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

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Outline

1. Introduction to LTE HetNets
2. Related Work
3. System Model and Proposed Work
4. Experimentation and Results
5. Conclusions and Future Work

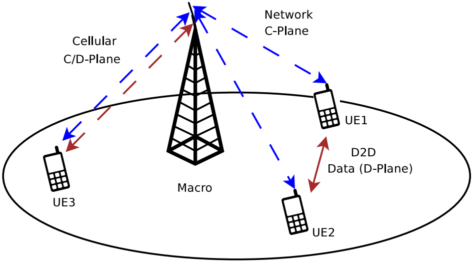
Motivation

- Tremendous increase in cellular traffic due to the availability of wide range of devices: smart phones, tablets etc.
- Mobile Data is expected to register a growth of almost 11 times in the next 4 years, reaching 18 exa-bytes per month by 2018.
- Mobile video will account for 69% of all mobile data by 2018, up by about 53% in 2013.

⇒ Bandwidth demand is increasing
⇒ Hunger for higher data rates

Device-to-Device Communication

- D2D is one of the most promising and challenging aspects towards 5G.
- In D2D, UEs directly exchange data with each other unlike in traditional cellular communication.
- Base station controls and optimizes the use of shared radio resources for cellular and D2D sessions.
- D2D is standardized by 3GPP in Release-12 for proximity-based services.
- Some of the D2D challenges include interference management, resource allocation, power control, mobility management, security, billing and location estimation.



Architecture of traditional cellular and D2D communication.

Related Work

- The authors in [1] considered 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 proposed 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.

Related Work (contd . . .)

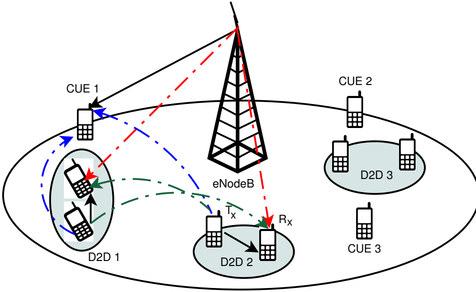
- In [2] authors have considered D2D transmissions with dedicated RBs as well as D2D transmissions with RBs reuse. They proposed a heuristic mode selection and resource allocation algorithm.
- A SINR target is set and the transmit power is adjusted to meet the SINR target. They formulated a resource 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.

Our work

- 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 cellular users (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.

System Model

- We consider a system consisting of one eNodeB serving a set C of CUEs.
- 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).
- 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).



D2D System Architecture

Notation used in our paper

Notation

Symbol	Meaning
$SINR_c$	SINR of CUE c
$SINR_{d^r}$	SINR of receiver d^r of D2D link d
$g_{BS \to c}$	Channel gain from BS to c
$g_{i \to c}$	Channel gain from the transmitter of D2D link i to CUE c
P_{BS}	Transmission power of BS
N	Overall noise in the system
P_i	Tranmission power of D2D i
$D^{'} \subseteq D$	Set of all D2D links which are scheduled in a TTI.
$g_{d^t \to d^r}$	Channel gain from transmitter to receiver of D2D link d
$g_{BS \to d^r}$	Channel gain from BS to the receiver of d
P_d	Transmission power of D2D link d
$\sum_{i \in D'/d} g_{i^t \to d^r} P_i$	Interference from other active D2Ds in a TTI

System Model (contd . . .)

The SINR of CUE c is given by:

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

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

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

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.

Throughput Maximization

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).

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

where $\bar{R}_i(t)$ is the average achieved data rate of D2D pair i till time slot t.

Allocation of Spectrum (Scheduling)

The value of $R_i(t)$ depends on the decision of the scheduler in time slot t and is updated as:

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

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.

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 ($SINR_D^{th}$).

ESPAD Algorithm contd. ...

Input: D, SINR$_{drop}$, $\bar{R}, \beta, divisions, P^i_{min}, P^i_{max}$
Output: W

for $k = 1 : |D|$ **do**
    $SINR^{th}_u = SNR_u$ - $SINR^{layer}_{drop}$;
    if $(SINR^{th}_u < SNR_u$ - $SINR_{drop})$ **then**
        break;
    end
    for $i = 1 : |D|$ **do**
        if $(i \notin W)$ **then**
            Calculate P^i_{min}, P^i_{max} using equations 6-9 (Refer paper)
            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
        else
            O(i) $\leftarrow$ - Inf; D2D i already selected
        end
    end
    $i^* \leftarrow$ 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 $SINR_u$;
    end
end

Utility Function

Input: β, P, W, D
Output: Utility

for $w = 1 : |W|$ **do**
  Calculate $SINR_w$ (t) using equation (2)
  Calculate R_w (t) by using equation (5), using $SINR_w$ (t)
end
for $i = 1 : |D|$ **do**
  if $(i \epsilon W)$ **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
end
Utility $= \sum_{i=1}^{|D|} log(\bar{R}_i(t));$
return Utility;

ESPAD Algorithm contd. . . .

- 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.
- The running time complexity of *ESPAD* algorithm is:

$$O(|D| + \Delta) \tag{6}$$

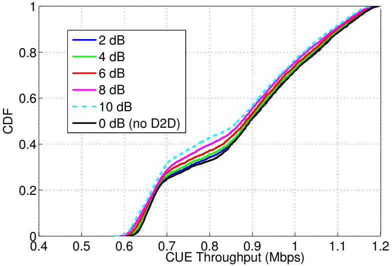
Experimentation and Results

- The above described system model 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 the below table.

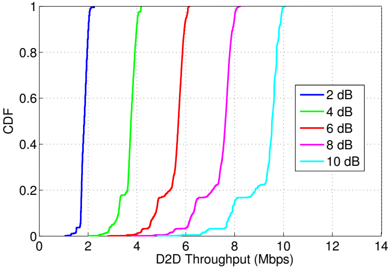
Simulation parameters

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	$148 + 40log10(d[km])$

Throughputs



CDF of CUE throughputs in ESPAD

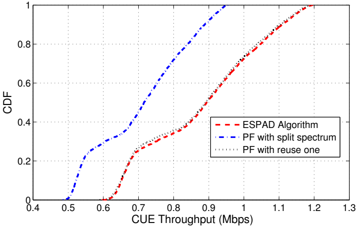


CDF of D2D throughputs in ESPAD

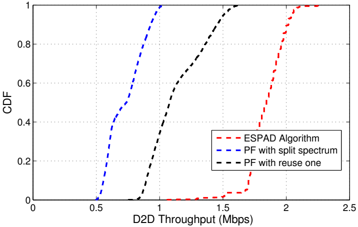
Notes

1. $SINR_{drop}$ is the overall permitted drop of CUEs SINR in each TTI. 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%).
2. 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 $SINR_{drop}$.

Comparison Throughputs



Comparison of CUEs throughputs



Comparison of D2Ds throughputs

Notes

1. 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.
2. 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.

Conclusions and Future Work

- We proposed ESPAD, a novel scheduling algorithm to schedule multiple D2Ds which reuse the same RBs used by the CUEs in a single TTI.
- Simulation results showed that D2D throughput can be increased drastically without compromising much on the CUEs throughput.
- We also compared ESPAD algorithm with two other algorithms and observed that ESPAD algorithm gives large improvements in D2D throughput.
- In future, we plan to consider the small cell (HetNet) deployment with mobility scenario where the users are mobile and validate our proposed ESPAD algorithm in such mobility scenarios also.

Related Work papers

[1] - D. H. Lee, K. W. Choi, W. S. Jeon, and D. G. Jeong, Resource allocation scheme for device-to-device communication for maximizing spatial reuse, in *IEEE WCNC, 2013*, pp. 112117, 2013.

[2] - M. Belleschi, G. Fodor, D. Penda, M. Johansson, and A. Abrardo, A joint power control and resource allocation algorithm for d2d communications, *KTH, School of Electrical Engineering (EES), Automatic Control, Tech. Rep, 2012*.

Thank You !!!