Management and Content Delivery for Smart Networks: Algorithms and Modeling

Academic Year 2021-2022

L1: Drone assisted communication system simulation

Summary

Nowadays, we are witnessing a staggering and rapid growth of mobile traffic volumes, featuring increasingly tighter Quality of Service constraints. Extensive densification of Radio Access Networks (RANs) is hence required to satisfy this huge and exacting service demand, especially in urban environments. Nevertheless, besides raising remarkable sustainability concerns due to the consequent energy consumption growth, the boundless expansion of terrestrial networks in smart city ecosystems may be limited by physical and regulatory constraints. In this context, aerial network nodes powered by renewable energy represent a promising solution to offer additional bandwidth capacity in locations where additional on-ground Base Stations cannot be installed, without increasing the energy demand from the power grid.

The purpose of this lab is to simulate the operation of a portion of an urban RAN where

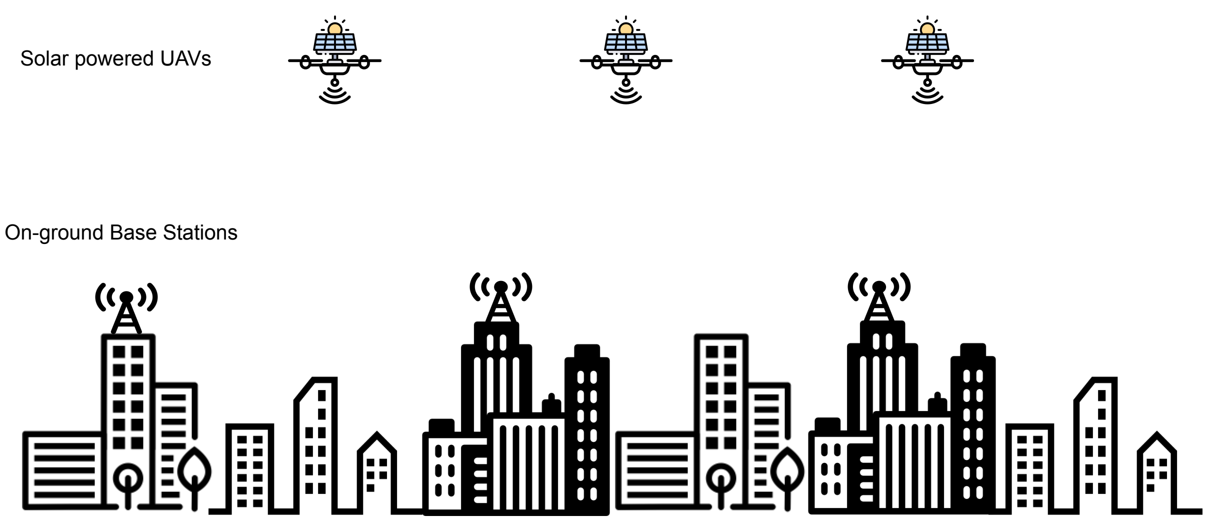

Figure 1: Scenario.

terrestrial Base Stations are supported by renewable powered Unmanned Aerial Vehicles

(UAVs), that are periodically sent to fly over a given area to provide additional capacity during peak periods, in order to offload the on-ground nodes and enable a better Quality of Service for the communication network. The network is modeled as a queuing system and this lab activity aims at investigating its performance under variable configurations, to understand how different parameter settings may affect the system behaviour and how modifying some parameters of the network system may impact on performance metrics.

The scenario is depicted in Fig. 1. Consider an 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. The drones are powered by a small photovoltaic panel, and they are equipped with a battery unit to storage extra solar energy that is not immediately used.
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.

Tasks

In order to investigate the performance of the network system, you should perform the following tasks:

- Considering the case in which a single drone is used to provide additional capacity during a traffic peak period, derive the metrics describing the system performance in the baseline scenario, characterized by m=1, considering both the cases with and without packet losses.

- Modify the baseline scenario varying the size of the buffer and considering a multi-server system, assuming that the aerial Base Station is equipped with two antennas. Test the system behaviour under different buffer sizes (infinite waiting line, medium to short finite waiting line, no buffer at all) and compare its performance with the single server scenario.

You can start from the network simulator code available in the course material, that represents the operation of an M/M/1 queuing system with infinite waiting line, based on an event scheduling approach: *queueMM1-ES.py*. You can make your modifications and integration to the code, in order to investigate the system performance via simulation.
Different metrics can be useful to understand the system operation and evaluate its performance, like:

- **number of transmitted packets**, i.e. the data packets that arrive at the and transmitted by the UAV mounted Base Station

- **average number of packets** in the system
- **average queuing delay**, i.e. the average time spent in the system
- **distribution of queuing delay**
- **average waiting delay** per packet, assuming that the packet waiting delay is the time elapsed from the moment at which a packet enters the system to the instant at which the service begins.
  It is useful to compute both of the following types of waiting delay:
  - the average waiting delay experienced by any packet (**averaging over all packets**);
  - the average waiting delay **considering only those packets that actually experience some delay**, since they enter the system while the server(s) is (are) busy and are hence buffered.
- **average buffer occupancy**, i.e. the average number of packets in the buffer
- **loss probability**, i.e. the fraction of packets that cannot be transmitted since the server(s) is (are) currently busy and no buffer is present in the system or, in case of finite buffer, it is full.
- **busy time**, i.e. the cumulative time that during the simulation each server spends in a busy state serving packets requests. In a single-server system, you can observe how it varies with the buffer size. In a multi-server system, based on the busy time analysis per each server, you can examine the distribution of the load among servers.

You can think of other metrics that may be helpful in your analysis to highlight specific aspects or critical issues in the system operation. When running your simulations, pay attention on setting appropriate values of the simulation duration.
In your analysis of the network operation and performance, focus on the following aspects:

1. Assuming that a single drone, featuring a single antenna and no buffer, is sent to provide additional capacity during peak time, investigate the system performance under different arrival rates, **keeping a fixed value for the average service rate**:
   (a) how is the performance affected? Highlight your findings by showing the variation of relevant performance metrics;
   (b) set a desired confidence level and, for one of the metrics reported in the graphs produced in task 1.a, show the confidence intervals of the performed measurements;
   (c) are the results of your analysis consistent with theoretical expected values?
2. Consider a drone equipped with two antennas and assume a finite buffer:
   (a) analyse its performance considering relevant performance metrics;

(b) compare its performance against the case with infinite buffer size;
(c) compare its performance with the single server case.

3. Assuming an infinite buffer size, compare the system performance in the following two cases:

    (a) a single drone equipped with two antennas;
    (b) two drones, each equipped with a single antenna.

    Now, considering both cases (a) and (b), assume a finite buffer size and try to vary the size of the buffers: how is the system performance affected in the two configurations?

4. Considering a single drone, try to vary the distribution of the service time, i.e. considering the case of M/G/1, and observe how the system performance changes, assuming one or more different distribution types for the service time instead of exponential distribution.

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.