Traffic Engineering

Project Task

Resource Scheduling in LTE

Institute of Communication Networks
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Winter Term 2020

1 Problem description

1.1 Medium access in Long Term Evolution (LTE)

In LTE cellular networks, a base station is responsible for the medium access of the network users inside a network cell. The LTE standard defines a resource block (RB) as a pair of $\{1\,\text{ms}, 180\,\text{kHz}\}$. This tells us that every millisecond, 180 kHz wide frequency bands are allocated to the users. The width of the licensed spectrum that the network operator has obtained (bought from the government) defines how many 180 kHz wide frequency bands are available each millisecond.

Recent literature proposes device-to-device (D2D) communication, where users are able to transmit directly to each other. A *cellular* user always transmits on the uplink to the base station, which forwards it to the destination on the downlink. A D2D user can skip this intermediate hop and instead communicates directly with the receiver on the uplink.

Resource allocation refers to the decision the base station has to make: out of our m RBs, which ones should be allocated to which of our n users? This becomes a difficult optimization problem, as the optimization goals are conflicting:

1. Spectral efficiency (make good use of the entire spectrum)
2. System throughput (maximize the total throughput)
3. Fairness (provide service to all users in a fair manner)
4. Quality of service (QoS) provisioning (meet respective QoS criteria)
5. Power efficiency (conserve power)

For example, allocating all RBs to the user that currently has the best channel conditions would optimize system throughput, but ignores fairness, QoS and possibly power efficiency.

With the introduction of direct links between users through D2D, researchers suggest to reuse already allocated RBs. In principle any two users can share a single RB if they have different transmission destinations – so a D2D user may reuse a cellular user's RB, or two D2D users may share one RB. This means that more than one user will simultaneously transmit on the same frequency band, causing interference at the respective receivers. Consequently, to do this in an intelligent way, well-matching user pairs must be found that cause least destructive interference on each other; preferably users at opposite ends of the network cell. Figure 1 depicts the interference scenario when one user transmits on the direct D2D link to their intended receiver, alongside a cellular user transmitting to the base station. The D2D transmitter causes interference at the base station, while the cellular transmitter causes interference at the D2D receiver.

1.2 Channel model

The interference caused at the respective receivers depends on the transmission power, and how much of it is attenuated on the path to the receiver. Assuming the simplest case of *free space path loss*, path attenuation can be formulated as

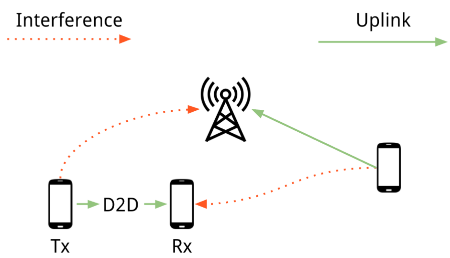

Figure 1: Interference scenario when uplink is used for a D2D transmission, as the majority of literature suggests.

in Equation 1, where d is the distance in kilometers, $f = 2\,\mathrm{GHz}$ the frequency and c the speed of light in meters per second.

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) \tag{1}$$

Equation 1 returns the path loss in terms of dB. If you are unclear about the relationship of the units dB, dBm, mW and W, please refer to `http://www.rfcafe.com/references/electrical/decibel-tutorial.htm` or another online tutorial.

We will assume a user transmission power of $26\,\mathrm{dBm} = 398.1\,\mathrm{mW}$. If, for example, a user transmits via a distance of $1\,\mathrm{km}$, the $FSPL = 20\log_{10}(1\,\mathrm{km}) + 20\log_{10}(2\,\mathrm{GHz}) + 92.45 = 98.47\,\mathrm{dB}$. The remaining power that arrives at the receiver is therefore

$$26\,\mathrm{dBm} - 98.47\,\mathrm{dB} = -72.47\,\mathrm{dBm} = 5.6 \cdot 10^{-8}\mathrm{mW}$$

1.3 Your task

For the number of users n we will assume

$$n \geq m$$

so our RBs are not sufficient to provide one RB to each user without resource reuse.

1. Please formulate an optimization problem that meets the following criteria:
   (a) Minimize the total interference from resource reuse,
   (b) schedule at least 1 RB to each user,
   (c) have no two cellular users share one RB. Two D2D users or one D2D and one cellular users may share a RB.
2. Next, implement the optimization problem in Gurobi, using a programming language interface of your choice. *We suggest to use Python, but you are free to use another one.*

   Please demonstrate good programming style! Keep in mind who causes interference at whom when defining the interference calculation.

3. To validate that your formulation and implementation are correct, please solve the problem for the two setups shown in Figures 2a and 2b, with $m = 2$ RBs. Please make clear which users get which RBs and explain why for both setups.

4. Implement a randomized network setup with arbitrary numbers of users and resource blocks. Solve problem instances for $n = 12, 14, 16, \ldots, 24$ users where $\frac{n}{2}$ are of cellular, and $\frac{n}{2}$ of D2D type, and with $\frac{n}{2}$ resource blocks. Present your results! Keep track of how long problem solving takes on your machine for each problem instance and plot the results!

Optional: Implement a heuristic approach to this problem. Please describe how your approach works, implement it, and compare the running time and the total caused interference to the optimal solution.
Solving this optional task may improve the grading on this assignment!

Until Tuesday, 08.12.2020 09:00:

Please hand in a written report. It should contain the optimization problem formulation and textual and graphical answers. Also hand in the code to your implementation with a short description on how to run it – we expect to be able to validate your implementation by running the network setups in Figure 2.

Send your submission to

`sebastian.lindner@tuhh.de` and **`k.fuger@tuhh.de`** and **`comnets@tuhh.de`**

with the subject

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Traffic Engineering Submission:  Team <your team number>
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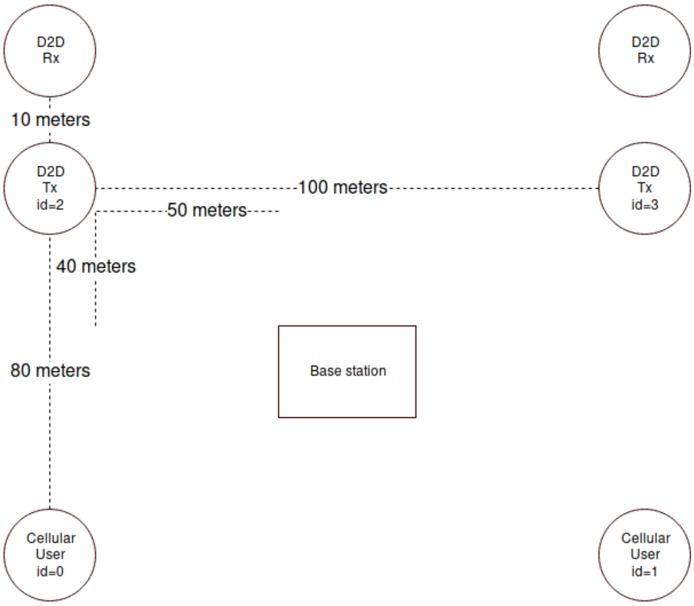
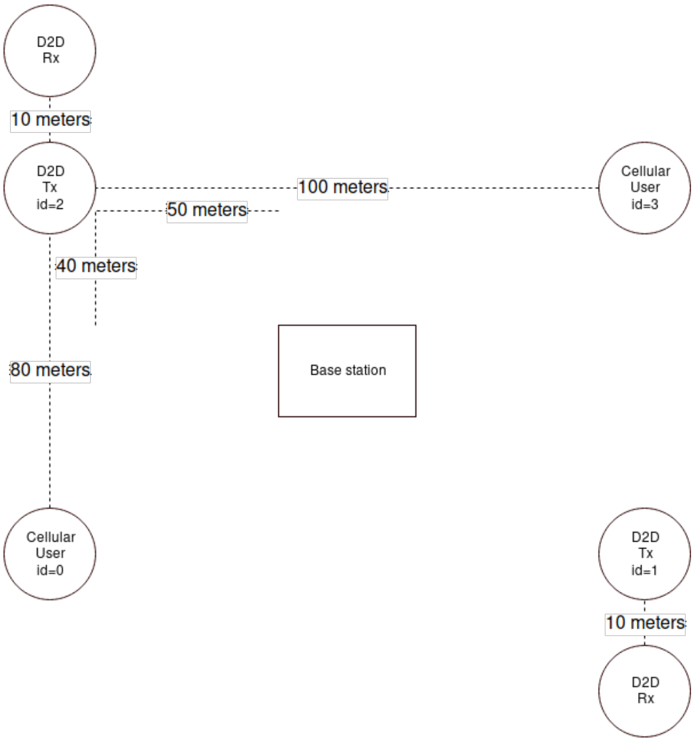
Please refer to StudIP for your presentation slot, which is also your team number. For the presentation we expect presentation slides where you present your results in no more than 10 minutes. Both team members should explain a roughly equal share.



(a) First validation network setup.



(b) Second validation network setup.

Figure 2: Validation network setups.