A Review Paper on Outage Probability for Flying Base Stations in D2D Environment

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Abstract- *Device-to-device(D2D) communication allows proximate devices to communicate to each other, thereby reducing 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 equipments(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) is 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 show that OP increases with increase in SINR Threshold (β) and with D2D distance (d_0) as well.*

Keywords- Device to device communication (D2D), Un- manned aerial vehicle (UAV), Long term evolution (LTE)

I. INTRODUCTION

D2D communication in cellular networks is defined as a method of creating direct communication link between two mobile users without traversing the Base Station (BS) or core network. It may appear invisible to cellular network. This communication can occur over licensed cellular spectrum or unlicensed spectrum depending upon demand and need. When it occurs over licensed cellular spectrum it is called in-band D2D and otherwise out-band D2D. Today cellular traffic is not just confined to voice and simple text, it includes sharing videos, online gaming, social networking, etc. These applications require high data rate and heavy load to BSS even when UEs are in proximity range. Such high data rate applications which can be served using a direct link between the UEs are overloaded from BSs in D2D communication. This not only mitigates the traffic burden of BSs but also increases the spectral efficiency of the entire network. It also improves the delay in reception, throughput and energy efficiency.

A. Features of D2D Communication

There are numerous features of D2D communication. We are mentioning some of them here.

1) High data rates: Devices located far from the BS can also experience high data rate from its D2D transmitter as D2D communication is not dependent on UEs distance from BS.
2) Reliable communication: D2D communications can ensure reliable communication between UEs even if there is fault in cellular network.
3) Establishing instant communications: Because of this independent nature from BS, it can provide instantaneous communication and is highly effective in situations like disasters and emergency.
4) Licensed spectrum: Unlike the other technologies such as Wi-Fi, Bluetooth it uses licensed spectrum thus reducing the interference from those devices.
5) Interference mitigation: Since the UEs are located nearby, it will cause less interference to other UEs.
6) Power efficient: In D2D communication, transmitter transmits very low power hence it saves a large amount of its power, thereby increasing the battery lifetime.

B. Taxonomy of D2D communication

Device-to-Device communication can be further classified based on frequency use and based on services.

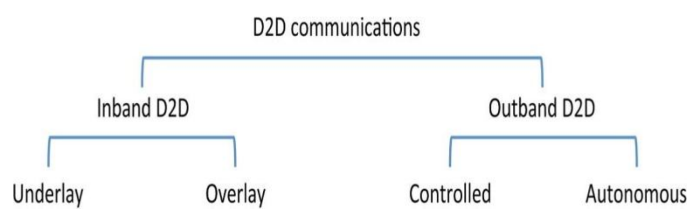

Fig. 1: Classification of D2D communication based on frequency of use.

C. Based on frequency of use

Based on frequency of use, there are two types of D2D communication:

1) In-band: In this D2D communication, cellular spectrum (licensed spectrum) is used for establishing the Direct

link between two D2D UEs. This In-band can be further classified as following:

a) Underlay: In such type of in-band D2D communication, cellular and D2D UEs share the same spectrum resource.

b) Overlay: In this type of D2D communication, D2D and cellular UEs get dedicated set of cellular spectrum.

The drawback of in-band D2D communication is the interference caused by D2D users to cellular communications and vice versa. This interference can be reduced by trading off with complexity of resource allocation methods. The later may add up to computational over- head of the BS.

2) Out-band: In this D2D communication, unlicensed spectrum is used for establishing the Direct link between two D2D UEs. This out-band can be further classified as following:

a) Controlled: In such D2D communication, control of the second interface/technology such as WiFi Direct, ZigBee or Bluetooth, is given to the cellular network.

b) Autonomous: In such D2D communication, cellular communications is controlled by BS but control of D2D communications is given to the users themselves.

Use of unlicensed spectrum in out-band mitigates the possibility of interference between D2D UEs and cellular UEs.

D. Based on services

Based on services, D2D communication can be classified as follow:

1) Emergency services: Serving emergency services is sole purpose of this type of D2D communication. It plays an important role in case of emergency and most importantly during disasters.

2) Commercial services: It is the commercial application of D2D communication where it could be used either for small area or for larger geographical location.

E. Importance of D2D in LTE-Advanced

One of the important area being researched and considered for 4G LTE Advanced is Device-to-Device communications. This form of communication uses direct communications link between two UEs located within a small area. This D2D communication is termed as Proximity service in LTE-Advanced. One major application where is can be widely used is emergency services. When cellular network fails to operate, D2D communication can rise as promising backup for establishing connection between UEs as no prior infrastructure is needed. LTE D2D was a feature that appeared in LTE REl 12.

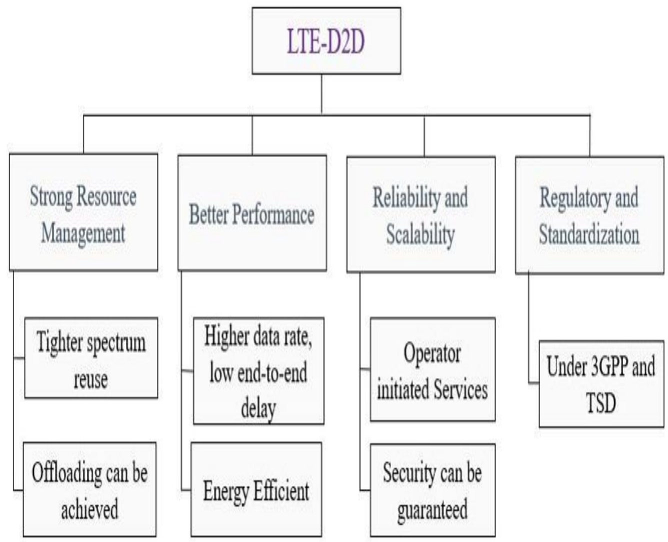

Fig. 2: Importance of D2D in LTE-Advanced.

II. LITERATURE SURVEY

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].

Device-to-device communication is assumed to be a promising solution to the above problem, hence we should get into some of its literature to get depth of the research challenges associated with it. We can broadly divide our literature survey in two parts. First is improving spectral efficiency and enhancing system capacity of D2D communication via different means and second is clubbing D2D communication with other research topics. Section 2.1 introduce different ways of improving spectral efficiency and enhancing system capacity of D2D communication. Section 2.2 shows possible merging of D2D communication with other research areas such as Opportunistic network and TV white space.

In [15] 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 l oad 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 ration increased. Another result depicted that increase in number of operational BSs will decrease the D2Dtransmission but will increase throughput.

Authors of [16] 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 each D2D transmitter. PO-RAVdm 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.

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Authors in [17] 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.

The objective of our work is to analyze spectral efficiency and outage probability of D2D users in cellular network. Use of a novel idea Unmanned Aerial Vehicle as flying base station is used here which was first presented in Unmanned Aerial Vehicle With Underlaid Device-to-Device Communications: Performance and Tradeoffs in IEEE Transaction on wireless communication, vol. 15, no. 6, June 2016. We here used this novel idea to analyze spectral efficiency and outage probability.

III. NETWORK MODEL

In this scenario, we will consider downlink communication between UAV and cellular users and assume that D2D users perform their communication in a 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 d_0). It is understood that D2D communication will not take place if distance is not d_0 . 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-

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

where $P_{r,d}$ 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-

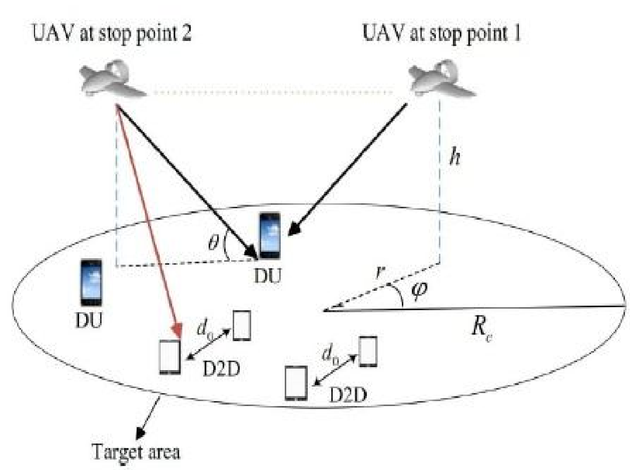

Fig. 3: Network model including a UAV, downlink users and D2D.

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

$$I_d = \sum_{i} P_d d_i^{-\alpha_d} g_i \tag{4}$$

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 combinedly 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-

$$\gamma_c = \frac{P_{r,c}}{I_d + N} \tag{5}$$

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-

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

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

$$P_{cov,c}(\beta) - \mathbb{P}[\gamma_c > \beta] \tag{7}$$

$$P_{cov,d}(\beta) = \mathbb{P}[\gamma_d \geq \beta] \tag{8}$$

where γc and γd 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 $O(\beta)$ is defined as

$$O(\beta) - \mathbb{P}[\gamma \leq \beta] \tag{9}$$

$$O(\beta) = 1 - \mathbb{P}[\gamma \geq \beta] \tag{10}$$

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,

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

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

Average achievable rate for the D2D user is obtained as follow

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

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-

$$\bar{C}_{sum} = R_C^2 \pi \lambda_d \bar{C}_d \quad (14)$$

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 d_0 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 as follow-

$$P_{cov,d}(r,\phi,\beta) = \exp\left(\frac{-2\pi^2\lambda_d\beta^{2/\alpha_d}d_0^2}{\alpha_d\sin(2\pi/\alpha_d)} - \frac{\beta d_0^{\alpha_d}N}{P_d}\right) \times \left[P_{LoS}\exp\left(\frac{-\beta d_0^{\alpha_d}P_u|X_u|^{-\alpha_u}}{P_d}\right) + P_{NLoS}\exp\left(\frac{-\beta d_0^{\alpha_d}\eta P_u|X_u|^{-\alpha_u}}{P_d}\right)\right] \quad (15)$$

where

$$|X| = \sqrt{h^2 + r^2} \quad (16)$$

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.

IV.RESULTS

In this segment, we are going to present numerical results based on our former analysis of outage probability and spectral efficiency with respect to SINR-threshold, D2D user density and ratio of D2D user density to cellular user density. Further sections 4.1 to 4.4 will include parameter settings, and plots of SINR CDF, outage probability and spectral efficiency with respect to SINR-threshold β, D2D density λ_d, and ratio of D2D user density to cellular user density λ_d / λ_c.

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 user density, λ_c	:	10 UE/Km^2
D2D user density, λ_d	:	40 UE/Km^2
D2D pair distance, d_0	:	10 m
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.4.1 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

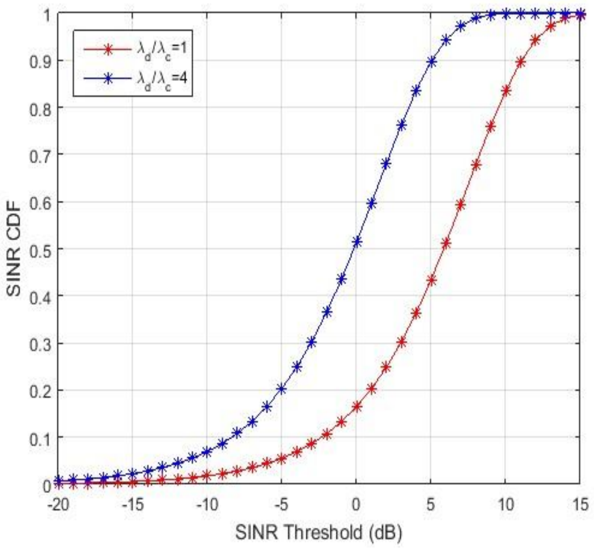

Fig. 4: SINR CDF Versus SINR Threshold β.

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 behavior 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 ration 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 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 favor the increase of SINR-CDF.

C. Outage probability of D2D user Versus SINR-Threshold

Fig.4.2 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 grater rate.

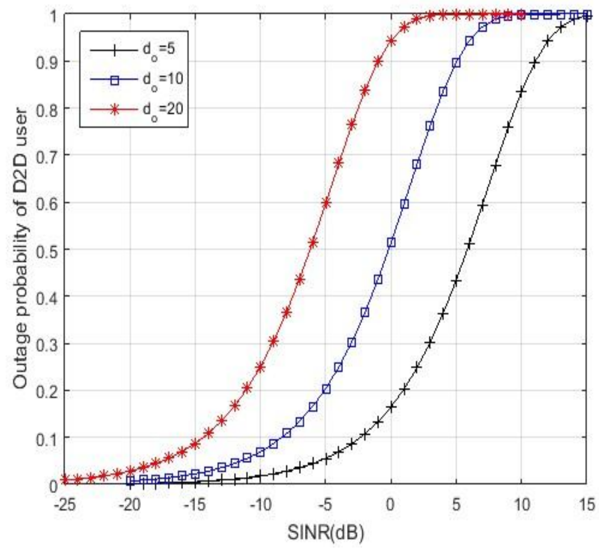

Fig. 5: Outage probability of D2D user Versus SINR-Threshold β.

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 favored by increase in SINR threshold, will results in increased outage probability.

V. CONCLUSION

Here we looked into the performance of a UAV that acts as a flying base station in an area in which 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 for D2D user. 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_c ratio and d_0 . It can be assumed that our D2D spectral efficiency will increased with SINR-threshold and D2D user density.

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