Article

Performance analysis of DF relay assisted D2D communication in 5G mm-Wave network

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Abstract: Enabling D2D communication in the mm-Wave band has many obstacles which must be mitigated. The primary concern is the introduction of interference from various sources. Thus, we focused our work on the performance of decode and forward (DF) relay assisted D2D communication in the mm-Wave band for increasing the coverage probability and energy efficiency (EE). Three modes are proposed for D2D communication to prevail. Bit-wise binary XOR operation is executed at the relay node which increases the security feature. Radius of coverage expression is derived which indicates the switching of the modes. The diffused incoherent scattering power is also considered as a part of power consumption. Furthermore, a unique relay selection scheme, Dynamic relay selection (DRS) method is proposed to select the optimal relay for information exchange. Comparison of the proposed DF relay scheme with amplify and forward (DF) scheme is also shown. Finally, simulation results prove the efficacy of the proposed work.

Keywords: Dynamic relay selection; Decode and forward; D2D communication; Radius of coverage; Coverage probability, Mode selection; mm-Wave network; Uplink channel.

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1. Introduction

Device-to-Device (D2D) communication poses to be the perfect candidate for 5G and beyond (B5G) communication at mm-Wave band due to its inherent advantages over other contemporary technologies. This is due to the larger bandwidth, increased data rate, ultra low latency, and lesser interference at the unused spectrum [1]. Also, it enhances the spectral (SE) and energy efficiency (EE) of the network by setting up a direct information transfer among the devices without the direct controlling of the base station (BS). However, setting up D2D communication at mm-Wave band of 28 GHz has some challenges attached to it [2]. Signal propagation in the mm-Wave band undergoes extensive degradation due to the interference and blockages such as, atmospheric attenuation, attenuation due to precipitation, human blockage, foliage loss etc. This significantly reduces the signal strength of the received signal at the user end which subsequently reduces the signal-to-interference plus noise ratio (SINR). In addition to it, this decrease in the SINR lowers the data rate of the overall network which results in decrease of the SE and EE [3].

Relay plays a pivotal role in extending the coverage area of the D2D communication network. As the distance between the D2D users increases or if the D2D user is located at the far edge of the cell, the signal strength also drops extensively which further diminishes the throughput of the D2D user. To solve this problem, relaying technique may be applied effectively for maintaining the SINR above a certain pre-defined threshold level and enhance the quality-of-service (QoS) of the communication network. In comparison to the direct communication, relay has more advantages such as, increased throughput, increased network coverage, better capacity etc [4]. Among all of the relay types, decode and forward (DF) relay is widely used in communication systems. DF relay node receives the signal transmitted from the D2D transmitter, decodes the transmitted signal and then forwards it to the receiving D2D user after self-interference cancellation procedure, which appears as an advantage over the amplify and forward (AF) relay. It also helps in enhancing the security of the network. However, the computational time for processing gets

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increased while implementing the DF relay, but the huge benefit that it provides, balances the minimal issues. Thus, in the next section we have presented the literature survey of the state-of-the-art works providing a glimpse of the current trends in the D2D communication using DF relay.

1.1. Related Works

As discussed in the earlier section about the advantages of implementing the DF relay for network coverage enhancement and for seamless operation of D2D communication to take place in the mm-Wave network while satisfying the QoS constraints, DF relay has widespread applications which enhances the SINR and thereby uplifts the data rate of the D2D users. Some of the techniques related to the performance enhancement of relay aided D2D communication are discussed as follows.

In [5], the authors address the power control problem between D2D source and relay node to a new angle-EE in DF relay aided D2D communication. The EE of the relay node to D2D link is maximized while satisfying the minimum data-rate of the cellular link. The maximization is done by obtaining the optimal power at both D2D transmitter and relay node. In [6], stochastic geometry is used to obtain the expressions for the coverage probability for a relay-aided mm-Wave cellular network in downlink channel. Blockages and beamforming gains are also considered while obtaining the coverage probability and SE for line of sight as well as for non line of sight paths. Now, in [7], three communication transmission modes are proposed to investigate the achievable sum-rates of D2D communication assisted by DF relay node. Corresponding expressions for the ergodic achievable sum-rates of each transmission mode are obtained to compare the performance metrics of direct communication to that of the DF relay D2D communication. It is found that the DF aided D2D communication exhibits better performance than the direct communication. Again, the authors in [8] derived the ergodic rate for a D2D communication system aided by a two-way DF relay node. They have formulated two scenarios, weak interference case and high SNR case which gives us a better insight and derives the closed-form power allocation strategy to showcase the improvement in the system performance. The authors derived closed form expressions of coverage probability and transmission capacity for a full duplex amplify and forward (FDAF) relay aided D2D communication network in [9]. The parameters such as, D2D user density, relay node density and the distance between D2D pairs are also considered for simulating the environment. The authors in [10] considered two interference cancellation models for evaluating the transmission capacity of relay-assisted D2D communication. Also, they have investigated the effect of these parameters in the overall network performance. The authors in [11] put forward a power control problem in which two optimization objectives are considered, i.e., maximization of the minimum SINR of D2D users and maximization of the sum-rate of D2D users for a two-way AF relay for assisting the underlay D2D communication. In [12], an interference free dual-hop D2D aided cooperative relaying strategy (CRS) based on spatial modulation has been proposed. Two scenarios are assumed acting in two different time slots. Interference free information is received at the end user node without allocating any fixed transmit power. Bit error rate and SE are also derived for showing the performance of the proposed work. A multi-objective combinatorial optimization problem is modelled in [13] which helps in balancing the trade-off between the total transmit power and system data rate. The authors also proposed a centralized relay selection and power allocation algorithm which achieved Pareto optimal solution in polynomial time. This method reduced the total transmit power and improved the system throughput. The authors in [14] proposes a scheme with manifold objectives in the form of the ability to improve SE by using underlay spectrum sharing mode, eradicate co-channel interference and enhance comprehensive performance while satisfying multiple QoS metrics. The relay selection overhead is reduced by implementing the greedy's algorithm based on a distributed local search that improves the EE along with the convergence time through a power adjustment scheme which is based on the improved potential game decision algorithm.

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As the relay selection is also an integral metric for a relay aided D2D communication, thus we have put forward some research works to get an insight into the various techniques through which we can optimally select the relay for D2D communication abetting seamless operation. The authors in [15] put forward a relay selection scheme for cooperative out-band D2D network based on channel gain value and transmission link distance. The suitable relay is selected based on the minimum distance between user and the relay node using the Quantization-and-Forward (QF) protocol. A cooperative electronic relay technique is proposed in [16] for a D2D communication system. The method uses three types of cooperative diversities together namely, compress and forward relay, DF relay and AF relay. It is found through numerical results that the D2D outage probability of the proposed method is lower than that of the traditional relay transmission, which is again further minimized with an increase in number of the electronic relays. Lastly, in [17], the authors proposed a global positioning system based, location aware, centralized approach for solving the problem of relay selection. A learning based approach is formulated for detecting the presence of static as well as dynamic obstacles present in the environment.

1.2. Motivation

The research works discussed in the above section portrays various techniques involving DF relay aided D2D communication. The optimal management of relays enhances the SE as well as the EE of the overall network. Some papers focused on extending the coverage area of the D2D communication. Relay selection is also an important area which needs attention. Many researches are carried out on these areas focusing on issues of coverage probability, EE, throughput, power optimization etc. but there is still more space for improvement. Thus, this work focuses on enhancing the coverage probability of the D2D users and also finding an optimal method for relay selection.

1.3. Contribution

Focusing the proposed work on enhancing the coverage probability of the D2D users using DF relay and also finding an optimal method for relay selection, the contribution of the proposed work are furnished as follows,
a) Bit-wise binary XOR operation is executed for encoding the message received at the relay node using a carrier frequency of 28 GHz in an uplink Rician fading channel.
b) Three modes are formulated for D2D communication to take place at two different frequencies, 2 GHz and 28 GHz respectively.
c) Radius of coverage for the D2D users is obtained for switching of modes.
d) A dynamic relay selection (DRS) method is proposed for optimal selection of DF relays based on higher sum SINR, lower distance and higher channel gain of the instantaneous SINR of the D2D communication.
e) The diffused incoherent scattering power (P_S) and circuit power P_C as a part of power consumption are also considered in the receiver node for the relay mode operating at mm-Wave band for a better realistic and accurate analysis of EE.
f) The performance metric, coverage probability of the D2D communication is derived to demonstrate the efficacy of the communication system. The EE for the proposed DF relay is also compared with the AF relay scheme. Numerical results also validate the efficiency of the proposed work.

1.4. Notations

The notations used in this paper are furnished as follows. The notation $\bigoplus$ represents bit-wise binary XOR operation. $\mathbb{P}$ denotes the probability function. The notation $f_y(.)$ is used to denote the probability distribution function (PDF) for the random variable y.
The remainder of the article is categorized as follows. Section 2 describes the system model where the basic assumptions along with the pathloss model and the information model are discussed. Section 3 gives us the problem formulation and analysis. Expressions for

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coverage probability of D2D users and relay selection technique are formulated in this section. In Section 4, simulation results are analyzed and discussed. Finally, Section 5 concludes the work with remarks about the proposed work along with a brief discussion about the future scopes and directions.

Table 1. List of Notations.

Sl. No.	Symbols	Significance
1	f_c	Operating frequency
2	d	Distance between T-R
3	α	Pathloss exponent
4	AT	Interference due to the atmospheric absorption
5	χ_σ	Log normal shadow fading having zero mean
6	σ	Standard deviation (in dB)
7	P_C, P_D, P_T, P_S	Cellular power, D2D power, Circuit power and Scattering power, respectively
8	h_{D2D}, h_{C2D}	Channel gain for D2D and CU to D2D, respectively
9	h_{C2B}, h_{D2B}	Channel gain for CU to BS and D2D to BS, respectively
10	d_{D2D}, d_{C2D}	Distance between D2D and CU to D2D, respectively
11	d_{C2B}, d_{D2B}	Distance between CU to BS and D2D to BS, respectively
12	n_D, n_C	AWGN noise at D2D and CU users, respectively
13	n_R, n_A, n_B	AWGN noise at relay node,D2D A and D2D B, respectively
14	γ_{th}	Threshold SINR
15	P_{AR}, P_{BR}	Received power at relay node from A and B D2D users, respectively
16	P_{RA}, P_{RB}	Received power at A and B D2D users from relay node, respectively
17	P_{SA}, P_{SB}, P_{CR}	Received power at A and B D2D users from BS, and from CU to relay, respectively

2. System Model

This section provides the system model for the proposed work along with the scenario description. Let us consider cellular and D2D users present in a cell communicating with each other in a 5G mm-Wave cellular network using an uplink channel through the assistance of a two-way DF (Decode and Forward) relay protocol as shown in Fig.1. The cardinality of cellular and D2D users may be denoted by N and M, respectively. In this scenario, the cellular users utilize the uplink channel of the spectrum for communicating with the BS. The D2D users reuse the uplink resources of the cellular spectrum for communicating among themselves. The D2D users are randomly distributed in the cell following a poisson point process (PPP) ϕ with density λ_d in a finite two dimensional plane $\mathbb{R}^2$. The cell consists of two zones for communication to take place among D2D users, namely Zone 1 and Zone 2, respectively. Additionally, the proposed work portrays three modes of communication for seamless communication to take place. D2D communication in the Zone 1 will take place at an operating frequency of 2 GHz. Here in the Zone 1, the D2D communication takes place in the Mode 1 while satisfying the QoS constraints. As the distance between the D2D users and the BS increases to a certain predefined value, the D2D communication occurs at 28 GHz frequency, i.e. in the Mode 2. In the Mode 2, if the radius of coverage between the D2D users is greater than a certain predefined threshold, the SINR ratio also reduces significantly. Thus, the data rate also diminishes which results in reduced QoS. Thus, to enhance the QoS constraints and to provide seamless operation among the D2D users, it switches to Mode 3. The communication in the Mode 3 takes place at 28 GHz frequency through the assistance of the two-way DF relay node. The relaying occurs at two time slots, $T1$ and $T2$, respectively.

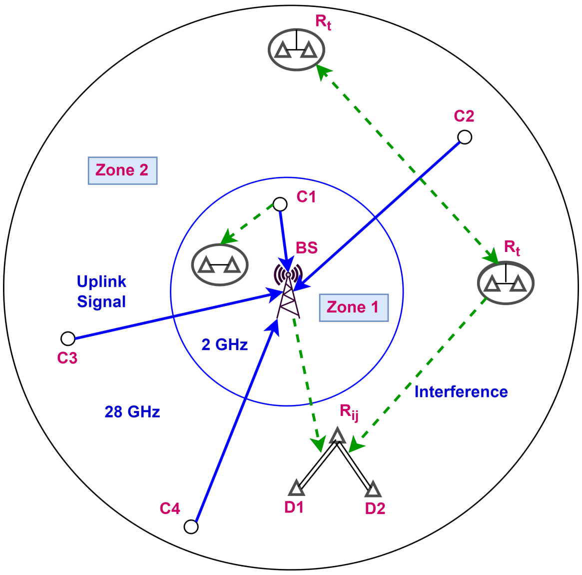

Figure 1. System model representing interference acting on D2D users

2.1. Information model

To realize the proposed scenario, some assumptions are considered. The BS has complete knowledge of the channel state information (CSI). Also, it has prior knowledge of the locations of the D2D users and their respective pathloss exponents. It has also been assumed that the total number of channels available is equal to the total number of cellular users present in the cell. Moreover, the distribution of the relay nodes follow PPP distribution in finite two dimensional plane $\mathbb{R}^2$ with density λ_{RN}.

2.2. Pathloss model

As the communication among D2D users take place in the mm-Wave band which is affected by several environmental factors causing interference, thus a pathloss model is required to maintain the signal strength above a certain threshold level. According to the NYUSIM channel model [18], the path loss model considered for free space pathloss (FSPL) is as follows,

$$\begin{aligned} FSPL(f,1m)[dB] &= 20\log_{10}\frac{(4\pi f_c \times 10^9)}{c} \\ &= 32.4[dB] + 20\log_{10} f_c \end{aligned} \tag{1}$$

where, f_c is the carrier frequency and c is the speed of light. $FSPL(f,1m)$ denotes the free space pathloss in dB with a transmitter-receiver (T-R) distance of 1m. For high penetration losses, large scale pathloss model is considered for 1m reference distance as per NYUSIM [18] which is shown as follows,

$$\begin{aligned} PL(f,d)[dB] &= FSPL(f,1m)[dB] + 10\alpha\log_{10}(d) \\ &+ AT[dB] + \chi_\sigma \end{aligned} \tag{2}$$

where, d is the separation distance (in 3-D) between T-R, α and χ_σ denotes the pathloss exponent and the log normal shadow fading having zero mean with σ standard deviation (in dB). AT represents the interference due to the atmospheric absorption. The channel gain (Rician fading channel) h between the two D2D users can be represented as [19],

$$h = 10^{-PL(f,d)[dB]/10} \tag{3}$$

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h is dependent on the distance between the T-R and is independently and identically exponentially distributed with a mean μ^{-1}.

3. Problem formulation and analysis

As stated in the earlier section 2, the cell is divided into two parts, Zone 1 and Zone 2. The carrier frequency in the Zone 1 is taken to be 2 GHz. The D2D users reuse the uplink cellular resources for direct communication among themselves. The D2D communication takes place in the Mode 1.

3.1. Zone 1

Thus, the received signal at the D2D end user can be expressed as,

$$Y_D^1 = \sqrt{P_D} h_{D2D} d_{D2D}^{-\alpha/2} x_1 + \sqrt{P_C} h_{C2D} d_{C2D}^{-\alpha/2} x_2 + n_D \quad (4)$$

Similarly, the received signal at the cellular user from the BS can be given as follows,

$$Y_C^1 = \sqrt{P_C} h_{C2B} d_{C2B}^{-\alpha/2} x_2 + \sqrt{P_D} h_{D2B} d_{D2B}^{-\alpha/2} x_1 + n_C \quad (5)$$

Thus, the SINR at the respective cellular and D2D users can be derived from equations (4) and (5) as follows,

$$\gamma_C^1 = \frac{P_C |h_{C2B}|^2 d_{C2B}^{-\alpha}}{P_D |h_{D2B}|^2 d_{D2B}^{-\alpha} + N_0} \quad (6)$$

$$\gamma_D^1 = \frac{P_D |h_{D2D}|^2 d_{D2D}^{-\alpha}}{P_C |h_{C2D}|^2 d_{C2D}^{-\alpha} + N_0} \quad (7)$$

Now, it is considered that the SINR at the receiver cellular user should be above a certain pre-defined threshold given by γ_{th}, i.e.,

$$\gamma_C^1 \geq \gamma_{th} \quad (8)$$

Also, the maximum tolerable interference that the cellular user can withstand is given by,

$$P_{max}^1 = P_D |h_{D2B}|^2 d_{D2B}^{-\alpha} \quad (9)$$

Thus, by equating equations (8) and (9), we get,

$$P_{max}^1 = \frac{P_C |h_{C2B}|^2 d_{C2B}^{-\alpha}}{\gamma_{th}} - N_0 \quad (10)$$

Considering the maximum transmit power, i.e., $P_D = P_{dmax}^1$ which can be attained by the D2D users in Zone 1, can be expressed as follows,

$$P_{dmax}^1 = \frac{P_C |h_{C2B}|^2 d_{C2B}^{-\alpha} - N_0 \gamma_{th}}{\gamma_{th} |h_{D2B}|^2 d_{D2B}^{-\alpha}} \quad (11)$$

EE is an important performance metric to evaluate the proposed communication system. For evaluating the total power consumption in the Zone 1, we have considered the circuit power consumption (P_T) along with the D2D transmission power (P_D) and the incoherent diffused scattering power P_S in the receiver node. Thus, the total power consumption in the Zone 1 can be expressed as,

$$P_{Total} = P_D + P_T + P_S \quad (12)$$

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Therefore, the EE of the D2D users in the Zone 1 can be expressed as,

$$EE^1 = \frac{Log(1+\gamma_D^1)}{P_{Total}} \tag{13}$$

Equation (13) gives us the expression for the EE of D2D users in Zone 1 considering different power consumption factors.

3.2. Zone 2

As the distance between the D2D user and the BS exceeds the value derived in equation (11), the mode gets switched to Mode 2. In the Zone 2, D2D communication may take place through two modes, Mode 2 and Mode 3. So, Zone 2 can be further sub-divided into primary and secondary phase.

3.2.1. Primary Phase

In the mode 2, the carrier frequency is taken to be 28 GHz (mm-Wave band). Here, direct communication will take place among the D2D users. Now, let us assume that R_t be the radius of coverage for the D2D users at the Zone 2. Thus, from the equation (7) it can be stated that the SINR at the receiver D2D at Zone 2 should be above the pre-defined threshold value for seamless operation to take place.

$$\begin{aligned}
\gamma_D^2 = \frac{P_D|h_{D2D}|^2 R_t^{-\alpha}}{P_C|h_{C2D}|^2 d_{C2D}^{-\alpha} + N_0} \geq \gamma_{th} \\
\implies R_t^{-\alpha} \geq \frac{(P_C|h_{C2D}|^2 d_{C2D}^{-\alpha} + N_0)\gamma_{th}}{P_D|h_{D2D}|^2} \\
\implies R_t \leq \left[\frac{P_D|h_{D2D}|^2}{(P_C|h_{C2D}|^2 d_{C2D}^{-\alpha} + N_0)\gamma_{th}}\right]^{1/\alpha} = R_t^*
\end{aligned} \tag{14}$$

This equation gives us the expression for the radius of coverage of the D2D users for direct communication in the Zone 2 operating in Mode 2.
If $R_t \leq R_t^*$, direct communication takes place between D2D users in Mode 2.
If $R_t > R_t^*$, mode switching takes place from Mode 2 to Mode 3 and communication between D2D users in Mode 3 occurs through the aid of two-way DF relay node. The operation of D2D communication in Mode 3 through the assistance of DF relay node is elaborated in the following subsection.

3.2.2. Secondary Phase

In this phase, D2D users are able to communicate with each other through the two-way DF relay node bidirectionally. The operation happens in two time slots, $T1$ and $T2$ as shown in Fig. 2. In $T1$ slot, the D2D users $D1$ and $D2$ transmit messages x_1 and x_2 respectively to the relay node simultaneously. The relay node is also affected by the interference from the cellular users. The received signal at the DF relay node is expressed as follows,

$$Y_R^2 = \sqrt{P_{AR}} h_{AR} d_{AR}^{-\alpha/2} x_1 + \sqrt{P_{BR}} h_{BR} d_{BR}^{-\alpha/2} x_2 + \sqrt{P_{CR}} h_{CR} d_{CR}^{-\alpha/2} x_3 + n_R \tag{15}$$

In time slot $T2$, the relay node then recovers the received messages x_1 and x_2 through maximum likelihood detection. After recovering the messages, it forms an encoded signal $(x_1 \bigoplus x_2)$ through bit-wise binary XOR operation. After this operation, the relay node transmits the encoded signal to the respective D2D users.

$$x_R = \sqrt{\eta} x_1 + \sqrt{1-\eta} x_2 \tag{16}$$

Here, the relay uses an average transmit power of ηP_{RA} in the forward direction and $(1-\eta)P_{RB}$ for the backward direction, where η is the power dividing factor. The BS also

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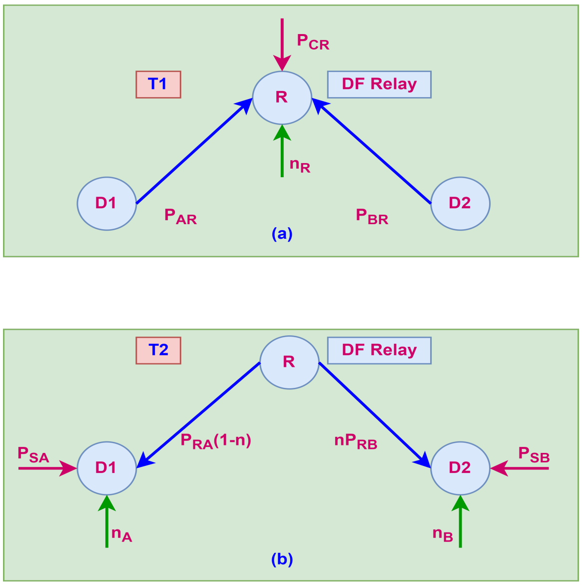

Figure 2. Line diagram representing the bi-directional exchange of information among $D1$ and $D2$ through DF relay in presence of interference and noise in different time slots. **2(a)**. $T1$ time slot, and **2(b)**. $T2$ time slot.

sends messages to the cellular link which will interfere with the received message at the users $D1$ and $D2$, respectively. After applying the self cancellation technique, the received signal at the respective D2D users can be expressed as follows,

$$Y_A^2 = \sqrt{P_{RA}(1-\eta)}d_{RA}^{-\alpha/2}h_{RA}(x_1 \bigoplus x_2) + \sqrt{P_{SA}}h_{SA}d_{SA}^{-\alpha/2}x_4 + n_A \tag{17}$$

and

$$Y_B^2 = \sqrt{P_{RB}\eta}d_{RB}^{-\alpha/2}h_{RB}(x_1 \bigoplus x_2) + \sqrt{P_{SB}}h_{SB}d_{SB}^{-\alpha/2}x_4 + n_B \tag{18}$$

Now, in the slot $T1$, the SINR at the respective $D1-R$ and $D2-R$ links can be expressed as follows,

$$\gamma_{AR}^2 = \frac{P_{AR}|h_{AR}|^2 d_{AR}^{-\alpha}}{P_{CR}|h_{CR}|^2 d_{CR}^{-\alpha} + N_0} = \frac{\gamma_1}{I_R + 1} \tag{19}$$

and

$$\gamma_{BR}^2 = \frac{P_{BR}|h_{BR}|^2 d_{BR}^{-\alpha}}{P_{CR}|h_{CR}|^2 d_{CR}^{-\alpha} + N_0} = \frac{\gamma_2}{I_R + 1} \tag{20}$$

where,

$$\gamma_1 = \frac{P_{AR}|h_{AR}|^2 d_{AR}^{-\alpha}}{N_0} \tag{21}$$

$$\gamma_2 = \frac{P_{BR}|h_{BR}|^2 d_{BR}^{-\alpha}}{N_0} \tag{22}$$

and

$$I_R = \frac{P_{CR}|h_{CR}|^2 d_{CR}^{-\alpha}}{N_0} \tag{23}$$

Therefore, the sum SINR at the relay node can be given by,

$$\gamma_{XR}^2 = \frac{P_{AR}|h_{AR}|^2 d_{AR}^{-\alpha} + P_{BR}|h_{BR}|^2 d_{BR}^{-\alpha}}{P_{CR}|h_{CR}|^2 d_{CR}^{-\alpha} + N_0} \tag{24}$$

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For the slot $T2$, the SINR at the respective $R-D1$ and $R-D2$ links can be expressed as follows,

$$\gamma_{RA}^2 = \frac{P_{RA}(1-\eta)|h_{RA}|^2 d_{RA}^{-\alpha}}{P_{SA}|h_{SA}|^2 d_{SA}^{-\alpha} + N_0} = \frac{\gamma_3}{I_{RA}+1} \tag{25}$$

and

$$\gamma_{RB}^2 = \frac{P_{RB}\eta|h_{RB}|^2 d_{RB}^{-\alpha}}{P_{SB}|h_{SB}|^2 d_{SB}^{-\alpha} + N_0} = \frac{\gamma_4}{I_{RB}+1} \tag{26}$$

The notations γ_3, γ_4, I_{RA} and I_{RB} in the above equations (25) and (26) can be represented as follows,

$$\gamma_3 = \frac{P_{RA}(1-\eta)|h_{RA}|^2 d_{RA}^{-\alpha}}{N_0} \tag{27}$$

$$\gamma_4 = \frac{P_{RB}\eta|h_{RB}|^2 d_{RB}^{-\alpha}}{N_0} \tag{28}$$

$$I_{RA} = \frac{P_{SA}|h_{SA}|^2 d_{SA}^{-\alpha}}{N_0} \tag{29}$$

and

$$I_{RB} = \frac{P_{SB}|h_{SB}|^2 d_{SB}^{-\alpha}}{N_0} \tag{30}$$

3.3. Performance Analysis

3.3.1. Coverage Probability of D2D users

In this subsection, expression for coverage probability of the D2D users is derived by using stochastic geometry as an analytical tool. The message transmitted from the $D1$ and $D2$ users to the relay node are encoded and broadcasted towards the received D2D users. Therefore, the coverage probability of the D2D users should be above a certain threshold value for seamless communication to occur and also maintaining the QoS constraints. The end-to-end SINR perceived at the D2D receiver is obtained through probabilistic theory which is given as follows,

$$\gamma_{e2e} = max\{\gamma_{AR}^2, \gamma_{BR}^2, \gamma_{RA}^2, \gamma_{RB}^2\} \tag{31}$$

Thus, the coverage probability of the D2D users in presence of the DF relay can be expressed as follows,

$$\begin{aligned} P_{cov} &= \mathbb{P}(\gamma_{e2e} \geq \gamma_{th}) \\ &= 1 - \mathbb{P}(\gamma_{e2e} \leq \gamma_{th}) \\ &= 1 - \mathbb{P}(max\{\gamma_{AR}^2, \gamma_{BR}^2, \gamma_{RA}^2, \gamma_{RB}^2\} \leq \gamma_{th}) \\ &= 1 - \mathbb{P}(\gamma_{AR}^2 \geq \gamma_{th})\mathbb{P}(\gamma_{BR}^2 \geq \gamma_{th})\mathbb{P}(\gamma_{RA}^2 \geq \gamma_{th})\mathbb{P}(\gamma_{RB}^2 \geq \gamma_{th}) \end{aligned} \tag{32}$$

The last expression in equation (32) is obtained by applying the independent property of random variables. As it is evident that γ_j where $\{j\epsilon 1, 2, ..., 4\}$ is an exponentially distributed random variable, the PDF of γ_j can be expressed as,

$$f_{y_1}(\theta) = \frac{1}{\bar{\gamma}_1} exp(-\frac{\theta}{\bar{\gamma}_1}) \tag{33}$$

where, $\theta > 0$ and the value for $\bar{\gamma}_1$ is given by,

$$\bar{\gamma}_1 = \frac{P_{AR} \nu h_{AR} d_{AR}^{-\alpha}}{N_0} \tag{34}$$

Here, ν represents the parameter of exponential distribution of random variable. Similarly, from equation (10), we get,

$$\bar{\gamma_{th}} = \frac{P_C \nu h_{C2B} d_{C2B}^{-\alpha}}{N_0} \tag{35}$$

Now, the probability of different SINR terms involved in equation (32) can be expressed as follows,

$$\begin{aligned}
\mathbb{P}(\gamma_{AR}^2 \leq \gamma_{th}) &= 1 - \mathbb{P}[\frac{\gamma_1}{I_R + 1}] \\
&= 1 - \int_0^{\infty} \mathbb{P}[I_R \leq \frac{\gamma_1}{\gamma_{th}} - 1] f_{y_1}(\theta) d\theta \\
&= 1 - \int_0^{\infty} [\frac{1}{\bar{I_R}} \int_0^{(\frac{\theta}{\gamma_{th}} - 1)} exp(\frac{-y}{\bar{\gamma_{th}}}) dy] f_{y_1}(\theta) d\theta \\
&= 1 + \frac{1}{\bar{\gamma_1}} \int_0^{\infty} [exp(\frac{1 - \frac{\theta}{\gamma_{th}}}{\bar{\gamma_{th}}}) - 1] exp(-\frac{\theta}{\bar{\gamma_{th}}}) d\theta \\
&= \frac{exp(\frac{1}{\bar{\gamma_{th}}})}{\bar{\gamma_1}(\frac{1}{\bar{\gamma_1}} + \frac{1}{\bar{\gamma_{th}}\gamma_{th}})}
\end{aligned} \tag{36}$$

Similarly, other relations can be obtained as follows,

$$\mathbb{P}(\gamma_{BR}^2 \leq \gamma_{th}) = \frac{exp(\frac{1}{\bar{\gamma_{th}}})}{\bar{\gamma_2}(\frac{1}{\bar{\gamma_2}} + \frac{1}{\bar{\gamma_{th}}\gamma_{th}})} \tag{37}$$

$$\mathbb{P}(\gamma_{RA}^2 \leq \gamma_{th}) = \frac{exp(\frac{1}{\bar{\gamma_{th}}})}{\bar{\gamma_3}(\frac{1}{\bar{\gamma_3}} + \frac{1}{\bar{\gamma_{th}}\gamma_{th}})} \tag{38}$$

and,

$$\mathbb{P}(\gamma_{RB}^2 \leq \gamma_{th}) = \frac{exp(\frac{1}{\bar{\gamma_{th}}})}{\bar{\gamma_4}(\frac{1}{\bar{\gamma_4}} + \frac{1}{\bar{\gamma_{th}}\gamma_{th}})} \tag{39}$$

Thus, substituting these values into equation (32), we obtain the expression for the coverage probability of the D2D users as follows,

$$\begin{aligned}
P_{cov} = 1 - \{1 - \frac{exp(\frac{1}{\bar{\gamma_{th}}})}{\bar{\gamma_1}(\frac{1}{\bar{\gamma_1}} + \frac{1}{\bar{\gamma_{th}}\gamma_{th}})}\} \times \{1 - \frac{exp(\frac{1}{\bar{\gamma_{th}}})}{\bar{\gamma_2}(\frac{1}{\bar{\gamma_2}} + \frac{1}{\bar{\gamma_{th}}\gamma_{th}})}\} \\
\times \{1 - \frac{exp(\frac{1}{\bar{\gamma_{th}}})}{\bar{\gamma_3}(\frac{1}{\bar{\gamma_3}} + \frac{1}{\bar{\gamma_{th}}\gamma_{th}})}\} \times \{1 - \frac{exp(\frac{1}{\bar{\gamma_{th}}})}{\bar{\gamma_4}(\frac{1}{\bar{\gamma_4}} + \frac{1}{\bar{\gamma_{th}}\gamma_{th}})}\}
\end{aligned} \tag{40}$$

3.3.2. Relay selection

In the Mode 3, while a D2D user, $D1$ communicates with another D2D user, say $D2$, it is assisted by a two-way DF relay node. But the most prominent task is choosing the best relay node. Thus, there should be a procedure for selecting the relay for overall D2D communication to prevail. This subsection portrays a dynamic relay selection (DRS) method for selecting the best relay node for D2D communication at 28 GHz frequency while satisfying the QoS constraints. The steps for selection of relay node for two D2D users, $D1$ and $D2$ to communicate with each other in the presence of R_{ij} relays, where $i, j \epsilon \mathbb{R}$ are furnished as follows,

1) The transmitter D2D user $D1$ sends request to all of the relays in proximity. The respective relay nodes receives the signal and decodes it.
2) The receiver relay sends back the acknowledge signal to the user $D1$ along with information of instantaneous sum SINR at the relay node, pathloss attenuation and distance

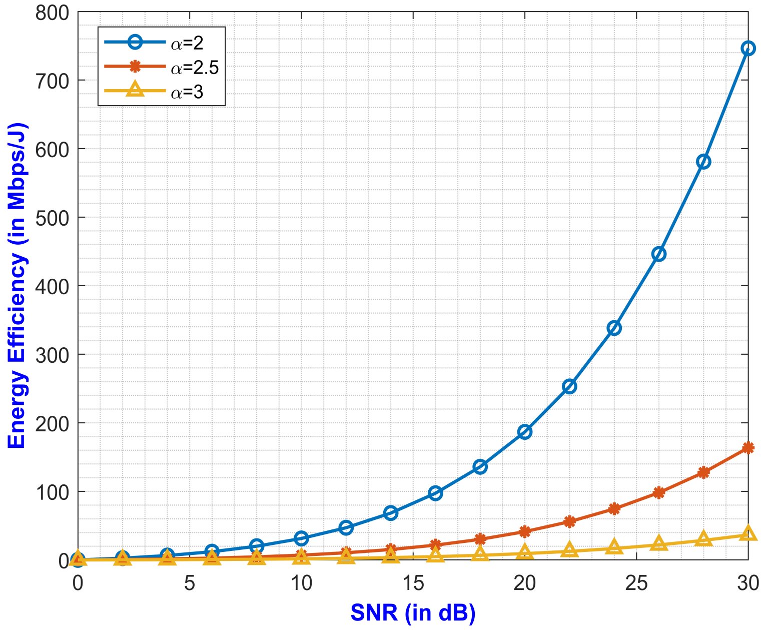

Figure 3. EE v/s Threshold SNR for varying pathloss exponents

between the relay node and D2D users $D1$ and $D2$. The instantaneous sum SINR at the relay node from equation (24) can be expressed as follows,

$$\gamma_{ij}^{in} = \frac{P_i|h_i|^2 d_i^{-\alpha} + P_j|h_j|^2 d_j^{-\alpha}}{P_{CR}|h_{CR}|^2 d_{CR}^{-\alpha} + N_0} \geq \gamma_{th} \quad ; \quad i, j \epsilon \mathbb{R} \tag{41}$$

3) The user $D1$ sorts the relays based on distance between the relay node and D2D users $D1$ and $D2$ in increasing order through a binary search method. The relay link exhibiting higher sum SINR, lower distance and higher channel gain would be chosen as the relay for D2D communication in Mode 3 as follows,

$$argmax\{\gamma_{ij}^{in}\} \tag{42}$$

4. Numerical Results and Discussion

This section presents the simulation results of the proposed scheme to evaluate its performance. A single cell mm-Wave network scenario has been considered for the simulation. The operating frequency is taken to be 28 GHz for mm-Wave band in the Mode 2 and Mode 3. The considered pathloss model for signal propagation are in accordance with the release 15 [18] of the 3GPP (3rd Generation Partnership Project) as per equations (1) and (2). The pathloss exponents considered for simulation are 2, 2.5 and 3. Higher system bandwidth of 1 GHz is chosen for simulation. The simulation parameters are listed in Table 2.

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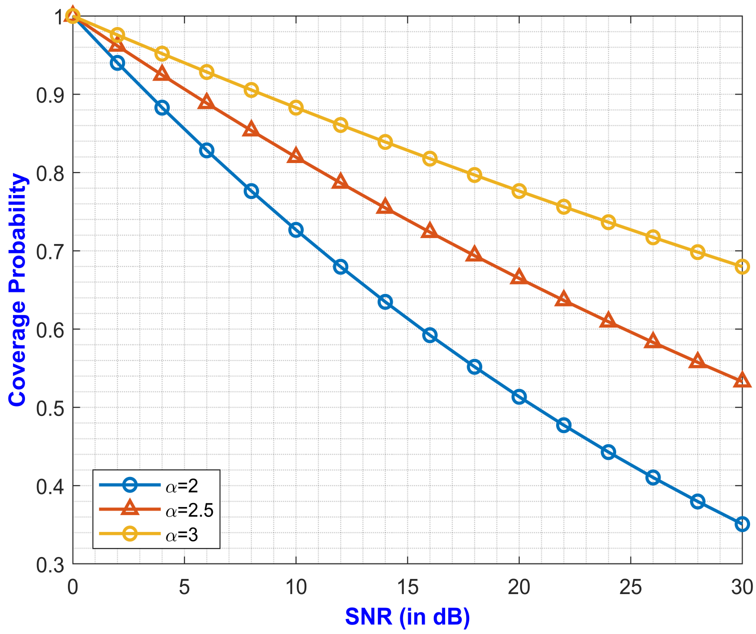

Figure 4. Coverage probability v/s Threshold SNR for varying pathloss exponents

Table 2. List of Notations.

Sl. No.	Symbols	Significance
1	Cell radius	500 m
2	Bandwidth Ω	1 GHz
3	Frequency (mm-Wave mode)	28 GHz
4	Thermal Noise density	-174 dBm/Hz
5	Cellular power P_c	30 dB
6	D2D power (relay mode) P_r	20 dB
7	Circuit power P_C	5 dB
8	Scattering power P_S	4 dB
9	SINR threshold γ_{th}	0-30 dB

In the Fig. 3, a graph has been plotted showing the variation in EE for change in the threshold SNR for varying pathloss exponents i.e. 2, 2.5 and 3, respectively. The scattering power and circuit power consumption are taken into consideration for an accurate analysis of the EE. It can be observed from the graph that as the SNR value increases, EE also increases exponentially. Again, EE is also affected by the pathloss exponent. The curve portraying EE with lower pathloss exponent has higher efficiency. It is due to the fact that higher pathloss exponents encounter more interference due to blockages and fading.
In the Fig. 4, coverage probability of the D2D users are portrayed for a variation in threshold SNR values for varying pathloss exponents i.e. 2, 2.5 and 3, respectively. Equation (40) justifies the curves which shows that higher pathloss exponents have lower coverage. Also, with an increase in SNR value, coverage area of the D2D users reduces.

Fig. 5 portrays the graph for the EE for increasing values of distance between the D2D transmitter and the relay node for varying pathloss exponents of 2, 2.5 and 3. Similar to the previous graphs, this graph also shows better performance for lower pathloss exponents. But the EE keeps on decreasing as we increase the distance between the D2D transmitter and the relay node. The maximum value of EE attained in the simulation for DF relay assisted D2D communication is over 700 Mbps/J.

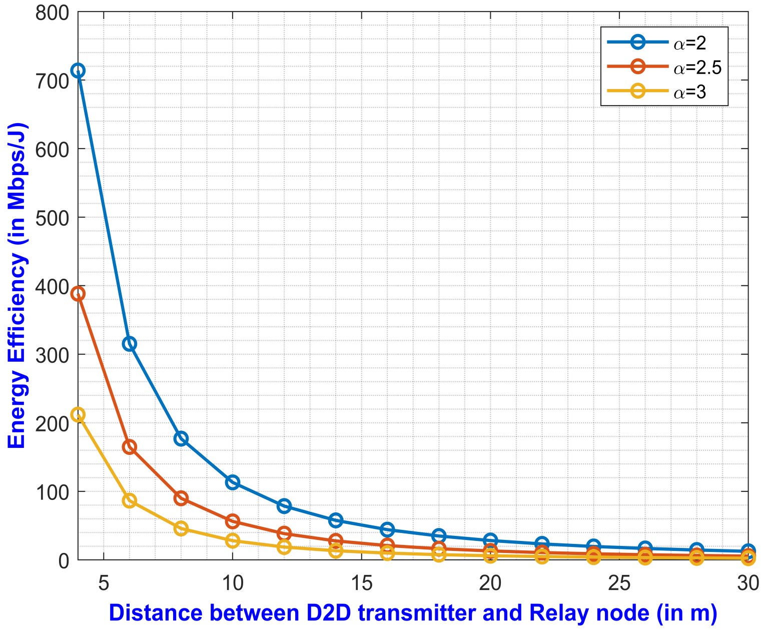

Figure 5. EE v/s Distance between D2D transmitter and relay node for varying pathloss exponents

Finally, in the Fig. 6, a graph is plotted showing the comparison of the proposed DF relay assisted D2D communication with the AF relay assisted D2D communication for varying pathloss exponents of 2 and 3, respectively. The same environment has been considered for the simulation with a carrier frequency of 28 GHz. It is clear from the graph that the proposed DF relay scheme outperforms the AF scheme. The value of EE for the DF scheme is much better than the AF scheme. This validates the efficacy of the proposed work which increases the EE with better coverage probability and higher SNR values.

5. Conclusion and Future Works

In the proposed work, we have introduced three modes for the D2D communication to prevail. D2D communication in Mode 1 occurs at 2 GHz frequency which is a direct communication using cellular uplink resources. In Mode 2, D2D communication takes place at carrier frequency of 28 GHz. If the radius of coverage exceeds a certain threshold, it switches to Mode 3. The D2D communication in the Mode 3 takes place through a DF relay. Bit-wise binary XOR operation is executed for encoding the message received at the relay node from the D2D transmitter at a carrier frequency of 28 GHz using uplink Rician fading channel. Radius of coverage is derived for switching of modes. Coverage probability is also derived to demonstrate the efficacy of the communication system. In addition, DRS method is proposed for optimal selection of DF relays based on higher sum SINR, lower distance and higher channel gain of the instantaneous SINR of the D2D communication. Simulation results also validate the efficiency of the proposed method. EE for the DF relay scheme is compared with AF relay for better understanding and showing the prowess of DF relay over AF relay. Nevertheless, there is scope of improvement in the coverage area of the D2D users by considering unknown CSI, which would make the problem statement more realistic in nature. The future works may also consider the dynamics of the interference introduced by the interacting users by applying machine learning and game theory methods.

Author Contributions: S.S.S. modelled the system for D2D communication in a 5G mm-Wave cellular network using an uplink channel through the assistance of a two-way DF relay protocol, implemented the case study, and analyzed the performance of the system under the supervision of R.H., and P.H.J.C.

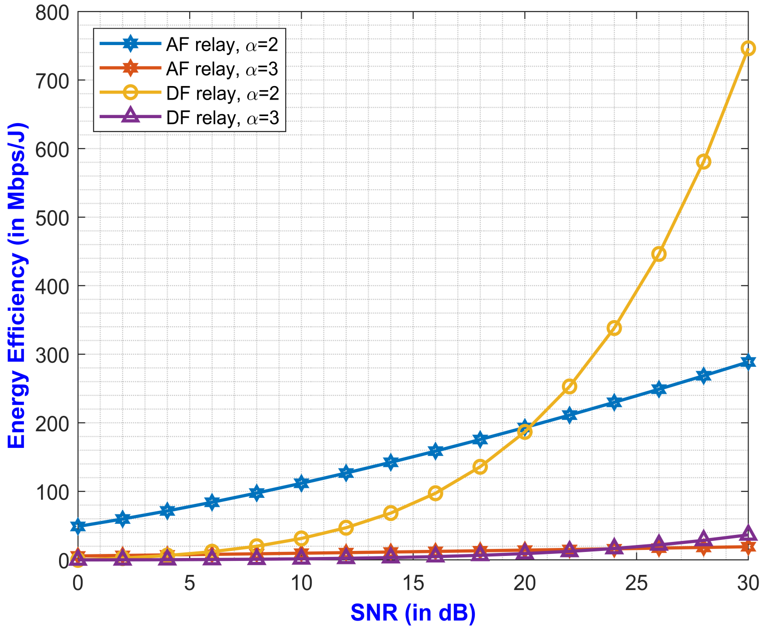

Figure 6. Comparison of EE for DF and AF relay schemes

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Abbreviations

The following abbreviations are used in this manuscript:

D2D	Device-to-Device
SE	Spectral efficiency
EE	Energy efficienc
BS	Base station
SINR	Signal-to-interference plus noise ratio
QoS	Quality-of-service
DF	Decode and forward
AF	Amplify and forward
FDAF	Full duplex amplify and forward
CRS	Cooperative relaying strategy
QF	Quantization-and-forward
PDF	Probability distribution function
PPP	Poisson point process
FSPL	Free space pathloss
CSI	Channel state information
DRS	Dynamic relay selection

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