Management and Content Delivery for Smart Networks: Algorithms and Modeling

Academic Year 2021-2022

L2: Drone assisted communication system simulation - Taking into account drone autonomy

Please note that, for this Lab activity, tasks come in two slightly different versions, A and B. Groups that have been assigned Version A must follow the corresponding requirements, whose peculiarities are highlighted in blue fonts, whereas Groups that have been assigned Version B must follow the requirement specifications that are highlighted in red fonts.
Please check which version you have been assigned in the updated list of lab groups.

Summary

Refer to the same drone assisted communication system considered in Lab. 1, that is reported below for your convenience in Fig. 1 and summarized hereafter. The scenario consists of an

Figure 1: Scenario.

urban area where baseline mobile coverage is provided by a number of on-ground Base Stations (BSs). During periods of traffic peaks, up to N drones equipped with a BS can be sent to fly over the considered area to provide additional capacity and offload a fraction of the traffic handled by the terrestrial BSs.
We focus on the aerial nodes, i.e. the UAVs. Each aerial BS is equipped with multiple antennas, using the Multi-User Multiple Input-Multiple Output (MU-MIMO). The MU-MIMO BS is modelled as a queuing system with m servers, where each server represents a single MIMO antenna. In the considered queuing system, the customers represent the data packets that arrive at a given drone. The service represents the transmission of the data by the UAV mounted BS.

We assume that the drones can be powered either by a battery unit or by a battery unit plus an additional small photovoltaic (PV) panel.

- If the **drone is equipped with a battery unit only**, its autonomy is **25 minutes**, after which the drone must reach the charging station where its battery must be fully recharged before the drone becomes operational again. **60 minutes** are required to fully recharge the drone battery.

- If the **drone is equipped with a battery unit and a PV panel**, its autonomy depends on the size of the photovoltaic (PV) panel capacity (that corresponds to the power that can be produced by the panel from the conversion of solar radiation under standard test conditions), according to the following table:

PV panel capacity [W]	**Drone autonomy [min]**
40	**30**
60	**35**
70	**40**

  Note that these values of autonomy only hold during daytime hours in which significant levels of renewable energy are produced, that we assume corresponding to the period from 8 a.m. to 4 p.m. During the rest of the day, the drone autonomy is **25 minutes**. In any case, once the drone battery is empty, **60 minutes** are required to fully recharge it.

The process including the full charging of the battery from an empty state and the progressive discharge of the battery during the drone activity until it becomes empty again represents a complete **charging/discharging cycle** of the battery. The deterioration of the battery is typically proportional to the number of complete charging/discharging cycles, and, after the number of cycles that the battery undergoes achieves a given threshold (typically of the order of several hundreds of cycles), the battery needs to be replaced.

Consider a realistic scenario in which the mobile traffic varies over time during the day, hence defining a traffic profile characterized by a different value of average packet arrival rate at every hour of the day (or every half an hour), depending on the type of considered area:

- **Business area** (Version A): in this area the traffic typically features two peak periods, one in the morning and one in the afternoon after lunchtime, whereas as the evening approaches the traffic rate tends to decrease.

- **Residential area** (Version B): in this area the traffic is relatively low in the morning hours, whereas it tends to gradually increase in the afternoon, to achieve the highest value in late afternoon-evening, when people get back home from work.

In this lab activity, you will be asked to implement various scheduling strategies to decide when it is more convenient to send one or more drones to handle a portion of the mobile traffic, considering different system configurations and autonomy constraints, as detailed in the various tasks described below.
You can perform your analysis considering a time window of few hours in a day, for instance 8 a.m.-8 p.m.

Tasks

1. Consider a drone hosting a BS and equipped with a battery unit as power supply, that can be sent to fly over a given traffic area, either a Business area (Version A) or a Residential area (Version B), to handle some of the mobile traffic. Design various drone scheduling schemes according to different scheduling strategies, aiming at taking decisions about when the drone should be sent and used to offload some mobile traffic in the considered traffic area, keeping into account the drone battery autonomy and the time required to fully recharge the battery unit once it has become empty.
Note that the drone can be sent to fly over the considered region even for periods of time shorter than 25 minutes. After having achieved a cumulative period of 25 minutes of activity, although not continuous, the battery will result empty and must be fully recharged to make the drone operational again.
Compare the system performance under the different scheduling strategies, and identify the scheduling scheme that allows to handle the largest fraction of traffic volume during the day.

2. Introduce a constraint on the maximum number of cycles of battery charging/discharging that the UAV battery can undergo during a day, in order to limit the battery degradation.
Test different values of this threshold, modifying the drone scheduling schemes/strategies to respect the new constraint. How is the system performance affected?

3. **Version A:** Consider a scenario in which up to three drones are used in a business

area, assuming they are powered by a battery only. Set a constraint on the maximum allowed number of battery charging/discharging cycles and keep the same value for each drone.
Design a specific drone scheduling strategy for each of the following cases:

- case with one drone;
- case in which up to two drones are available;
- case in which up to three drones are available.

(a) Highlight the differences in the proposed scheduling approaches and compare the system performance in the different cases.

(b) Provide some comments about the fraction of volume handled by the drone and the number of battery charging/discharging cycles observed in the different cases.

Version B: Focus on a mobile network scenario in which a residential area is additionally served by a single drone, that is equipped with a battery and a PV panel. Considering different values of the PV panel capacity, design a specific drone scheduling strategy for each of the following cases:

- case of a drone equipped with a PV panel characterized by a capacity of 40 W;
- case of a drone equipped with a PV panel characterized by a capacity of 60 W;
- case of a drone equipped with a PV panel characterized by a capacity of 70 W.

(a) How are the scheduling schemes and system performance affected by the varying PV panel capacity?

(b) Provide some comments about the fraction of volume handled by the drone and the number of battery charging/discharging cycles observed in the different cases.

4. Now consider a scenario with N available drones, that can be of different types, like, for example:

   - **Type A:** the drone is powered by a battery only; its BS is equipped with 2 antennas featuring the same service rate μ, and the buffer size is equal to s_A;
   - **Type B:** the drone is powered by a battery and a PV panel with small capacity; its BS is equipped with 1 antenna featuring service rate 2μ, and the buffer size is equal to s_A;
   - **Type C:** the drone is powered by a battery and a PV panel with larger capacity; its BS is equipped with 1 antenna featuring service rate μ, and the buffer size is equal to $2s_A$.

   Keeping the value of N fixed, consider different combinations of types of drones. For example, in a scenario with N=2 drones, you could consider: configuration I = 1 drone of type A, 1 drone of type C; configuration II = all drones are of type B; configuration III = ...

Define a drone scheduling strategy aiming at maximizing the volume of traffic handled during peak periods and compare the performance of the proposed strategy under the different drone type configurations.

(a) Which is the configuration that allows to better trade off the volume of traffic handled by the available drones, the number of battery charging/discharging cycles and the Quality of Service (e.g. in terms of experienced delay)? Motivate your answer.

Discuss in your report the main findings emerged from the various investigated scenarios. Support your claims and observations by plotting graphs that report the most significant performance metrics from different cases and help to highlight the relevant findings under variable configuration settings. Remember to always specify the unit of measure for the parameters and metrics represented in the graphs. For each graph, check that the main configuration settings that have been adopted to obtain the corresponding simulation results are reported.

Group and Final Reporting

You are expected to work in groups of up to three students. Each group is required to prepare a **single** report describing results of **all labs in the course**. This report must not exceed 15 pages. You need to delivery both the written report and your source code before the end of exam session in September.