Resource Allocation For Device-To-Device Communication In Millimeter Wave Underlay Network

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Abstract: High expectations are placed on the Device-to-Device (D2D) communication operating in the millimeter spectrum band to improve the capacity of future 5G network. However, D2D communication underlaying cellular network if not properly designed introduces interference in the system. Therefore, an efficient resource sharing scheme is desirable to provide a proper interference management system. In this paper, resource allocation in D2D communication in millimeter wave (mmWave) spectrum to maximize the throughput while meeting the minimum Quality of Service (QoS) requirements of the users, is investigated. A resource sharing algorithm which allocates power to a single DUE-CUE pair using the geometric programming method and then performs allocation of resource blocks (RBs) to multiple DUEs using the Hungarian Algorithm, is proposed. The efficiency of the resource allocation scheme it tested through simulation using the Close-In (CI) path loss model. The integration of mmWave technology and D2D communications is found to averagely increase the throughput of the system by 64.8 %.

Key Words: Device-to-Device, Hungarian Algorithm, Millimeter Wave, Power Allocation, Spectrum Allocation, 5G.

1. INTRODUCTION

THE rise of applications in need of large amount of data such as online games, video sharing and content sharing have spurred an explosion in the demand of mobile data, consequently leading to an increase of mobile traffic. These high data rate demands area challenge to the existing cellular framework. This can be attributed to scarcity of spectrum resources experienced in the current fourth generation (4G) technologies as it has attained its maximum theoretical data rates[1]. Currently, the 4G network has a latency of 15ms per 1ms sub-frame [2] compared with the required latency of between 2ms and 5ms per 1ms sub-frame for 5G. Millimeter wave (mmWave) spectrum has been proposed to be used commercially in the cellular networks to reduce congestion in the microwave spectrum[3]. The mmWave frequency band has poor propagation due to free space path loss, oxygen absorption effect, requirements of high gain directional antennas and inter-symbol interference as a result of the many reflective paths. These propagation characteristics make the mmWave spectrum better suited for short range communication of about 100m where a loss of about 20 dBm/km is negligible[4]. According to [5], this enables increased spatial reuse with beam forming techniques, highly directional antennas and interference avoidance to mitigate path loss. Device-to-Device (D2D) communication permits close proximity devices to communicate directly with less involvement of the evolved Node B (eNB)[5], [6]. Therefore, D2D communication extends the coverage of eNB through multi-hop transmission and decreases the load on the network. However, D2D communication faces some challenges in its implementation one of them being the spectrum allocation[6]. As seen in Fig.1[5], D2D communication may be classified as either inband or outband, depending on the frequency spectrum it operates in. In the outband D2D communication, the D2D users (DUs) operate in the unlicensed spectrum band[7], normally referred to as outband D2D communications. In this scenario, the cellular users (CUs) operating in the licensed spectrum band are not likely to suffer interference from DUs; also the DUs receive no interference from the CUs. However, controlling communications in the unlicensed spectrum is difficult owing to the limited rules governing communication in this band.

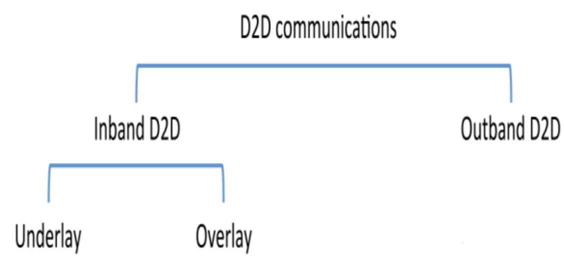

Fig. 1 *D2D communication.*

The other approach, normally referred to as inband D2D communication, is whereby the CUs along with the DUs operate in the licensed spectrum[8]. InbandD2D communication has two modes: underlay mode and overlay mode. In overlay mode, CUs and DUs utilize orthogonal Resource Blocks (RBs). The DUs operate in a dedicated spectrum band, eliminating interference on the CUs. In the underlay mode, D2D user equipment (DUE) utilize the spectrum assigned to the CUs for communication [9], [10]. It is therefore an efficient mode, as it accommodates more users in users sharing the same resource blocks. Therefore, the need for an intelligent resource allocation algorithm arises. In the case where DUs reuse spectrum resources of CUs, Ferdouseet al.[11] utilized a throughput efficient subcarrier allocation (TESA) and optimal power allocation based on geometric water-filling (OPAGWF) method for cellular D2D systems, with the objective of maximizing data rate while ensuring interference constraints are adhered to.Simet al.[12] integrated D2D communication with mmWave technology at 60 GHz. They established that the system throughput doubled and interference mitigation was possible among DUs due to the directional nature of mmWave signals. In[13], a greedy algorithm for allocating resources to DUs operating as underlay in a cellular network is presented. They assume that D2D pairs in the network are less than CUs, an assumption which can be unrealistic for the future generation of communications. Yu et al. [10], present a resource allocation scheme that is limited to resource allocation only. The impact of users' transmit power on interference is not studied in the algorithm, therefore the users either do not transmit or they transmit at the peak power. However, most times the greedy algorithms fail to converge to the global optimum solutions as they get trapped in their local optimum solutions.In [14], Wang et al. propose a resource allocation scheme which allows the DUs to reuse resource blocks of multiple CUs, but the Quality of Service (QoS) of CUs is not necessarily met. In [15] power control is investigated such that the DUs reuse resources of multiple CUs, while meeting QoS of CUs. However, they make an assumption that only one D2D pair exists in the network.The works in [16], 17, [18], investigate the problem of allocating resources to D2D communications operating in the mmWave band for the outdoor scenario. The authors propose greedy and heuristic algorithms for spectrum allocation. However, power allocation to the network users is not considered leading to throughput deterioration with the increase in number of DUs. In this paper, a resource allocation scheme for D2D communication in mmWave cellular network, to maximize throughput of the network, is formulated. At the same time, the concept of gain in system throughput as a result of the CUs sharing their resources is considered. The gain informs the decision on whether to share or not share cellular spectrum resources. The gain can either be positive or negative, indicating the benefit accrued in the network from sharing cellular resources or the negative consequence of sharing respectively. The rest of the paper is organized as follows. In Section II the system model is described and the assumptions made are given. In Section III the resource allocation problem is formulated. In Section IV a novel resource allocation scheme is proposed. In section V simulation results are presented and discussed. The paper finally draws conclusions in Section VI.

2 SYSTEM MODEL

2.1 Network Model

This paper considers an Underlay Inband D2D communication system, where multiple CUs and DUs co-exist and D2D communication only reuses spectrum resources assigned to the CUs due to radio resource constraints. The system model is illustrated in Fig. 2. To improve on the rate attained by DUs, the D2D pairs are permitted to reuse either the uplink or downlink resources for direct transmission. Moreover, it is assumed that in the system there are MD2D pairs and NCUEs. The D2D pairs' index set is defined as $\mathrm{D} = \{1, \dots, \mathrm{M}\}$and CUs' index set is defined as $\mathrm{C} = \{1, \dots, \mathrm{N}\}$. Each CU is allocated separate resource blocks (RBs) which are denoted by $\mathrm{RB_c}$. Thus, the cth CU's bandwidth is characterized as $\mathrm{BW} = \mathrm{RB_c} \times \mathrm{B_{RB}}$, with $\mathrm{B_{RB}}$ being the bandwidth of a single RB. The CUs are assumed to occupy orthogonal uplink and downlink spectrum resources, hence co-channel interference among CUs is ignored in the work. The eNB is also assumed to haveknowledge of the instantaneous channel state information (CSI) of all the links in the network.

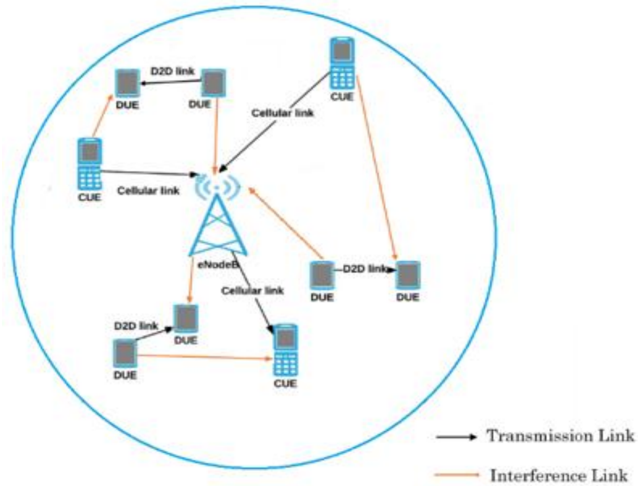

***Fig. 2**. System model*

2.2 Channel Model

The frequency bands in the mmWave spectrum that are being explored for 5G communication and their characteristics are shown in Table 1 [19]. Results show that the bands provide ubiquitous throughput, massive antenna deployment and wireless links with better quality. However, signals in these bands are highly directive and usually suffer signal attenuation because of atmospheric absorption and obstacles as seen in Table1.

TABLE 1
MMWAVE SPECTRUM BANDS

Frequency (GHz)	Rain attenuation (dB)		Oxygen absorption (dB)
	5 mm/h	25mm/h	
28	0.18	0.90	0.04
38	0.26	1.40	0.03
60	0.44	2.00	3.20
73	0.60	2.40	0.09

In this paper, the 28 GHz band is considered for the propagation model. The atmospheric absorption in the 28 GHz frequency band is low as compared to the 60 GHz frequency band[18]. In an environment, which is characterized by many users and a number of obstacles, a path loss model which takes care of both line of sight (LOS) and non-line of sight (NLOS) propagation is desirable[3]. The path loss is given by (1) [17].

$$\mathrm{PL} = \mathrm{PL_{LOS}} + \mathrm{PL_{NLOS}} \quad (1)$$

The CI path loss model is considered for path loss modeling in this research. The model is expected to play a greater role in the 5G communication. The CI model is based on a standard free space reference distance of 1 m. It is a function of the carrier frequency and a parameter called the path loss exponent (PLE) denoted by α. The choice of $\mathrm{d_o} = 1\,\mathrm{m}$ provides mode accuracy and excellent parameter stability for outdoor Urban Micro cell channels[20]. The CI path loss at a distance d is given by (2)

$$\mathrm{PL(f,d)[dB]} = \mathrm{FSPL} + 10\alpha\log_{10}\left(\frac{\mathrm{d}}{\mathrm{d_0}}\right) + \chi_\sigma \quad (2)$$

Where f is frequency in GHz, $\mathrm{d_0}$ is the reference distance in meters, and χ_σ is the lognormal shadowing with zero mean and standard deviation σ. FSPL term represents the free space path loss for a carrier frequency f and is given by (3).

$$\mathrm{FSPL[dB]} = 20\log_{10}\left(\frac{4\pi f}{c}\right) \quad (3)$$

Where c is the speed of light.
To take care of both NLOS and LOS cases, probability is incorporated in the path loss equation in (1). By that D2D links are expected to have more LOS signals due to their close proximity and hence the path loss in the D2D links is given by (4). The path loss for rest of the links (eNB-D2D, CU-eNB, and D2D-CU links) is given by (5) [18].

$$PL_1 = p_1 PL_{LOS} + (1 - p_1) PL_{NLOS} \quad (4)$$

$$PL_2 = p_2 PL_{LOS} + (1 - p_2) PL_{NLOS} \quad (5)$$

Where p_1 denotes the path loss probability for LOS of the D2D links and p_2 denotes the path loss probability for LOS for the non D2D links.

3. PROBLEM DESCRIPTION AND FORMULATION

3.1 Problem Description

A summary of frequently used notations in this paper is presented in Table 2. The D2D communication scenario in Fig. 2 is referred. In the uplink phase of the cellular network, the cellular user transmits to the eNB while the D2D transmitter (DTx) transmits data to the D2D receiver (DRx). During this phase the DRx receives interference from the CUE. Also, the eNB suffers interference from the DTx. If the cth cellular user shares its uplink resource blocks (RBs) with the d^{th} D2D pair, the SINR at the eNB is given by (6).

$$\gamma^{UL}{}_c = \frac{P_c g_{cb}}{\sum_{c=1}^{N} \rho_c^{d,UL} P_d g_{db} + N_0} \quad (6)$$

Similarly, the received SINR the d^{th}DRx is given by (7).

$$\gamma^{UL}{}_d = \frac{P_d g_{dd}}{\sum_{d=1}^{M} \rho_c^{d,UL} P_c g_{cd} + N_0} \quad (7)$$

The optimization variables $\rho_c^{d,UL}$ and $\rho_c^{d,DL}$ are the binary indicator functions which are set to 1 if the d^{th} D2D pair reuses RBs of the c^{th} CU, or to 0 if the d^{th} D2D pair does not reuse RBs of the c^{th} CU, in the uplink and downlink phases respectively. N_o is the noise spectral density.During the downlink phase, the CUE suffers interference from the DTx, and the DRx experiences interference from the eNB. If the c^{th} cellular usershares its downlink Resource Blocks (RBs) with the d^{th}D2D pair. The SINR at the c^{th}CU is then given by (8).

$$\gamma^{DL}{}_c = \frac{P_b g_{bc}}{\sum_{c=1}^{N} \rho_c^{d,DL} P_d g_{dc} + N_0} \quad (8)$$

Similarly, the received SINR at the d^{th}DRx is given by (9).

$$\gamma^{DL}{}_d = \frac{P_d g_{dd}}{\sum_{d=1}^{M} \rho_c^{d,DL} P_b g_{bd} + N_0} \quad (9)$$

To manage interference properly, the d^{th}DTx is allowed to reuse either the uplink RBs or the downlink RBs of c^{th}CU at a time. Therefore the SINR at the d^{th}DRx is expressed as (10)

$$\gamma_d = \frac{P_d g_{dd}}{\sum_{d=1}^{M} \rho_c^{d,UL} P_c g_{cd} + \sum_{d=1}^{M} \rho_c^{d,DL} P_b g_{bd} + N_0} \quad (10)$$

The achievable channel rates, R_c^{UL}, R_c^{DL} and R_d corresponding to $\gamma^{UL}{}_c$, $\gamma^{DL}{}_c$ and γ_d, respectively, are calculated using the Shannon's Capacity Theorem [21].

$$\begin{aligned} R_c^{UL} &= BW * \log_2(1 + \gamma_c^{UL}) \\ R_c^{DL} &= BW * \log_2(1 + \gamma_c^{DL}) \\ R_d &= BW * \log_2(1 + \gamma_d) \end{aligned} \quad (11)$$

TABLE 2
SUMMARY OF NOTATIONS

Notation	Description
M, N	The set of Cellular Users and D2D pairs
P_d, P_c, P_b	The transmission power of d^{th}D2D pair , c^{th} CU and eNB
g_{cb}	CU c – eNB link gain
g_{bc}	eNB – CU c link gain
g_{bd}	eNB – DU d link gain
g_{cd}	CU c – DU d link gain
g_{dd}	DTx – DRx link gain
g_{dc}	D2D pair d –CU c link gain
$\gamma_c^{UL}, \gamma_c^{DL}$	SINR value of CU c in the uplink and downlink phases
γ_d	SINR value of the D2D pair d
$\gamma_c^{UL,th}, \gamma_c^{DL,th}$	SINR threshold values for CU c in uplink and downlink phase
γ_d^{th}	The threshold SINR value of d^{th}D2D pair
R_c^{UL}, R_c^{DL}	The achievable rate in the uplink and downlink phase of CU c
R_d	The achievable rate of d^{th}D2D pair

3.2 Problem Formulation

This research aims to maximize total system throughput while taking into account the minimum SINR requirements of users. To achieve this the problem is formulated as in (12).

$$\max_{\rho,P}\left(\sum_{c=1}^{N} R_c^{UL} + \sum_{c=1}^{N} R_c^{DL} + \sum_{d=1}^{M} R_d\right) \quad (12)$$

Maximization in (13) is subject to constraints (13) – (20).

$$\gamma_c^{UL} \geq \gamma_c^{UL,th}, \quad \forall c \in C \quad (13)$$
$$\gamma_c^{DL} \geq \gamma_c^{DL,th}, \quad \forall c \in C \quad (14)$$
$$\gamma_d \geq \gamma_d^{th}, \quad \forall d \in D \quad (15)$$
$$P_c \leq P_c^{max}, \quad \forall c \in C \quad (16)$$
$$P_d \leq P_d^{max}, \quad \forall d \in D \quad (17)$$
$$P_b \leq P_b^{max}, \quad \forall c \in C \quad (18)$$
$$\left(\sum_{d=1}^{M} \rho_c^{d,UL}\right)\left(\sum_{d=1}^{M} \rho_c^{d,DL}\right) = 0, \forall d \in D, \quad (19)$$
$$\rho_c^{d,UL}, \rho_c^{d,DL} \in \{0,1\}, \forall d \in D, \forall c \in C \quad (20)$$

Constraints (13) and (14) ensures that the minimum target SINR for CUs for uplink and downlink is met. Constraint (15) provide the minimum target SINR values for the D2Dpair, to ensure that a minimum rate is maintained in the D2D pair communication. Constraints (16) and (17) put a limitation on the power transmitted by the CUE and DUE respectively. Constraint (18) puts a limitation on the maximum power transmitted by the eNB to the cellular user. In (12), ρis the binary indicator for RB assignment to DUEs and P is the transmission power set for the users. Constraint (19) ensures that the D2D pair reuses only the uplink or downlink RB at the time. Constraint (20) is the binary indicator of reuse of cellular user resources.

4 RESOURCE ALLOCATION SCHEME

Problem (12) is a mixed integer non-linear programing (MINLP) problem. Therefore to solve it, it is broken into a two-step problem: a power allocation problem, and a resource block assignment problem. In the first step the transmission power of each CU and DUE that maximize the throughput for both the uplink and downlink cases is obtained. In the second step, resource blocks of CUs to the D2D pairs are assigned using Hungarian algorithm with the aim of maximizing the throughput of the system.

4.1 Power Allocation

The MINLP problem given in equation (12) is converted to a geometric programming problem by fixing binary reuse indicator at 1 to yield an equation, which is in the class of convex optimization problems. The resulting problem is then solved for one resource block shared by the d^{th}D2D pair and c^{th}CU. Considering the uplink phase first the problem reduces to (21).

$$\max_{P_c,P_d}\left(BW * \log_2\left(1+\frac{P_c g_{cb}}{P_d g_{db}+N_0}\right)+BW * \log_2\left(1+\frac{P_d g_{dd}}{P_c g_{cd}+N_0}\right)\right) \quad (21)$$

Subject to constraints (22) – (25).

$$\gamma_c^{UL} \geq \gamma_c^{UL,th}, \quad \forall c \in C \quad (22)$$
$$\gamma_d \geq \gamma_d^{th}, \quad \forall d \in D \quad (23)$$
$$P_c \leq P_c^{max}, \quad \forall c \in C \quad (24)$$
$$P_d \leq P_d^{max}, \quad \forall d \in D \quad (25)$$

The feasible region for transmit power allocation for the DUE-CUE pair, represented by Ψ, is shown in Fig. 3-5. ∂Ψ is the boundary of Ψ. Further, Ψ is bounded by four lines T_1: $\gamma_c^{UL} = \gamma_c^{UL,th}$, T_2: $P_c = P_c^{max}$, T_3:$P_d = P_d^{max}$ and T4: $\gamma_d = \gamma_d^{th}$. Also, the shape of Ψ changes with varying values of the interference and direct link gains, maximum transmission powers and SINR values

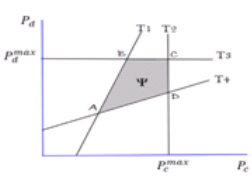

Fig. 3. *Feasible region when* $\gamma_c^{UL} \geq \gamma_c^{UL,th}$ *and* $\gamma_d \geq \gamma_d^{th}$

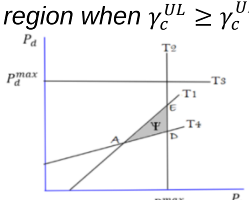

Fig. 4. *Feasible region when* $\gamma_c^{UL} \leq \gamma_c^{UL,th}$ *and* $\gamma_d \geq \gamma_d^{th}$

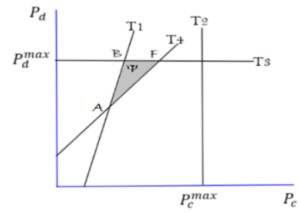

Fig. 5: *Feasible region when* $\gamma_c^{UL} \geq \gamma_c^{UL,th}$ *and* $\gamma_d \leq \gamma_d^{th}$

To determine the optimal power allocation (P_c^*, P_d^*) for problem (21), the lemmas proved in [22] are applied.

Lemma 1: Either the CUE or the DUE transmits at its maximum power, that is, $(P_c^* = P_c^{max})$or$(P_d^* = P_d^{max})$

Proof: According to the power and SINR constraints, region Ψ is a bounded and closed set. Further, if $R(P_c^*, P_d^*)$ is a continuous function, then problem (21) is a convex function.

$$R(P_c^*, P_d^*) = BW * \log_2\left(1+\frac{P_c g_{cb}}{P_d g_{db}+N_0}\right)+BW * \log_2\left(1+\frac{P_d g_{dd}}{P_c g_{cd}+N_0}\right) \quad (26)$$

Applying the logarithmic manipulation to problem (26) gives (27).

$$R(P_c^*, P_d^*) = BW * \log_2\left(\left(\frac{P_c^* g_{cb}}{P_d^* g_{db}+N_0}\right)\left(\frac{P_d^* g_{dd}}{P_c^* g_{cd}+N_0}\right)\right) \quad (27)$$

Substituting(P_c^*, P_d^*) in equation with $(\mu P_c^*, \mu P_d^*)$ for $\forall \mu > 1$, $\mu \in R^+$ and $(P_c^*, P_d^*) \in \Psi$ results in (28).

$$R(\mu P_c^*, \mu P_d^*) = BW * \log_2\left(\left(\frac{P_c^* g_{cb}}{P_d^* g_{db}+\frac{N_0}{\mu}}\right)\left(\frac{P_d^* g_{dd}}{P_c^* g_{cd}+\frac{N_0}{\mu}}\right)\right) \quad (28)$$

With an increase in the value of μ, $R(\mu P_c^*, \mu P_d^*) > R(P_c^*, P_d^*)$ contradicting the initial assumption that (P_c^*, P_d^*) is the optimal power allocation. Thus lemma 1 is proved through contradiction. From lemma 1, the optimal transmit power resides along line BC or CD for Fig. 3, or ED for Fig. 4 or BF for Fig. 5.

Lemma 2:(P_c^*, P_d^*) only resides at the extreme corners of Ψ.

Proof: Let: $T_x^{'}: T_n \cap \partial\Psi(x = 1 \text{ to } 4)$and

$$R(P_c^*, P_d^*) = BW * \log_2\left(\left(\frac{P_c^* g_{cb}}{P_d^* g_{db}+N_0}\right)\left(\frac{P_d^* g_{dd}}{P_c^* g_{cd}+N_0}\right)\right) \quad (29)$$

If $(P_c, P_d) \in T_2^{'}$, $\frac{\partial^2 R}{\partial P_d^2} \geq 0$. And if $(P_c, P_d) \in T_3^{'}$, $\frac{\partial^2 R}{\partial P_c^2} \geq 0$.

If $(P_c, P_d) \in T_1^{'} \cup T_4^{'}$, then R is always monotonically increasing with the value of P_c or P_d. It has also been proved in [22], that $R(P_c^*, P_d^*)$ is a convex function and it increases monotonically since it is a logarithmic function, therefore (P_c^*, P_d^*) only resides at the extreme corners of Ψ.Therefore, from lemma 1 and lemma 2 the optimal power allocation vector for region Ψ, is $\partial\Psi = \{A, B, C, D, E, F\}$, where the values are given in (30) – (35).

$$A(P_c,P_d)=\begin{cases}\dfrac{\left(g_{d,d}\gamma_c^{th,UL}+g_{d,b}\gamma_d^{th,UL}\gamma_c^{th,UL}\right)N_0}{g_{d,d}g_{cb}-\gamma_d^{th,UL}\gamma_c^{th,UL}g_{d,b}g_{c,d}}\\ \dfrac{\left(g_{c,b}\gamma_d^{th,UL}+g_{c,d}\gamma_d^{th,UL}\gamma_c^{th,UL}\right)N_0}{g_{d,d}g_{c,b}-\gamma_d^{th,UL}\gamma_c^{th,UL}g_{d,b}g_{c,d}}\end{cases} \quad (30)$$

$$B(P_c,P_d)=\begin{cases}\dfrac{\gamma_c^{th,UL}\left(N_0+P_d^{max}g_{d,c}\right)}{g_{c,b}}\\ P_d^{max}\end{cases} \quad (31)$$

$$C(P_c,P_d)=\begin{cases}P_c^{max}\\ P_d^{max}\end{cases} \quad (32)$$

$$D(P_c,P_d)=\begin{cases}P_c^{max}\\ \dfrac{\gamma_d^{tgt}\left(N_0+P_c^{max}g_{d,b}\right)}{g_{c,d}}\end{cases} \quad (33)$$

$$E(P_c,P_d)=\begin{cases}P_c^{max}\\ \dfrac{P_c^{max}g_{c,c}-N_0\gamma_c^{th,UL}}{\gamma_c^{th,UL}g_{d,c}}\end{cases} \quad (33)$$

$$F(P_c,P_d)=\begin{cases}\dfrac{P_d^{max}g_{d,b}-N_0\gamma_d^{th,UL}}{\gamma_d^{th,UL}g_{c,b}}\\ P_d^{max}\end{cases} \quad (34)$$

The feasible optimal transmit power of the DUEs in the uplink and downlink phases should be overlapped to enable the DUE to reuse the resource blocks of the CU in both uplink and downlink phases. Therefore obtaining the power allocation for downlink phase the same method is applied.

4.2 Resource Block Allocation

To this end optimal transmit power allocation, (P_c^*,P_d^*), for a single DUE-CUE pair has been obtained. In order to ensure that there is an improvement in the network capacity as a result of sharing cellular resources, in this section the gain in throughput when the d^{th}D2D pair reuses the resource block of the c^{th}CU, is determined. The throughput gain, can either be positive or negative, representing the benefit accrued from the reuse of cellular resource blocks or the consequence for interference on CUs respectively. Further, the D2D pair is only permitted to access the network if it results in a positive throughput gain. Let $T_{cd}^{g,UL}$ represent throughput gain when d^{th}D2D pair reuses the uplink RBs of the c^{th} CU, and $T_{cd}^{g,DL}$ to represent throughput gain when d^{th}D2D pair reuses downlink RBs of the c^{th} CU. Then,

$$T_{cd}^{g,UL}=BW*\log_2\left(1+\frac{P_dg_{dd}}{P_cg_{cd}+N_0}\right)+BW*\log_2\left(1+\frac{P_cg_{cb}}{P_dg_{db}+N_0}\right)-BW*\log_2\left(1+\frac{P_cg_{cb}}{N_0}\right) \quad (35)$$

$$T_{cd}^{g,DL}=BW*\log_2\left(1+\frac{P_dg_{dd}}{P_cg_{bd}+N_0}\right)+BW*\log_2\left(1+\frac{P_cg_{bc}}{P_dg_{dc}+N_0}\right)-BW*\log_2\left(1+\frac{P_cg_{bc}}{N_0}\right) \quad (36)$$

In (35) and (36), the first term represents achievable rate of d^{th}D2D pair, with the second term is the achievable rate of the c^{th}CU when sharing its resource with the d^{th}D2D pair, while the third term is the achievable rate when the c^{th}CU is not sharing its resource. For a positive throughput gain, (35) and (36) should be greater than zero.

Since the system has multiple D2D pairs, the problem of resource block allocation is modeled as a maximum weight bipartite matching problem, which is represented in (37).

$$\max_{\rho_c^{d,UL},\rho_c^{d,DL}}\sum_{d=1}^{M}\sum_{c=1}^{N}\left(\rho_c^{d,UL}T_{cd}^{g,UL}+\rho_c^{d,DL}T_{cd}^{g,DL}\right) \quad (37)$$

Subject to the constraints (39) and (40)

$$\rho_c^{d,UL},\rho_c^{d,DL}\in\{0,1\},\forall d\in D,\forall c\in C \quad (38)$$

$$\left(\sum_{d=1}^{M}\rho_c^{d,UL}\right)\left(\sum_{d=1}^{M}\rho_c^{d,DL}\right)=0,\forall d\in D \quad (39)$$

This matching problem is then solved using the Hungarian Algorithm[23]. Algorithm 1 presents the pseudo code for the resource sharing scheme.

TABLE 3
RESOURCE ALLOCATION ALGORITHM

Algorithm 1: Resource Sharing algorithm

C –Set of existing CUs
D – Set of D2D pairs
Υ_d – Cellular reuse partners of the d^{th}DU

1. for $d\in D$do
2. Obtain the optimal forc $\in C$ do
3. Power allocation (P_c^*,P_d^*) for both uplink and downlink phases and then determine the throughput gains $(T_{cd}^{g,UL}$and $T_{cd}^{g,DL})$
4. if $T_{cd}^{g,UL}(P_c^*,P_d^*)\geq 0$ or $T_{cd}^{g,DL}(P_c^*,P_d^*)\geq 0$ then
5. $c\in\Upsilon_d$;
6. end if
7. end for
8. end for
9. Obtain the reuse pattern for multiple DUEs by feeding the throughput gain matrix to the Hungarian Algorithm.

5 SIMULATION RESULTS AND DISCUSSION

In this section the simulation results obtained are presented in to validate the proposed power and spectrum allocation scheme for the mmWave underlay network. In the simulation M potential DU pairs and NCUEs are distributed randomly in the coverage area of the eNB with a radius R. The cluster radius, r, is defined as the distance between transmitter and receiver of a D2D pair. Simulation parameters are set as in Table 4[16], [17], [18], [24] unless specified otherwise.

TABLE 4
SIMULATION SYSTEM PARAMETERS

Parameter	Value
Cell radius (R)	500 m
Radius of DUEs (r)	10 m
Total system bandwidth (BW)	1 GHz
Carrier Frequency (f_c)	28 GHz
Bandwidth per RB (B_{RB})	180 kHz
Maximum transmit power of DUE or CUE (P_d^{max},P_c^{max})	25 dBm
Maximum transmit power of eNB(P_b^{max})	46 dBm

SINR threshold for CUE or DUE $(\gamma_c^{UL,th}, \gamma_c^{DL,th}$ or $\gamma_d^{th})$	0 dB
D2D links path loss probability , (p_1)	0.2
Non-D2D links path loss probability, (p_2)	0.8
Path loss exponent α; (LOS, NLOS)	2, 2.92
Shadowing coefficient σ ; (LOS, NLOS)	5.8 dB, 8.7 dB
Noise Spectral density (N_0)	-174 dBm/Hz

Four metrics are used to evaluate the performance of the proposed scheme: TheD2D throughput,R^{DU}, Cellular throughput,R^{CU}, system throughput, R^{Sys}, and the success rate. These are given in (40) – (42).

$$R^{DU} = \sum_{d=1}^{M} R_d \quad (40)$$

$$R^{CU} = \sum_{c=1}^{N} R_c^{DL} + \sum_{c=1}^{N} R_c^{UL} \quad (41)$$

$$R^{Sys} = R^{CU} + R^{DU} \quad (42)$$

The success rate is the ratio of the D2D pairs that find a cellular reuse partner to the total number of D2D pairs in need of resources for communication. The proposed scheme is compared with an algorithm in [25], which permits D2D pairs to only reuse uplink (ORU) RBs. In [25], a resource allocation scheme which maximizes the throughput gain is proposed and solved in two steps. It first calculates the throughput gain for a single D2D-CU pair and then uses the maximum weight bipartite matching to assign RBs to multiple D2D pairs.

5.1 Varying DUE density

In the first simulation, the number of CUs was maintained at $N = 20$, while the number of DUs was varied. Other parameters were as per Tables 4. The results of Fig. 6 and Fig. 7 were obtained.

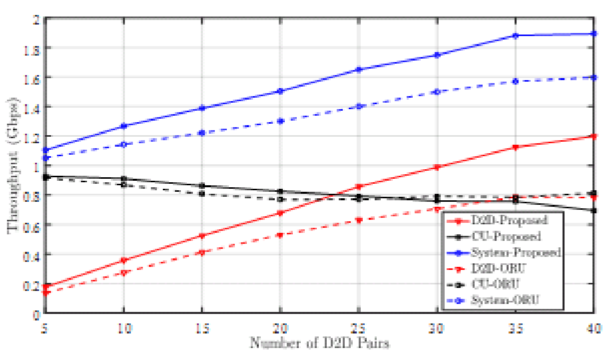

Fig. 6.*Variationof throughput with number of D2D pairs*

The D2D throughput and system throughput increase as the number of D2D pairs increases from 5 to 40, and performance of proposed scheme outperforms the ORU algorithm. It is also observed that the CUs decreases by14%inferring that the system can allow D2D communication as underlay while still meeting the QoS requirements of CUs. As the number of D2D pairs increase, the system throughput increases, indicating the significance of allowing D2D communication in the cellular network.

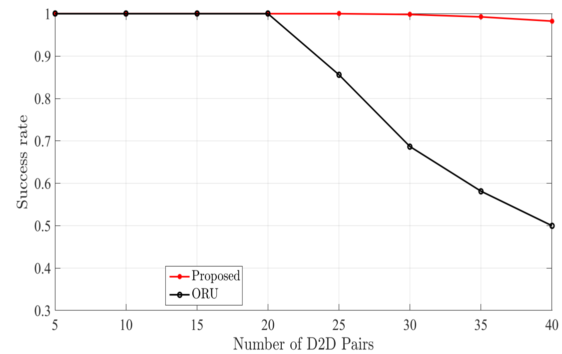

Fig. 7: *Variation of success rate of D2D pairs with number of D2D pairs*

Since, the number of CUs is constant in this simulations set, the success rate reduces as the number of D2D pairs increase. The success rate of the proposed scheme is better as compared of the ORU scheme, for instance when $M = 35$ the success rate for the proposed scheme is 1 while that of ORU scheme is 0.59. This is because in the proposed scheme the D2D pairs are allowed to reuse both uplink and downlink RBs while the ORU scheme only permits the D2D pairs to reuse the uplink RBs of CUs.

5.2 Varying D2D cluster radius

In the second simulation, the D2D cluster radius was varied while the number of CUs was maintained at $N = 20$ and the D2D pairs at $M = 40$. The other parameters were as per Table 4. The results of Fig. 8 and Fig. 9 were obtained.

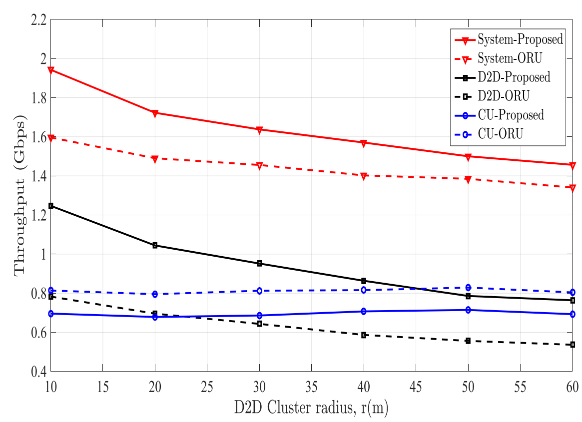

Fig. 8. *Variation of system throughput with D2D cluster radius*

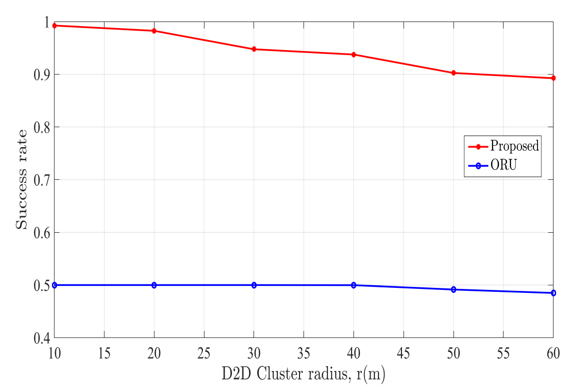

Fig. 9*. Variation of success rate of D2D pairs with D2D cluster radius*

As the D2D cluster radius increases from 10 m to 60 m, the system throughput, D2D throughput and success rate decreases for both the proposed and the benchmark scheme. The increase in the D2D cluster radius results in an increase in the D2D transmit power and a consequent increase in the interference level, hence a decrease in D2D throughput and success rate. As the D2D cluster radius increases from 10 m to 60 m, the D2D throughput of the proposed scheme decreases by 38.9%, while that of ORU decreases by 31.6 %. The cellular throughput remains relatively constant as its minimum SINR requirements are satisfied, hence a decrease in the system throughput by 24.7% and 16.3% for the proposed and ORU scheme respectively.

5.3 Varying CU cell radius

In this simulation, the cell radius was varied while maintaining $N = 20$ and $M = 40$, and the other parameters as per Tables 3 and 4. The results of Fig. 10 and Fig. 11 were obtained.

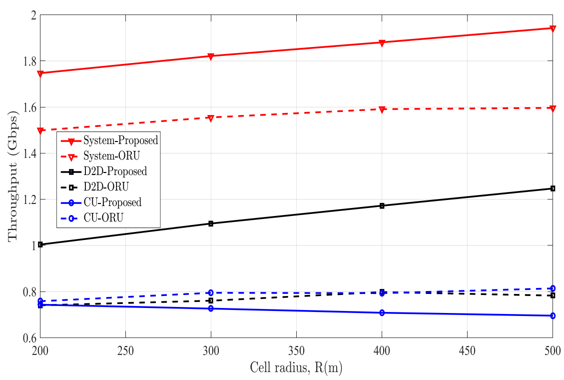

Fig. 10. *Variation of system throughput with CU cell radius*

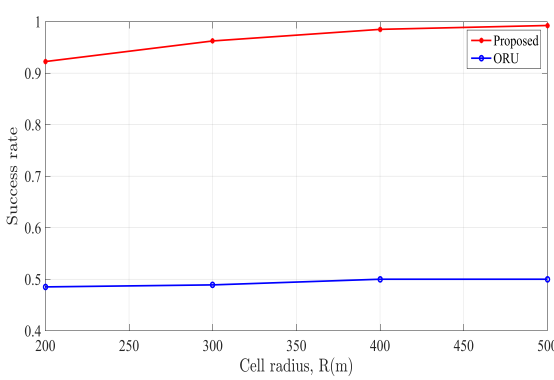

Fig. 11. *Variation of D2D success rate with CU cell radius*

The D2D throughput and success rate increases with an increase in the cell radius from 200 m to 500 m. With an increase in the cell radius, the distance between D2D pairs and CUs and the distance to the eNB increases. Hence, in the uplink phase the interference at the D2D receiver from the CUs and interference from D2D transmitter to the eNB is reduced, also in the downlink phase the interference at the D2D receivers from the eNB and the interference from D2D transmitters to the CUs is reduced. However, as the cell radius increases from 200 m to 500 m, the CU throughput decreases by 6.33 %, due to reduced link gain between the eNB and the CUs. Since in this simulation case the number D2D pairs exceeds that of CUs, the D2D throughput is dominant, hence an increase in the system throughput by 10.9% as the cell radius increases.

5.4 Varying SINR thresholds

In this simulation, the SINR thresholds$\left(\gamma_c^{UL,th} = \gamma_c^{DL,th} = \gamma_d^{th} = \gamma^{th}\right)$were varied while maintaining $N = 20$ and $M = 40$, and the other parameters as per Tables 4. The results of Fig. 12 and Fig. 13 were obtained.

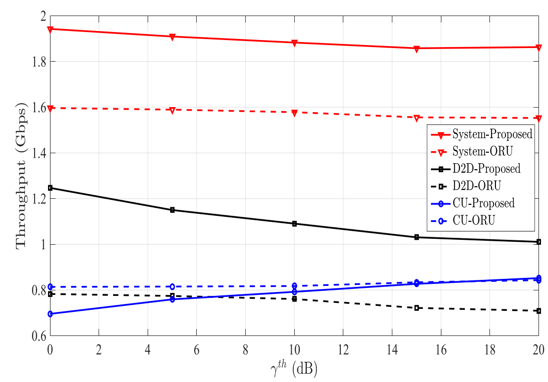

Fig. 12. *Variation of system throughput with SINR threshold*

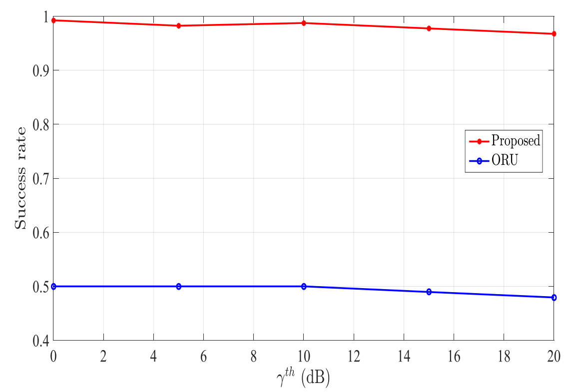

Fig. 13. *Variation of D2D success rate with SINR threshold*

From the plots it is seen that the system throughput and the D2D throughput decreases by 4.12% and 19.2% respectively, as the SINR threshold increases from 0 to 20 dB. The success rate also decrease from 0.99 to 0.97. This is because an increase in the SINR threshold lowers chances of a D2D user obtaining a cellular reuse partner. In both cases the proposed scheme performs better compared to the ORU scheme. However the CUs throughput relatively increases by 22.4 % as the SINR threshold increases since the chances of D2D pairs reusing the cellular resources is reduced.

6 CONCLUSION

In this paper D2D communication in mmWave underlay network scenario is presented, where the D2D pairs share both the uplink and downlink RBs of the cellular users. A two-step resource allocation scheme is proposed where the power allocation to a single DUE-CUE pair is first optimized before employing weight bipartite graph to determine the resource block allocation, resulting in a matching problem which was solved using the Hungarian Algorithm.The resource allocation scheme is evaluated through simulations using to determine its efficiency. The simulation results indicate that there is an increase of 64.8%in the system throughput by allowing the D2D communication to operate as underlay in mmWave network. The throughput of the CUs averagely decreases by 14%thus guaranteeing the QoS for both the DUs and CUs.

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