Politecnico di Torino

UAVs SIMULATOR

REPORT

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1 Introduction

We take into consideration the “MATRICE 300 RTK” UAV[1] that is useful for a mission with low temperature, and we considered its specifications[2] for setting up our UAV parameters.
During the realization of the simulator, we constantly asked ourselves questions about its usefulness. The most important part is the communication, which is influenced by the movement of the UAVs.
To enable Beyond-Line-Of-Sight communication, we considered a relay positioned above the mountain obstacle. Without the latter, all UAVs that have the mountain in their communication range are unable to communicate and will start losing packets as soon as their queues fill up, thus losing important information regarding their telemetry data. In this report, we want to consider two distinct scenarios: with and without missing persons.
In the two separate scenarios, the expected result is different due to the difference in the information sent regarding the presence of the missing person: the communication channel saturates earlier and therefore there are more lost packets.
The intended use case is to find out a reliable generation rate of packets such that all the UAVs are able to transmit correctly/efficiently in a fair way.

1.1 Assumptions

In order to develop this simulator we did several assumptions:

- when the UAV is in LOS, the bitrate remains constant for 2km at 100kbit/s, then it decreases linearly till it reaches the 0kbit/s value for 2.5km.
- there are no obstacles for the UAVs movement, but only for the communication. This is a strong but real assumption because we assume that each vehicle flies at a different height with respect to the others. For the communication, each cloud halves the bitrate, whereas the mountain interrupts completely the direct communication;
- there is no communication interference with external electromagnetic fields because the considered scenario consists in a zone where there is a lack of network coverage;
- each UAV exploits all the available power for the movement, maintaining the apparent velocity at 23m/s. The external wind can modify the final velocity, but the power consumption is always the same. In this way, only the temperature can modify the power consumption;
- the UAVs are only able to communicate with the ground station or the relay, but not between themselves;
- the communication channel between the UAVs and the ground station has been modeled as CSMA-0 persistent, with a maximum number of trials before the pack is dropped. Moreover, only one UAV at a time can communicate with the GS. If the UAV is BLOS, it uses the relay to overcome the mountain. Finally, we considered two distinct communication channels, one directly linked with the ground station and one to the relay;
- each UAV sends periodically a JSON file containing the telemetry data. Each transmission is asynchronous with respect to the others, in order to avoid collisions. Moreover, we do not consider the propagation delay so there can’t be collisions.
  When the missing person has been found, the UAV tries to send a JPEG file containing the image and the JSON file which indicates the estimated coordinate of the missing. Notice that this file is much bigger than the telemetry data, so it is more difficult to send because it occupies the channel for a longer time.

1.2 Parameters Initialization

As we said before, we simulated the performance in two different scenarios. One is characterized by no missing person, whereas for the other one we considered 5 missing people. Notice that all the other parameters are the same in the two cases, as represented below.

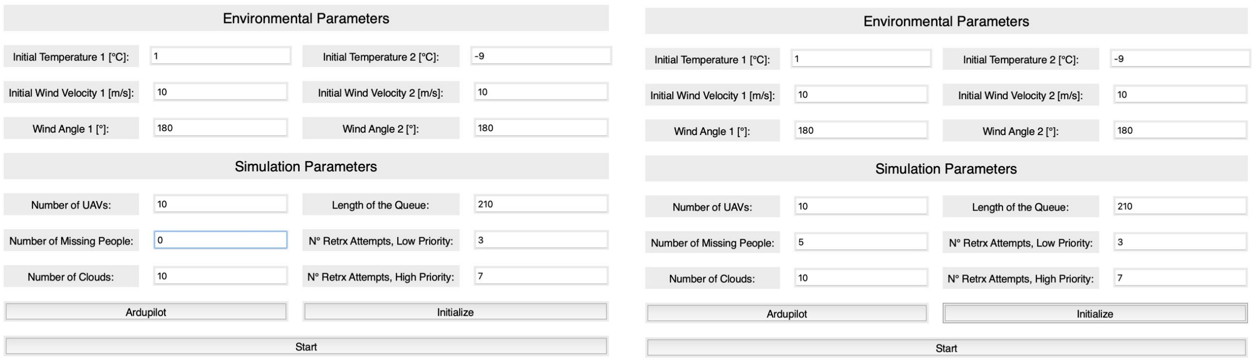

Figure 1: GUI Parameters: first and second scenario

Moreover, we did not use Ardupilot for the mission planning, and the length of the queue is small in order to speed up the simulation.

2 Battery Model

We describe the model used for power consumption: we considered a very simplified relation between power consumption and environmental conditions. Starting from the wind force, we assumed that this does not change the power used: indeed, the UAV pushes itself always at its maximum speed, and the wind modifies only the resulting velocity. According to that, for the movement purpose, it has to compensate for the shift given by the wind force.
Considering instead the temperature, it is the only environmental effect that modifies the power consumption. We introduced two different parameters, namely η and α. The first one characterized the instantaneous consumption, whereas the second the initial available battery. We considered three possible temperature ranges, in which we have different behaviors for the parameters involved:

- the first one (starting from the top) runs from 20°C to 40°C and both η and α are constant and equal to 1. This is the best range for the UAV, with the minimum power used;
- the second one is $[0; 20]$°C and both the parameters have a linear relation, described by the laws below;
- the last runs form -20°C to 0°C. This is the worst possible condition, involving a linear relation for η and a constant coefficient α equal to $\frac{2}{3}$. The power consumption, in this case, is bigger than the ones in the other ranges.

Notice that beyond the upper limit and below the lower one the UAV is not able to fly and, in the mission planning activity, the user must choose not to start the rescue operation.
The parameters' behavior has been reported below.

The model equation is the following one.

$$E(t + \Delta t) = \{\alpha(T), 1\}E(t) - \eta(T)P\Delta t \tag{1}$$

$$
\begin{cases}
\eta = 1 & 20°C \leq T \leq 40°C \\
\alpha = 1 & \\
& \\
\eta = 1 + |20 - T| \cdot 0.02 & 0°C \leq T < 20°C \\
\alpha = 1 - \frac{1}{3}\frac{|20-T|}{20} & \\
& \\
\eta = 1 + |20 - T| \cdot 0.02 & T < 0°C \\
\alpha = \frac{2}{3} &
\end{cases}
$$

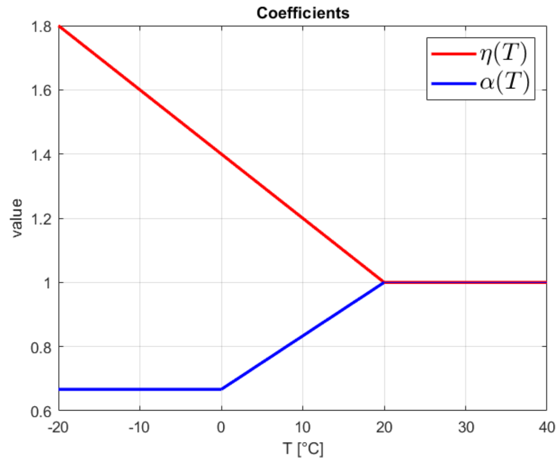

Figure 2: Temperature Coefficients

Notice that the value of α is updated only once when changing the range, otherwise, it is set to 1.

In the picture below it is possible to see the energy profiles with respect to time for different temperatures. It is possible to clearly see the difference between the two limit cases: in the best case, the UAV flies for around 53 minutes, whereas in the worst case only 18 minutes.

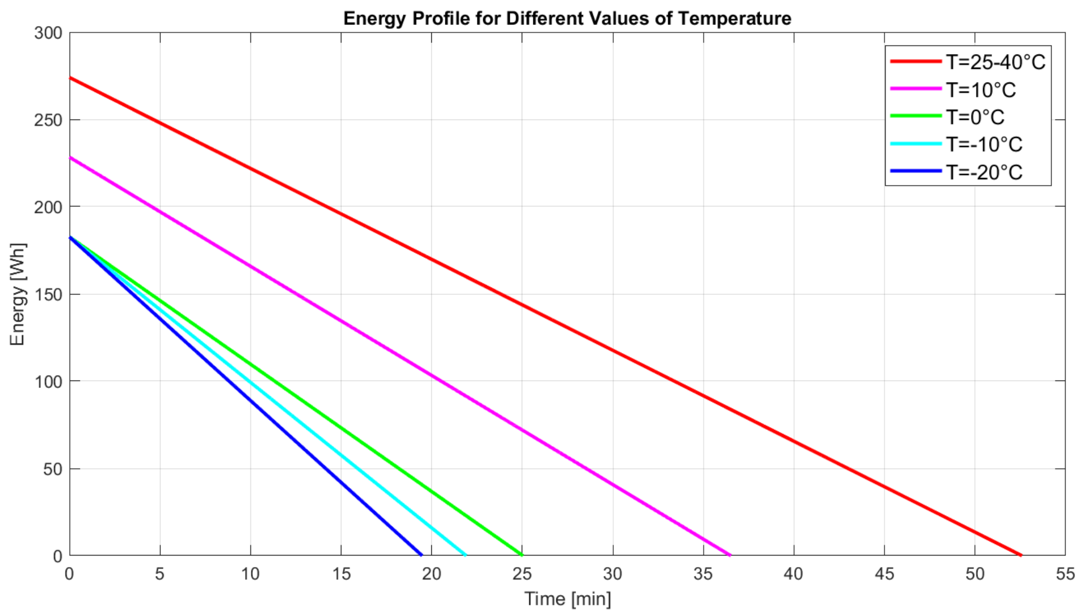

Figure 3: Energy Profiles

3 Simulation

In order to better characterize the communication behavior, we considered multiple *seed* and $DELTA\_t\_MSG\_TO\_SENT$ parameters. Specifically, the values involved were the ones in the table below.

Seed	DELTA_t_MSG_TO_SENT									
4	4	2	1	0.85	0.7	0.5	0.35	0.25	0.15	0.1
5	4	2	1	0.85	0.7	0.5	0.35	0.25	0.15	0.1
6	4	2	1	0.85	0.7	0.5	0.35	0.25	0.15	0.1
12	4	2	1	0.85	0.7	0.5	0.35	0.25	0.15	0.1
87	4	2	1	0.85	0.7	0.5	0.35	0.25	0.15	0.1
220	4	2	1	0.85	0.7	0.5	0.35	0.25	0.15	0.1

Table 1: Simulation Parameters

Notice that the same *DELTA_t_MSG_TO_SENT* parameters have been used for all the seeds. Moreover, we considered these values for visualizing better the behavior of the communication channel when it starts to saturate.
The seeds have been chosen according to the missing people's positions on the Simulation map, in order to a sparse distribution of them. Furthermore, it has been assured, through code, to have them not on top of the mountain, namely not under the relay, and they are spread in such a way that half of them are on the left part of the map, and the other half on the right side.

3.1 UAVs Movement & Communication

In our simulator, it has been realized a dynamic grid map according to the number of UAVs. In this way, each of them searches in a different zone in order to speed up the search for missing people: at first, each UAV goes to its specific zone, then each one moves randomly inside that region.

Figure 4: UAV map

For the communication, if the UAVs are in "Line Of Sight" (without any obstacles and below 2 km distance), they can directly communicate with the ground station, with the maximum available bitrate of 100 kbit/s (green circle). If instead, they are behind the clouds, for each one the bitrate is halved, so the effect of each cloud accumulates (orange circle). Finally, if they are too distant from the ground station or behind the mountain ("Beyond Line of Sight"), there is no direct link (red circle).
To overcome the obstacle and the maximum range of communication limit, they communicate

with the relay on the mountain, which has been positioned to be always in "Line Of Sight" with the Ground Station. Its maximum bitrate is affected only by the clouds.

4 Results

In this section, we reported the principal outputs of our system, considering different scenarios. This is important to validate the simulator.

4.1 Scenario Without Missing Person

Throughput

The graph below depicts three lines representing the total throughput, the throughput of UAVs directly communicating with the Ground Station (GS), and the throughput of a single relay acting as an intermediary between obstructed UAVs and the GS.
The throughput is computed by considering the packets that are received over the simulation time. It represents the actual transmission rate of packets that have been received.

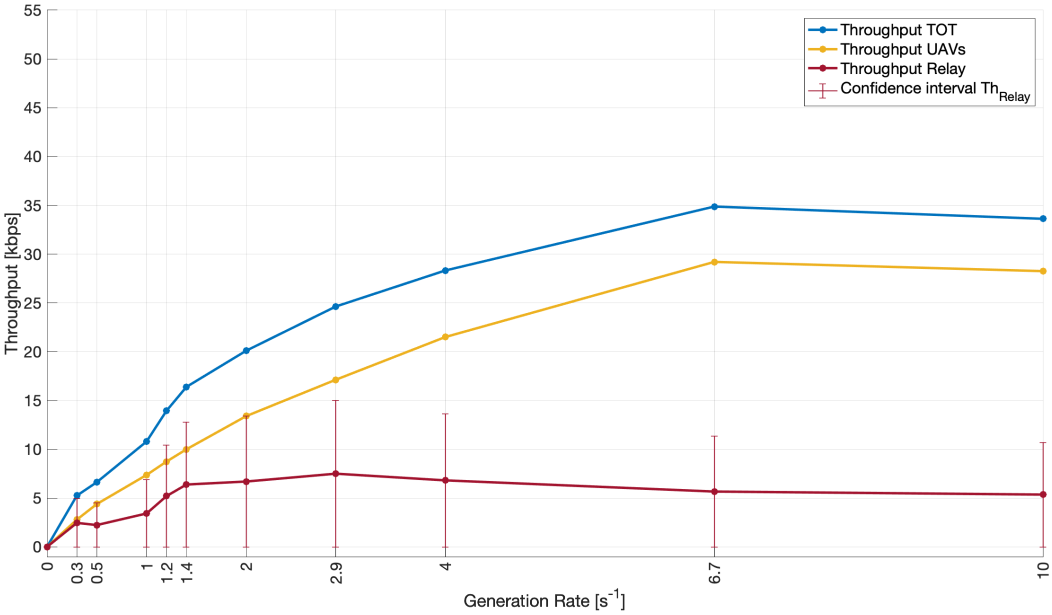

Figure 5: Throughput without missing people

In the graph, it can be observed that as the packet generation rate increases in the given scenario, the ability of both the relay and the UAVs to handle packet transmission is compromised due to channel congestion. This congestion occurs because both the relay and the UAVs communicating directly with the Ground Station (GS) contend for channel access. Despite the relay receiving packets from multiple obstructed UAVs, it competes for channel access with the same probability as a normal UAV. As a result, as the packet generation rate rises, the performance of the relay deteriorates, making it challenging to effectively manage packet transmission.

The aim of this analysis is to determine the optimal packet generation rate by examining various scenarios with different rates of packet generation. It is evident that, once the generation rate surpasses a certain threshold, the relay's performance saturates, and the throughput no longer increases. This limitation arises because the relay struggles to cope with the volume of incoming packets it receives.

Bitloss

Packet loss is caused by two main factors. Firstly, the limited number of transmission attempts by the UAVs, which can be influenced by various factors such as channel congestion or resource occupation. Secondly, packets can be lost due to the finite size of the queues in each UAV and relay. When the queues reach their maximum capacity, incoming packets that cannot be queued are lost.

The figure illustrates the number of lost packets from both the UAVs and the relay. It is crucial to take into account that if the relay's queue, which has the same capacity as other regular UAVs, becomes congested and reaches its maximum limit, any hidden UAVs that attempt to send packets to the relay, with the intention of transmitting them to the GS, will still direct them towards the relay. However, due to the congestion, the relay will be unable to "accept" these packets, leading to permanent packet loss.

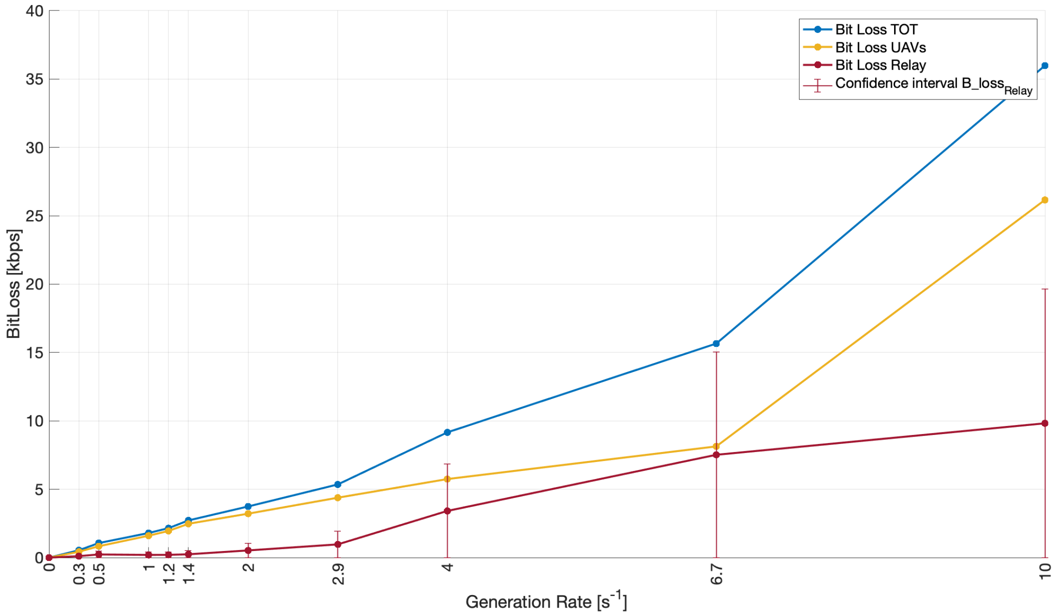

Figure 6: Bitloss without missing people

It can be observed that the behavior of the relay in terms of lost packets saturates at a certain value of generation rate. This means that after a certain rate, the relay is consistently congested and exhibits the same behavior in terms of channel contention and packet loss. On the other hand, regarding the other line representing the behavior of normal UAVs, it is observed that as the generation rate increases, the number of lost packets also increases.

Latency

In the latency figure, it is generally observed that the latency is quite high on average. This is primarily due to the choice of a low bitrate, specifically 100 kbps. It is important to note that this value represents the maximum bitrate, but considering the presence of obstacles or clouds between the transmitter and receiver, the effective bitrate is reduced.

Going into further detail, in this graph, the red line represents the latency of packets passing through the relay; it indicates the time it takes for these packets to travel from the point of generation by the individual UAV, through the relay's queue, to the transmission by the relay, and finally to the reception by the ground station.

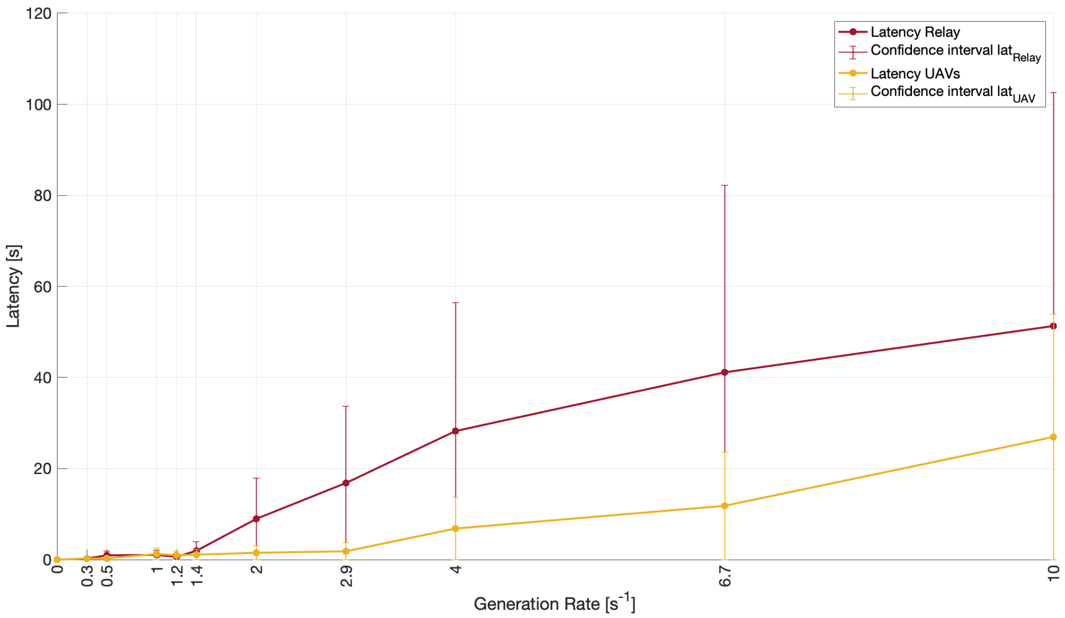

Figure 7: Latency without missing people

It can be observed that for both curves, as the generation rate increases, the latency also increases. This is because the capacity of the queue becomes gradually filled, resulting in a significantly longer time from when a packet is inserted into the queue to when it is processed and transmitted.

The elevated latency values indicate that there is a notable delay in the packet transmission process, which can impact real-time applications or time-sensitive communications. It may be necessary to optimize the system parameters or consider alternative strategies to reduce latency and improve the overall performance of the communication system.

4.2 Scenario With 5 Missing People

In this part of the simulation, a scenario was created with 5 missing persons. Three of them were located on the obstructed side of the mountain, requiring communication through a relay, while the other two were on the direct communication side. The relay played a crucial role in managing the data transmission between the obstructed drones and the ground station, as well as handling communication contention with the drones on the direct communication side. This scenario aimed to test the simulator's performance under challenging conditions, where the relay had to handle data from both obstructed drones and direct communication drones related to the missing persons.
In addition, in this new scenario, it should be noted that in addition to synchronous packets, there are also asynchronous packets, resulting in increased channel access demands from both the relay and the unhindered UAVs.

Throughput

Here, a noticeable difference from the scenario without missing persons is observed: at a low generation rate of synchronous packets, the relay's throughput is higher, indicating successful reception of both synchronous and asynchronous packets. It is important to note that the throughput of the relay and the UAVs, which can communicate directly with the GS, is almost identical. This indicates that the channel occupancy time is distributed evenly between them, with a 50:50 ratio. Furthermore, considering that the UAV transmits various types of data, such as images and telemetry files of multiple UAVs, the low generation rates, up to 2 pps, ensure a packet fairness. This fairness guarantees that all data types have an equal opportunity for transmission.

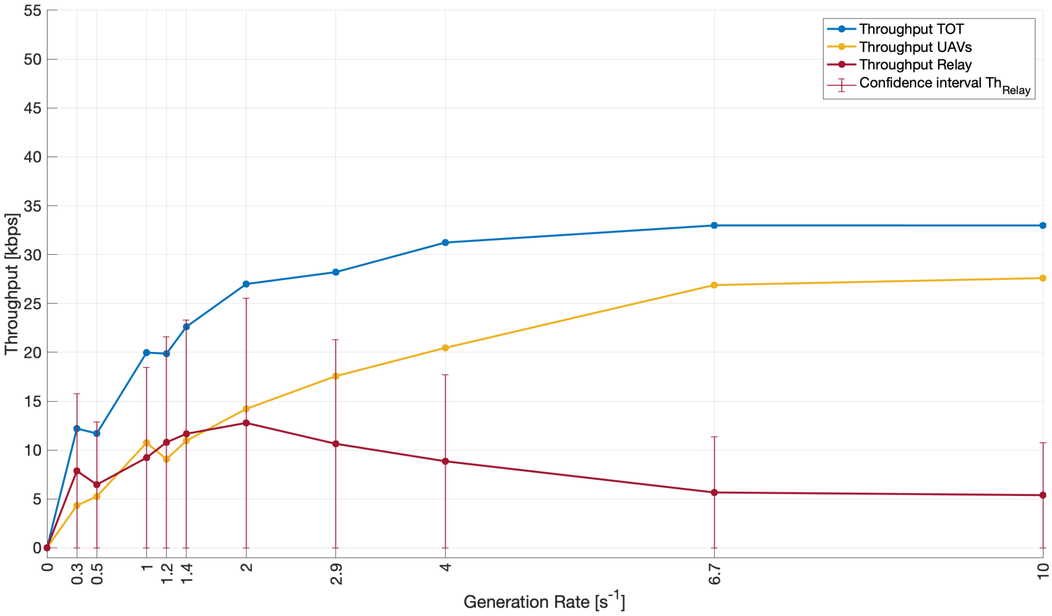

Figure 8: Throughput with missing people

However, as the generation rate increases, the system's performance deteriorates. The higher number of synchronous packet generation overwhelms both the UAVs' and the relay's queues, resulting in system inefficiency. This inefficiency leads to an increased number of packet losses, including those containing data related to missing persons. As a result, the probability of successfully receiving the data related to missing persons decreases.

Bitloss

The figure represents the bit loss behavior that has similar behavior to the previous scenario. However, the presence of images related to the missing persons further exacerbates the issue of packet loss. As the generation rate increases, the limited capacity of the queue becomes a bottleneck, resulting in a higher number of lost packets. The congestion of the channel and the insufficient space for images and telemetry data contribute to the overall degradation of the system's performance in terms of bit loss.

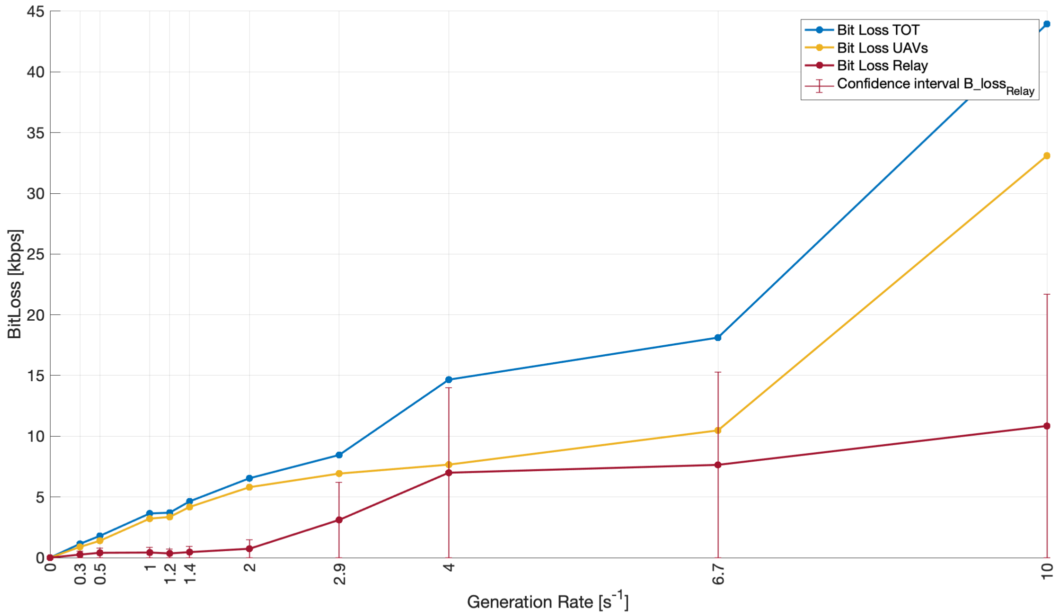

Figure 9: Bitloss with missing people

Latency

In this final graph, we observe the latency behavior, which exhibits a similar pattern to the previous scenario. It is important to note that the high latency values are primarily attributed to the chosen maximum channel capacity. Increasing the bitrate would significantly reduce the latency.

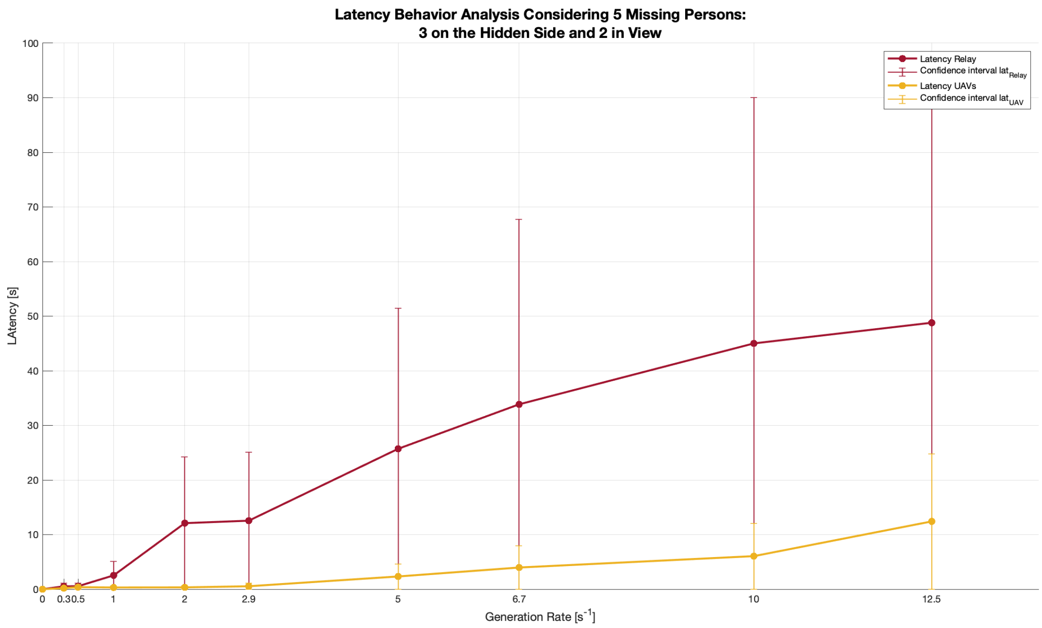

Figure 10: Latency with missing people

5 Conclusions

In the conducted analysis, it was observed that an increase in the generation rate leads to channel congestion and degradation of system performance, resulting in an increase in packet loss. The relay plays a critical role in the communication between hidden UAVs and the Ground Station but can become congested and inefficient due to the additional load. The channel capacity and management of asynchronous packets also impact overall performance. It is important to properly balance these variables to ensure the high efficiency and reliability of communications.

References

[1] dji ENTERPRISE. Uav model. https://www.dji.com/it/matrice-300.

[2] dji ENTERPRISE. Uav specifications. https://enterprise.dji.com/it/matrice-300/specs.