальних перешкод представлено як функцію різних параметрів системи. На основі виразу характеристичної функції ймовірність збоїв представлено як функцію довільних параметрів загасання каналу, міжканальних перешкод і загасання на шляху. Вплив міжканальних перешкод на ймовірність збоїв проаналізована за допомогою числових результатів при різних канальних і інтерференційних умовах.

Ключові слова: завади в суміщеному каналі; зв'язок D2D; гамма-розподіл; ймовірність відмови

Анализ сбоев систем связи вида устройство-устройство

Хусейн З., Хан А. Р., Мехди Х., Салем С.М. А.

В этой статье анализируется производительность систем связи "устройство-устройство" (D2D) при наличии межканальных помех (CCI). Для моделирования коэффициентов усиления случайного канала системы связи D2D и межканальных помех используется гамма-распределение. Выражение характеристической функции системы связи D2D в присутствии межканальных помех представлено как функцию различных параметров системы. На основе выражения характеристической функции вероятность сбоев представлено как функцию произвольных параметров затухания канала, межканальных помех и затухания на пути. Влияние межканальных помех на вероятность сбоев проанализирована с помощью числовых результатов при различных канальных и интерференционных условиях.

Ключевые слова: межканальное вмешательство; D2D-связь; гамма-распределение; вероятность отказа