Relay-Assisted D2D Communication over Extended $\eta-\mu$ Fading Channels

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In this paper, two cases of Device-to-Device (D2D) communication over a recently introduced extended $\eta-\mu$ fading channel are analyzed. Case A considers a direct D2D communication. While in case B, amplify-and-forward relay-assisted D2D communication is discussed. The effects of cochannel interference at the relay and D2D destination are also included. To combat fading, selection combining- and maximal ratio combining-based diversity schemes are also incorporated at the receiver. Power harvesting based on power splitting technique is also engulfed. Expressions of success and outage probabilities are derived with the help of characteristic function approach. Success and outage probability expressions are functions of path loss, distance between various devices and channel parameters. Based on these expressions, numerical results are presented and discussed.

1. Introduction

To keep up with the advancement in smart devices and applications such as multimedia communication and online gaming which require high data rate, wireless and cellular communication technologies have also evolved exponentially [1, 2]. Device-to-Device (D2D) communication is one of the proposed technologies of future cellular communication systems. In D2D communication systems, devices in proximity can communicate without relaying the base station (BS). D2D communication systems can significantly minimize the traffic load on BS and decrease the battery usage of devices for communication as it is designed for short distance communication and greatly improve the bandwidth utilization [3, 4]. To fully utilize the advantages of D2D communication system for long-distance communications, relay-assisted D2D communication system technology was introduced. In a relay-based D2D communication system, a device works as intermediate device that is capable of amplifying and forwarding the data to the end devices [5, 6]. The D2D devices coexisting with cellular devices can saturate the network. The competition for the limited bandwidth resource between the devices in network can cause cochannel interference (CCI) issue. Therefore, it is important to consider the effects of CCI in the analysis of communication systems [7, 8]. To increase the energy efficiency of D2D communication systems, the receiver devices are enabled to reutilize the transmitted radio frequency (RF) energy from the transmitter devices. In this paper, it is considered that receiver devices can harvest power from the received RF signals and use the harvested power for information communication [9]. Authors in [10] have studied outage probability performance of a multihop D2D communication over Rayleigh fading channel. Authors have considered shortest path routing algorithm for the network. In [11], authors have investigated outage probability performance of D2D communication system over Suzuki distributed channels. In [12], authors have analyzed full-duplex device-to-device (D2D) communication underlaying a cellular network. The authors have considered a simple Rayleigh fading model for the network. Success probability performance of D2D communication system over Rician faded channel using stochastic geometry is discussed by authors in [13]. In [14], authors discussed ergodic channel capacity (ECC) of various generalized fading channels for mobile communication based on the random waypoint mobility model. Authors derived analytical expressions for the ECC in the mobile
communication. In [15], author examined Wyner’s wiretap composite multipath/shadowing fading channel model and presented physical layer security secrecy performance. The analysis for average secrecy capacity in heavy shadowing is presented.

The main contributions of this paper are as follows: a newly proposed extended η-μ fading distribution [16] is considered for the outage probability and success probability performance analyses of the D2D communication system in an interference limited scenario. Two cases are considered in this paper. In case A, a direct D2D communication is analyzed. While in case B, amplify-and-forward relay-assisted communication is presented. The cochannel interference (CCI) signals are considered at the relay and the D2D receiver. CCI and D2D channels are considered to be independent and nonidentically distributed. The path loss conditions are included in the expressions. Power splitting- (PS-) based power harvesting technique is also considered. Selection combining (SC) and maximal ratio combining (MRC) diversity schemes are being used to tackle the effects of fading. To the best of our knowledge, no published work has considered the newly proposed extended η-μ faded channels for the relay-assisted D2D communication system with CCI signals, pathloss, diversity reception, and power harvesting. The extended η-μ fading distribution is a flexible, generalized, and more realistic fading model that includes fading distribution like, classic η-μ and the Nakagami and Hoyt as special cases [16]. The rest of the paper is organized as follows. The section named System Model presents the considered system and expressions of outage probability and success probability. In the Numerical Analysis, numerical results are presented and discussed. Finally, this paper is concluded in last the section.

2. System Model

Device-to-device (D2D) communication schemes with direct and amplify-and-forward (AF) relay-assisted are shown in Figures 1(I) and 1(II), respectively. In Table 1, parameters of Figures 1(I) and 1(II) are defined. There are M cochannel interferers at the relay and N cochannel interferers at the D2D receiver. Cochannel interference (CCI) is assumed to be independent and nonidentically distributed. Two types of D2D communication cases are considered here. In case A, D2D signal is directly received by the D2D receiver from the source. In case B, the D2D signal from the source is received by the relay. There are M CCI signals at the relay. The relay then amplifies and forwards the D2D and CCI signals to the D2D receiver.

The extended η-μ fading channel is assumed for all the signals in the system. The probability density function (PDF) of envelope R of extended η-μ is [16]

\[
f_R(r) = \frac{2(\mu \xi)^{\alpha}}{\Gamma(\mu)} \left( \frac{\mu}{\xi} \right)^{\frac{\gamma}{\mu - 1}} \frac{1}{r^{\mu}} \exp \left( -\frac{\mu \xi r^\gamma}{\xi - r^\gamma} \right) \text{P}_{1} \left( \frac{mp}{1 + \mu} ; \mu \xi (\eta - p)r^\gamma \right) \tag{1}\]

where \( iF_1(\cdot) \) is the confluent hypergeometric function [17] and \( \mu \) is the total number of clusters. Also, \( \xi = 1 + \eta/1 + p \) and \( r^2 \) is the total mean power. Extended η-μ fading modeling follows two formats. Based on Format 1, \( \eta \) is the ratio of in-phase and quadrature power components and, in Format 2, \( \eta \) is the normalized power’s difference of in-phase and quadrature components. In Format 1, \( p \) is the ratio of the number of multipath clusters and, in Format 2, it represents the normalized difference of the number of multipath clusters.

The fading of the relay D2D receiver path is assumed to be negligible; however, the signal is affected by path loss. Mobile wireless communication systems can have strong direct line-of-sight (LoS) component. Under such conditions, there will be negligible fading. Therefore, we have considered negligible fading conditions between relay and the receiver. The D2D receiver employs an L-branch selection combining (SC) or maximal ratio combining- (MRC-) based diversity scheme to combat fading effects of the channel.

2.1. Case A. For case A, the received signal in the l-th branch of D2D receiver is

\[
y_A = \sqrt{P_k^{-\mu}h_l(t)} s_0(t) + \sum_{n=1}^{N} \left( \sqrt{P_{L,n}^{-\mu}a_n} \right) s_n(t), \tag{2}\]

where \( s_0(t) \) is the desired signal and \( s_n(t) \) is the n-th CCI signal. \( E[|s_0(t)|^2] = 1 \) and \( E[|s_n(t)|^2] = 1, n = 1, 2, 3, \ldots, N \).

2.1.1. SC Scheme. The D2D receiver employs a L-branch selection combining (SC) or maximal ratio combining- (MRC-) based diversity scheme. The signal-to-interference noise power ratio (SINR) at the l-th branch of D2D receiver is

\[
\frac{S_l}{I_l} = (1 - \beta) \frac{P_k^{-\mu}h_l}{(1 - \beta) \sum_{n=1}^{N} P_{L,n}^{-\mu}g_n^{-\mu}a_n + \sigma^2}. \tag{3}\]

where \( S_l \) is the D2D signal power in the l-th branch of the D2D receiver, \( h_l \) is the independent extended η-μ fading variable in the l-th branch, and \( S_l \) is the total power of CCI at the D2D receiver. The receiver incorporates a power splitting- (PS-) scheme, based on which, a fraction of the received signal is provided for the desired data retrieval and the rest is used by the power harvester [18]. The fraction \( (0 \leq \beta \leq 1) \), known as the power splitting ratio, controls the amount of received signal used by the power harvester. \( \sigma^2 \) is the variance of the additive white Gaussian noise (AWGN) introduced by the power harvesting circuit. \( P \) is the power of the D2D signal and \( u \) is the path-loss exponent for the D2D signal from source to relay. \( P_{L,n} \) is the power of the n-th CCI signal at the D2D receiver and \( \epsilon_n \) is the path-loss exponent of the n-th CCI signal. The outage probability \( P_{out} \) is defined as the probability when the SINR of the system falls below a threshold value \( \Gamma \).

\[
P_{out} = \Pr \left( R_{S_l} < S_{MAX} \right), \tag{4}\]

where \( \Pr(\cdot) \) is the probability and \( S_{MAX} = \max_{l=1,2,\ldots,L}(S_l) \). In this work, SC scheme selects the diversity branch with the
maximum SINR. However, the power is harvested from every branch of the SC scheme. A characteristic function-(CF-) based approach is used here for the outage analysis. A decision parameter $\theta_j = R_S - S_j$ is considered. The CF of the decision variable is [16]

$$\phi_{\theta_j}(\omega) = E\left(e^{j\omega (R_S - S_j)}\right) = E\left(e^{j\omega S_j} e^{-j\omega S_j}\right)$$

$$= E\left(e^{j\omega (1-\beta) \sum_{n=1}^{N} P_{\text{th}} g_n^{-\alpha_n} \sigma^2 - j\omega (1-\beta) P_{\text{th}} h_l}\right)$$

$$= E\left(e^{-j\omega (1-\beta) P_{\text{th}} h_l} E\left(e^{j\omega (1-\beta) \sum_{n=1}^{N} P_{\text{th}} g_n^{-\alpha_n} \sigma^2}\right)\right)$$

$$= E\left(e^{-j\omega (1-\beta) P_{\text{th}} h_l} \prod_{n=1}^{N} E\left(e^{j\omega (1-\beta) P_{\text{th}} g_n^{-\alpha_n} \sigma^2}\right)\right)$$

$$= E\left(e^{-j\omega \lambda h_l} \prod_{n=1}^{N} E\left(e^{j\omega \lambda h_l} e^{j\omega \sigma^2}\right)\right)$$

$$\phi_{\theta_j}(\omega) = \left[1 + \frac{j\omega \lambda h_l}{\xi_{\text{th}}} \left(1 + \frac{j\omega \eta \lambda h_l}{p_{\text{th}} \xi_{\text{th}}} \right)\right]^{\frac{1}{m}} e^{j\omega \tau_{\text{th}}}$$

$$\times \prod_{n=1}^{N} \left[1 - \frac{j\omega \lambda h_n}{\xi_{\text{th}} R_n} \left(1 - \frac{j\omega \eta \lambda h_n}{p_{\text{th}} \xi_{\text{th}} R_n} \right)\right]^{\frac{1}{m}} e^{j\omega R_n},$$

where $\Omega_l = E[h_l]$ and $\Omega_n = E[\alpha_n]$ are average powers and $\mu_l$ and $\mu_n$ are the total number of clusters of the l-th branch D2D and n-th CCI signals, respectively. Based on Format 1, $\eta_l$ and $\eta_n$ are the ratios of in-phase and quadrature power components and, in Format 2, $\eta_l$ and $\eta_n$ are the normalized powers‘ difference of in-phase and quadrature components in the l-th branch D2D signal and of n-th CCI signal, respectively. In Format 1, $p_l$ and $p_n$ are the ratio of the number of multipath clusters and, in Format 2, they represent the normalized difference of the number of multipath clusters of the l-th branch D2D and n-th CCI signals, respectively. Also, $\xi_l = 1 + \eta_l/1 + p_l$, $\xi_n = 1 + \eta_n/1 + p_n$, $\lambda_l = (1 - \beta) P_{\text{th}} h_l^\omega$ and $\lambda_n = (1 - \beta) P_{\text{th}} g_n^{-\alpha_n}$. The outage probability can be obtained by using the formula

$$P_{\text{out}} = \frac{1}{2} \left(1 - \frac{1}{\pi} \int_{0}^{\alpha} \frac{\text{Im} \left(\phi_{\theta_j}(\omega)\right)}{\omega} d\omega\right)$$

$$\phi_{\theta_j}$$ is given in (4). Success probability is the probability for which the SINR of the received signal exceeds a predefined threshold $R$. For our case the success probability is

$$P_s = 1 - \frac{1}{\pi} \int_{0}^{\alpha} \frac{\text{Im} \left(\phi_{\theta_j}(\omega)\right)}{\omega} d\omega$$.

For an IID situation,

$$P_s = s$$
Total average power harvested, $P_{H,SC}$, by the receiver will be

$$P_{H,SC} = \beta \sum_{l=1}^{L} \left( pk^{-\alpha} \Omega_l + \sum_{n=1}^{N} P_{1,n} \gamma_n^{-\alpha_n} \Omega_n \right)$$  \hspace{1cm} (11)

2.1.2. MRC Scheme. For an $L$-branch maximal ratio combining (MRC-) based diversity scheme, the SINR is

$$S_{\text{MRC}} = \frac{\sum_{l=1}^{L} h_l}{\sum_{n=1}^{N} P_{1,n} g_n^{-\alpha_n} \omega_n + \sigma^2}$$  \hspace{1cm} (12)

where $S_{\text{MRC}}$ is the D2D signal power for the MRC case. Outage probability for this case will be $P_{out} = \Pr (R_{SI} > S_{\text{MRC}})$. A decision parameter $q_1 = R_{SI} - S_{\text{MRC}}$ is considered. The CF of the decision variable is

$$\phi_q(\omega) = \prod_{l=1}^{L} \left[ \left( 1 + \frac{j \omega \lambda_l \Omega_l}{\xi_l h_l} \right) \left( 1 + \frac{j \omega \eta_l \lambda_l \Omega_l}{\mu_l} \right) \right]^{\frac{n_l}{n_m}} \times \prod_{n=1}^{N} \left[ \left( 1 - \frac{j \omega \lambda_n \Omega_n}{\xi_n n_l} \right) \left( 1 - \frac{j \omega \eta_n \lambda_n \Omega_n}{\mu_n} \right) \right]^{\frac{m_n}{m_u}} e^{j \omega \theta_k}.$$  \hspace{1cm} (13)

The outage probability will be

$$P_{out} = \frac{1}{2} + \frac{1}{\pi} \int_0^\infty \frac{\Im \left( \phi_q(\omega) \right)}{\omega} d\omega,$$  \hspace{1cm} (14)

where $\phi_q$ is given in (6). The CF of the decision variable for IID case is

$$\phi_q(\omega) = \left[ \left( 1 + \frac{j \omega \lambda \Omega}{\xi} \right) \left( 1 + \frac{j \omega \eta \lambda \Omega}{\mu} \right) \right]^{\frac{n}{n_m}} \times \prod_{n=1}^{N} \left[ \left( 1 - \frac{j \omega \lambda_n \Omega_n}{\xi n_l} \right) \left( 1 - \frac{j \omega \eta_n \lambda_n \Omega_n}{\mu_n} \right) \right]^{\frac{m_n}{m_u}} e^{j \omega \theta_k}.$$  \hspace{1cm} (15)

Outage probability can be found by using the expression

$$P_{out} = \frac{1}{2} + \frac{1}{\pi} \int_0^\infty \frac{\Im \left( \phi_q(\omega) \right)}{\omega} d\omega.$$  \hspace{1cm} (16)

The success probability for MRC scheme is

$$P_s = \frac{1}{2} - \frac{1}{\pi} \int_0^\infty \frac{\Im \left( \phi_q(\omega) \right)}{\omega} d\omega,$$  \hspace{1cm} (17)

where $\phi_q$ is given in (6). Success probability for IID case of MRC scheme is

$$P_s = \frac{1}{2} - \frac{1}{\pi} \int_0^\infty \frac{\Im \left( \phi_q(\omega) \right)}{\omega} d\omega,$$  \hspace{1cm} (18)

where $\phi_q$ is given in (6).

By considering the maximum distance between D2D transmitter-receiver to be $Q$ meters, the transmitter-receiver distance $k$ can have a random value in range $(0 \leq k < Q)$ meters. The distance $k$ follows a linear distribution. The PDF of $k$ can be written as [19]

$$f_k(k) = \frac{2k}{Q^2}, 0 < k < Q.$$  \hspace{1cm} (20)

Under such conditions, the outage probability will be

$$P_{out} = \frac{1}{2} + \frac{1}{\pi} \int_0^Q \frac{\Im \left( \phi_q(\omega) \right)}{\omega} f_k(k) dkd\omega.$$  \hspace{1cm} (21)

Similarly, the success probability will be

$$P_s = \frac{1}{2} - \frac{1}{\pi} \int_0^Q \frac{\Im \left( \phi_q(\omega) \right)}{\omega} f_k(k) dkd\omega.$$  \hspace{1cm} (22)

2.2. Case B. For case B, the received signal at the relay is

$$y_R = \sqrt{P x^{-\alpha} h_l} s_0(t) + \sum_{m=1}^{M} \left( \sqrt{P_L x^{-\alpha_L} y_m} \right) s_m(t),$$  \hspace{1cm} (23)

where $s_m(t)$ is the m-th CCI signal. $E[|s_m(t)|^2] = 1, m = 1, 2, 3, \ldots, M$.

The received signal in the l-th branch of D2D receiver is

$$y_B = \sqrt{GP x^{-\alpha} y^{-\beta}} h_l s_0(t) + \sum_{m=1}^{M} \left( \sqrt{P_L x^{-\alpha_L} y^{-\beta} \gamma_m} \right) s_m(t) + \sum_{m=1}^{M} \left( \sqrt{G y^{-\beta} P_L x^{-\alpha_L}} \gamma_m \right) s_m(t).$$  \hspace{1cm} (24)

2.2.1. SC Scheme. The D2D signal is first received by the relay which then amplifies and forwards it to the D2D receiver. The D2D receiver employs a $L$-branch SC-based diversity scheme.
The SINR at the \( l \)-th branch of D2D receiver is

\[
S_l = \frac{(1 - \beta)GPx^{-\gamma}y^{-b}h_l}{(1 - \beta)\sum_{n=1}^{N}P_{L_m}E_{m_0}E_{m_0}^{+}a_n + \Delta_m + \sigma^2},
\]

(25)

where \( \Delta_m = (1 - \beta)Gy^{-b}\sum_{m=1}^{M}P_{L_m}E_{m_0}E_{m_0}^{+}y_m \). \( P_{L_m} \) is the is the power of the \( m \)-th CCI signal at the relay, \( y_m \) is the path-loss exponent of the \( m \)-th CCI at the relay, \( y_m \) is an independent extended \( \eta-\mu \) fading variable of the \( m \)-th CCI and, \( \alpha \) and \( \beta \) are path-loss exponents. \( G \) is the relay’s amplification factor given as [20]

\[
G = \frac{P_2}{P_{x^{-\mu}} + \sum_{m=1}^{M}P_{L_m}E_{m_0}^{+}m_{m_0}^{+}\Omega_m},
\]

(26)

where \( P_2 \) is the relay amplifying power, \( \Omega = E[h] \) and \( \Omega_m = E[y_m] \) are average powers of D2D and \( m \)-th CCI signals at the relay, respectively. The CF of the decision variable \( \theta_l = RS_l - S_l \) is

\[
\phi_{\theta_l}(\omega) = \left[ \left( 1 + j\omega \lambda\Omega_{\xi_{l}\Omega_{1}} \right) \left( 1 + j\omega \lambda_{m}\Omega_{\xi_{l}\Omega_{1}} \right) \right]^{M_{m}}
\]

\[
\times \prod_{n=1}^{N} \left[ \left( 1 - j\omega \lambda\Omega_{\xi_{l}\Omega_{1}} \right) \left( 1 - j\omega \lambda_{m}\Omega_{\xi_{l}\Omega_{1}} \right) \right]^{M_{m}}
\]

\[
\times \prod_{m=1}^{M} \left[ \left( 1 - j\omega \lambda\Omega_{\xi_{m}\Omega_{1}} \right) \left( 1 - j\omega \lambda_{m}\Omega_{\xi_{m}\Omega_{1}} \right) \right]^{M_{m}}
\]

(27)

where \( \mu_m \) is the total number of clusters of the \( m \)-th CCI signal at the relay. Based on Format 1 of the extended \( \eta-\mu \) fading model, \( \eta_m \) is the ratio of in-phase and quadrature power components, and in Format 2, \( \eta_m \) is the normalized powers’ difference of in-phase and quadrature components of \( m \)-th CCI signal. In extended \( \eta-\mu \) Format 1, \( \rho_m \) is the ratio of the number of multipath clusters and, in Format 2, it represents the normalized difference of the number of multipath clusters of the \( m \)-th CCI signal at the relay. Also, \( \xi_{m} = 1 + \eta_m^{1/2} + \xi_m \), \( \lambda_{m}(1 - \beta)GPx^{-\gamma}y^{-b} \), \( \lambda_{n}(1 - \beta)R P_{L_{m}}E_{L_{m}}^{+}y^{-b} \), and \( \lambda_{m}(1 - \beta)R P_{L_{m}}E_{L_{m}}^{+}y^{-b} \). The outage probability will be

\[
P_{out} = \prod_{l=1}^{L} \left( 1 + \frac{1}{\pi} \int_{0}^{\infty} \frac{\phi_{\theta_l}(\omega)}{\omega} d\omega \right). \]

(28)

For an IID case,

\[
P_{out} = \left( 1 + \frac{1}{\pi} \int_{0}^{\infty} \frac{\phi_{\theta}(\omega)}{\omega} d\omega \right)^L. \]

(29)

where

\[
\phi_{\theta}(\omega) = \left[ \left( 1 + j\omega \lambda_{\Omega_{\xi_{l}\Omega_{1}}} \right) \left( 1 + j\omega \lambda_{m}\Omega_{\xi_{l}\Omega_{1}} \right) \right]^{M_{m}}
\]

\[
\times \prod_{n=1}^{N} \left[ \left( 1 - j\omega \lambda_{\Omega_{\xi_{l}\Omega_{1}}} \right) \left( 1 - j\omega \lambda_{m}\Omega_{\xi_{l}\Omega_{1}} \right) \right]^{M_{m}}
\]

\[
\times \prod_{m=1}^{M} \left[ \left( 1 - j\omega \lambda_{\Omega_{\xi_{m}\Omega_{1}}} \right) \left( 1 - j\omega \lambda_{m}\Omega_{\xi_{m}\Omega_{1}} \right) \right]^{M_{m}}
\]

\[
\times \frac{e^{j\omega \Delta_{m}a_n}}{\omega \eta_{m}} \]

(30)

Success probability is

\[
P_{S} = 1 - \left( 1 + \frac{1}{\pi} \int_{0}^{\infty} \frac{\phi_{\theta}(\omega)}{\omega} d\omega \right)^L, \]

(31)

\( \phi_{\theta} \) is given in (27). For an IID situation success probability is

\[
P_{S} = 1 - \left( 1 + \frac{1}{\pi} \int_{0}^{\infty} \frac{\phi_{\theta}(\omega)}{\omega} d\omega \right)^L, \]

(32)

where \( \phi_{\theta} \) is given in (30). Total average power harvested, \( P_{H,RSC} \), for this case is

\[
P_{H,RSC} = \beta \sum_{l=1}^{L} \left( GPx^{-\gamma}y^{-b} \Omega_{1} + \sum_{n=1}^{N} P_{L_{m}}E_{L_{m}}^{+}y^{-b} \Omega_{n} + Gy^{-b} \sum_{m=1}^{M} P_{L_{m}}E_{L_{m}}^{+}y^{-b} \Omega_{m} \right). \]

(33)

2.2. MRC Scheme. For an \( L \)-branch MRC-based diversity scheme, the SINR is

\[
\frac{S_{MRC}}{S_l} = \frac{(1 - \beta)Gy^{-b}\sum_{l=1}^{L}h_l}{(1 - \beta)\sum_{m=1}^{M}P_{L_m}E_{m_0}E_{m_0}^{+}a_n + \Delta_m + \sigma^2},
\]

(34)

where \( \Delta_m = (1 - \beta)Gy^{-b}\sum_{m=1}^{M}P_{L_m}E_{m_0}E_{m_0}^{+}y_m \). Outage probability for the case is \( P_{out} = Pr(S_{MRC} > S_{MRC}) \). The CF of the decision variable \( \psi_{l} = RS_l - S_{MRC} \)

\[
\phi_{\psi_{l}}(\omega) = \prod_{l=1}^{L} \left[ \left( 1 + j\omega \lambda_{\Omega_{\xi_{l}\Omega_{1}}} \right) \left( 1 + j\omega \lambda_{m}\Omega_{\xi_{l}\Omega_{1}} \right) \right]^{M_{m}}
\]

\[
\times \prod_{n=1}^{N} \left[ \left( 1 - j\omega \lambda_{\Omega_{\xi_{l}\Omega_{1}}} \right) \left( 1 - j\omega \lambda_{m}\Omega_{\xi_{l}\Omega_{1}} \right) \right]^{M_{m}}
\]

\[
\times \prod_{m=1}^{M} \left[ \left( 1 - j\omega \lambda_{\Omega_{\xi_{m}\Omega_{1}}} \right) \left( 1 - j\omega \lambda_{m}\Omega_{\xi_{m}\Omega_{1}} \right) \right]^{M_{m}}
\]

\[
\times \frac{e^{j\omega \Delta_{m}a_n}}{\omega \eta_{m}} \]

(35)

The outage probability is

\[
P_{out} = \left( 1 + \frac{1}{\pi} \int_{0}^{\infty} \frac{\phi_{\psi_{l}}(\omega)}{\omega} d\omega \right)^L. \]

(36)
For an IID case, ϕΨ in above expression will be

\[
\phi_\Psi(\omega) = \left[ \left( 1 + \frac{j \omega \lambda \Omega}{\xi \mu} \right) \left( 1 + \frac{j \eta \lambda \Omega}{\rho \kappa \mu} \right)^\frac{n_m}{n}\right]^{\frac{n_m}{n_m}}
\]

\[
\times \prod_{n=1}^{N} \left[ \left( 1 - \frac{j \omega \lambda \Omega}{\xi \mu} \frac{\Omega_n}{\xi_n \mu_n} \right) \left( 1 - \frac{j \eta \lambda \Omega}{\rho \kappa \mu} \frac{\Omega_n}{\xi_n \mu_n} \right)^{\frac{n_m}{n_m}} \right]^{\frac{n_m}{n_m}}
\]

\[
\times \prod_{m=1}^{M} \left[ \left( 1 - \frac{j \omega \lambda \Omega}{\xi \mu} \frac{\Omega_m}{\xi_m \mu_m} \right) \left( 1 - \frac{j \eta \lambda \Omega}{\rho \kappa \mu} \frac{\Omega_m}{\xi_m \mu_m} \right)^{\frac{n_m}{n_m}} \right]^{\frac{n_m}{n_m}} e^{j\frac{\omega}{\omega}}.
\]

The success probability is

\[
P_s = \frac{1}{2} - \frac{1}{\pi} \int_0^\infty \frac{\text{Im} \left( \phi_{\Psi}(\omega) \right)}{\omega} d\omega,
\]

where \( \phi_{\Psi} \) is given in (10). For an IID scenario, success probability is

\[
P_s = \frac{1}{2} - \frac{1}{\pi} \int_0^\infty \frac{\text{Im} \left( \phi_{\Psi}(\omega) \right)}{\omega} d\omega,
\]

where \( \phi_{\Psi} \) is given in (11). Total average power harvested \( P_{HRMRC} \) is

\[
P_{HRMRC} = \beta \left[ G_{P_\Psi}^{\text{-}\gamma} \sum_i^{i} \sum_{n=1}^{N} P_{L_s} f_{\Omega_s} + G_{P_\Psi}^{\text{-}\gamma} \sum_{m=1}^{M} P_{L_m} \sum_{n=1}^{N} z_n \right].
\]

For the relay-based MRC system, by considering the maximum distance between relay-receiver to be A meters. The relay-receiver distance, y can have a random value in the range \( 0 \leq y \leq A \) meters. The PDF of y can be written as

\[
f_y(y) = \frac{2y}{A^2}, 0 < y < A.
\]
Figure 2: Outage performance with various path-loss conditions for the relay-based system with SC.

Figure 3: Outage performance with various path-loss conditions for the relay-based system with MRC.
Figure 4: Outage performance with varying total number of clusters for the relay-based system.

Figure 5: Outage performance with varying ratio of in-phase and quadrature power components for the relay-based systems.
The outage probability will be
\[ P_{\text{out}} = \frac{1}{2} + \frac{1}{\pi} \int_{0}^{\infty} \int_{0}^{\infty} \frac{\text{Im} \left( \frac{\Phi_{r}(\omega)}{\omega} \right) f_{\gamma}(y) dy d\omega}{\omega} \quad (42) \]

Similarly, the success probability will be
\[ P_{S} = \frac{1}{2} - \frac{1}{\pi} \int_{0}^{\infty} \int_{0}^{\infty} \frac{\text{Im} \left( \frac{\Phi_{r}(\omega)}{\omega} \right) f_{\gamma}(y) dy d\omega}{\omega} \quad (43) \]

The double integral in the outage and success probability expressions can be solved with the help of MATLAB.

3. Results and Analysis

The numerical results based on the analysis of System Model are presented in this section. Expressions presented in System Model are valid for arbitrary values. Here, numerical analysis is presented for various assumed values of the parameters. Table 2 shows the parameters whose values are fixed. In Figures 2 and 3, outage performance comparisons with varying path-loss exponents for the relay-based systems are presented. The performance is also compared when the total distance between the D2D source and receiver is varied. For the relay-based system, the total distance between the D2D source and receiver is considered to be \( x + y \). Now, \( \beta = 0.3, c_{t} = [3, 2.8, 3.1], v_{m} = [2.7, 3, 3.5], \eta_{n} = [2, 0.8, 4], \eta_{l} = [2-4], \eta_{m} = [2, 0.2, 2], \mu_{n} = [2, 4], \mu_{l} = [2, 3, 5], \mu_{m} = [2, 3], p_{l} = [0.8, 0.1, 2], p_{n} = [1, 0.2, 2], p_{m} = [2, 0.5, 2] \). From the figures, it is clear that as the total distance between D2D devices is increased, the outage performance of the system degrades for all scenarios. In Figure 2, SC-based diversity is considered. From the figure, it is clear that the relay-based system performs well as compared to the system without relay. However, as the path-loss exponent is increased from the relay to D2D receiver, the outage performance for the relay-based system degrades. Also, when there is no SC scheme, performance degrades. In Figure 3, MRC-based diversity is considered. By comparing Figures 2 and 3, it is clear that MRC-based systems outperform SC-based systems with and without relay cases.

In Figure 4, outage performance with varying total number of clusters for the relay-based system is presented. MRC diversity is considered: \( \beta = 0.3, b = 3, c_{n} = [3, 2.8, 3.1], v_{m} = [2.7, 3, 3.5], \eta_{n} = [2, 0.8, 4], \eta_{l} = [2-4], \eta_{m} = [2, 0.2, 2], \mu_{n} = [2, 4], \mu_{l} = [2, 3, 5], \mu_{m} = [2, 3], p_{l} = [0.8, 0.1, 2], p_{n} = [1, 0.2, 2], p_{m} = [2, 0.5, 2] \). From the figure, it is observed that as the number of total clusters are decreased, the performance of the relay-based system degrades and underperforms the nonrelay-based system for the distance of 20 m to 30 m; however, the gap is reduced as the distance between D2D source and receiver is increased.

In Figure 5, outage performance with varying ratio of in-phase and quadrature power components for the relay-based system is presented. MRC diversity is considered: \( \beta = 0.3, b = 3, c_{n} = [3, 2.8, 3.1], v_{m} = [2.7, 3, 3.5], \eta_{n} = [2, 0.8, 4], \eta_{m} = [2, 0.2, 2], \mu_{n} = [2, 4], \mu_{l} = [2, 3, 5], \mu_{m} = [2, 3], p_{l} = [0.8, 0.1, 2], p_{n} = [1, 0.2, 2], p_{m} = [2, 0.5, 2] \). From the figure, it is
Figure 7: Outage performance with varying total number of clusters for the cochannel interferers at the relay and receiver.

Figure 8: Outage performance with varying ratio of the number of multipath clusters for the cochannel interferers at the relay and receiver.
observed that as the ratio of in-phase and quadrature power components is increased, the performance of the relay-based system degrades.

In Figure 6, outage performance with varying ratio of the number of multipath clusters \( p_i \) for the relay-based system is presented. MRC diversity is considered: \( \beta = 0.3, b = 3, c_n = [3, 2.8, 3.1], v_m = [2.7, 3, 3.5], \eta_l = [2–4], \eta_n = [2, 0.8, 4], \eta_m = [2, 0.2, 2], \mu_n = [2, 4], \mu_l = [2, 3, 5], \mu_m = [2, 3], \rho_n = [1, 0.2, 2], \) and \( \rho_m = [2, 0.5, 2] \). From the figure, it is observed that the system shows best performance when the values \( \eta_l \) and \( p_i \) are the same. As the values of \( p_i \) are varied, either increased or decreased, outage performance degrades.

In Figure 7, outage performance with varying total number of clusters for the cochannel interferers at the relay and
receiver for the relay-based system and the system without relay is presented. MRC diversity is considered, $\beta = 0.3$, $b = 3$, $\eta_m$ = [2, 3, 5], $\eta_p$ = [2, 0.8, 4], $\eta_m$ = [2, 0.2, 2], $\mu_i$ = [2, 3, 5], $p_n$ = [1, 0.2, 2], $p_i$ = [0.8, 0.1, 2], and $p_m$ = [2, 0.5, 2]. From the figure, it is clear that the outage performance is unaffected by any variation in the total number of clusters for the cochannel interferers at relay and D2D receiver.

![Figure 11: Outage performance with varying PS ratio and varying maximum distance between relay-receiver.](image1.png)

![Figure 12: Outage performance with varying transmit power of the D2D signal.](image2.png)
In Figure 8, outage performance with varying the ratio of the number of multipath clusters for the cochannel interferers at the relay and receiver is presented. MRC diversity with relay is considered. And, performance of the system degrades. In Figure 10, success performance, it is clear that as the transmit power of the D2D is presented. MRC diversity with relay-receiver path, the outage performance degrades. However, by increasing the path-loss exponent of the system. It is also observed that SC incorporated relay-based system shows best performance in terms of power harvesting. Also, the success probability performance of the system degrades, as the PS ratio is increased.

Data Availability
No data were used to support this study.

Conflicts of Interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

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