Performance Analysis of Device -to- Device Users in Unmanned Aerial Vehicle as Flying Base Station

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Abstract

Device-to-device(D2D) communication allows proximate devices to communicate to each other, thereby mitigate cellular traffic on the base station and improving overall performance of the network. To establish a connected cellular network in remote locations, base stations(BSs) are assumed to be unmanned aerial vehicle(UAV) flying above the ground and user equipment(UE) located in the remote areas. The UAV- UE link may or may not be a LoS, but here LoS approach is consider. Closed form expression for Outage Probability (OP) and system sum rate are derived here, and variation of OP is observed with respect to different network parameters such as SINR Threshold (β) and D2D distance (d_0). Results shows that on increasing SINR Threshold and D2D user Density, We are able to increase system sum rate. We also show that outage probability is increased with SINR threshold and λ_d / λ_{du}.

Keywords

Device to Device Communication (D2D), Un-manned Aerial Vehicle (UAV), System Sum Rate, Outage Probability (OP).

I. Introduction

Lately, the data rate demand of UEs has grown sharply. New techniques have been proposed for new wireless technologies to meet this demand. One of these techniques is Device-to-device communication (D2D), a scenario in which two mobile nodes communicate directly without traversing the Base Station (BS) or the core network [1]. Advantages of D2D communication include increasing the capacity of the network, enhancing the system sum rate, and extending the battery life of the mobile stations. Another technique is Massive MIMO where the central BS is equipped with large number of antennas. Massive MIMO improves the energy efficiency of the network due to its ability to concentrate all the energy into the direction of the intended receivers [2]. D2D devices can communicate either through the same frequency resources used by the network (inband D2D) or using other frequency bands (outband D2D). Inband D2D is divided to underlay D2D, in which devices are admitted communication using the same frequency resources used by the cellular user equipment's (CUEs), or overlay D2D using dedicated frequency resources that CUEs are not allowed to use. Since inband underlay D2D reuses the frequency resources, it increases the system sum rate of the network, but raises the problem of interference between the D2D communicating devices and the CUEs [1]. Many interference management techniques were proposed in the literature to solve the issue of mutual interference between D2D devices and CUEs.

In most of those techniques, D2D pairs are not admitted to operate on the frequency resources in which they will violate required Quality of Service (QoS) constraints on the CUEs, e.g., [3]. Other algorithms were proposed based on the locations of the users, prohibiting any CUE and D2D pair to operate in the same area [4]. Other researchers satisfy these QoS constraints while aiming at optimizing some objective function such as maximizing the total sum rate of the network [5], or minimizing the total power

consumption [6]. The common characteristic of all these trials is that they involve mode selection, i.e., D2D pairs may not operate on some resources at all.

To address the increasing demand for mobile data communication and assuage the BSs from increasing traffic, academicians poured much of their ink on finding a possible solution. Many researchers came with different ideas such as Femtocell [1], cognitive radio [2], TV white space [3], and device-to-device communication [4-5].

Plenty of research work has been done on D2D communication in terms of energy efficiency [6], public safety network [7], delay tradeoff [8], resource allocation [9], maximizing offloading of cellular traffic [10], access schemes [11], throughput [12], and interference calculation [13-14].

In [12] researchers proposed the idea to schedule the base station operation to increase spectral efficiency and enhance system capacity. They believed that if base stations could be scheduled optimally for D2D communication, we can offload major portion of the traffic from one BS to other BS with the help of D2D UEs, thereby shutting down the former BS. This would result in saving of energy and will not affect much the overall system performance. They formulated above problem into a flow maximization problem that optimized the data transmission from the base stations to the users. Their extensive simulation results showed that when numbers of relay units were increased, throughput of the system and D2D transmission ratio increased. Another result depicted that increase in number of operational BSs will decrease the D2D transmission but will increase throughput.

Authors of [6] proposed a less complex combined power and resource block (RB) allocation (JPRBA) algorithm which mitigated the intra-and-inter-cell interference. They introduced a power control and resource allocation vector (PORAVdm) for E ach D2D transmitter. PORAVdm had two functions: one is to select appropriate reused RBs for each D2D link, and second is to determine the optimal power for D2D transmitters on each selected RB. Simulation results verified their approach by increasing the throughput of the network.

Authors in [8] focused on increasing the system throughput by considering the impact of delay on quality-of-service in D2D communication. They also proposed an optimal power allocation scheme for two different channel modes: first is co-channel mode, where D2D UEs and cellular UES will share the same frequency-time resource, second is orthogonal-channel mode, where the frequency-time resource is divided into two parts each for D2D devices and cellular devices separately.

II. Network Model

In this paper, we consider downlink communication link between UAV and cellular users and assume that D2D users perform their communication in underlay fashion with respect to flying BSs. We also assume that D2D users establish a communication link with their corresponding receivers located in the neighborhood at a

specific distance (say d0). It is understood that D2D communication will not take place if distance is not d0. This restriction on distance for D2D communication is taken so that unnecessary interference can be eliminated from the network. But this also makes our network less flexible for D2D communication. Hence one can perform further network analysis by eliminating these restrictions and making more dynamic network scenario.

In our analysis model, we assume that power received at any user follows general principle of Friss equation. According to friss equation, power received at a user is directly proportional to transmitted power, channel gain and inversely proportional to alpha raised to the distance between them.

$$P_{r,d} = P_d d_0^{-\alpha_d} g_0 \qquad (1)$$

The signal-to-interference-plus-noise ratio (SINR) for a D2D user is given by-

$$\gamma_d = \frac{P_{r,d}}{I_d^c + I_u + N} \qquad (2)$$

$P_{r,d}$ is the signal power received from D2D transmitter, I_d^c is total interference from other D2D users, I_u is the interference from the UAV, and N is the noise power.

Interference terms in the network are given by-

$$I_d^c = \sum_{i \neq 0} P_d d_i^{-\alpha_d} g_i \qquad (3)$$

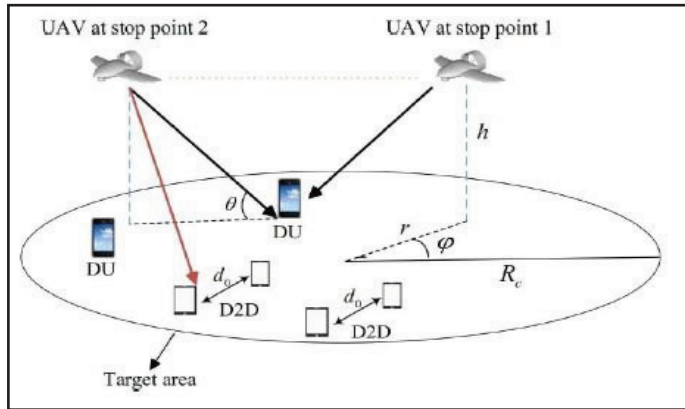$$I_d = \sum_i P_d d_i^{-\alpha_d} g_i \qquad (4)$$

Fig. 1: Network model including a UAV, Downlink Users and D2D.

Where i = 0 stand for selected D2D transmitter/receiver pair taking part in D2D communication. g_0 and g_i are the channel gains for D2D transmitter/receiver pair and for i^{th} interfering D2D transmitter. For D2D communication we generally assume Rayleigh fading channels with mean g. Typical value for channel gain is assumed to be unity, but it always depend upon how badly the channel is affected by noise, pressure, temperature and external factors. All these factors combined, affect the channel and deteriorate the received signal at receiver.

P_d is called D2D transmit power and is approximately same as transmit power of cellular users. P_d is fixed and is equal for all D2D users also. d_i is distance between a D2D receiver and any i^{th} D2D transmitter. α_d is defined as the path loss exponent between D2D users. It should always be noted that received signal powers are normalized with a factor called path loss coefficient.

When we considered the case of D2D users, we encapsulated interference from other UAVs which were providing interference to D2D receiver along with interference from undesired D2D transmitter. But, when we consider the case of cellular users which are connected to UAV, we assume no such unwanted UAV is interfering in the reception if the signal.

The SINR expression for the cellular user that is connected to UAV is given by-

$$\gamma_c = \frac{P_{r,c}}{I_d + N} \qquad (5)$$

Where $P_{r,c}$ is the signal power received from UAV BS, I_d is total interference from other D2D transmitter and N is the noise power. $P_{r,c}$ also follows Friss equation and is given as-

$$P_{r,c} = P_c d_c^{-\alpha_c} g_i \qquad (6)$$

SINR-based coverage probability for the D2D users and cellular users are given as per following formulas.

$$P_{cov,c}(\beta) = \mathbb{P}[\gamma_c \geq \beta] \qquad (7)$$
$$P_{cov,d}(\beta) = \mathbb{P}[\gamma_d \geq \beta] \qquad (8)$$

Where γ_c and γ_d are the SINR values at the desired place of the cellular users and D2D receivers, and β is the SINR threshold. SINR threshold is that minimum value of received signal below which we assume that no signal is been received, as this low level of signal is difficult to process and estimate its original value. When received signal is below this specified threshold value, it adds up to outage probability. Hence, outage probability O(β) is defined as

$$O(\beta) = \mathbb{P}[\gamma \leq \beta] \qquad (9)$$
Or
$$O(\beta) = 1 - \mathbb{P}[\gamma \geq \beta] \qquad (10)$$

We have made some assumptions here:
1. Power transmit of all BSs are same.
2. Same channel model for every link in cellular network
3. UEs inside the imaginary circle and black in color operate in cellular mode and those in red color operate in D2D mode.
Radius of Imaginary circle depends upon β.

A. Outage Probability and System Rate

Outage probability of D2D user is defined as the probability when the received signal strength at the D2D receiver is less than the predefined threshold β. mathematically,

$$O_{D2D}(\beta) = \mathbb{P}[\eta \leq \beta] \qquad (11)$$

$$
\begin{aligned}
O_d(\beta) &= 1 - P_{cov,d}(r, \phi, \beta) \\
&= 1 - \exp\left(\frac{-2\pi^2 \lambda_d \beta^{2/\alpha_d} d_0^2}{\alpha_d \sin(2\pi/\alpha_d)} - \frac{\beta d_0^{\alpha_d} N}{P_d} \right) \\
&\quad \times \left[P_{LoS} \exp\left(\frac{-\beta d_0^{\alpha_d} P_u |X_u|^{-\alpha_u}}{P_d} \right) \right. \qquad (12) \\
&\quad \left. + P_{NLoS} \exp\left(\frac{-\beta d_0^{\alpha_d} \eta P_u |X_u|^{-\alpha_u}}{P_d} \right) \right]
\end{aligned}
$$

$$\bar{P}_{\text{cov,du}}(\beta) = \int_0^{\min\left[\left(\frac{P_u}{\beta N}\right)^{1/\alpha_u}, R_c\right]} P_{\text{LoS}}(r)\frac{2r}{R_c^2}dr$$
$$+ \int_0^{\min\left[\left(\frac{\eta P_u}{\beta N}\right)^{1/\alpha_u}, R_c\right]} P_{\text{NLoS}}(r)\frac{2r}{R_c^2}dr.$$

Average achievable rates for the D2D user and downlink users are obtained as follow

$$\bar{C}_d = W \log 2(1 + \beta)\bar{P}_{cov,d}(\beta) \qquad (13)$$

$$\bar{C}_{du} = W \log 2(1 + \beta)\bar{P}_{cov,du}(\beta) \qquad (14)$$

Where W is the transmission bandwidth. Here we are ignoring the contribution of cellular user in system sum rate, because we wanted to evaluate the performance of the D2D system, therefore the system sum rate consists of only the D2D users only. Hence, the $\bar{C}_{sum}$ is given by-

$$\bar{C}_{sum} = R_C^2 \pi \lambda_d \bar{C}_d + R_C^2 \pi \lambda_{du} \bar{C}_{du} \qquad (15)$$

B. Coverage Probability for D2D Users
In this section, we are going to evaluate the coverage probability of D2D users as our prime motive. For this evaluation, we consider that UAV is flying at an altitude of h meters above the ground level and at the center of the area of service. The UAV will be serving cellular users in the downlink fashion. D2D users will be participating in the communication with other intendant D2D users in an underlaying fashion. In such a method. D2D users will not be needing any kind of assistance from the base station, hence termed as underlaying fashion. It can be understood that uniform distribution of such flying BSs in the service area will maximize the probability of the downlink users.

Let us consider that our D2D receiver is located at (r, φ), where r and φ are the radius and angle in a polar coordinate system assuming that the flying base station is located at the center of the desired geographical area. We assume that our D2D transmitter is d0 distance spaced from the intendant D2D receiver, and this distance is fixed in order to minimize the interference generated in the network due to D2D transmitters. For our context of D2D communication, the coverage probability for D2D users is derived follow-

$$P_{cov,d}(r,\phi,\beta) = \exp\left(\frac{-2\pi^2 \lambda_d \beta^{2/\alpha_d} d_0^2}{\alpha_d \sin(2\pi/\alpha_d)} - \frac{\beta d_0^{\alpha_d} N}{P_d}\right)$$
$$\times \left[P_{LoS} \exp\left(\frac{-\beta d_0^{\alpha_d} P_u |X_u|^{-\alpha_u}}{P_d}\right) \right.$$
$$\left. + P_{NLoS} \exp\left(\frac{-\beta d_0^{\alpha_d} \eta P_u |X_u|^{-\alpha_u}}{P_d}\right)\right] \qquad (16)$$

where

$$|X| = \sqrt{h^2 + r^2} \qquad (17)$$

From the above equation, it can be observed that increase in altitude of UAV doesn't necessarily always decrease the interference from UAV for the D2D users. It is evident from the fact that as the altitude of UAV increases, NLoS link gets converted to LoS link which is highly undesirable for D2D users as signal from UAV via LoS link will be more and D2D receiver will face more

interference. But this fact of increasing the altitude of UAV will definitely benefit the cellular users as they will receive more signal strength. The effect of altitude on D2D receiver is shown in paper. The D2D users always prefer to have an NLoS link with UAV because of lesser interference from the UAVs. D2D users also prefer to have a maximum distance from the UAVs, but actually having both the possibilities simultaneously is not possible.

III. Results
In this section, we are going to present panoptical numerical results based on our former analysis of outage probability and system sum rate with respect to SINR-threshold, D2D user density and ratio of D2D user density to cellular downlink user density.

A. Parameter Settings
In the following numerical results, parameter setting for network is selected as per the LTE instructions

Carrier freq, f_c	: 2 GHz
UAV transmit power, P_u	: 5 W
D2D transmit power, P_d	: 100 mW
Path loss coefficient, K	: −30 dB
Pathless exp. for D2D link, α_u	: 3
Pathless exp. for UAV-user link, α_d	: 2
Cellular downlink user density, λ_{du}	: 10^{-4}U E/m²
D2D user density, λ_d	: $4*10^{-4}$ U E/m²
D2D pair distance, d_0	: 10m
Outage threshold, β	: 10 dB
Channel bandwidth, W	: 10 MHz
Noise power density, N	: −120 dBm
Constant values, B, C	: 0.136, 11.95

B. SINR CDF Versus SINR Threshold
Fig. 2 illustrates the variation of Signal-to-interference cumulative density function with respect to SINR threshold value. In our analysis we will range our SINR threshold value from -20 dB to 15 dB. Here we have plotted the SINRCDF variation for two different value of D2D user density. Red line represents the SINRCDF when number of D2D users' density are equal to cellular users around a given BS. Blue line represents SINRCDF when D2D users' density is four times that of cellular user in that given BS area. The nature obtained here is monotonically increasing, but this increase is not uniform over the entire range. The lower portion of the curve, i.e. from -20 dB to -10 dB, increases at a lower rate while the middle section ranging from -10 dB to 10 dB increases with considerable rate.

The reason for such behaviour lies in the fact that, when D2D users' density is equal to cellular users' density, distance between corresponding D2D transmitter and receiver is more which results in small amount of received signal strength at D2D receiver. Thus signal strength is less as compared to cumulative interference received at this receiver from all other D2D transmitters When SINR threshold is increased from -20 dB to -10 dB, the SINR ratio will be very small. This ratio will increase as we increase the SINR threshold, and the SINR-CDF will increase at a greater rate. The increase in SINR-CDF can be
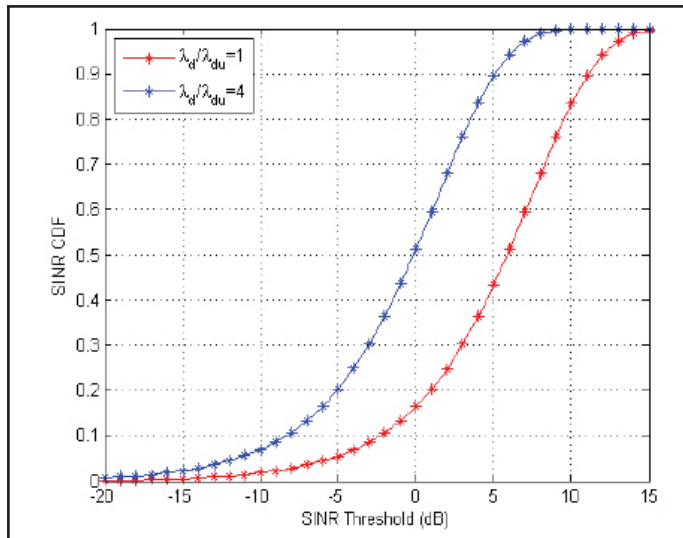
Fig. 2: SINR CDF Versus SINR Threshold β.

Made more is we increase the D2D users' density, With increase in D2D users' density, distance between nearest D2D transmitter and its intendant receiver will decrease, which will eventually increase the strength of the received signal at receiver. The interference term will also increase, but its rate of increase will be less. Increase in SINR threshold will also favour the increase of SINR-CDF.

C. Outage Probability of D2D User Versus SINR-Threshold

Fig. 3 illustrates the variation of outage probability of D2D user against the SINR threshold. The nature of the variation is increasing, but this increase is not same over the entire SINR threshold range. Outage probability increases at a slow rate over -25 dB to -5 dB for D2D pair distance (d_0) of 5m, -25 dB to -10 dB for d_0 =10m, and -25 dB to -15 dB for d_0 =20m. Thereafter outage probability increase at a greater rate.
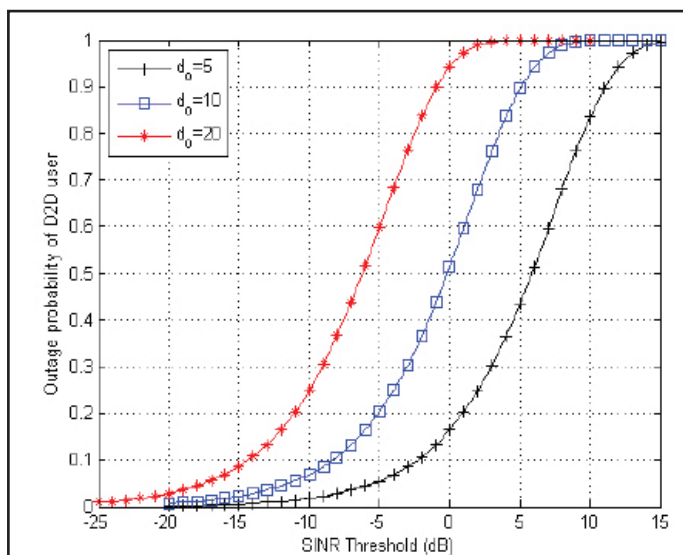

Fig. 3: Outage probability of D2D user Versus SINR- Threshold β.

The reason for such nature is as follow. When D2D pair distance (d_0) =5m, the signal strength received at the D2D receiver is good enough, therefore the outage probability is small, but it increases when SINR threshold is increased. This increase of outage is due to reason that as SINR threshold is increased, more signal strength is required at receiver for successful decoding and estimation of

signal, which eventually will result in lesser number of D2D pairs. But as we increase d_0, signal strength received at D2D receiver will decrease, and outage probability increases. This increases is also favoured by increase in SINR threshold, will results in increased outage probability.

D. Outage Probability of D2D user Versus Ratio of D2D Density and Cellular Downlink User Density (λ_d/λ_{du})

Fig. 4 illustrates the variation of outage probability versus the ratio of D2D density and cellular downlink user density (λ_d /λ_{du}). The increase is linear for smaller values of d0 but is sub-linear for greater values of d_0.
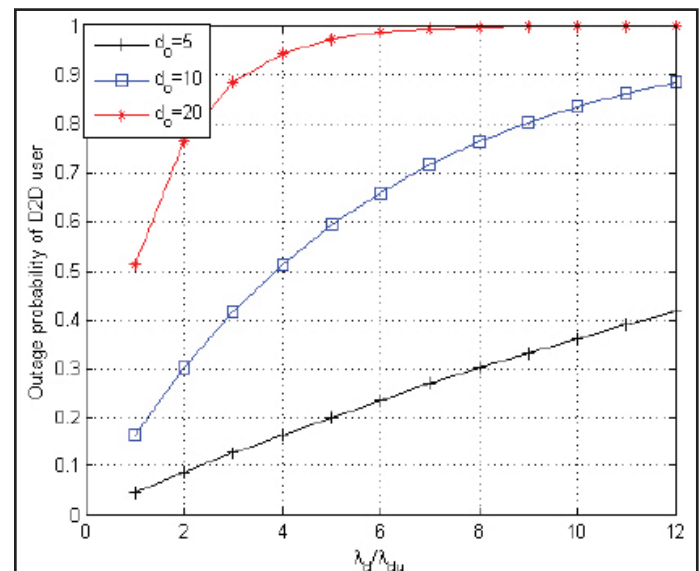

Fig. 4: Outage Probability of D2D user Versus Ratio of D2D density and cellular downlink user density (λ_d /λ_{du}).

Let us understand the reason behind such variation. When d_0=5m, the D2D transmitter and receiver are close enough, so received signal strength at the receiver is good. This increases SINR value, which means outage probability will be small. When d_0 is increased at same λ_d /λ_{du}, D2D pair separation increases, which results in decreased received signal strength at receiver. Due to this, outage probability increases as shown by red and blue lines in the above figure.

But when λ_d /λ_{du} increases, it means that number of D2D users are increased. For d_0=5m, interfering D2D users will increase at a greater rate and thus will support the increase of outage probability. When d_0 is increased to 10 meters, signal is received from a transmitter which is located at a distance of 10m but interfering D2D pairs will be available everywhere, hence SINR will decrease and outage will increase at a much greater rate than previous case. Similar will be the case when d_0 is increased to 20m.

E. System Sum Rate of D2D user Versus SINR-Threshold

For D2D pair distance d_0=10 meters, received signal strength from D2D transmitter at D2D receiver is fixed, hence system sum rate can be increased by increasing D2D user density. We can observe that when SINR in below -25 dB, the system sum rate is below 0.1 Gbps. System sum rate increases at a greater rate for higher D2D user density that is λ_d =10-4. We observe that maximum Gbps is attained for SINR β=10 dB for λ_d =10-4. The reason for this increase is that by increasing λ_d, initially total number of interfering users increase at a lower rate. Due to this

reason system sum rate increases and is shown by red line. Higher D2D user density for higher SINR threshold yields in increased system sum rate.
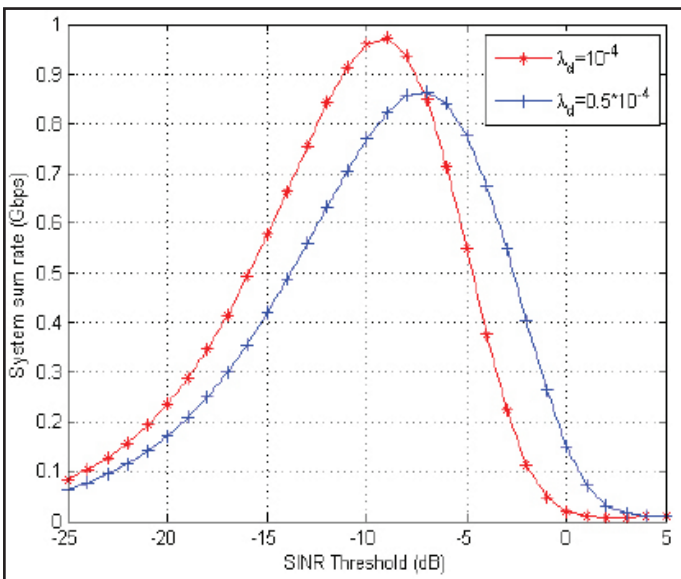

Fig. 5: System sum rate of D2D user versus SINR-Threshold β.

F. System Sum Rate of D2D user Versus D2D User Density λ_d

Fig. 6 explains the variation of system sum rate of D2D user with respect to D2D user density. The nature is increasing for small value of D2D user density but it decreases after attaining a maximum value. This system sum rate can be increased by increasing downlink user density λ_{du}.
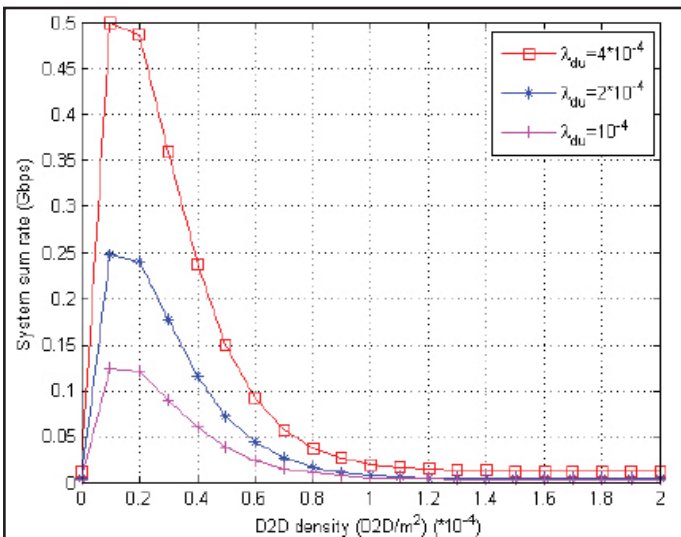

Fig. 6: System sum rate of D2D User Versus D2D User Density λ_d.

When we increase D2D user density, we mean that we are increasing total number of D2D users keeping in mind that D2D pair distance is fixed. For d_0=10m, received signal strength at the D2D receiver will always be small. With increasing λ_d from 0 to 2, we are adding more D2D users who will add to interference, and thus our system sum rate will decrease. This decreasing nature will persist even if we increase the downlink user's λ_{du}, which is clearly shown in figure. But when λ_{du} = 4*10^-4, initial increase in λ_d will enable more D2D users but probability of these D2D users lying near proximity with distance even closer to d_0 is very less.

Hence it is evident that distance of these new D2D users form our D2D receiver will be more than d_0, and therefore will give less interference. This is the reason that initial increase in D2D user density will increase the system sum rate and will attain a maximum at a value near λ_d =0 to 1.

G. Comparison Tables Between Base Paper Results and Our Thesis Results

Table 1: Comparison Result Between System Sum Rate and SINR Threshold

SINR Threshold (dB)	Base paper results System sum rate (Gbps)		Our results System sum rate (Gbps)		SINR(dB) Threshold (dB)
	$\lambda_d = 0.5*10^{-4}$	$\lambda_d = 10^{-4}$	$\lambda_d = 0.5*10^{-4}$	$\lambda_d = 10^{-4}$	
2	0.35	0.38	0.075	0.085	-25
4	0.42	**0.395**	0.18	0.23	-20
6	0.48	0.38	0.42	0.58	-15
8	**0.5**	0.32	**0.78**	**0.96**	-10
10	0.49	0.23	**0.78**	0.55	-5
12	0.41	0.13	0.16	0.03	0
14	0.28	0.05	0.04	0.02	5

Table 2: Comparison Result Between System Sum Rate and D2D Density.

D2D density λ_d	Base paper results System sum rate (Gbps)			Our results System sum rate (Gbps)			D2D density λ_d
	$\lambda_{du}=4*10^{-4}$	$\lambda_{du}=2*10^{-4}$	$\lambda_{du}=1*10^{-4}$	$\lambda_{du}=4*10^{-4}$	$\lambda_{du}=2*10^{-4}$	$\lambda_{du}=1*10^{-4}$	
0	0.220	0.130	0.075	0	0	0	0
0.1	0.223	0.140	0.080	**0.5**	**0.25**	**0.14**	0.1
0.2	0.226	0.145	0.100	0.48	0.24	0.12	0.2
0.3	**0.230**	0.155	0.110	0.35	0.18	0.08	0.3
0.4	0.227	0.160	0.120	0.24	0.13	0.06	0.4
0.5	0.225	**0.165**	0.130	0.15	0.07	0.04	0.5
0.6	0.220	0.163	0.132	0.1	0.049	0.025	0.6
0.7	0.215	0.161	0.134	0.06	0.04	0.02	0.7
0.8	0.210	0.160	**0.135**	0.04	0.03	0.02	0.8
0.9	0.200	0.159	**0.135**	0.03	0.01	0.01	0.9
1.0	0.195	0.157	**0.135**	0.02	0.01	0.01	1.0

V. Conclusion

Here we looked into the performance of a UAV that acts as a flying base station in an area, where users are capable of D2D communication. We have considered two types of users in the network: the downlink users served by the UAV and D2D users that communicate directly with one another. We have derived coverage probability, outage probability and system sum rate for D2D user. Analyzing system sum rate was our sole purpose. The results have shown that SINRCDF and outage probability of D2D users increases with increase in SINR threshold. Outage probability increase even with λ_d / λ_{du} ratio. Finally we have shown that our system sum rate can be increased with SINR threshold and D2D user density. This increase in D2D user system sum rate decreases if both SINR threshold and λ_d are increased beyond the range. Hence maximum value is attained over a small range of β and λ_d and this is where a tradeoff is made.

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