A Novel Scheduling Algorithm to Maximize the D2D Spatial Reuse in LTE Networks

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***Abstract*—In order to offload base station (BS) traffic and to enhance efficiency of spectrum, operators can activate many Device-to-Device (D2D) pairs or links in LTE networks. This increases the overall spectral efficiency because the same Resource Blocks (RBs) are used across cellular UEs (CUEs) (*i.e.,* all UEs connected to BS for both C-Plane and D-plane communication) and D2D links (*i.e.,* where the UEs are connected to BS only for C-plane communication). However, significant interference problems can be caused by D2D communications as the same RBs are being shared. In our work, we address this problem by proposing a novel scheduling algorithm, Efficient Scheduling and Power control Algorithm for D2Ds (ESPAD), which reuses the same RBs and tries to maximize the overall network throughput without affecting the CUEs throughput. *ESPAD* algorithm also ensures that Signal to Noise plus Interference Ratio (SINR) for each of the D2D links is maintained above a certain predefined threshold. The aforementioned properties of *ESPAD* algorithm makes sure that the CUEs do not experience very high interference from the D2Ds. It is observed that even when the $SINR_{drop}$ (*i.e.,* maximum permissible drop in SINR of CUEs) is as high as 10 dB, there is no drastic decrease in CUEs throughput (only 3.78%). We also compare our algorithm against other algorithms and show that D2D throughput improves drastically without undermining CUEs throughput.**

I. Introduction

Currently operators are experiencing lots of traffic especially for file exchange within a single base station (BS) [1], [2]. This heavily loads the BS and drains battery of the UEs who are located at the cell-edge. One solution to offload the BS and boost the spectral efficiency at the same time is by enabling/activating more D2D communication [3], [4] within the same BS. 3GPP standardized D2D communication in Release 12 [5] for proximity-based services. Some of the research challenges in D2D include location estimation, power control, interference management, resource allocation, mobility management, security, and multi-hop D2D. In this work, the terms BS, Macro and eNodeB are used interchangeably. Fig. 1 shows a typical example of traditional cellular D2D communication. In traditional cellular networks, during communication between two users (devices), both control plane (C-Plane) and data plane (D-Plane) are under the control of BSs (for example: UE3 as shown in Fig. 1). In D2D communication, only C-Plane is handled by BSs while data exchange between two devices is done directly without involving BSs (for example: UE1 & UE2 are the D2D pair as shown in Fig. 1). Due to its shorter distance, D2Ds have the potential to reuse the same radio resource across different D2D pairs. In our work, we propose an ESPAD (Efficient Scheduling and Power Control Algorithm for D2Ds) which maximizes the reuse of spectrum in LTE-A networks.

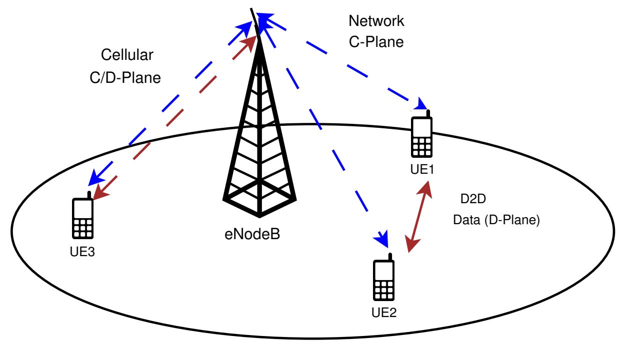

Fig. 1. Typical example of traditional cellular and D2D communication

The rest of the paper is organized as follows. Section II explains the recent related work. Section III presents the system model with assumptions and proposed *ESPAD* algorithm. Section IV describes the experimental setup and numerical results. Finally, Section V presents conclusions and directions for future work.

II. Related Work

In D2D communications without relays, two UEs communicate with each other instantly, without intermediate nodes, by transmitting in the D-Plane. In [6], the authors proposed an allocation scheme in which RBs are shared between D2D pairs and cellular UEs (CUEs). A dynamic and quick resource scheduling in heterogeneous networks or small cells was proposed in [7] to support D2D and in [8], a Phantom Cell concept (Control and User plane split) was used with D2D links to reduce traffic load. In [9], authors proposed a D2D based relay concept in LTE HetNet system to offload the users traffic in the interference zone region.

In [10], authors explored a method of offloading cellular data onto direct connections between CUEs who are in close proximity. In their system model, they combine a cellular network in licensed band with a D2D network in unlicensed band. CUEs are connected with BSs uninterruptedly and manage their direct connections in unlicensed spectrum using this connectivity. They also validate that assisted offloading of CUE sessions onto the D2D links enhances the extent of spatial reuse and lowers the effect of interference.

The authors in [11] consider a scenario having both Uplink (UL) and Downlink (DL) traffic for UEs and D2Ds with the assumption that they use different RBs. RBs allocated to D2D can be reused multiple times. They propose a semi-distributed algorithm and use this to solve the RB allocation problem. The division of RBs between D2D and legacy UEs as well as allocation of RBs to each D2D is centralized whereas the D2Ds assign transmission power to themselves in a distributed manner. One drawback is with the assumption that UEs and D2D link use different RBs and another is with the presumption that there are adequate RBs to fulfil the resource requests of all the D2D links. While solving the RB allocation problem, the authors have also assumed that the D2D links are transmitting with maximum power.

In [12], authors have considered D2D transmissions with dedicated RBs as well as D2D transmissions with RBs reuse. They proposed a heuristic mode selection and resource allocation algorithm. A SINR target is set and the transmit power is adjusted to meet the SINR target. They formulated a resource allocation problem with an objective to maximize the overall spectral efficiency assuming fixed transmission powers for each user. Here also it was presumed that there are abundant RBs to meet the resource requests of all D2D links. Similarly in [13], the authors have considered mode selection and power control of D2D links in a centralized as well as distributed manner. But the above papers have not considered time domain scheduling of RBs. The authors in [14] have considered a D2D environment which is dense, *i.e.,* the number of D2D UEs (DUEs) are greater than the number of CUEs. The channels allocated to CUEs and their transmission powers are fixed while D2Ds share the channel with CUEs. They modeled a Stackelberg game wherein they group a CUE and a DUE forming a leader-follower pair. The proposed method cannot be extended for sharing DL resources as during the downlink period, the D2D receivers experience high interference from the eNodeB. Another flaw with this approach is that one channel is allowed to be used by only one CUE and one DUE.

In this paper, we design an efficient D2D scheduling algorithm (*ESPAD*) which maximizes the count of active D2D pairs by reusing same RBs. We maintain the SINR for each of the D2D links above a certain threshold. The CUEs are scheduled through any of the legacy scheduling algorithms (Round Robin / Proportional Fair / etc). We also ensure that drop in SINR of CUEs on account of forming D2D pairs does not fall beyond a fixed constant.

III. Proposed work

In this section, we present the system model and the assumptions, and then propose ESPAD for efficient time domain scheduling of D2Ds.

A. System Model

We consider a system consisting of one eNodeB serving a set C of CUEs as shown in Fig. 2. Since there is only one cell in the system, the interference from neighboring cells are not considered. The eNodeB helps in establishing a maximum of D D2D links (*i.e.,* $2|D|$ D2D UEs). Due to heavy interference, all D2D links may not transmit data in a given Transmission Time Interval (TTI). Here, TTI refers to the scheduling interval. In LTE network, each frame is divided into ten sub-frames. Each sub-frame has 2 slots with a total duration of 1 ms (*i.e., TTI*), making 20 slots in a frame. In each sub-frame, the scheduler running inside the BS allocates radio resources to UEs in terms of RBs. RB is the smallest unit of radio resources which can be allocated to an UE. If the scheduler allocates one RB to an UE, it means that 180 KHz bandwidth has been allocated to that UE for the next TTI. Each RB of 180 KHz bandwidth will contain 12 sub-carriers, each with 7 OFDM symbols. Hence, it constitutes 84 resource elements. Depending upon the modulation and coding schemes (QPSK, 16-QAM, 64-QAM), each symbol or resource element in the RB carries 2, 4 or 6 bits per symbol, respectively.

D2Ds which transmit in a given TTI are called as active D2Ds. In order to boost the system capacity, we have considered the eNodeBs and D2Ds to operate on the same frequency band (*i.e.,* reuse one). In every TTI, when a CUE is receiving downlink data from the eNodeB, it may experience interference from the transmitter of D2D communication (dotted blue line as shown in Fig. 2). On a similar note, when the receiver of D2D communication receive data from its corresponding transmitter, it may experience interference from the eNodeB, in addition to which there is also co-tier interference from other D2D transmitters (dotted green line as shown in Fig. 2).

The SINR of CUE c is given by:

$$SINR_c = \frac{g_{BS \to c} P_{BS}}{N + \sum_{i \in D'} g_{i \to c} P_i} \tag{1}$$

where $g_{BS \to c}$ and $g_{i \to c}$ are the channel gains from BS to cellular user c and channel gain from the transmitter of D2D link i to CUE c, respectively, P_{BS} is the transmission power of BS, N is the overall noise in the system, P_i is the transmission power of D2D i, and $D^{'} \subseteq D$ is the set of all D2D links which are scheduled in a TTI.

The SINR of receiver d^r in D2D link d is given by:

$$SINR_{d^r} = \frac{g_{d^t \to d^r} P_d}{N + g_{BS \to d^r} P_{BS} + \sum_{i \in D'/d} g_{i^t \to d^r} P_i} \tag{2}$$

where $g_{d^t \to d^r}$ and $g_{BS \to d^r}$ are the channel gain from transmitter to receiver of D2D link d and channel gain from BS to the receiver of d, respectively, $\sum_{i \in D'/d} g_{i^t \to d^r} P_i$ represents the interference from other active D2Ds in a TTI and P_d is the transmission power of D2D link d.

We also assume that all the users (CUEs and D2Ds) have infinitely backlogged data. Hence, only one CUE and multiple D2Ds are scheduled in every TTI. In order to select a CUE in each TTI, any of the existing user scheduling

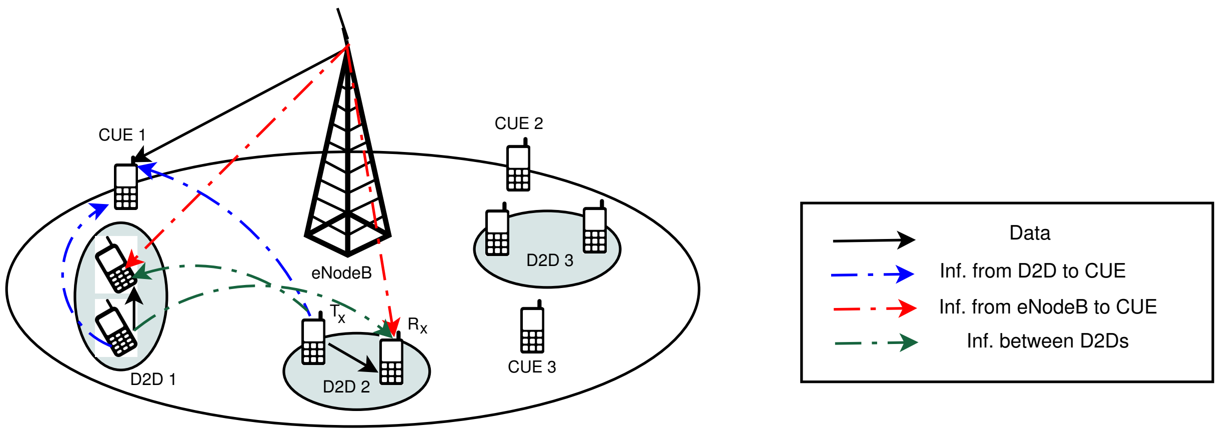

Fig. 2. D2D System Architecture

algorithms (such as Round robin and Proportional fair) can be used. The system throughput is a measure of the system performance which changes with respect to the system noise, the transmitting power of the source and the interference. Since computing the system throughput in every TTI is cumbersome, we define an utility function derived from the system throughput. To increase the network throughput and to ensure some level of throughput fairness to all D2D links, the objective of *ESPAD* in each TTI is to maximize the logarithmic sum of the average rates of all the D2D links as shown in (3).

$$Maximize \sum_{i \in D} log(\bar{R}_i(t)) \quad (3)$$

where $\bar{R}_i(t)$ is the average achieved data rate of D2D pair i till time slot t. The value of $R_i(t)$ depends on the decision of the scheduler in time slot t and is updated as [15],

$$\bar{R}_i(t) = \begin{cases} (1-\beta)\bar{R}_i(t-1) + \beta\hat{R}_i(t), & \text{if i is scheduled in timeslot t} \\ (1-\beta)\bar{R}_i(t-1), & \text{otherwise} \end{cases} \quad (4)$$

where β is a weighing constant which varies between 0 and 1, and $\hat{R}_i(t)$ is the instantaneous data rate of D2D i that can be achieved in TTI t and is calculated as shown in (5).

$$\hat{R}_i(t) = B \times SE(SINR_i) \quad (5)$$

where B is the bandwidth, $SINR_i$ is the SINR of D2D i and $SE(SINR_i)$ is the spectral efficiency corresponding to $SINR_i$ and it can be calculated using LTE CQI table [16]. Now, we present *ESPAD* algorithm for selection of D2D links and power control.

B. ESPAD Algorithm

The proposed algorithm ensures the following:

1) Drop in SINR of CUEs on account of forming D2D pairs does not fall beyond $SINR_{drop}$. *i.e.,* $SINR_c \geq SNR_u - SINR_{drop}$. Here, $SINR_c$ is SINR of CUEs after considering the D2D interference, SNR_u is the signal to noise ratio of CUE c from BS without considering interference and $SINR_{drop}$ is the maximum permissible drop in SINR of CUEs.
2) SINR for each of the D2D links is also maintained above a certain threshold ($SINR_D^{th}$).

A layer wise approach is followed to select D2D pairs in every TTI. Set W keeps track of selected D2D pairs in each layer and P_D keeps track of their corresponding transmission powers. In every layer, a D2D pair which is not already included in W is selected and its transmission power is set as given in Algorithm 1. For instance, if the D2Ds for the first k layers have been selected and updated in W, to find a D2D pair for $(k+1)^{th}$ layer, we choose a new D2D pair which is not already selected and find the optimal power between the minimum required transmission power (P_i^{min}) and the maximum permitted transmission power (P_i^{max}) so that the overall utility is maximized. P_i^{min} and P_i^{max} are calculated as follows:

$$P_i^{min} = \frac{SINR_D^{th} * (N + \sum_{j \in W} g_{j^t \to i^r} P_j)}{g_{i^t \to i^r}} \quad (6)$$

P_i^{min} is the minimum required transmission power to ensure that $SINR_D^{th}$ for D2D pair i is guaranteed. P_i^{max} is calculated by taking the following into consideration. The addition of a new D2D link in layer $(k+1)$ can lead to SINR degradation of selected D2D links in the first k layers due to co-tier interference. $P_{i,k}^{max}$ is calculated by ensuring that the threshold SINR of selected D2D links in the first k layers is still maintained and is given by:

$$P_{i,k}^{max} = \frac{g_{a^t \to a^r} P_a - SINR_D^{th} * (N + \sum_{j \in W/a} g_{j^t \to a^r} P_j + g_{BS \to a^r} P_{BS})}{SINR_D^{th} * g_{i^t \to i^r}} \quad (7)$$

where, a = k^{th} element of W, $1 \leq k \leq |W|$
$P_{i,|W|+1}^{max}$ is an upper limit ensuring that selection of new D2D link in $(k+1)^{th}$ layer does not lead to degradation in SINRs of CUEs and is still maintained above $SINR_u^{th}$. $SINR_u^{th}$ is layer dependent (line 3 of Algorithm 1) and this

Algorithm 1 ESPAD Algorithm

Input : D (Set of all D2D links), $SINR_{drop}$ (Maximum permissible drop in SINR of CUEs), $\bar{R}$ (Average achieved data rate of D2D pair), β (Weighing constant which varies between 0 and 1), $divisions$ (Constant which decides the interval with which power varies between P^i_{min} and P^i_{max}).
Output : W (Set consisting of selected D2D pairs in each layer)

Initialization ();
$\{Inf = 10^{10}$,W= ϕ,P= $\phi\}$

$maxUtility^0$ **= -**Inf {max utility value in each layer}
for k=1 to $|D|$ **do**
  ($SINR^{th}_u$ = SNR_u - $SINR^{layer}_{drop}$);
  if ($SINR^{th}_u < SNR_u$ - $SINR_{drop}$) **then**
    break;
  end if
  for i=1 to $|D|$ **do**
    if i $\notin W$ **then**
      Calculate P^i_{min}, P^i_{max} using equations (6) to (9).
      if ($P^i_{max} > P^i_{min}$) **then**
        O(i) $\leftarrow$ utility($W \cup \{i\}$, $P \cup \{P^i_{max}\}$, D)
      else
        O(i) $\leftarrow$ - Inf; {Virtually large value}
      end if
    else
      O(i) $\leftarrow$ - Inf; {D2D i already selected}
    end if
  end for
  if max(O) $\leq$ - Inf **then**
    break;
  end if
  $i^* \leftarrow$ argmax(O);
  $\triangle \leftarrow \frac{(P^i_{max} - P^i_{min})}{divisions}$;
  $P^s \leftarrow \{P^{i*}_{min}, P^{i*}_{min} + \triangle, P^{i*}_{min} + 2\triangle, \ldots, \ldots, P^{i*}_{max} - \triangle, P^{i*}_{max}\}$
  $P^* \leftarrow argmax(utility(W \cup i^*, P \cup P^s, D))$
  $maxUtility^k \leftarrow utility(W \cup i^*, P \cup P^*, D)$
  if ($maxUtility^k \geq maxUtility^{k-1}$) **then**
    $W \leftarrow W \cup i^*$;
    $P \leftarrow P \cup P^*$;
    Calculate $SINR_u$ using equation (1).
  end if
  if ($maxUtility^k < maxUtility^{k-1}$) **then**
    break;
  end if
end for
Update $\bar{R}$ using equation (4).

assures that SINR of CUEs does not drop by the maximum permissible drop ($SINR_{drop}$) in the first layer itself.

$P^{max}_{i,|W|+1}$ is given by:

Algorithm 2 Utility Function

Input : β, P, W, D
Output : Utility

for w=1 to $|W|$ **do**
  Calculate $SINR_w(t)$ using equation (2)
  Calculate $\hat{R}_w(t)$ by equation (5), using $SINR_w(t)$
end for
for i=1 to $|D|$ **do**
  if (i ϵ W) **then**
    $\bar{R}_i(t) \leftarrow (1-\beta)\bar{R}_i(t-1) + \beta\hat{R}_i(t)$;
  else
    $\bar{R}_i(t) \leftarrow (1-\beta)\bar{R}_i(t-1)$;
  end if
end for
Utility = $\sum_{i=1}^{|D|} log(\bar{R}_i(t))$;
return Utility;

$$P^{max}_{i,|W|+1} = \frac{g_{BS\to u}P_{BS} - SINR^{th}_u * (N + \sum_{j\in W} g_{j^t\to u}P_j)}{SINR^{th}_u * g_{i^t\to u}} \tag{8}$$

Let P^{max}_D is the maximum permitted transmission power of D2D link.

$$P^{max}_{i,|W|+2} = P^{max}_D \tag{9}$$

P^{max}_i is given by the minimum of above $|W| + 2$ equations.

Every D2D link i is included in W and then the utility is calculated using Algorithm 2 assuming that i operates under P^{max}_i. The D2D link i which maximizes the utility is selected in $(k+1)^{th}$ layer. The overall utility can be enhanced by adjusting the transmission power of currently chosen D2D link i. In order to estimate the optimal power of the chosen D2D link i, we check the utility value for transmission power values from P^{min}_i to P^{max}_i in intervals of $\triangle$ (divisions). Transmission power of D2D is fixed with that value at which utility is maximum. If the addition of new D2D links leads to increase in overall utility, then W and P are updated. We stop at the point when addition of new D2D does not boost overall utility or when the allowable $SINR_{drop}$ for CUE is exceeded. The running time complexity of *ESPAD* algorithm is:

$$O(|D| + \Delta) \tag{10}$$

IV. Experimentation and Results

The system model which is described in Section III-A is simulated using MATLAB. We considered a system having one BS which is 30 m high and the coverage of the BS is 500 m. Other simulation parameters are shown in Table I.

Fig. 3 shows the variation of CUEs throughput as we vary the $SINR_{drop}$ in Algorithm 1. This $SINR_{drop}$ is the

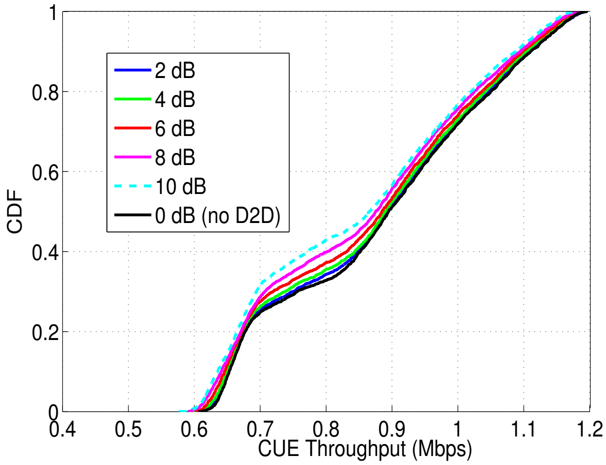

Fig. 3. CDF of CUE throughputs in ESPAD

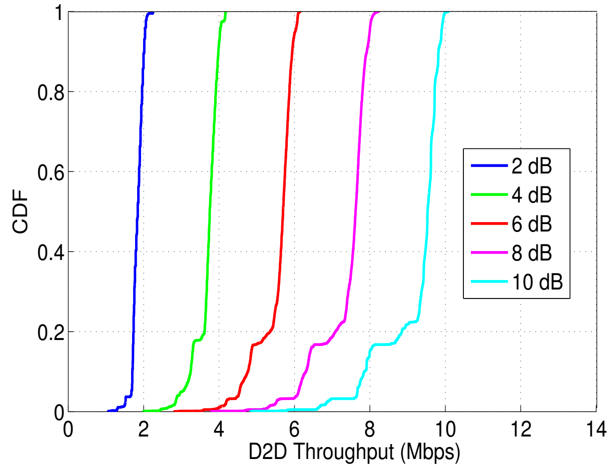

Fig. 4. CDF of D2D throughputs in ESPAD

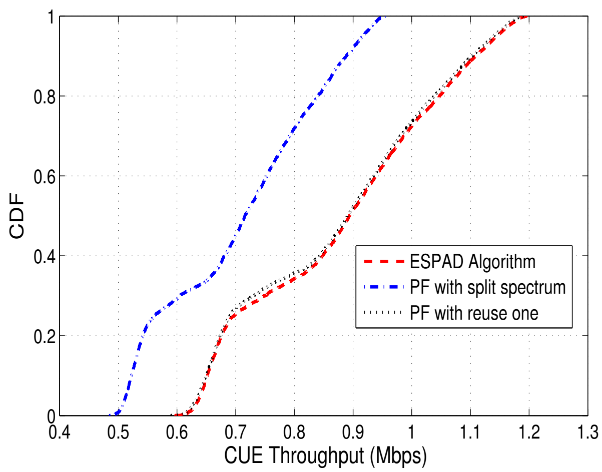

Fig. 5. Comparison of CUEs throughputs

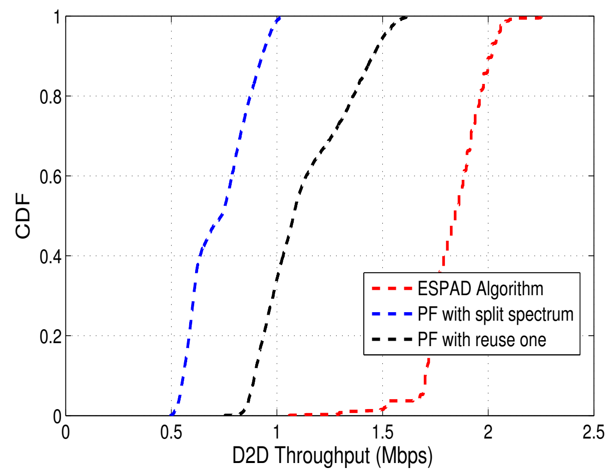

Fig. 6. Comparison of D2Ds throughputs

TABLE I
SIMULATION PARAMETERS

Parameter	Value
P_D^{max}	20 dBm
P_{BS}	46 dBm
Number of CUEs	50
Number of D2D links	50
Bandwidth	10 MHZ (*i.e.,* 50 RB)
No. of seeds	50
UE deployment	Random
Traffic	Downlink
LTE Mode	FDD
$SINR_D^{th}$	5 dB
Path loss model for cellular link	$128.1 + 37.6log10(d[km])$
Path loss model for D2D link	$148 + 40log10(d[km])$

overall permitted drop of CUEs SINR in each TTI. When the drop is 0 dB, there are no active D2D pairs in the experiment and hence the throughput of CUEs is the maximum. We considered 0 dB (drop) as the best case to compare the efficiency of *ESPAD*. As the $SINR_{drop}$ increases, the count of active D2D pairs increases and hence CUEs throughput decreases due to interference. As the $SINR_{drop}$ varies from 2 dB to 10 dB in intervals of 2 dB, CUEs throughput decreases by 0.35%, 0.91%, 1.67%, 2.71%, 3.78%, respectively. Even in the case when $SINR_{drop}$ is as high as 10 dB, there is no drastic decrease in CUEs throughput (only 3.78%).

Fig. 4 shows the variation of D2D links throughput as the $SINR_{drop}$ increased from 2 dB to 10 dB in intervals of 2 dB. It can be seen that as the $SINR_{drop}$ increases, the D2D throughput also increases and it reaches the maximum when the drop is 10 dB. This trend is observed because the number of active D2D pairs increases with increase in $SINR_{drop}$.

The exact values of average D2D transmitter power and CUE throughput difference (the reduction in CUEs throughput due to the activation of D2Ds) are given in Table II. The negative value of CUE throughput difference indicates decrease in CUEs throughput due to interference from the active D2D pairs. As the $SINR_{drop}$ increases, the average D2D transmission power decreases. This ensures that the CUEs do not experience very high interference from the

TABLE II
VARIATION OF AVERAGE TRANSMISSON POWER AND REDUCTION IN CUE THROUGHPUT WITH $SINR_{drop}$

SINR drop	**2 dB**	**4 dB**	**6 dB**	**8 dB**	**10 dB**
Average D2D transmitter power	0.089351	0.0787	0.073741	0.070157	0.06857
CUE throughput difference	-0.354192	-0.907012	-1.671779	-2.716093	-3.782880

D2Ds. The effectiveness of the proposed algorithm is evident from Table II. Even when the $SINR_{drop}$ is as high as 10 dB, there is not drastic decrease in CUEs throughput (only 3.78%).

Further, we compare the performance of proposed *ESPAD* algorithm with two different base scheduling algorithms defined below.

- *Proportional Fair (PF) with Split Resource:* In order to avoid the cross-tier interference between the CUEs and D2D, we divided the radio spectrum separately for CUEs and D2Ds. Traditional PF scheduling algorithm takes care of allocating the RBs for respective users.
- *PF with Reuse One:* In this algorithm, we permit a D2D pair to reuse the same RB which is used by the CUE exactly one time.

Fig. 5 shows the CUE throughputs for different scheduling algorithms. When compared to *PF with Split Resource*, the CUE throughput in our algorithm has improved by 24.56 %. On the other hand, we can observe that *PF with Reuse One* is very close to our *ESPAD* algorithm. It is because we allow the D2D pairs to reuse the same RB used by the CUE. Fig. 6 shows the D2D throughputs for different scheduling algorithms. When compared to *PF with Split Resource*, the D2D throughput in our algorithm has improved by 152.38 %. Similarly, the D2D throughput in our algorithm shows 62.29 % improvement over that in *PF with Reuse One* because of limited RB reuse in the latter algorithm.

V. CONCLUSIONS AND FUTURE WORK

In this work, we proposed *ESPAD*, a novel scheduling algorithm to enable multiple D2D links which reuse the same RBs used by the CUEs in LTE networks. Simulation results showed that D2D throughputs can be increased drastically without compromising much on the CUE throughput. We also compared *ESPAD* with two other algorithms and observed that *ESPAD* gives large improvements in D2D throughputs when compared to those algorithms.

In future, we plan to consider the small cell (HetNet) deployment with mobility scenario where the users are mobile and study its performance of our proposed *ESPAD* algorithm in such mobility scenarios also.

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