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doi:10.15199/48.2024.03.29

Analysis of Relay-Assisted Device-to-Device Communication over Fisher–Snedecor *F* Fading Channels

***Abstract**. Outage and Success performances of an amplify-and-forward (AF) relay-assisted Device-to-Device (D2D) communication system over Fisher–Snedecor F composite fading channels in the presence of co-channel interference (CCI) are discussed in this work. The CCIs are assumed to degrade the quality of D2D data at relay as well as destination. Selection combining (SC) scheme is also incorporated at the D2D receiver to mitigate fading conditions. Analytical expressions for success and outage probabilities are derived with the help of characteristic function. These expressions depend on the path-loss exponents, distance between relay and the D2D source, distance between the D2D receiver and the relay, distances between CCI sources and the relay node, distances between the D2D receiver and CCI sources, and channel fading conditions. The numerical results for various scenarios are presented and discussed.*

***Streszczenie.** W tym omówiono wydajność przestojów i sukcesów systemu komunikacji Device-to-Device (D2D) wspomaganego przez amplifikację i przekazywanie (AF) przez kompozytowe kanały zanikające Fisher-Snedecor F w obecności zakłóceń współkanałowych (CCI) praca. Zakłada się, że CCI obniżają jakość danych D2D zarówno w punkcie pośrednim, jak i docelowym. Schemat łączenia wyboru (SC) jest również wbudowany w odbiornik D2D w celu złagodzenia warunków zanikania. Wyrażenia analityczne dla prawdopodobieństw sukcesu i awarii wyprowadzane są za pomocą funkcji charakterystycznej. Wyrażenia te zależą od wykładników tłumienia ścieżki, odległości między przekaźnikiem a źródłem D2D, odległości między odbiornikiem D2D a przekaźnikiem, odległości między źródłami CCI a węzłem przekaźnikowym, odległości między odbiornikiem D2D a źródłami CCI, warunków zaniku kanału. Przedstawiono i omówiono wyniki liczbowe dla różnych scenariuszy. (**Analiza komunikacji między urządzeniami za pośrednictwem przekaźników za pośrednictwem kanałów zanikających Fisher-Snedecor F**)*

Keywords: CCI signals; D2D Communication; Fisher–Snedecor F; Outage Probability; Relay.
Słowa kluczowe: sygnały CCI; Komunikacja D2D; Fisher-Snedecor F; prawdopodobieństwo awarii; Przekaźnik.

Introduction

There has been an overwhelming increase in the demand for mobile devices and mobile data communication [1]. The idea of Device-to-Device (D2D) communication has been introduced to acquire high-capacity benefits to mobile data users [2-3]. In a D2D architecture, nearby cellular users can form a direct link for data transmission bypassing the base station. However, a D2D network sometimes may not perform properly due to increase in distances of D2D nodes. A relay-assisted D2D system can mitigate such an issue. Hence, an amplify-and-forward (AF) relay-assisted D2D system is assumed in this research. Also, in a cellular system consisting of high density of D2D devices along with different types of wireless devices the probability of co-channel interference (CCI) is increased. Therefore, CCI conditions are also considered in this work. Authors in [4], investigated the outage performance of a D2D assisted mmWave network with interference and practical hardware distortion noises. Channels are modelled as Nakagami-*m* faded. Authors in [5], studied cooperative D2D communication in an uplink cellular network. Optimal spectrum and power allocation for maximizing the total average achievable rate under the outage constraint was given. In [6], authors introduced a location-based power control technique to mitigate the severe interference components for D2D communication for a multicell case. Area spectral efficiency analysis was performed using the proposed power control and cooperation approach. Authors in [7], proposed transmit power control schemes for the D2D system without increasing the outage probability of the cellular user. For asymptotic analysis, a lower bound on the D2D outage was given.

Different from previously mentioned work, the aim of this paper is to present outage as well as success probability of relay-assisted D2D system with CCI over Fisher–Snedecor F composite fading channels proposed in [8]. Fisher–Snedecor F composite model gives the composite effects of shadowing and multipath fading. Fisher–Snedecor F model reduces to one-sided Gaussian, Rayleigh, and Nakagami-*m* when shadowing is absent. CCI is assumed to be caused by rogue wireless devices in the system. D2D and CCI signals are Fisher–Snedecor *F* faded. To mitigate fading conditions, selection combining (SC) based diversity scheme is incorporated at the D2D receiver. Success and outage expressions based on characteristic function (CF) approach are derived under various channel and CCI conditions. System model and various expressions are derived in Section named System Model. Numerical analysis is presented under heading named Numerical Analysis. Finally, research work is concluded under last heading.

System Model

Amplify-and-forward (AF) relay-assisted D2D system is shown in Fig. 1. There are *N* CCI sources near the relay and *L* co-cannel interferers are at the D2D receiver. CCI signals are independent and non-identically distributed. Fisher–Snedecor *F* composite fading [8] channel is assumed for D2D and CCI signals. The signal from the D2D source is received by the relay over a Fisher–Snedecor *F* composite fading channel. The relay amplifies and forwards the received D2D signal and CCI signals to the D2D receiver. Wireless communications can have strong direct line-of-sight component. Under such conditions there will be negligible fading. In this work, relay to D2D receiver communication channel is assumed to exhibit negligible fading effects. The effects of path-loss are considered on this link. The overall signal-to-interference power ratio (SIR) from D2D source to D2D receiver is,

$$(1)\qquad \frac{S_d}{S_I}=\frac{GPx^{-w}y^{-q}h}{Gy^{-q}\sum\limits_{n=1}^{N}P_{I,n}z_n{}^{-k_n}\beta_n+\sum\limits_{l=1}^{L}P_{I,l}g_l{}^{-e_l}\alpha_l}$$

where, S_d is the desired D2D signal power from relay, S_I is CCI power, transmitted D2D signal power is *P*, path-loss exponent between D2D source and the relay is *w* and the Fisher–Snedecor *F* independent gain is *h* for the channel between D2D source and relay. *n-th* CCI power at the relay is $P_{I,n}$, *n-th* CCI path-loss exponent is k_n and *n-th* CCI Fisher–Snedecor *F* independent 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 e_l and α_l is an independent Fisher–Snedecor *F* fading variable of the *l-th* CCI. *G* is amplification factor of the relay.

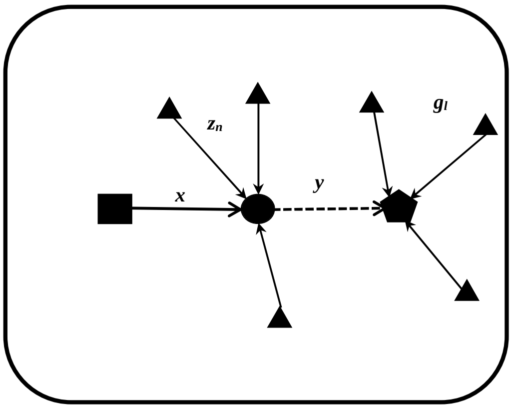

Fig.1. System Model

(2) $$G=\frac{P_R}{Px^{-u}\;\Omega_d+\sum\limits_{n=1}^{N}P_{I,n}{z_n}^{-k_n}\;\Omega_n}$$

where, P_R is the relay power, $\Omega_d=E\left[h\right]$ and $\Omega_n=E\left[\beta_n\right]$ are average powers of D2D and *n-th* CCI signals, respectively. Outage probability P_{out} with threshold R is $P_{out}=Pr\left(RS_I>S_d\right)$ where Pr(.) denotes the probability. Consider $\gamma=RS_I\text{-}S_d$, such that $\gamma\begin{cases}>0 & \text{Outage}\\ \le 0 & \text{Acceptable Transmission}\end{cases}$. With the help of CF approach P_{out} is obtained.

Table 1. Nomenclature for Fig. 1.

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	z_n
l-th CCI to receiver link length	g_l

$$\phi_\theta\left(\omega\right)=\frac{\Gamma\left(m_{S,d}+m_d\right)}{\Gamma\left(m_{S,d}\right)}\left(\frac{j\omega m_{S,d}GPx^{-w}y^{-q}\Omega_d}{m_d}\right)^{m_{S,d}}U\left(m_{S,d}+m_d,m_{S,d}+1;\frac{j\omega m_{S,d}GPx^{-w}y^{-q}\Omega_d}{m_d}\right)$$

(3) $$\times\prod_{n=1}^{N}\frac{\Gamma\left(m_{S,n}+m_n\right)}{\Gamma\left(m_{S,n}\right)}\left(-\frac{j\omega m_{S,n}RGP_{I,n}{z_n}^{-k_n}y^{-q}\Omega_n}{m_n}\right)^{m_{S,n}}U\left(m_{S,n}+m_n,m_{S,n}+1;-\frac{j\omega m_{S,n}RGP_{I,n}{z_n}^{-k_n}y^{-q}\Omega_n}{m_n}\right)$$

$$\times\prod_{l=1}^{L}\frac{\Gamma\left(m_{S,l}+m_l\right)}{\Gamma\left(m_{S,l}\right)}\left(-\frac{j\omega m_{S,l}RP_{I,l}{g_l}^{-e_l}\Omega_l}{m_l}\right)^{m_{S,l}}U\left(m_{S,l}+m_l,m_{S,l}+1;-\frac{j\omega m_{S,l}RP_{I,l}{g_l}^{-e_l}\Omega_l}{m_l}\right)$$

In (3), where U(.) is confluent hypergeometric function [9] and $\Omega_l=E\left[\alpha_l\right]$. Also, m_d and $m_{S,d}$ are Fisher–Snedecor *F* parameters of the D2D signal. m_d is the fading severity parameter and $m_{S,d}$ controls the shadowing severity of the D2D signal. And m_n and $m_{S,n}$ are relay CCI Fisher–Snedecor *F* parameters that control the fading and shadowing severity. Similarly, m_l and $m_{S,l}$ are receiver's CCI Fisher–Snedecor *F* parameters. Based on $\phi_\theta\left(\omega\right)$, $P_{out}=\frac{1}{2}+\frac{1}{\pi}\int\limits_0^\infty\frac{\operatorname{Im}\left(\phi_\theta\left(\omega\right)\right)}{\omega}d\omega$, where Im (.) is the imaginary part. The success probability P_S is the probability for which SIR exceeds threshold value *R*. The success probability is $P_S=\frac{1}{2}-\frac{1}{\pi}\int\limits_0^\infty\frac{\operatorname{Im}\left(\phi_\theta\left(\omega\right)\right)}{\omega}d\omega$.

The analysis with a selection combining (SC) based diversity is now considered at the D2D receiver. A *C* branches SC diversity receiver is considered. The SIR of the *c-th* diversity branch will be,

(4) $$\frac{S_{SC,c}}{S_I}=\frac{GPx^{-w}y^{-q}h_c}{Gy^{-q}\sum\limits_{n=1}^{N}P_{I,n}{z_n}^{-k_n}\beta_n+\sum\limits_{l=1}^{L}P_{I,l}{g_l}^{-e_l}\alpha_l}$$

where $S_{SC,c}$ is the received power in the *c-th* diversity branch of the receiver, h_c is the Fisher–Snedecor *F* variable in the *c-th* branch of the receiver. Outage probability P_{out} will be $P_{out}=\Pr\left(RS_I>S_{SC,MAX}\right)$ where $S_{SC,MAX}=\max\limits_{c=1,2,\ldots,C}\left(S_{SC,c}\right)$. The CF of $\lambda=RS_I-S_{SC,c}$ is given in (5). Based on $\sigma_\lambda\left(\omega\right)$ the outage probability of a SC based relay-assisted D2D system is $P_{out,SC}=\prod\limits_{c=1}^{C}\left(\frac{1}{2}+\frac{1}{\pi}\int\limits_0^\infty\frac{\operatorname{Im}\left(\sigma_\lambda\left(\omega\right)\right)}{\omega}d\omega\right)$. Similarly, the success probability is $P_{S,SC}=1-\prod\limits_{c=1}^{C}\left(\frac{1}{2}+\frac{1}{\pi}\int\limits_0^\infty\frac{\operatorname{Im}\left(\sigma_\lambda\left(\omega\right)\right)}{\omega}d\omega\right)$.

$$\begin{aligned}\sigma_{\lambda}(\omega)=&\frac{\Gamma\left(m_{S,d,c}+m_{d,c}\right)}{\Gamma\left(m_{S,d,c}\right)}\left(\frac{j\omega m_{S,d,c}GPx^{-w}y^{-q}\Omega_{d,b,c}}{m_{d,c}}\right)^{m_{S,d,c}}U\left(m_{S,d,c}+m_{d,c},m_{S,d,c}+1;\frac{j\omega m_{S,d,c}GPx^{-w}y^{-q}\Omega_{d,b,c}}{m_{d,c}}\right)\\&\times\prod_{n=1}^{N}\frac{\Gamma\left(m_{S,n}+m_{n}\right)}{\Gamma\left(m_{S,n}\right)}\left(-\frac{j\omega m_{S,n}RGP_{I,n}z_{n}^{-k_{n}}y^{-q}\Omega_{n}}{m_{n}}\right)^{m_{S,n}}U\left(m_{S,n}+m_{n},m_{S,n}+1;-\frac{j\omega m_{S,n}RGP_{I,n}z_{n}^{-k_{n}}y^{-q}\Omega_{n}}{m_{n}}\right)\\&\times\prod_{l=1}^{L}\frac{\Gamma\left(m_{S,l}+m_{l}\right)}{\Gamma\left(m_{S,l}\right)}\left(-\frac{j\omega m_{S,l}RP_{I,l}g_{l}^{-e_{l}}\Omega_{l}}{m_{l}}\right)^{m_{S,l}}U\left(m_{S,l}+m_{l},m_{S,l}+1;-\frac{j\omega m_{S,l}RP_{I,l}g_{l}^{-e_{l}}\Omega_{l}}{m_{l}}\right)\end{aligned}\tag{5}$$

Numerical Analysis

Numerical analysis of relay assisted D2D system over a composite Fisher–Snedecor *F* channel is presented. Expressions presented in above Section are general and are valid for arbitrary values. In this section, numerical analysis is presented for various assumed values of the parameters. Table 2. shows the parameters whose values are fixed in the numerical analysis. In Fig. 2 outage performance with varying source to relay distance is shown. Also, q = 2.7, y = 15 m, $m_{d,c}$ = [2, 4, 1], $m_{S,d,c}$ = [2.5, 1.5, 3.5], m_n = [4, 3, 2], $m_{S,n}$ = [2.5, 3.4, 1.5], $m_{S,l}$ = [1.5, 4.5, 2.5] and m_l = [5, 4, 1]. From the figure, it is clear that the outage performance is degraded as the D2D source moves away from the relay. Furthermore, as the diversity branches are increased from C = 1 to 3 the performance is improved. Therefore, C = 3 branches case will be considered for the subsequent analysis.

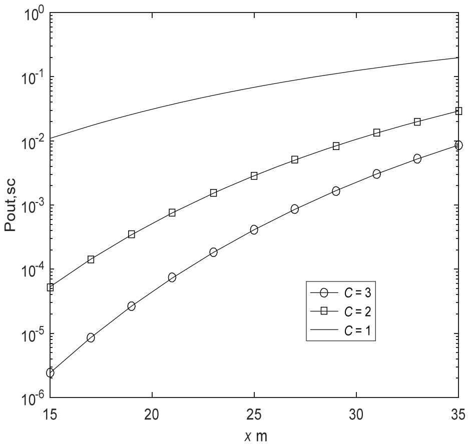

Fig.2. Outage with various diversity branches

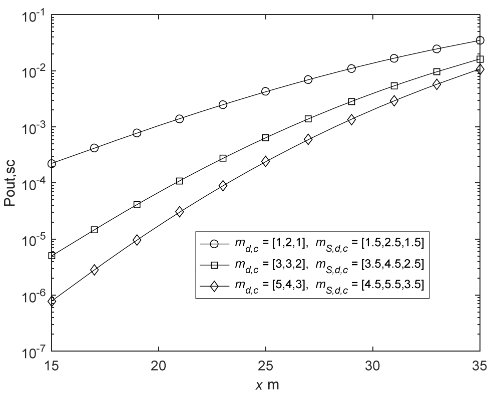

Fig. 3. Outage performance under various fading and shadowing conditions

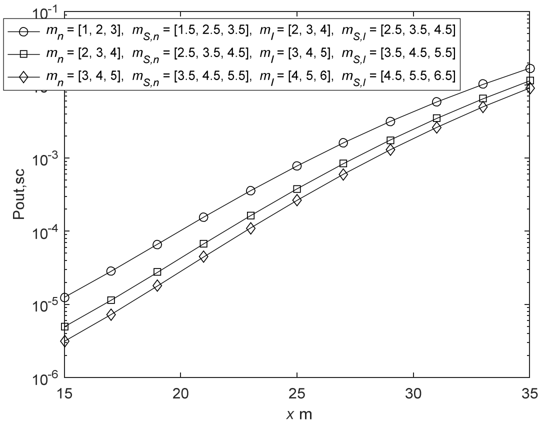

Fig. 4. Outage with various CCI shadowing and fading values at the D2D receiver and relay

Fig. 3 shows the outage performance with various shadowing and fading conditions of the D2D signal. Also, q = 3, y = 20 m, m_n = [4, 3, 2], $m_{S,n}$ = [2.5, 3.4, 1.5], $m_{S,l}$ = [1.5, 4.5, 2.5] and m_l = [5, 4, 1]. From the figure, it is clear that outage is improved when the values of m_n and $m_{S,d}$ are increased, i.e., under better fading and shadowing conditions outage performance is improved.

Fig. 4 shows the outage performance with various shadowing and fading conditions of CCI signals at relay and receiver. Also, q = 3, y = 20 m, $m_{d,c}$ = [1, 3, 2] and $m_{S,d,c}$ = [3.5, 4.5, 2.5]. From the figure, it is observed that outage performance of the system is improved as the CCI shadowing and fading conditions improve at the D2D receiver and relay.

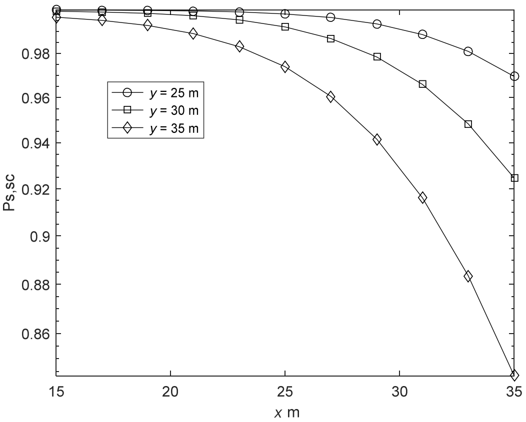

Fig. 5. Success performance with varying distance between relay and D2D receiver.

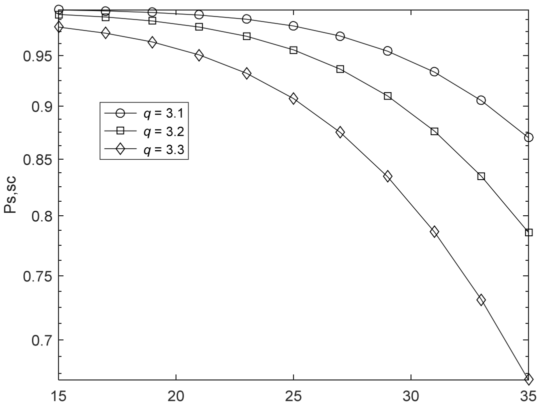

Fig. 6. Success performance with path-loss exponent for the relay to D2D receiver link.

Fig. 5 shows the success performance when the distance between the relay and the D2D receiver is varied. Also, q = 3, $m_{d,c}$ = [1, 3, 2], $m_{S,d,c}$ = [3.5, 4.5, 2.5], m_n = [2, 3, 4], $m_{S,n}$ = [2.5, 3.5, 4.5], $m_{S,I}$ = [3.5, 4.5, 5.5] and m_I = [3, 4, 5]. From the figure, it is observed that the success performance is degraded as the distance between the relay and the D2D receiver is increased.

Fig. 6 shows the success performance when the path-loss exponent for the relay to D2D receiver link is varied. Also, y = 30 m, $m_{d,c}$ = [1, 3, 2], $m_{S,d,c}$ = [3.5, 4.5, 2.5], m_n = [2, 3, 4], $m_{S,n}$ = [2.5, 3.5, 4.5], $m_{S,I}$ = [3.5, 4.5, 5.5] and m_I = [3, 4, 5]. From the figure, it can be seen that the success probability is degraded when the path-loss exponent between the relay and the D2D receiver is increased.

Conclusion

Success and outage performances of a relay-assisted D2D systems over Fisher–Snedecor F composite fading channels are presented. CCI at the replay and D2D receiver are also considered. Outage and success probabilities expressions are derived using a CF based approach. These expressions are functions of interference parameters, channel conditions, and path-loss parameters of communication links. From the numerical analysis it was observed that the fading and shadowing, and path-loss degrade the D2D system performance. Also, variations in the fading and shadowing conditions of the CCI showed clear influence on the performance. Degradation in the performance was also noticed when the distance and path-loss exponent between the relay and the D2D receiver link was increased.

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