Traffic Engineering Project Report

On

Resource Scheduling in LTE

Submitted By:

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1. Objectives:

- Provide service to all users.
- Minimize the interference between users in a LTE network infrastructure.
- Make fare use of the resources.

2. Introduction:

LTE (Long Term Evaluation) is implemented in any network for providing flexible bandwidth allocation and high data rate deploying resource blocks (rb) and distributing among users supporting cellular, device-to-device (d2d) or other modes of communication. Cellular communication is a structure for communicating using mobile phones through an access point or base station [1] and d2d provides the users with the facility of communicating directly with each other in a close proximity without the help of any base station [2]. Due to the scarcity of frequency spectrum the available resource blocks in LTE infrastructure they are shared between users. This sharing of resource blocks create interference among users at the receiver. This interference can be mitigated by transmit power control, antenna pattern adjustment, resource scheduling or proper coding scheme implementation. In this project we use resource blocks scheduling to reduce interference in LTE network infrastructure.

3. Problem Statement:

In the given problem, there is an LTE network with m number of resource blocks and n number of users (cellular and d2d) where $m < n$. All the users should have at least one resource block, two cellular users cannot share the same resource blocks but two d2d users or 1 cellular and 1 d2d pair can share it. We have to create an infrastructure where every user gets a single or shared rb. Here only three interference is considered:

- Interference at base station due to d2d transmitters
- Interference at d2d receiver due to cellular transmitter
- Interference at d2d receiver due to other d2d transmitter

We have to optimize the network minimizing the total interference.

4. Theory:

Due to lesser amount of available frequency spectrum, number of resource blocks are always lower than the total users in a network so sharing the resource blocks is suggested. When two users have different destination, they face least amount of interference due to each other, again distance among receiver and transmitter play a role in interference – with the increasing distance the amount of interference reduced. As d2d transmit data directly with each other without the help of base station, so they can be placed to the already allocated rb to the cellular users. The d2d pair with longer distance from the cellular user can be placed together, so they will face least amount of interference.

5. System Model:

In this given problem only uplink communication is considered. Cellular users transmit to base station in uplink and d2d transmitters transmit to d2d receivers in uplink. Here is one base station for the whole network, base station and d2d receivers will act as receivers and cellular users and d2d transmitters will act as transmitters. Two cellular users placed in same RB transmitting to the same BS will create the highest amount of interference, so they are not placed together. According to figure 1, if cellular user and d2d pair share same RB, BS experiences interference while getting signal from cellular user due to the transmitter of d2d pair and receiver of d2d pair will receive interference due to cellular user while getting signal from d2d transmitter. The receiver of one d2d receives interference from transmitter of another d2d pair if two d2d pairs share same RB.

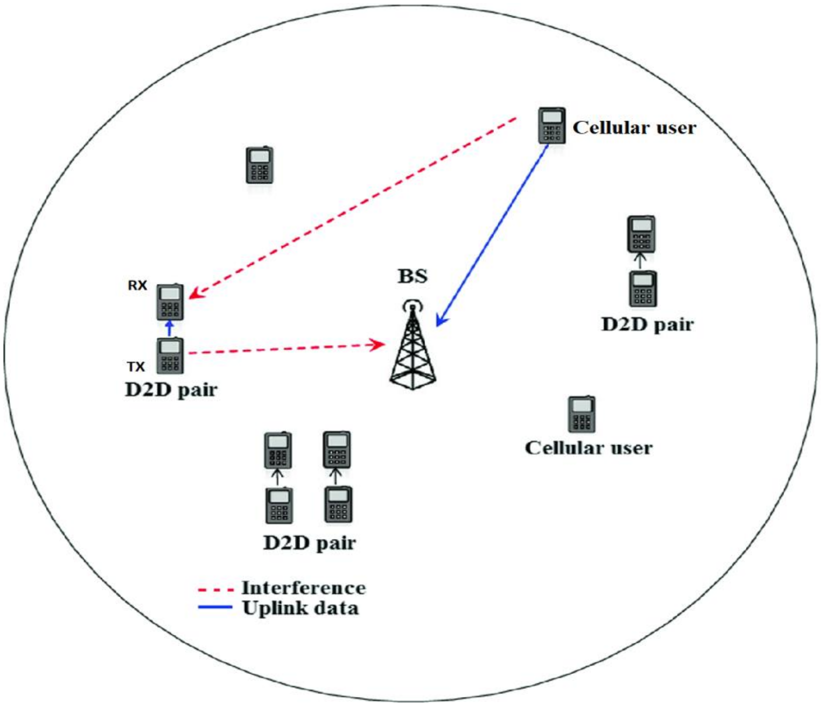


Figure 1: Uplink communication scenario for cellular user and d2d user with interference [3]

6. System Design:

For mitigating the interference users situated at longer distance should be placed in same resource block. The interference can be calculated from the free space path loss and received power:

$$FSPL = 20 * \log_{10}(d) + 20 * \log_{10}(f) + 20 * \log_{10}\left(\frac{4\pi}{c}\right)$$

Here,

d = distance between transmitter and receiver of interfering entity

f = frequency

c = speed of light

From the above equation we will get the value of FSPL in dB. The transmitting power is mentioned in the task as 26 dBm. So, the receive power can be calculated from the following equation:

$$P_r = 26 - FSPL$$

6.1 Objective Function:

The main objective of this given problem is to minimize the total interference of the network which is caused by cellular users and d2d transmitters at base station and d2d receivers. The objective then can be formulated as follows:

$$\min \sum_{rb} \Big(\sum_{cell,d2d} P_I\,(b, d2d) X_{rb}^{cell} X_{rb}^{d2d} + \sum_{cell,d2d} P_I\,(\,d2d, cell) X_{rb}^{d2d} X_{rb}^{cell} + \sum_{d2d1,d2d2} P_I\,(d2d1, d2d2) X_{rb}^{d2d1} X_{rb}^{d2d2} \Big)$$

Here,

$P_I\,(b, d2d)$ = Interference power at base station due to d2d transmitter

$P_I\,(d2d, cell)$ = Interference power at d2d receiver due to cellular

$P_I\,(d2d1, d2d2)$ = Interference power at d2d1 receiver due to d2d2 transmitter and vice versa

X^{cell}_{rb} = 1, when cellular user (cell) uses the resource block rb
0, otherwise

X^{d2d}_{rb} = 1, when d2d pair uses the resource block rb
0, otherwise

X^{d2d1}_{rb} = 1, when d2d1 pair uses the resource block rb
0, otherwise

X^{d2d2}_{rb} = 1, when d2d2 pair uses the resource block rb
0, otherwise

6.2 Linearization:

The above objective is in non-linear form with the product of two binary variables. For solving this problem with Integer Linear Programming, this nonlinear equation has to be converted to linear form. The product of the binary variables can be replaced by another variable. Then the objective function will be turned as follows:

$$\min \sum_{rb} \Big(\sum_{cell,d2d} P_I\,(b, d2d) X_{3\,(rb)}^{cell,d2d} + \sum_{cell,d2d} P_I\,(\,d2d, cell) X_{3\,(rb)}^{cell,d2d} + \sum_{d2d1,d2d2} P_I\,(d2d1, d2d2) X_{4\,(rb)}^{d2d1,d2d2} \Big)$$

Here,

$X_{3\,(rb)}^{cell,d2d} = X_{rb}^{cell} X_{rb}^{d2d}$

$X_{4\,(rb)}^{d2d1,d2d2} = X_{rb}^{d2d1} X_{rb}^{d2d2}$

6.3 Constraint Description:

There are mainly 5 constraints. The descriptions are given below:

1. Each cellular user should get at least one rb.

$$\sum_{rb} X_{rb}^{cell} \geq 1 \quad \forall\, cell$$

2. Each d2d pair should get at least one rb.

$$\sum_{rb} X_{rb}^{d2d} \geq 1 \quad \forall\, d2d$$

3. No two cellular should share the same rb.

$$\sum_{cell} X_{rb}^{cell} \leq 1 \quad \forall\, rb$$

4. Cellular user and d2d pair can share the same rb.

$$\sum_{cell} X_{rb}^{cell} + \sum_{d2d} X_{rb}^{d2d} \leq 2 \quad \forall\, rb$$

5. Two d2d pairs can share the same rb.

$$\sum_{d2d1} X_{rb}^{d2d1} + \sum_{d2d2} X_{rb}^{d2d2} \leq 2 \quad \forall\, rb$$

For linearization for each shared resource block three more constraints have to be added as the theory of linearization of binary product variables:

For the shared rb between cellular user and d2d pair-

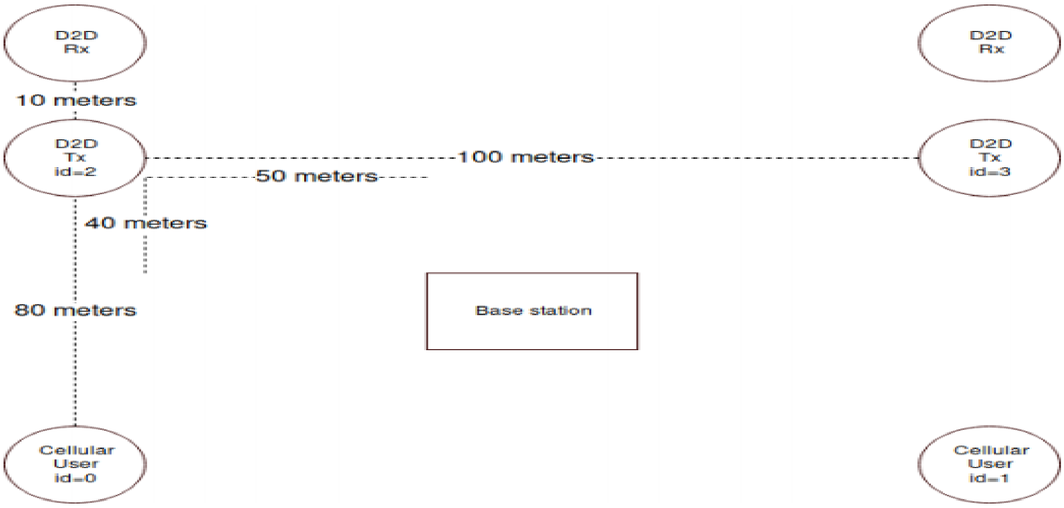
6. $\mathrm{X}_{3\,(\mathrm{rb})}^{\mathrm{cell,d2d}} \leq \quad \mathrm{X}_{\mathrm{rb}}^{\mathrm{cell}} \qquad \forall\, rb, cell, d2d$
7. $\mathrm{X}_{3\,(\mathrm{rb})}^{\mathrm{cell,d2d}} \leq \quad \mathrm{X}_{\mathrm{rb}}^{\mathrm{d2d}} \qquad \forall\, rb, cell, d2d$
8. $\mathrm{X}_{3\,(\mathrm{rb})}^{\mathrm{cell,d2d}} \geq \quad \mathrm{X}_{\mathrm{rb}}^{\mathrm{cell}} + \mathrm{X}_{\mathrm{rb}}^{\mathrm{d2d}} - 1 \qquad \forall\, rb, cell, d2d$

For the shared rb between two different d2d pairs-

9. $\mathrm{X}_{4\,(\mathrm{rb})}^{\mathrm{d2d1,d2d2}} \leq \quad \mathrm{X}_{\mathrm{rb}}^{\mathrm{d2d1}} \qquad \forall\, rb, d2d1, d2d2$
10. $\mathrm{X}_{4\,(\mathrm{rb})}^{\mathrm{d2d1,d2d2}} \leq \quad \mathrm{X}_{\mathrm{rb}}^{\mathrm{d2d2}} \qquad \forall\, rb, d2d1, d2d2$
11. $\mathrm{X}_{4\,(\mathrm{rb})}^{\mathrm{d2d1,d2d2}} \geq \quad \mathrm{X}_{\mathrm{rb}}^{\mathrm{d2d1}} + \mathrm{X}_{\mathrm{rb}}^{\mathrm{d2d2}} - 1 \qquad \forall\, rb, d2d1, d2d$

7. Result Validation:

For the result formulation of the above system model, a random network with random users and random distance was implemented using Gurobi solver using Integrate Linear Programming. For programming, python IDE was used. For the validation of the random network, two following network scenarios were used with 4 users and 2 resource blocks.



(a) First validation network setup.

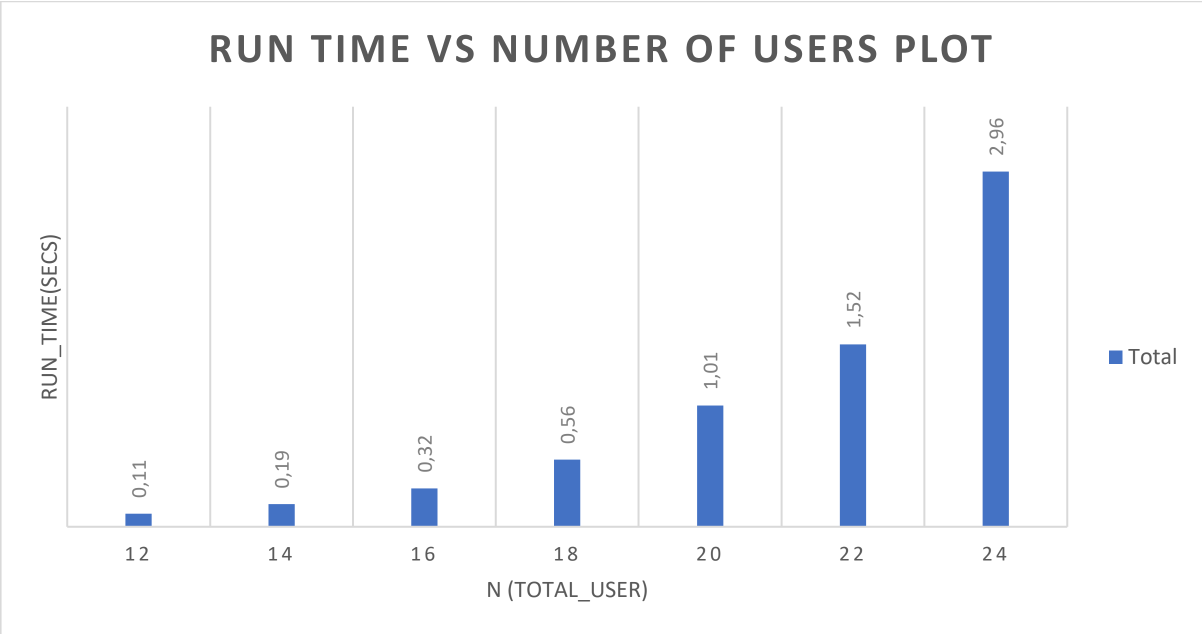
Total Interference power of the above network is -207. 26 dBm where cellular user with Id = 0 shares same resource block rb = 0 with d2d pair Id = 3 and cellular user with Id = 1 shares rb = 1 with d2d pair with Id = 2.

(b) Second validation network setup.

Total Interference power of the above network is -202. 192 dBm where cellular user with Id = 0 shares same resource block rb = 0 with d2d pair Id = 1 and cellular user with Id = 3 shares rb = 1 with d2d pair with Id = 2.

The runtimes for the random network for 12, 14, ….24 users were also recorded presented in the following graph:

N= (total number of Users	Run_Time(Sec)	No. of Iterations
12	0,11	1247
14	0,19	2182
16	0,32	3302
18	0,56	4476
20	1,01	6483
22	1,52	8124
24	2,96	10857



Graph 1: Run time vs number of users plot for random network

We can see from the plot and the table that as the user number increases network becomes more complex, and Gurobi needs to run more iterations to find the optimum value. Thus the run time increases with the number of users. It takes almost 3 seconds to find the optimum value when there are 24 users in the random network.

References:

[1] M. Mamman, Z. H. Hanapi, A. Abdullah, and A. Muhammed, ''Quality of service class identifier (QCI) radio resource allocation algorithm for LTE downlink,'' PLoS One, vol. 14, no. 1, 2019, Art. no. e0210310

[2] National Instruments. “Applications of Device-to-Device Communication in 5G Networks”. Internet:https://spectrum.ieee.org/computing/networks/applications-of-devicetodevice-communication-in-5g-networks.

[3] Sarma S.S., Hazra R. (2020) Interference Mitigation Methods for D2D Communication in 5G Network. In: Mallick P., Balas V., Bhoi A., Chae GS. (eds) Cognitive Informatics and Soft Computing. Advances in Intelligent Systems and Computing, vol 1040. Springer, Singapore. https://doi.org/10.1007/978-981-15-1451-7_54.