Traffic Engineering

Project Task

Optimal Relay Selection in LTE/4G/5G UAV Networks

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1 Problem description

1.1 UAV Communication

Advances in Unmanned Aerial Vehicle (UAV) technology are promising to revolutionize many industries. Especially use cases such as transportation, remote inspection and surveillance are likely candidates to be taken over by UAVs in the near future. While the mechanical capabilities of UAVs would allow those applications for many years already, the communication capabilities are lacking behind. Although some pilot projects with single UAVs show promising results, a reliable and efficient communication network is necessary to enable the large scale deployment of UAVs in urban environments. Currently, many companies rely on the current available generation of cellular networks (LTE/4G/5G) to control and monitor their UAVs as it is the only available infrastructure that covers their entire range of operation and delivers the required Quality of Service (QoS), even in rural areas. While this works well if only a few UAVs are located in every cell, once urban skies are swarming with UAVs, the amount of radio resources used by UAVs must be minimized so that enough resources for other users remain.

1.2 LTE/4G/5G

The cellular network is one of the advanced communication networks in existence. Since the LTE standard, a TDMA/FDMA approach is used to subdivide the available spectrum into resource block (RB). A RB is defined as a pair of $\{0.5\,\text{ms}, 180\,\text{kHz}\}$. Each RB is further subdivided into $7 \cdot 12$ resource elements. In each resorce element one symbol is transmitted carrying bits according to Table 1.2. There are different methods of assigning resources to users, but each user always gets an integer number of RBs.

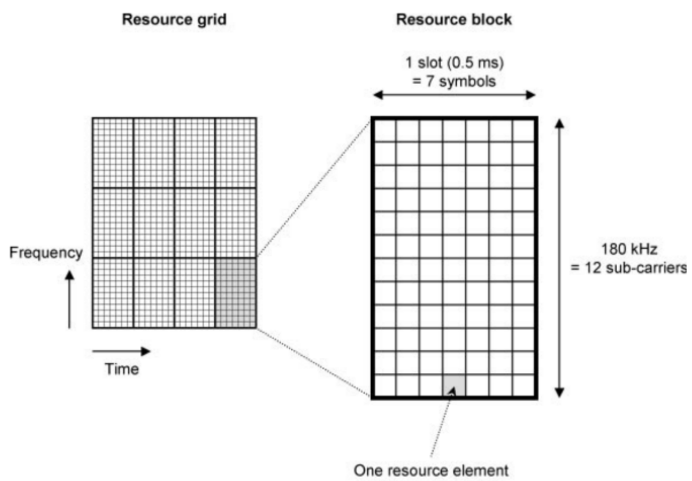

Figure 1: LTE Resource Grid [2]

One important feature of LTE/4G/5G communication is adaptive modulation and coding. Here, devices measure the radio channel quality to their communication partner and are able to either use more robust modulation schemes (MCS) with a lower throughput or less robust schemes with a high throughput. The selected MCS defines the number of bits that can be sent in a single resource element. Further, the channel quality is expressed with the Channel Quality Indicator (CQI). The CQI is a number between 0 and 15 where 15 denotes the highest quality and 0 means no communication is possible. To calculate the CQI for a channel between two users, we can perform a link budget calculation (Figure 2). Here, we assume a transmit power P_{tx} of 23 dBm, a frequency f of 1500 MHz and free-space path loss. We summarize all other losses with a constant value of $L_E = 28\,\text{dB}$ The signal power at the receiver P_{rx} can now be expressed as

$$P_{rx} = P_{tx} - \text{FSPL} - L_E \tag{1}$$

with

$$\text{FSPL} = 20\log_{10}(d) + 20\log_{10}(f) - 147.55 \;\; | \, \text{dB} \tag{2}$$

where d is the distance between sender and receiver. Which MCSs can be used for a given P_{rx} now depends on the receiver sensitivity S_{rx}. This is a quantity describing for each MCS the minimal P_{rx} so that a signal can be received sucessfully. The receiver sensitivities for all MCSs are given in Table 1.2. We always select the highest MCS so that $P_{rx} \geq S_{rx}$.

CQI	MCS	Coding rate	Bits per symbol	Receiver sensitivity [dBm]
0	n/a	0.00	0.00	$-\infty$
1	QPSK	0.08	0.15	−107.11
2	QPSK	0.12	0.23	−104.91
3	QPSK	0.19	0.38	−103.71
4	QPSK	0.30	0.60	−103.01
5	QPSK	0.44	0.88	−100.01
6	QPSK	0.59	1.18	−97.71
7	16-QAM	0.37	1.48	−96.51
8	16-QAM	0.48	1.91	−95.81
9	16-QAM	0.60	2.41	−94.11
10	64-QAM	0.46	2.73	−90.71
11	64-QAM	0.55	3.32	−89.81
12	64-QAM	0.65	3.90	−89.21
13	64-QAM	0.75	4.52	−86.71
14	64-QAM	0.85	5.12	−84.51
15	64-QAM	0.93	5.55	−83.41

For example: Assume we have two users with a distance of 1000 m. The received power from one user to the other would be −100.97 dBm. This corresponds to a CQI of 4 and 50.4 bits can be transmitted in a single RB.
With this information we can now calculate based on the distance between two users which MCS should be used and with that, how many bits we can transmit within a single RB. One common problem here is, that users that are far away from their communication partner are forced to use one of the lowest MCS and

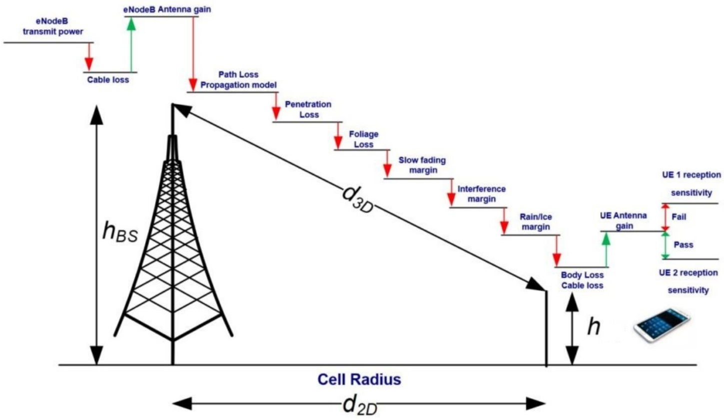

Figure 2: Link Budget [1]

therefore need a large amount of RBs to transmit their data. This can be solved by "Relays". Here, users will not send their data directly to the destination, but first send it to an intermediate node to which they have a good channel quality. This intermediate node now forwards the data to the destination or to another intermediate node and thereby forming a multi-hop path. If all links along this path have a good channel quality, this can safe resources compared to the direct transmission. Another benefit of relay communication is concatenation of packets. As stated above, only full RBs can be assigned to users, but sometimes they only have enough data to fill a fraction of the RB. For example, if a user sends data over a link for which he needs 1.1 RBs, he must be assigned 2 RBs. If the user now has to forward data over the same link that would need 0.7 RBs he still must only be assigned 2 full RBs.

1.3 Your task

In this task, we assume that all channel qualities are known by a central scheduler. This scheduler has to calculate the optimal resource assignment. Consider a scenario where UAVs are uniformly random distributed within a circle of radius 1500 m around a ground station. All UAVs are trying to send 100 B of data to the ground station. Here they may communicate directly with the ground station or use relays. The goal is to minimize the total amount of RBs required to send all data.

1. Please formulate an optimization problem that meets the following criteria:
   (a) Minimize the total amount of RBs used.
   (b) Allow users to use relays along the way.
   (c) Make sure only integer numbers of RBs are assigned to users.
   (d) Allow for packet concatenation.
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!

3. To validate that your formulation and implementation are correct, please solve the problem for the scenario in Figure 3. How many RBs are required? Verify that your solution is indeed optimal.

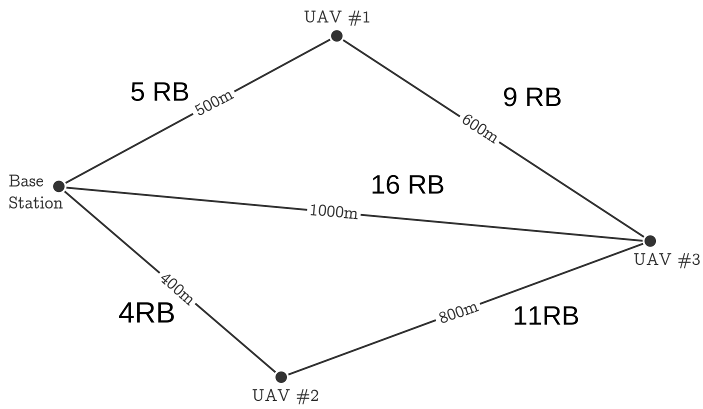

Figure 3: Verification Scenario

4. Implement a randomized network setup with arbitrary numbers of UAVs. Solve problem instances for an increasing numbers of UAVs. Present your results! Keep track of how long problem solving takes on your machine for each problem instance and plot the results! Choose the numbers of UAVs on your own in such a way that the increase in computation time becomes clearly visible. In which way does the computation time increase with the numbers of UAVs?

5. Implement a heuristic approach to this problem. Please describe how your approach works, implement it, and compare the computation time to the optimal solution.

Until Wednesday, 30.11.2022 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 replicate the graphs in your report.

Send your submission to

k.fuger@tuhh.de and **comnets@tuhh.de**

with the subject

```
Traffic Engineering Submission:  Team <your team number>
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For the presentation we expect presentation slides where you present your results in no more than 10 minutes.

References

[1] *4G LTE Link Budget Calculator*. June 2022. URL: `https://5g-tools.com/4g-lte-link-budget-calculator/`.

[2] Christopher Cox. *An introduction to LTE: LTE, LTE-advanced, SAE and 4G mobile communications*. John Wiley & Sons, 2012.