Energy Efficiency for Device-to-Device Communication based on Lagrange Optimization Technique

Radwa Ahmed Osman

Basic and Applied Science Department, College of Engineering and Technology, Arab Academy for Science and Technology (AAST), Alexandria, Egypt. P.O.Box 1029
radwa.ahmed[at]aast.edu

Abstract: ***Device-to-device (D2D) communication is considered one of the most promising technique for 5G communication. D2D communication allows the cellular user equipment (CUE) to communicate with each other without the need of the existence of base station (BS). In D2D communication, all the devices are sharing the same spectrum of cellular network, this leads to increasing the interference among receiving devices and affecting the system performance. Increasing the system energy efficiency (EE) of D2D communication while maintaining the required performance of cellular network is one of the main issues that should be addressed. This paper aims to optimize the D2D energy efficiency with minimum required cellular network spectral efficiency during downlink data communication. To achieve the goal of the proposed model Lagrange optimization technique is used as optimization method. Based on the optimization technique the m optimum required distance between the transmitting D2D and the receiving CUE to maximize the D2D EE is determined. Simulation results show that the proposed model can reach the optimum energy efficiency of D2D communication and can outperform other existing techniques while keeping the required CUE system requirements.***

Keywords: Device-to-device communication, 5G, interference, energy efficiency, cellular networks

1. Introduction

Today the number of mobile devices is dramatically increased with the increase of the number of required daily applications. Furthermore, satisfying the user requirements with the best required quality-of-service (QoS) is a challenge that should be addressed. The fifth generation (5G) is demanded to fulfill these requirements. The importance of Device-to-device (D2D) communication didn't gain much attention in the previous generations of the wireless communication network, but in 5G communication it is expecting that D2D communication will be the upcoming new paradigm that plays an important role in enhancing the performance of the cellular networks [1]. D2D allows all the cellular user to send and receive data directly with each other without the need of infrastructure or base station (BS). This is expected to enhance the reliability, spectral efficiency and capacity [2], and reduce the system latency. Extending D2D battery life time and save energy in order to enhance user's experience is a challenge, since the D2D devices are powered by batteries.

There are many important issues in D2D communication is still need solution, in D2D communication users reuse the uplink or the downlink time-frequency resource block (RB), and both D2D and cellular user (CUE) share the same spectrum. Under this situation all the receiving devices and BS are exposed to interference during uplink data communication, while during downlink communication, all receiving devices and CUE are exposed to this interference. Additionally, increasing the deployment of D2D link increases the occurred mutual interference [3]. Interference in D2D communication is considered as one of the main issues that affect the system performance, different techniques have been proposed to mitigate the interference [4]and resource management [5] in order to achieve high network performance. Another important issue that should be addressed is the energy efficiency (EE) as it plays an important role in enhancing system performance [6]. Furthermore, to meet the required QoS for both D2D and CUE interference at the same cell has been investigated [7]. Additionally, considering the maximization of the spectral efficiency while keeping the minimum required QoS is also considered in [8].Additionally, enabling multiple D2D pairs for share the same spectrum can help improve the resource efficiency [9].

Most of the proposed methods are focused on enhance the performance of uplink data communication, while the downlink is ignored. In this paper, the enhancing of D2D communication performance during downlink data communication is considered. During down link data communication, D2D link exposed to severe interference due to the high transmission power of the base station (BS). The proposed model aims to improve the energy efficiency (EE) of D2D communication under different environmental condition and with required CUE QoS constraint. First, Lagrange optimization technique is considered as optimization method for the problem formulation. Then, the required distance between transmitting device and receiving CUE is determined in order to enhance D2D system performance. Finally, the proposed model is evaluated in terms of D2D spectral efficiency under channel parameters such as transmission power, pathloss, transmission distance and interference can affect D2D communication and BS-CUE communication as well.

The reminder of this paper is divided as follow Section 2 discusses the related work, Section 3 explains the system model and problem formulation. Simulation and discussion are presented in Section 4. Finally, the Conclusion is discussed in Section 5.

2. Related Work

Many researchers have been proposed to enhance energy efficiency of D2D communication. [10] demonstrated how the energy efficiency can be improved by the integration of D2D communication in cellular systems operating under dynamic time division duplex (TDD). Additionally, [11] addressed the relation between power control and spectrum resource allocation in order to enhance the energy efficiency (EE). Furthermore, the energy efficiency power control for D2D and cellular users in orthogonal frequency division multiple access was investigated in [12] to maximize the energy efficiency. Moreover, [13] enhanced the energy efficiency by implementing multihop D2D communications where one UE may work as a relay for other UEs in order to exchange information to any CUE or BS. In addition, [14] aims to maximize the energy efficiency for the downlink D2D communication while guaranteeing the quality of service of cellular users (CUs) and the required power forD2D links and base station as well.

For EE optimization, [15] considered a two-stage EE optimization problem based on a joint spectrum and power allocation problem in order to maximize the system EE of D2D communication. On the other hand, [16] investigated the trade-off between energy efficiency (EE) and spectral efficiency (SE) during the uplink D2D communication in a network composed of macro base station (BS), several pico BSs, and D2D link. Furthermore, [17] proposed an optimization problem based on optimizing the resource allocation and power in order to maximize the EE and enhance the system performance. Moreover, [18] investigated the energy efficiency power control for uplink D2D communication where there are multiple D2D link that share the resource block of one cellular user equipment. In addition, an optimization problem based on four constraints proposed in [19] to maximize the EE for the whole cellular networks underlaid with D2D communication with randomly distributed users on multiple bands. Additionally, stochastic traffic arrivals and time-varying channel conditions is considered in [20] to investigate the problem of revealing the tradeoff between energy efficiency (EE) and delay. A stable matching approach is proposed in [21] in order to address the optimization of EE and test the scalability issues in large networks.

In this work, a proposed approach is investigated to enhance the D2D system performance which could be affected during the downlink data communication due to the highest transmission power of the BS. The aim of the proposed model is to maximize the EE of D2D communication during the downlink data communication while satisfying the required QoS for cellular network. The proposed approach is based on applying Lagrange optimization technique in order to maximize the downlink EE by determine the optimum required distance between transmitter devices and receiving CUE. The proposed model is evaluated under different channel conditions such as transmission power, transmission distance, pathloss and interference to show the effectiveness of the proposed model.

3. System model and Problem formulation

In this section, the analytical of the proposed model is established for enhancing the EE of D2D communication with the minimum required cellular networks QoS. As shown in Figure 1, a cellular network consists of one BS, CUE and D2D link, where D2D link shares the same spectrum of cellular networks. D2D links has one transmitter device (DTx) and one receiver device (DRx). The proposed model aims to maximize the EE of D2D with minimum required cellular network QoS which is expressed as:

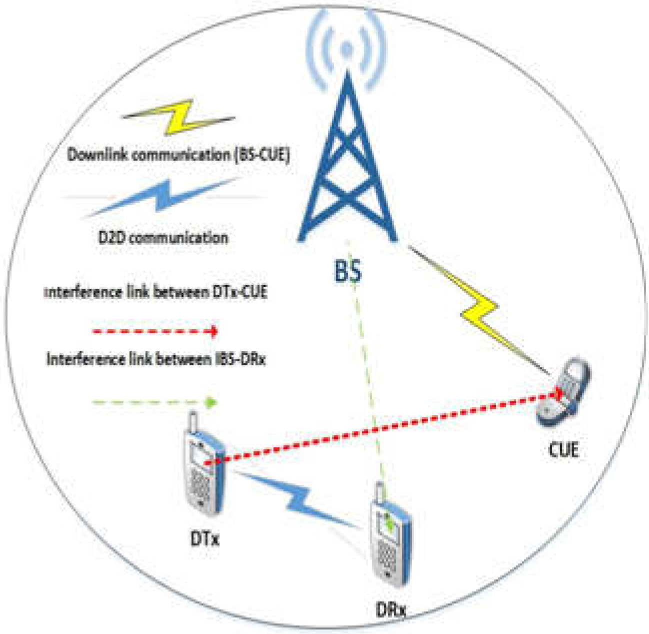

Figure 1: System model

$$\begin{aligned} &Max\ \{EE_{D2D}\} \\ &s.t. S_{CUE} \geq S_{CUEmin} \\ &s.t. P_D \leq P_{Dmax} \end{aligned} \quad (1)$$

where EE_{D2D} is the D2D link energy efficiency in bit/J/Hz. S_{CUE} and S_{CUEmin} represent the spectral efficiency and the minimum required spectral efficiency of the cellular communication, respectively. P_D and P_{Dmax} represent the transmission power and the maximum transmission power of any transmitter device (DTx), respectively. S_{CUE} can be expressed as:

$$S_{CUE} = log_2\left(1 + \frac{P_B\, PL_{BC}}{P_D\, PL_{DC} + N_o B}\right) \quad (2)$$

where $P_B$is the BS transmission power. PL_{BC} represents the pathloss for the transmission between BS-CUE.P_D and $PL_{DC}$are the DTx transmission power and the pathloss for the transmission between DTx-CUE. N_o is the thermal noise power spectral density per Hertz. B is the channel system bandwidth. For the proposed model, it is assumed that the transmission links are subjected to a narrowband Rayleigh fading channel with additive White Gaussian Noise (AWGN) and propagation pathloss.

3.1 Communication scenario.

For the proposed scenario, during the downlink data communication BS sends data to CUE while there is a D2D link sharing the same spectrum of the cellular network. Due to the sharing spectrum between BS-CUE and D2D links, CUE and DRx always suffer from interference. However, DRx suffers from severe interference due to the highest BS transmission power (P_B). Additionally, CUE may expose to a network resource limitation due to the sharing spectrum. According to these conditions, EE_{D2D} is optimized with CUE QoS satisfaction. The received signal at CUE (r_{BC}) and DRx (r_{DD}) due to the transmission can be expressed as [22]:

$$r_{BC} = \sqrt{P_B}H_{BC}X_1 + \sqrt{P_D}H_{DC}Y_1 + n_1 \quad (3)$$

$$r_{DD} = \sqrt{P_D}H_{DD}X_2 + \sqrt{P_B}H_{BD}Y_2 + n_2 \quad (4)$$

where H_{BC} and X_1 are the channel gain coefficient and the transmitted symbol of BS-CUE link, respectively. H_{DC} is the channel gain coefficient between DTx and receiving CUE.Y_1 represents the noise symbol received by CUE. H_{DD} and H_{BD} are the channel gain of D2D link and BS-DRx, respectively.X_2 and Y_2 represent the signal and the interference signal received by DRx, respectively. n_1 and n_2 represent are the independent and identically distributed (i.i.d.) additive white Gaussian noise (AWGN) of the BS-CUE and D2D link, respectively. Additionally, the corresponding signal-to-interference-plus-noise ratio at CUE and DRX can be given as [22]:

$$SINR_{BC} = \frac{P_B\,PL_{BC}}{P_D\,PL_{DC}+N_oB} \quad (5)$$

$$SINR_{DD} = \frac{P_D\,PL_{DD}}{P_B\,PL_{BD}+N_oB} \quad (6)$$

where PL_{DD} and PL_{BD} represent the pathloss for the transmission between D2D link and BS-DRx, respectively. The path loss between any to node i and node j (PL_{ij}) can be written as [23]:

$$PL_{ij} = PL_o {d_{ij}}^{-\alpha} \quad (7)$$

where PL_o and d_{ij} are the pathloss constant and the distance between i and j, respectively. α is the pathloss exponent, thus Equation (5) and Equation (6) can be rewritten as:

$$SINR_{BC} = \frac{P_B\,PL_o {d_{BC}}^{-\alpha}}{P_D\,PL_o {d_{DC}}^{-\alpha}+N_oB} \quad (8)$$

$$SINR_{DD} = \frac{P_D\,PL_o {d_{DD}}^{-\alpha}}{P_B\,PL_o {d_{BD}}^{-\alpha}+N_oB} \quad (9)$$

Therefore, the energy efficiency of D2D communication (EE_{D2D}) can be expressed as:

$$EE_{D2D} = \frac{1}{P_D+P_o} log_2\left(1+\frac{P_D\,PL_o {d_{DD}}^{-\alpha}}{P_B\,PL_o {d_{BD}}^{-\alpha}+N_oB}\right) \quad (10)$$

The main objective of the performance optimization of the proposed model is to maximizeEE_{D2D}under different environmental conditions. The solution of the optimization problem specified in (1) can be found by investigating the first-order optimality conditions. The Lagrangian of the optimization problem can be calculated as:

$$l\{EE_{D2D},\lambda,\mu\} = EE_{D2D} + \lambda\,(S_{CUE} - S_{CUEmin}) + \mu\,(P_{Dmax} - P_D). \quad (11)$$

where $\boldsymbol{\lambda}$ and $\mu$are the non-negative Lagrangian multipliers for the optimization problem. By taking the derivative of Equation (11) with respect to P_B and P_D, thus the optimal solution to (1) can be found as:

$$\frac{\partial l\{EE_{D2D},\ S_{CUE},\ P_D\}}{\partial P_B} = 0. \quad (12)$$

$$\lambda = \left(\frac{P_B\,PL_o {d_{BD}}^{-\alpha}+P_D\,PL_o {d_{DD}}^{-\alpha}+N_oB}{PL_o {d_{BC}}^{-\alpha}}\right)\left(\frac{P_D\,PL_o {d_{DD}}^{-\alpha} PL_o {d_{BD}}^{-\alpha}}{(P_B+P_o)(P_B\,PL_o {d_{BD}}^{-\alpha}+P_D\,PL_o {d_{DD}}^{-\alpha}+N_oB)(P_B\,PL_o {d_{BD}}^{-\alpha}+N_oB)}\right) \quad (13)$$

$$\frac{\partial l\{EE_{D2D},\ S_{CUE},\ P_D\}}{\partial P_D} = 0. \quad (14)$$

$$\mu = \left(\frac{1}{(P_B+P_o)^2}\right) log_2\left(1+\frac{P_D\,PL_o {d_{DD}}^{-\alpha}}{P_B\,PL_o {d_{BD}}^{-\alpha}+N_oB}\right) - \left(\frac{PL_o {d_{DD}}^{-\alpha}}{(P_B+P_o)(P_B\,PL_o {d_{BD}}^{-\alpha}+P_D\,PL_o {d_{DD}}^{-\alpha}+N_oB)}\right) + \lambda\left(\frac{P_B\,PL_o {d_{BC}}^{-\alpha} PL_o {d_{DC}}^{-\alpha}}{(P_B\,PL_o {d_{BC}}^{-\alpha}+P_D\,PL_o {d_{DC}}^{-\alpha}+N_oB)(P_D\,PL_o {d_{DC}}^{-\alpha}+N_oB)}\right) \quad (15)$$

Equation (13) and Equation (15) shows the value of λ and μ that satisfy the constraint of the optimization problem.

By taking the derivative of Equation (11) with respect to λ and μ, it can be found that:

$$\frac{\partial l\{EE_{D2D},\ S_{CUE},\ P_D\}}{\partial \lambda} = 0. \quad (16)$$

$$d_{DC} = \left[\frac{P_B PL_o {d_{BC}}^{-\alpha}}{(1-e^{SCUEmin})PL_oP_D} - \frac{N_oB}{PL_oP_D}\right]^{-\alpha} \quad (17)$$

$$\frac{\partial l\{EE_{D2D},\ S_{CUE},\ P_D\}}{\partial \mu} = 0. \quad (18)$$

$$P_D = P_{Dmax} \quad (19)$$

where d_{DC} and P_D are the required distance between DTx and CUE and DTx transmission power, respectively, in order to achieve maximum EE_{D2D} with the required cellular network spectral efficiency.

Table 1: Simulation parameters

Parameters	Value
N_o	174 dBm/Hz [13]
B	10 Mb/s
P_B	46 dBm [13]
P_D	20 dBm [13]
α	3.5 [13]
S_{CUEmin}	12 bits/s/Hz or 15 bits/s/Hz [13]
cellular Link Path loss	128.1 + 37.6 $\log_{10}$[d(km)] dB [23]
D2D link Path loss	148 + 40 $\log_{10}$[d(km)] dB [23]

4. Numerical Results and Discussion

The performance proposed model is evaluated in this section through MATLAB simulation in term of energy efficiency (EE_{D2D}) of D2D communication and is compared with the model proposed in [13]. The network parameters considered for simulation is listed in Table 1. Figure 2 depicts the required distance between DTx and CUE with different distance between DTx and DRx in order to enhance system performance. It has been mentioned that increasing the required spectral efficiency of cellular network leads to increasing the required distance DTx and CUE. As increasing the distance between DTx-CUE decreases the interference at CUE which enhances the system performance for cellular networks and enhances EE_{D2D}. Additionally, it has been noticed that increasing the distance between DTx-DRx increases the distance DTx-CUE, e.g. when S_{CUE} is 12 bit/s/Hz the distance between DTx-DRx is 40 m, then the required distance between DTx-CUE is 38 m while when DTx-DRx distance is 100 m the required DTx-CUE distance is 64 m. On the other hand, when S_{CUE} is 15 bit/s/Hz and he distance between DTx-DRx is 40 m and 100m, then the required distance between DTx-CUE is 88 m and 150 m, respectively. The obtained result proves that in order to maintain high spectral efficiency for cellular network with better performance for D2D communication, CUE should be allocated at a suitable distance which increases or decreases depending on its required S_{CUE}.

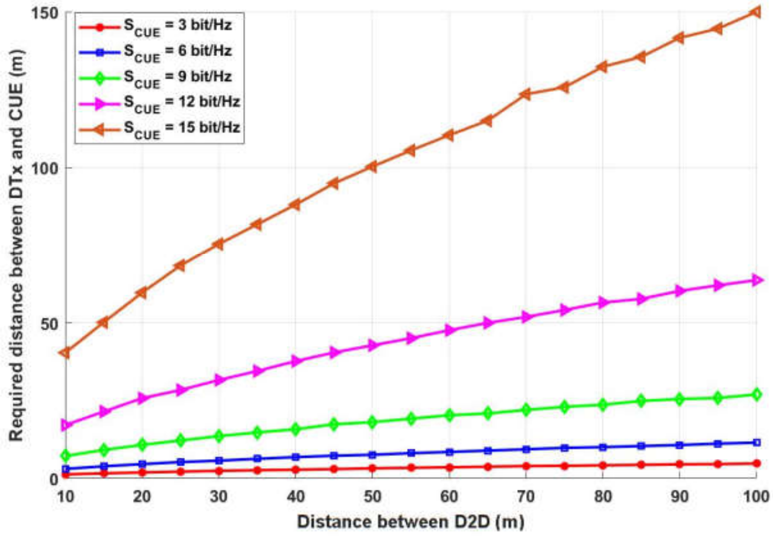

Figure 2: Distance between D2D vs required distance between DTx and CUE

The total energy effieicncy for D2D communication (EE_{D2D}) with different required S_{CUE} with different D2D transmission distance is evaluated in Figure 3. It has been observed from Figure 3 that when increasing the required S_{CUE} energy effieicncy for D2D communication (EE_{D2D}) increases. This due to the proposed model is targering finding the optiumu required DTx-CUE to achieve the maximum EE_{D2D} while satisfying the required S_{CUE}. The obtained result is corrolated with the result obtain in Figure 2 which shows that increases the distance between DTx-CUE enhnaces EE_{D2D} regardless the required S_{CUE}.

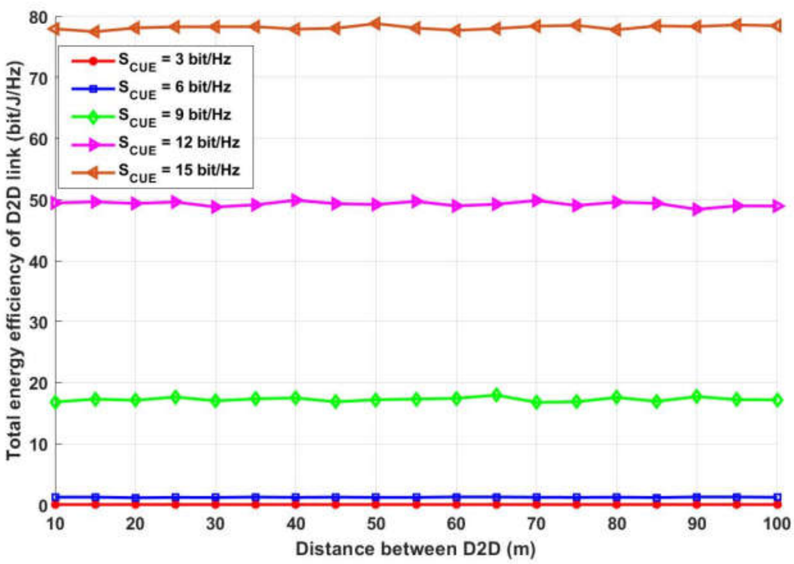

Figure 3: Distance between D2D vs Total energy efficiency of D2D link (bit/J/Hz)

Figure 4 shows the effect of increasing the required S_{CUE}versus the required distance between DTx-CUE. Assuming that there are have five difference transmission distance between DTx-DRx which are 20 m, 40 m, 60 m, 80 m, and 100 m. It has been mentioned that when the required $S_{CUE}$is small (≤ 6 bits/Hz) regardless the distance between any D2D link, there is no need to be adapted the distance berween DTx-CUE and it can be guarantee that the required S_{CUE}will be fulfilled. However, when S_{CUE}exceeds 6 bits/Hz the distance between DTx-CUE should be adapted in order to fulfil the required S_{CUE}. For example, when $S_{CUE}$is 13 bits/Hz it can be found that the required distance between DTx-CUE to fulfill the required S_{CUE} and maximize EE_{D2D}should be 33.92 m, 50.95 m, 63.83 m, 74.73 m and 86.15 m for the five assumed D2D transmission distance, respectively.

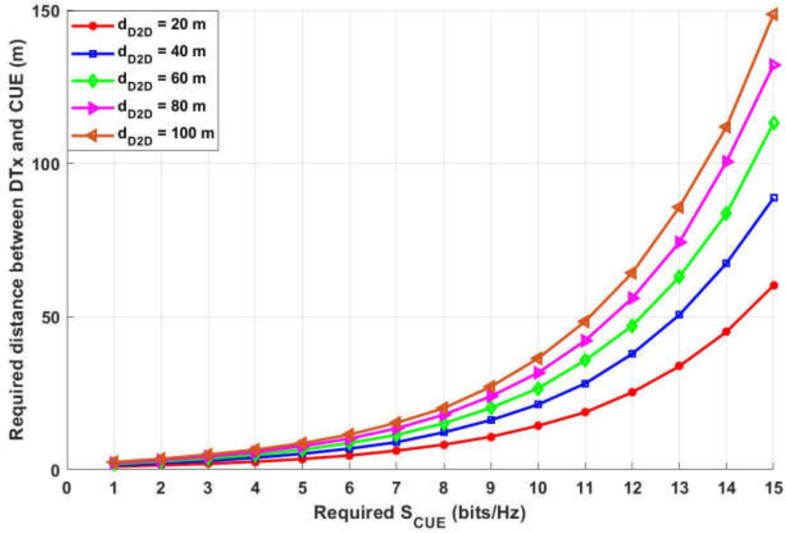

Figure 4: Required S_{CUE} (bits/Hz) vs Required distance between DTx and CUE (m)

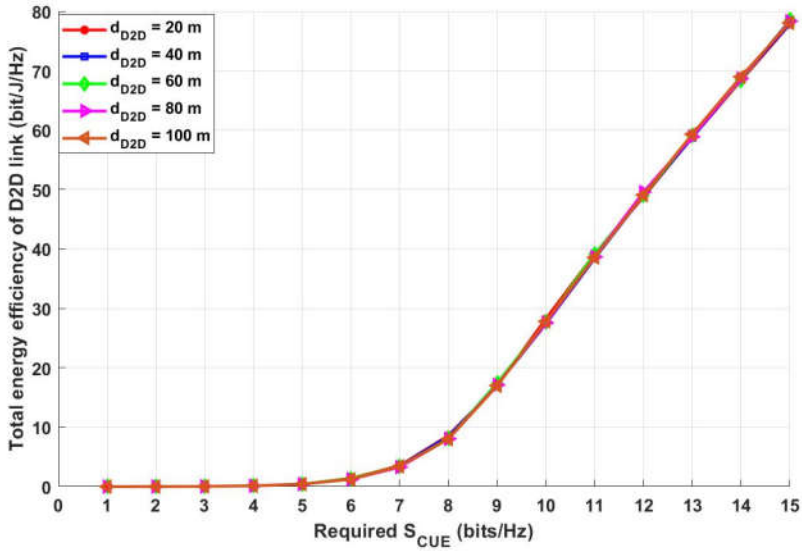

Figure 5: Required S_{CUE}(bits/Hz) vs Total energy efficiency of D2D link (bit/J/Hz)

Based on the result obtained in Figure 4, Figure 5 is presented to acertain that the proposed model always maximizes EE_{D2D} regardless the required $S_{CUE}$and the transmission distance between DTx and DRx. Additionally, it can be depicted from Figure 5 that the maximimum $EE_{D2D}$is alwaysachieved due to the continous distance adaptation between DTx-CUE which will be varied based on the required S_{CUE}. The result obtained show the effectivness of the proposed model and ensure that the proposed model is a vey efficient method to enhance the system performance for both cellular network and D2D communication

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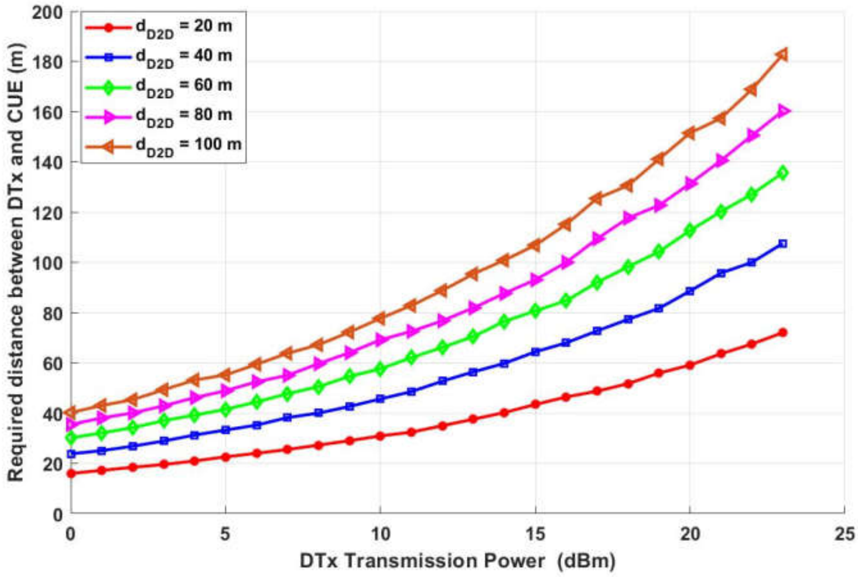

Figure 6: DTx Transmission power (dBm) vs Required distance between DTx and CUE (m)

The required distance between DTx and CUE is evaluated once again but this time versus the required transmission power of DTx (P_D) for five different transmission distance D2D communication link as shown in Figure 6. It can be observed from Figure 6, that increasing the transmission power increases the required distance between DTX-CUE. Additionally, it showed that increasing the distance between DTx and DRx increases also the required DTX-CUE. This result ascertain that the transmission power affects the system performance as increases the transmission power increases the interference at receiving CUR. For this reason, when the transmission power increase the distance between DTx-CUE should increase to maximize $EE_{D2D}$and at the same time maintain the requiredS_{CUE}. For example, as it can be seen from Figure 6 when d_{D2D} is 20 m and P_D is 5 dBm the required distance between DTx and CUE is 22.54 m while it should be 59.09 m when P_D is 20 dBm. However, when d_{D2D} is 100 m the distance between DTx and CUE should be 55.17 m and 151.4 m for P_D equals to 5 and 20 dBm, respectively.

The total energy efficiency for D2D communication is evaluated with different DTx transmission power (P_D) as shown in Figure 7. Figure 7 shows that the transmission distance between D2D won't affect the system performance in terms of D2D energy efficiency, this is due to the fact that the proposed model aimed to improve EE_{D2D} regardless the D2D transmission distance. It also shows that for all assumed D2D transmission distances the optimum required power to achieve the maximum EE_{D2D} is between 19 and 20 dBm. The obtained result is correlated with the results obtained in Figure 6 which is the distance between DTx and CUE must be adapted based on the transmission conditions in order to achieve the required cellular user and D2D communication requirements.

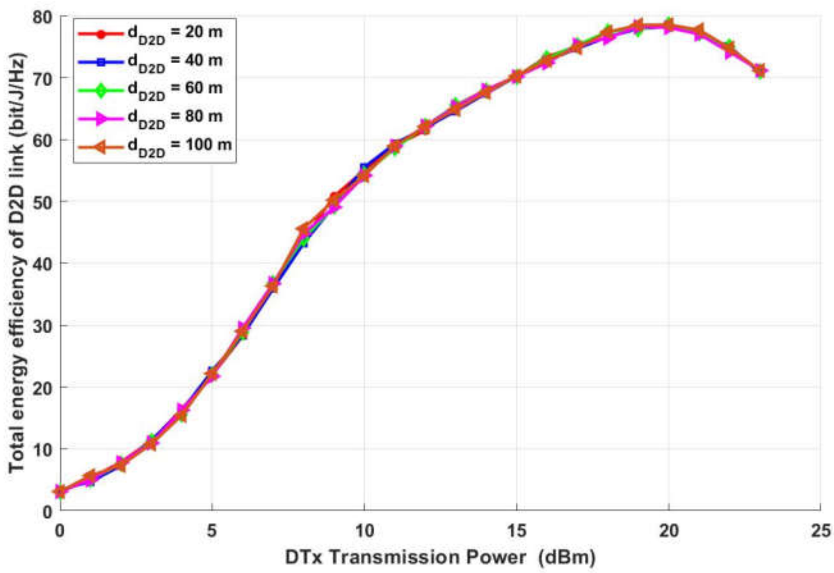

Figure 7: DTx Transmission power (dBm) vs total energy efficiency of D2D link (bit/J/Hz)

To ascertain that the proposed model performs well, the proposed model should be compared with other existing method. Therefore, the proposed model has been compared with the model proposed in [13] as it can be depicted from Figure 8. Figure 8 shows that the proposed model outperforms the model proposed in [13] in terms of D2D energy efficiency. Additionally, that the model proposed in [13] had lower EE when the required S_{CUE} increases. However, the EE of the proposed approach increases when S_{CUE} increases. This results prove that both D2D communication and cellular networks can both achieve a better performance but with distance adaptation between DTx and CUE.

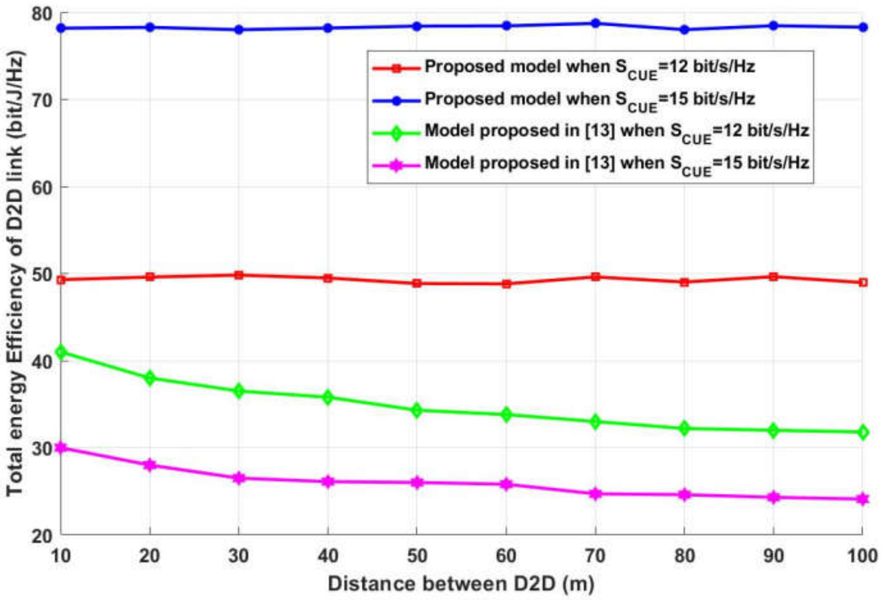

Figure 8: Distance between D2D (m) vs total energy efficiency of D2D link (bit/J/Hz)

It can be concluded from Figure 2 to Figure 8 that both D2D communication and cellular networks can achieve the required system performance with some network adaptation. This network adaptation will be held based on the network condition such as transmission distance, transmission power, pathloss, pathloss exponent and interference. The proposed approach provides effective guidance for deciding what should the suitable distance between DTx-CUE be. For achieving the maximum EE_{D2D} with the requires S_{CUE}, the proposed optimization approach can be recommended for the given transmission conditions. Therefore, based on the presented results, the enhancement of D2D communication while maintating the required cellular network performance can be achieved by adaptively determining the appropriate position of CUEfrom DTx under different network and transmission conditions.

5. Conclusion

An energy efficient D2D communication optimization was proposed to maximize D2D EE while maintaining the required performace cellular network during downlink data communication.The proposed optimization problem to maximize EE_{D2D} is deduced based on using the Lagrange optimization technique. Based on the obtained D2D energy efficiency it has shown that the proposed model can exhibit the higher EE under different environmental conditions compared with other proposed models. Based on the network conditions, the optimum required DTx-CUE can be identified to maximize $EE_{D2D}$with minimum required cellular network performance. The obtained results based on the solve optimization problem shown the effectivness and the accuarcy of the proposed model.

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