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Interference Mitigation in D2D Communication Underlying Cellular Networks: Towards Green Energy

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Abstract: Device to Device (D2D) communication is emerging as a new participant promising technology in 5G cellular networks to promote green energy networks. D2D communication can improve communication delays, spectral efficiency, system capacity, data off-loading, and many other fruitful scenarios where D2D can be implemented. Nevertheless, induction of D2D communication in reuse mode with the conventional cellular network can cause severe interference issues, which can significantly degrade network performance. To reap all the benefits of induction of D2D communication with conventional cellular communication, it is imperative to minimize interference's detrimental effects. Efficient power control can minimize the negative effects of interference and get benefits promised by D2D communication. In this work, we propose two power control schemes, Power Control Scheme 1 (PCS 1) and Power Control Scheme 2 (PCS 2), to minimize the interference and provide performance analysis. Simulation results observe improvements with PCS 1 and PCS 2 as compared to without using any power control scheme in terms of data rate in both uplink and downlink communication modes of Cellular User Equipment (CUE).

Keywords: Interference mitigation; green IoT; green networks; D2D; power control; spectral efficiency; reuse mode

1 Introduction

Over the years, cellular communication networks have evolved rapidly from 1G to 5G or Next-Generation Mobile Networks (NGMN) in the last several decades. Day by day, increasing the number of connected devices and consumers, data-hungry applications push the traditional network to its very limits (Fig. 1). The Internet of things, smart homes, and more advanced applications with higher data rates and latency requirements urge academia and industry to develop a new cellular network paradigm. One which has increased capacity and faster data rates fulfill the desired requirements. The number of connected devices to the Internet will be almost 9.4 billion in 2022 [1]. It is expected that 5G will be a heterogeneous network with multiple participating technologies, including MIMO, massive MIMO, millimeter waves, femtocells, Pico cells, and D2D communication [2]. In this paper, we restrict ourselves to D2D communication, a key technology enabler for 5G heterogeneous cellular networks. D2D communication can significantly improve spectral efficiency, and less delay can enhance the network's capacity and reliability between devices [3]. However, with the advantageous nature of D2D communication, induction of D2D communication also cause unwanted interference for primary cellular users while reusing the same resources, resultantly degrading the network's performance. To yield the benefits of induction of D2D communication, we need to minimize interference in both uplink and downlink transmissions [4]. Proper power control helps mitigate inter or intracellular interference; thus, we can achieve the required results of the co-existence of D2D communication with conventional cellular communication [5].

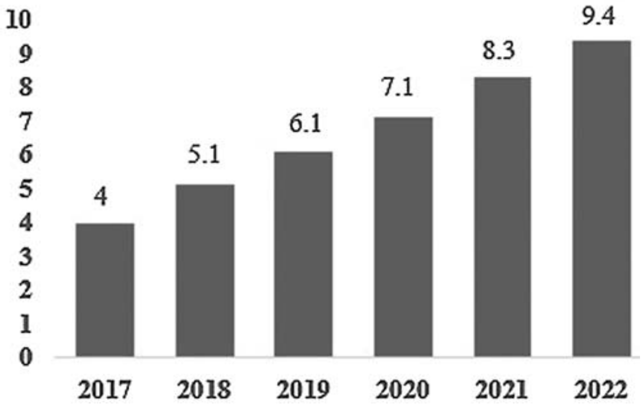

Figure 1: Expected increment in the number of connected devices till 2022

Two power control algorithms are based on stochastic geometry proposed by authors in [5] for effective power control with the intention of interference coordination and analysis performed in underlaid D2D cellular networks. The authors presented that it is possible to enhance the sum-throughput of the network with acceptable levels of interference while taking uplink transmission channels into account in a hybrid random network. A novel power control scheme was presented in [6] for hybrid cellular networks in reuse mode. This proposed mechanism relayed on putting limits on transmitting powers of D2D to minimize harmful effects from D2D devices. The study is done in a single scenario, and the results showed the possibility of increment in system capacity with the induction of D2D communication as compared to without inducing D2D communication with cellular networks. Dynamic power control scheme proposes in [7] to reduce interference and enhance overall network performance. According to the current situation in a periodic manner, power control enhances overall system throughput. In [8], the authors proposed a power control mechanism in smart grids with the induction of recent communication technologies to cope with power supply management problems. The proposed scheme's outcomes exhibited better performance compared to existing relevant schemes.

In [9], the authors proposed an optimal joint rate and power control scheme for the cellular users intending to maximize the cellular users' transmission data rate while protecting the D2D users from the interference caused by cellular communication. Distance-based resource allocation and power control approaches are proposed [10,11]. In [12], the authors proposed power optimization schemes to coordinate interference between communication links and prioritize cellular communication, and applied an upper limit on transmission rates for all links. Performance analyses showed prominent improvement in sum-rates in different considered scenarios. A Stackelberg game theory-based power allocation scheme is proposed in [13]. The authors considered macro and femtocells as leaders and D2D pairs as followers of this game to analyze network entities' rational behaviors. Equilibrium of the proposed game was analyzed to determine charging prices by leaders and the proper transmit power of followers. Another joint resource and power allocation based on the Stackelberg game approach presented in [14] in which the authors considered eNB as seller and D2D pairs as buyers. Interference over Thermal (IoT) threshold being used to protect eNB from harmful interference from D2D in uplink transmission mode. In [15], the authors presented the scheme to optimize power management in the Internet of Things (IoT) networks, which are widely accepted as part of fifth-generation communication networks. Experiment results showed that the proposed scheme performed well to predict battery life better to keep network communication up to a certain level.

The motivation of this work is to develop efficient power control schemes to mitigate the interference issues so we can get all the benefits promised by the induction of D2D communication in the existing cellular networks. Although different authors proposed different schemes for different power control scenarios, we focused on dynamically power control schemes as network conditions are dynamic in real scenarios. In this work, we present two dynamic power control schemes based on a comparison between estimated Signal to Interference Plus Noise Ratio (SINR) with target SINR during uplink and downlink transmission modes to increase the data rate of the cellular user by mitigating interference caused by D2D pairs. For this purpose, we first set our system scenario and then implement our proposed schemes in this system model. Then we present a simulation result analysis of this work to compare the existing state of the artwork to show our proposed schemes' performance.

The rest of the paper is organized as follows. Section 2 contains details about the system model. Section 3 is based on simulation results to verify our proposed power control schemes. Section 4 provides the performance of the proposed model. Finally, Section 5 describes the conclusion and future work required in this direction.

2 System Model

The simulations are performed for a single cell scenario where eNB is located in the cell's center. Here X represents one cellular user and $\mathrm{Y} = \{1, 2, \ldots, N\}$ represents N number of D2D pairs which are located randomly in the cell range. We assume D2D communications will reuse resources with the cellular user, which will cause harmful interference for our network. In the first scenario of the downlink communication mode, interference is caused by the D2D transmitter (D2DTx) for the cellular user, as shown in Fig. 2.

Fig. 3 here exhibits SINR in uplink transmission mode with PCS1, PSC2, and without any PCS. We can note that SINR values are better when we used proposed schemes, power control scheme 1 (PCS1) and power control scheme 2, compared to SINR values without power control. SINR values are decreasing with the increment in the number of D2D pairs, but still, both proposed schemes performed better. As we can see, when the number of D2D pairs increased to 10, SINR values decreased from 5 to 3.6 dB, 2.2 and 1.7 dB for PCS 1, PCS 2, and PCS, respectively.

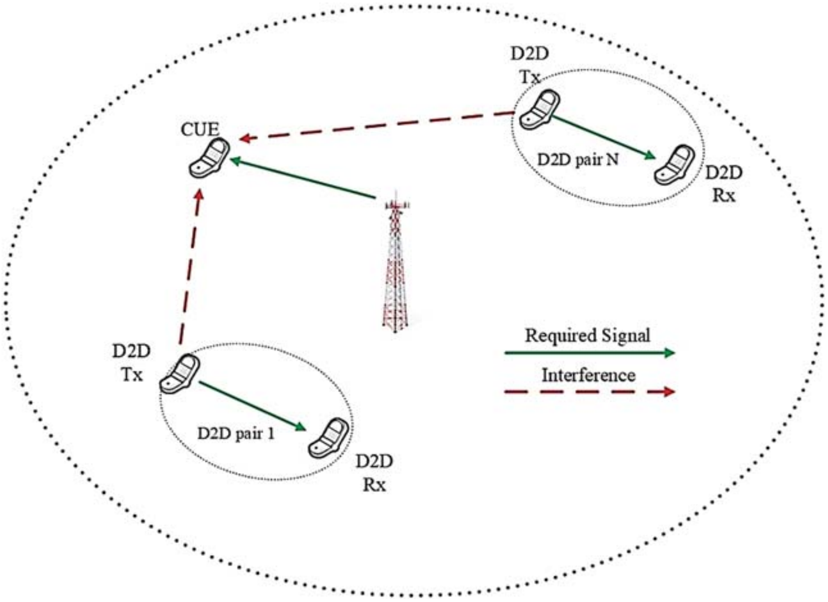

Figure 2: Downlink transmission

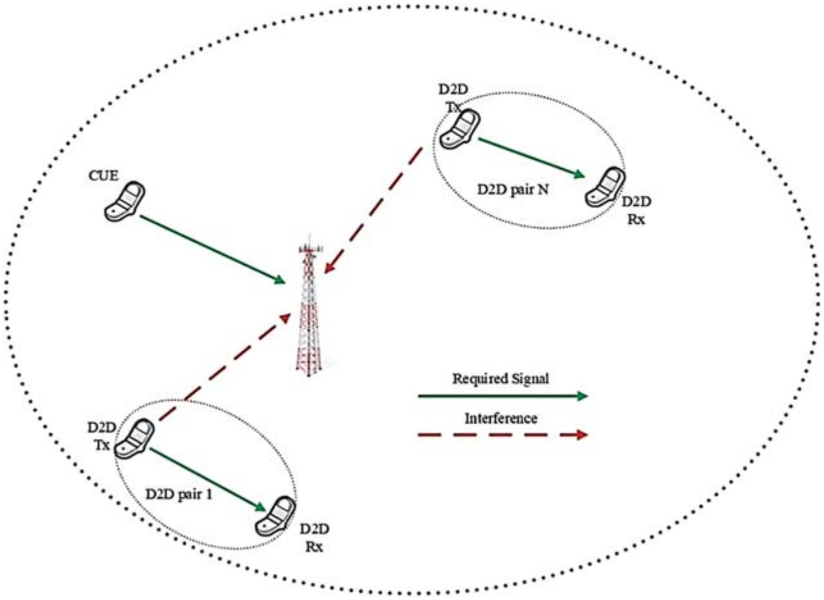

Figure 3: Uplink transmission

Similarly, in the second scenario of uplink communication mode, D2D users will cause interference for eNB, as shown in Fig. 3. Let us first discuss the scenario given in Fig. 2, which is downlink transmission. Suppose P_B denotes power transmitted by eNB in downlink transmission. P_{r_x} denotes received power at cellular user X in downlink transmission, which can be formulated as:

$$P^{\downarrow}_{r\_X} + P^{\downarrow}_{B} \cdot G_{B,X} + \sum_{1}^{N} P^{\downarrow}_{Y} \cdot G_{Y,X} \tag{1}$$

Here, $G_{B,X}$, and $G_{Yj,X}$ denotes channel gain between eNB to X CUE and interfering channel gain between D2D transmitter to X CUE. $G_{B,X}$, $G_{Y,X}$ can be formulated as:

$$G_{B,X} = PL_{B,X} \cdot \xi_{B,X} \tag{2}$$

$$G_{Y,X} = PL_{Y,X} \cdot \xi_{Y,X} \tag{3}$$

Where $PL_{B,X}$ represents Pathloss between eNB and CUE.

Where $PL_{Y,X}$: represents Pathloss between D2D pair and CUE.

While $\xi_{B,X}$, $\xi_{Y,X}$ denotes small-scale fading of the channel from eNB to CUE and from D2D pair to CUE, respectively. The path loss depends on propagation loss, which occurs due to the distance between transmitters and receivers. The general distance between transmitter and receiver can be calculated as [10]:

$$L_{Yj} = \sqrt{r_Y^2 + r_X^2 - 2YXcos_{\theta_Y}} \tag{4}$$

Eq. (4) formulates distance from D2D Tx to CUE. Signals received at CUE in a downlink can be formulated, as in [13].

$$S = \xi_{B,X}\sqrt{P^{\downarrow}_{B} L_B^{-\alpha}}h_B + \xi_{Y,X}\sqrt{P^{\downarrow}_{Y} L_Y^{-\alpha}}h_Y \tag{5}$$

In Eq. (5), h_B, h_Y represents signals transmitted from eNB and D2D pair, respectively. $\xi_{B,X}$, and $\xi_{Y,X}$ denote small-scale fading from eNB to CUE and from D2D pair to CUE, respectively. $P^{\downarrow}_{B}$, $P^{\downarrow}_{Y}$ represent transmitted power by eNB and D2D Tx in the downlink. $-\alpha$ is the path loss coefficient, and terms $P^{\downarrow}_{B} L_B^{-\alpha}$, $P^{\downarrow}_{Y} L_Y^{-\alpha}$ show the received power from eNB and interfering D2D link, respectively. Here we consider the propagation path loss model as formulated in [16].

$$PL_B[\text{dB}] = 128.1 + 37.6 \log \text{d} \ [\text{Km}] \tag{6}$$

Eq. (6) calculates propagation loss in different communication links, i.e., from D2D tx to eNB or from CUE to eNB and vice versa. Here d is the distance between different entities of the network in Km. i.e., the distance between D2D and CUE or distance between CUE and eNB, and so on.

$$PL_Y[\text{dB}] = 148 + 40 \log \text{d} \ [\text{Km}] \tag{7}$$

Eq. (7) helps to calculate propagation loss between the D2D transmitter and the D2D receiver. Here d is the distance between D2D transmitter and receiver in Km. SINR in downlink transmission at CUE can be formulated as

$$\gamma_X^{\downarrow} = \frac{P_B^{\downarrow} \cdot G_{B,X}}{\sum_1^N \omega P_Y^{\downarrow} \cdot G_{Y,X} + \mathrm{No}} \tag{8}$$

Here $\omega \in [0, 1]$, the value of ω will be one if the D2D pair use the same resources with its CUE; otherwise, the value of ω will be 0. No represent system noise. In uplink (UL), SINR at eNB can be formulated as:

$$\gamma_B^{\uparrow} = \frac{P_X^{\uparrow} \cdot G_{X,B}}{\sum_1^N \omega P_Y^{\uparrow} \cdot G_{Y,B} + \mathrm{No}} \tag{9}$$

In Eq. (9) $P_X^{\uparrow}$, $P_Y^{\uparrow}$ represents transmit power of CUE and interfering transmitted signal power of D2D, respectively. $G_{X,B}$, $G_{Y,B}$ denote channel gain between CUE to eNB and interfering channel gain between D2D pair to eNB respectively in UL.

3 Proposed Power Control Schemes

Proper power control can play a vital role in minimizing interference between different network entities in uplink and downlink, and the improvement of network performance can be achieved. In this work, power control is applied to both sides, i.e., cellular network and D2D communication. To minimize interference, the transmitted power of the desired transmitter, i.e., (eNB, D2D Tx) can be adjusted according to the current situation. Let us suppose first we consider adjusting the transmit power of eNB. In the case of eNB, the transmit power of eNB can be calculated using Eq. (1). As we can see in Eq. (8) the transmit power of eNB at the time frame of transmission $P_B^{\downarrow}(\mathrm{ti})$ can be adjusted in the next time frame of transmission, producing the dynamic value of transmit power $P_B^{\downarrow}(\mathrm{ti}+1)$. Here we introduce a variable Φ to show the change occurring in the transmitter's power on the next time frame transmission based on a comparison of the estimated value of SINR at the current time frame with the target value of SINR. Another variable Ω is introduced here to show whether a change is positive or negative, or there is no change in transmit power on the next time frame according to the current situation. So, the transmit power of eNB can be written as:

$$P_B^{\downarrow}(\mathrm{ti}+1) = P_B^{\downarrow}(\mathrm{ti}+1) + \Omega\Phi \tag{10}$$

The values of Ω can be determined according to the following conditions:

$$\begin{cases} \mathit{if}\ \ SINR_{est} > SINR_{tar} & \mathit{Value\ of}\ \Omega\ \ -\mathrm{ve} \\ \mathit{if}\ \ SINR_{est} = SINR_{tar} & \mathit{Value\ of}\ \Omega\ \ 0 \\ \mathit{if}\ \ SINR_{est} < SINR_{tar} & \mathit{Value\ of}\ \Omega\ \ +\mathrm{ve} \end{cases} \tag{11}$$

Here $SINR_{est}$ and $SINR_{tar}$ denote SINR estimated and SINR target, respectively. In this work, we applied two power control methods, PCS1 (power control scheme 1) and PCS2 (power control scheme 2). The accurate value of Ω and Φ depends on which PCS is applied. Here, it is important to mention another condition that should be meet by PCS is the value of $P_B^{\downarrow}(\mathrm{ti}+1)$

must not be lower than the minimum or should not exceed the maximum value of eNB transmit power values. So, the value of transmit power at the next time frame of transmission using power control methods can be formulated using the following expressions:

$$\begin{cases} if\ \ SINR_{est} > SINR_{tar} & \max\{P_B^{\downarrow *}(\mathrm{ti}+1)\,, \mathrm{Pmin}\} \\ if\ \ SINR_{est} = SINR_{tar} & P_B^{\downarrow *}(\mathrm{ti}+1) \\ if\ \ SINR_{est} < SINR_{tar} & min\{P_B^{\downarrow *}(\mathrm{ti}+1)\,, \mathrm{Pmax}\} \end{cases} \tag{12}$$

Pmax and Pmin represent maximum power and minimum power. Eq. (12) guarantees the output power of PCS within the allowed transmit power limits of D2D Tx and eNB. In the case of power control at D2D, the Eqs. (10)–(12) can be used after changing indices accordingly.

3.1 Power Control Scheme 1 (PCS 1)

Power control scheme 1 is simpler and can be implemented easily. In previous work [17], a similar scheme was used in the femtocell and macro-cell scenario. Here Φ is considered as a simulation parameter, and we use a fixed value of Φ for PSC1. While the value of Ω depends on the current situation as described above, the value of Ω dependent on $SINR_{est}$, and it can be written as expression below:

$$\Omega = \begin{cases} -1 & if\ \ SINR_{est} > SINR_{tar} \\ 0 & if\ \ SINR_{est} = SINR_{tar} \\ +1 & if\ \ SINR_{est} < SINR_{tar} \end{cases} \tag{13}$$

Algorithm for PCS 1

```
1. $X = 1$ (CUE)
2. $Y = 20$ (D2D pairs)
3. $\Phi = 1$ for PCS1
4. $t = t + 1$
5. Calculate transmit power using Eq. (8)
6. if $SINR_{est} > SINR_{tar}$
        $\Omega = -1\ (max\{P_B^{\downarrow *}(ti+1)\,, Pmin)$
7. else if $SINR_{est} = SINR_{tar}$
        $\Omega = 0\ (P_B^{\downarrow *}(ti+1))$
8. else
        $SINR_{est} > SINR_{tar}$
        $\Omega = +1\ (min\{P_B^{\downarrow *}(ti+1)\,, Pmax)$
9. go to step 4
10. end
```

3.2 Power Control Scheme 2 (PCS 2)

In power control scheme 2, different values of Ω and Φ for multiplication is used purposely to decrease or increase transmit powers according to the situation and requirement.

$$\begin{cases} -3 & if\ \ SINR_{est} > SINR_{tar} \\ 0 & if\ \ SINR_{est} = SINR_{tar} \\ +3 & if\ \ SINR_{est} < SINR_{tar} \end{cases} \tag{14}$$

Here the idea of using various values of Ω is intended to control increased or decreased transmit power accordingly in such scenarios where $SINR_{est} > SINR_{tar}$ or $SINR_{est} < SINR_{tar}$. In power control scheme 2, the value of Φ is not fixed and can be calculated based on the mean of interference received power at a specific communication terminal, which is under observation. The Moving mean method is used to formulate mean interfering power. So, the mean interfering power can be formulated as:

$$\bar{I} = \frac{1}{n}\sum_{i=1}^{n} Ii \tag{15}$$

With the help of Eq. (15), we can calculate the value of Φ as:

$$\Phi = |P_B^{\downarrow}(ti) - \bar{I}| \tag{16}$$

Algorithm for PCS 2

```
1. X = 1 (CUE)
2. Y = 20 (D2D pairs)
3. $\Phi = 1$ calculate according to the Eq. (16)
4. t = t + 1
5. Calculate transmit power using Eq. (8)
6. if $SINR_{est} > SINR_{tar}$
       $\Omega = -3\ (max\{P_B^{\downarrow *}(ti+1), Pmin)$
7. else if
       $SINR_{est} = SINR_{tar}$
       $\Omega = 0\ (P_B^{\downarrow *}(ti+1))$
8. else
       $SINR_{est} > SINR_{tar}$
       $\Omega = +3\ (min\{P_B^{\downarrow *}(ti+1), Pmax)$
9. go to step 4
10. end
```

4 Performance Analysis

Simulations were performed to exhibit interference mitigation in a cellular network with induction of D2D communication as an underlay. In a single-cell scenario where eNB is located in the cell's center. In 1 km (1000 m) of the coverage area of a cell, the location of D2D pairs randomizes ten times in each simulation. The value of ϕ is fixed at two dBm for power control scheme 1. In comparison, the value of white noise spectral density used for simulations is −174 dBm. To exhibit interference management in DL and UL, both CUE and D2D pairs are randomly distributed in the cell. Channel bandwidth is set to 15 MHz, and the antenna type is Omni-directional. In this system scenario, we considered the deployment of multiple D2D pairs with a single CUE. First, we consider power control in uplink transmission mode where CUE sends a signal to eNB and D2D transmitter (D2DT) sends a signal to their corresponding receivers (D2DR), and these signals are sent by different transmitters of D2D pairs create interference with CUE signal toward eNB. Tab. 1 denotes the values of the parameters used in this work.

Table 1: Simulation parameters

Parameters	Values
Number of cells	1
Coverage area	1 Km
Maximum separation between D2D devices	40 meters
Max. D2D Tx power	23 dBm
Max. CUE Tx power	23 dBm
Max. eNB Tx power	46 dBm
Frequency band	1900 MHz
Bandwidth per channel	15 MHz
No.	−174 dBm/Hz
Antenna type	Omni-Directional
ϕ for PCS 1	2 dBm

In this scenario, Quality of Service (QoS) parameters like a signal to interference plus noise ratio at receiving end formulated at receiving devices in DL can be used. Similarly, in the second scenario, we considered power control in downlink transmission mode. In this scenario, a single eNB located in the center of the cell sends signals to CUE while D2D transmitters send signals to their corresponding D2D receivers. Here transmission signals from different D2D transmitters will interfere with CUE, and as a resulted network performance can degrade. This scenario uses the same QoS parameters formulated in the downlink scenario and as used in the uplink scenario.

Fig. 4 here exhibits SINR in uplink transmission mode with PCS1, PSC2, and without any PCS. Power control plays a crucial role in managing interference when both cellular and D2D pair are sharing resources. It is clear from Fig. 3 that SINR values are better when we used our proposed schemes, power control scheme 1 (PCS1) and power control scheme 2, compared to SINR values without power control. This shows proper power control helps the efficient utilization of resources, and thus we can achieve all the benefits promised after induction of D2D communication in a conventional cellular network. SINR values are decreasing with the increment in the number of D2D pairs, but still, both proposed schemes performed better. We can see this decreasing trend in all the simulation graphs as the number of D2D pairs increases, but it is clear that the decreasing trend is a bit slower in the case of both proposed schemes. As we can see, when the number of D2D pairs increased to 10, SINR values decreased from 5 to 3.6 dB, 2.2 and

1.7 dB for PCS 1, PCS 2, and PCS, respectively. Thus, it is evident that both proposed schemes outperformed the normal conditions when there is no power control algorithm is applied.

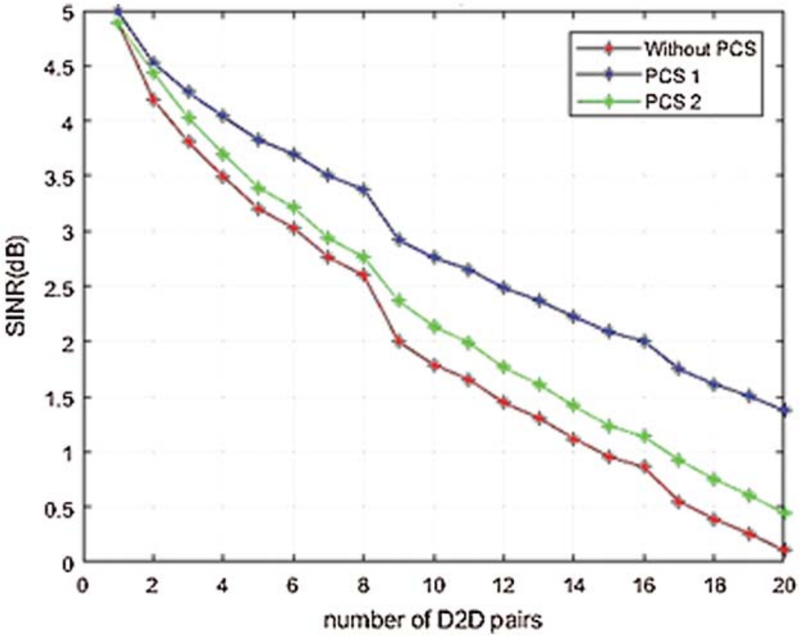

Figure 4: SINR in UL transmission mode

Similarly, Fig. 5 represents SINR values in the downlink transmission mode. Normally there is more signaling overhead as eNB sends control signals in downlink transmission mode, so it is more critical to handle resource sharing in the downlink communication channel. Otherwise, it can degrade network performance drastically. It can be observed that both proposed power control schemes performed well in downlink transmission mode too. Although it can be seen that all three graphs are following the decreasing trend as the number of D2D pairs are increasing but still performance decreasing trend is slower in the case of both proposed schemes. Performance decrement is a bit rapid when there is no power control scheme applied. For example, when the number of D2D pairs increased to 10, SINR values decreased from 25.15 to 25.02 dB, 25 and 24.9 dB for PCS 1, PCS 2, and with PCS, respectively. It indicates the SINR graph curves are less steep with our proposed power control schemes than without using any power control scheme.

As we can note from Fig. 6, the CUE data rate in uplink transmission mode improved up to 0.40% and 0.20% with PCS 1 and PCS 2, respectively. Similarly, in downlink transmission mode, we can note an improvement in the CUE data rate up to 0.48% and 0.35% with PCS1 and PCS2, respectively. Thus, these simulation results showed that both power control schemes can maintain better SINR levels and can bear more no. of D2D pairs with a lesser decrement in CUE data rates in both uplink and downlink transmission modes. As a result, interference mitigation achieved an inefficient way for better performance of our network, and our aim to enhance the data rate of CUE while facilitating more no. of D2D pairs is achieved.

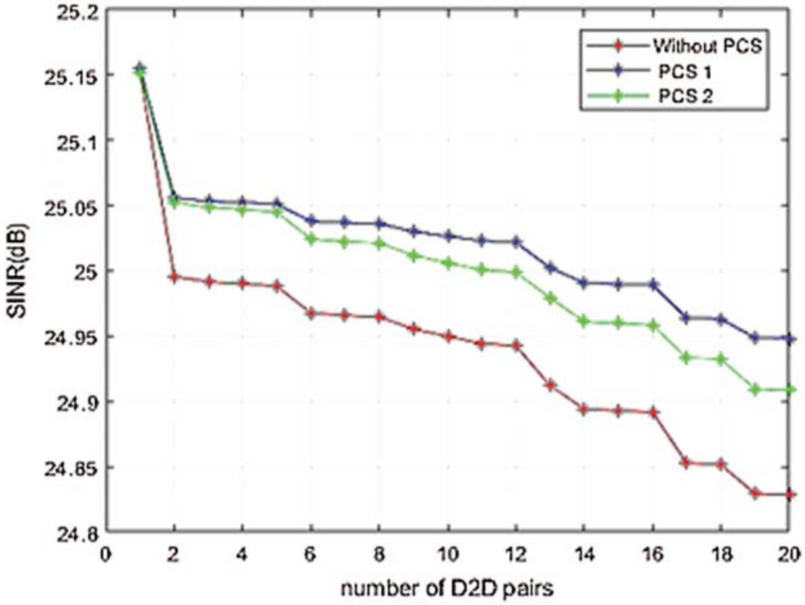

Figure 5: SINR in DL transmission mode

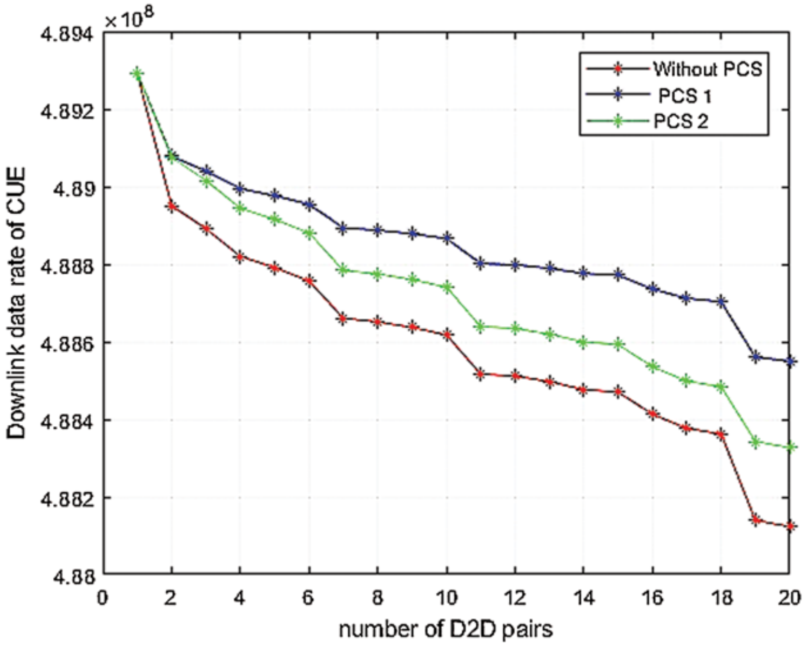

Figure 6: CUE data rate in uplink

Fig. 6 exhibits the data rate of CUE in uplink while the number of D2D pairs is increasing, and it is considered that the maximum 20 pairs of D2D pairs can be induced to share resources. Without any power control scheme, the induction of more and more D2D pairs creates more trouble for CUE in terms of interference results in the decrement of the data rate of CUE. While it can be seen that with the help of proposed power control schemes, the CUE data rate can be maintained to a bit higher level even if no. of D2D pairs is increasing. The simulation graphs show a decreasing trend in all the cases because an increasing number of D2D pairs create more disturbance for CUE. It can be noticed in Fig. 5 that more D2D users can be induced with lesser degradation of network performance with the help of proposed schemes. Thus, it is clear that proper power control can help induce more D2D pairs into the network to share resources, resulting in better performance of the network in terms of enhanced data rate.

In Fig. 7, it can be noticed that proposed power control schemes PCS1 and PCS2 performed well in downlink communication mode while the number of D2D pairs is increasing as compared to when there is no power control scheme deployed in the same scenario. As we can note from Fig. 5, the data rate of CUE in uplink transmission mode improved up to 0.40% and 0.20% with PCS 1 and PCS2, respectively. Similarly, in downlink transmission mode, we can note the CUE data rate improvement up to 0.48% and 0.35% with PCS1 and PCS2, respectively. Thus, these simulation results showed that both power control schemes can maintain better SINR levels and can bear more no. of D2D pairs with a lesser decrement in CUE data rates in both uplink and downlink transmission modes. As a result, interference mitigation is achieved in an efficient way for better performance of the network, and our aim to enhance the data rate of CUE while facilitating more no. of D2D pairs is achieved.

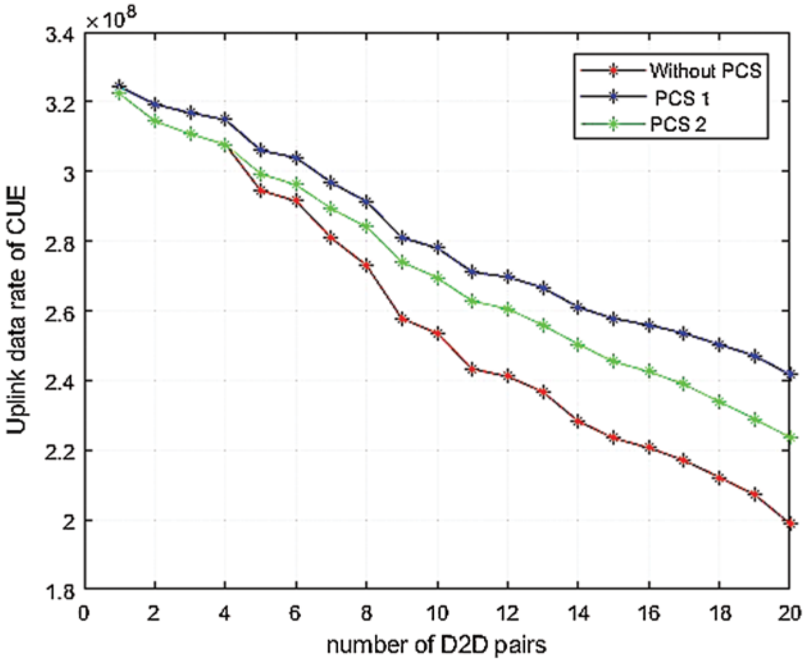

Figure 7: CUE data rate in downlink

5 Conclusion

D2D is one of the promising technologies of next-generation wireless communication networks, and it is critical to deal with the complexities and challenges that the network faces after induction of D2D in conventional cellular networks. In this work, we proposed two power control schemes (PCS1 & PCS2) to mitigate the interference in D2D communication, and simulation results show that both schemes performed well in terms of maintaining SINR levels and bearing induction of more D2D pairs with improved CUE data rates in both communication links. Proper power control can help efficient resource sharing, which results in better performance of the network in terms of better SINR levels and improved data rates. Game theory is an analytical tool that is currently used by many researchers in their work to analyze the rational and irrational behaviors of different network entities for better decision making dynamically. In the future, an extension of this work for further improvement of this work is using game theory, which is helpful in intelligent decision making.

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