universidade de aveiro deti departamento de eletrónica, telecomunicações e informática

WiFi Mesh Laboratory Exploration

Mobile Communications Project

Álvaro Frazão **97912**

Boris Teixeira **98472**

David Ferreira **93444**

Developed under the orientation of professors Daniel Corujo and Francisco Fontes

January 2023

Index

1. Introduction

A mesh network is a network in which devices - or nodes - are linked together, branching off other devices or nodes. These networks are set up to efficiently route data between devices and clients. They help organizations provide a consistent connection throughout a physical space.

Mesh network topologies create multiple routes for information to travel among connected nodes. This approach increases the network's resilience in case of a node or connection failure. More extensive mesh networks may include multiple routers, switches, and other devices, which operate as nodes. A mesh network can include hundreds of wireless mesh nodes, which allows it to span a large area.

As a project, the team intends to quantify the impact of mesh networks in common problematic scenarios for traditional Wi-Fi networks. This has an objective to highlight the advantageous qualities of mesh networks but also the limitations that can result from having a Wi-Fi network for large physical areas.

2. Objectives

This laboratory work has the objective, not to characterize the devices with which the experiments are run, but to measure the impact of mesh networks in opposition to traditional network topologies in a set of real-world scenarios. These scenarios are based on two basic concepts of mesh network tied with the disposition of the topology, these are **star** and **waterfall** topologies, as shown in Figure 1.

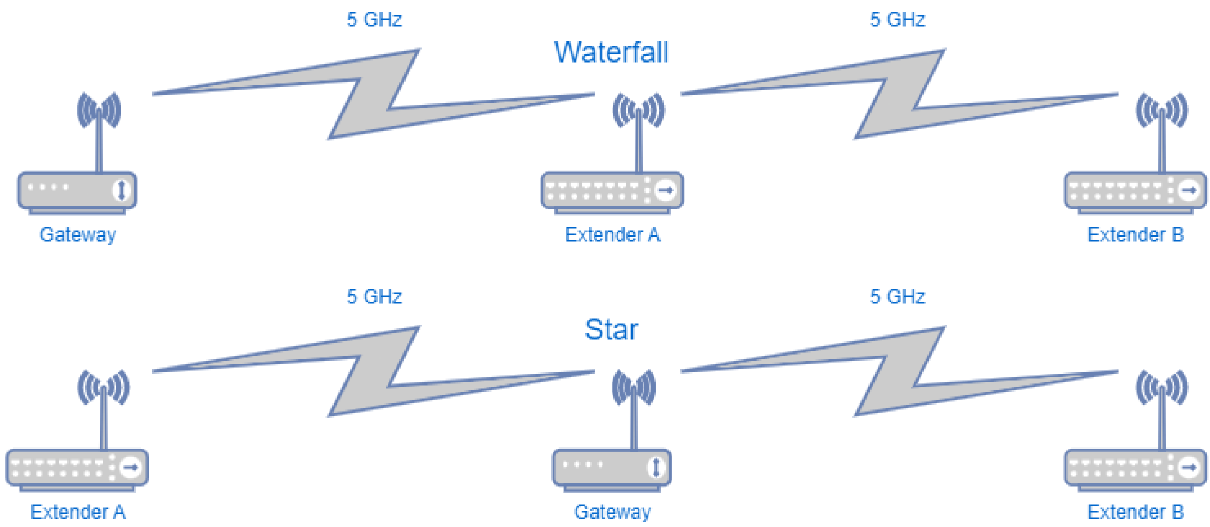


Figure 1
Illustration of device disposition in *waterfall* and *star* topologies.

The objective of the procedures, to be described in the next section, is mainly to comprehend how the mesh network can improve connectivity in scenarios of large physical distances and obstacle avoidance which are two of the main downfalls of traditional wireless networks.

It is expected a noticeable improvement in connectivity with a mesh network as opposed to a traditional one when two hosts are trying to communicate in a network deployed in a physical space containing multiple obstacles, like walls, between the hosts or when one of the hosts is mobile and during the connection moves to a relatively large distance from the other host.

The results expected are a noticeable drop in packages lost during communications and, as a mere exploratory example, discover if communications over a large distance of a single hop over 2.4 GHz is better or worse than a short distance 2.4 GHz connection combined with a medium distance connection over 5 GHz.

3. Proceedings

For experimentation, two scenarios were developed in order to emulate real-world scenarios where traditional networks would experience communication difficulties and where, on paper, mesh networks would prove to be advantageous.

To test them, there were also developed small tools to automate and replicate the experiments in the most exact manner possible.

3.1 Tools

For the experiments, *iperf3* and *ping* tools were used. The selection of these tools is justified by the fact that the measures in observation are directly tied to the speed and the throughput of the connection.

A script was built for the use of *iperf3* in an automated fashion. This script runs the *iperf3* during sixty seconds, in bidirectional mode, with three parallel socket in order to create an average reading between them..

The data of interest given by *iperf3* are the bit per second (*bitrate*) and the number of retransmissions. The first one is important to measure the throughput of the connection and the second, since the connections are of the TCP kind, allows us to visualize directly the impact that the environment has on the transmissions of packets and the loss of these to the obstacles.

The ping tool is particularly useful for the second scenario where the objective is to observe the impact on the connection speed when the Client moves away from the connection point, and in the mesh scenario, how the *handover* of the connection between the Extender is able to impact said speed.

At the end of the connection, the *iperf3* tools exports all the data to JSON files witch are then used by a Python program (*jsonDigest.py*) which by using the *matplot* package is able to calculate the *bitrate*, *RTT* and *retransmissions* values and plot graphs for data visualization.

4. Experiments

4.1 Scenario 1 - Obstacle Avoidance

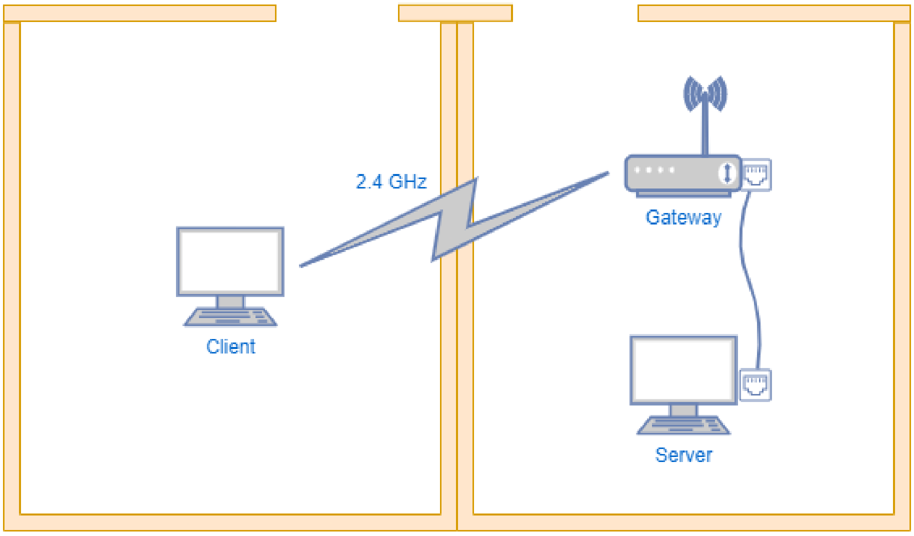


Figure 2
Traditional wireless network with hosts in different physical locations.

Figure 2 demonstrates a common scenario in real-world applications, where two network hosts communicate with an obstacle in between. The server is connected via a physical UTP link to the main gateway to eliminate the natural variability of wireless connections between the Server and Gateway and by doing so, correlate as much as possible the results of the experiments to the variation of the wireless connection via the obstacle between the Client and the Gateway.

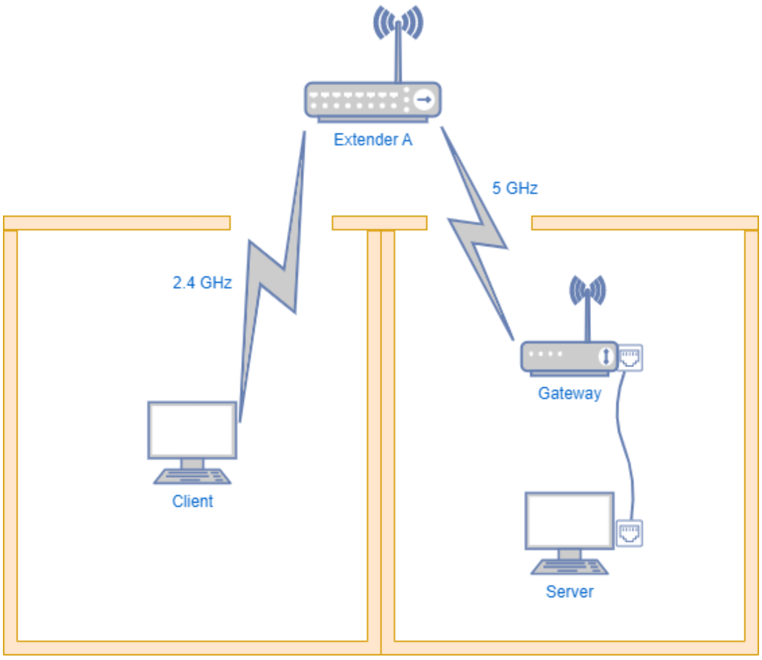


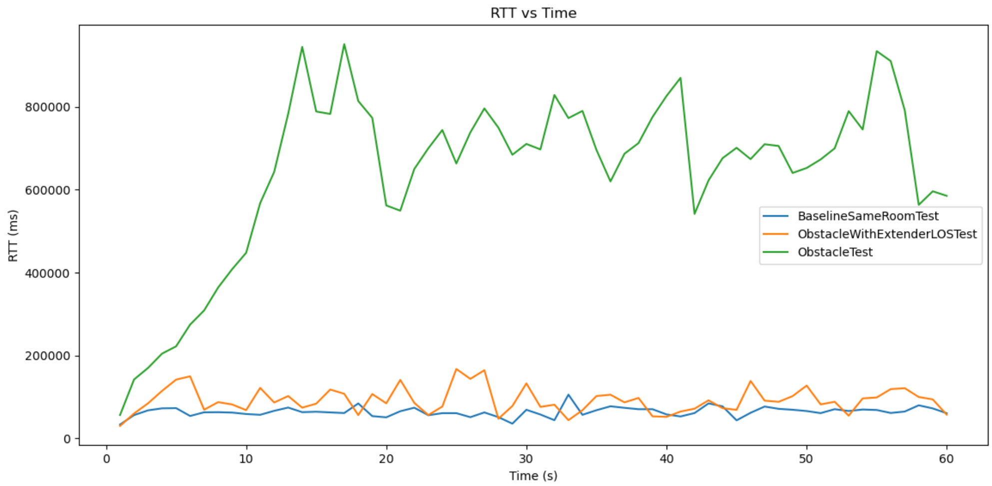
Figure 3
Mesh topology for obstacle avoidance.

After running the testing tool with this network topology, the mesh topology shown in Figure 3 was applied and the tests were re-run. This topology relies on the Extender being located at the line of sight between the Gateway and the Client, with the Client and the Gateway still at their original positions and with no change applied to them.

What is expected to occur is for the connection to automatically change and start to be relaid through Extender A which will reflect mainly in a decrease in retransmissions, meaning fewer packets are being lost now that the obstacle is being avoided. Latency however can be an issue with an extra hop in the connection and this can reflect in the bitrate lowering since the round-trip delay will increase.

As a baseline measurement, the test is also performed without the experiment, and all the devices are in the same room at a relatively short distance from each other.

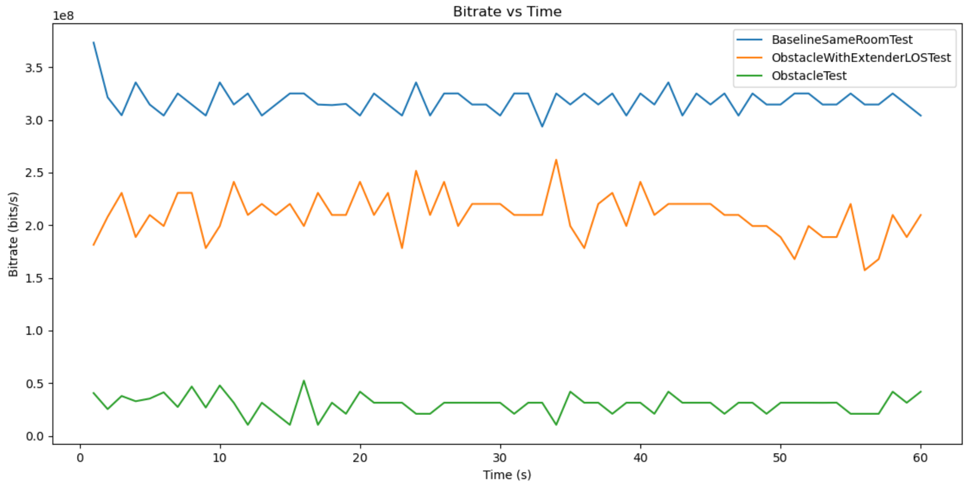
4.1.1 Results



Graph 1
Comparison of Round-trip-time (RTT) over time between the two scenarios and a baseline

As expected, the effect of physical obstacles has a tremendous negative effect on the latency of communication in a wireless network. In Graph 1 we can observe the contrast between the two scenarios, in green, we have the communication through the obstacle, and in orange, the communication with the use of an extender that allows the connection to avoid the obstacle.

What is also visible is that, although the extender decreases the RTT substantially, it does so with the addition of some latency resulting from the extra *hop* in the communication. What can also be a factor in the improvement of the overall latency is the fact that for purposes of obstacle avoidance, the extender is placed closer to the Client, thus decreasing the distance of the 2.4 GHz connection, and because the communication between APs occurs in the 5 GHz bands, the communication is then much faster with the Gateway.



Graph 2
Comparison of bitrate over time between the two scenarios and a baseline

When comparing the bitrate, which is also dependent on the latency of the connection, the result also meets the expectation with the scenario with the Extender approaching the baseline measurements.

4.2 Scenario 2 - Mobile Client

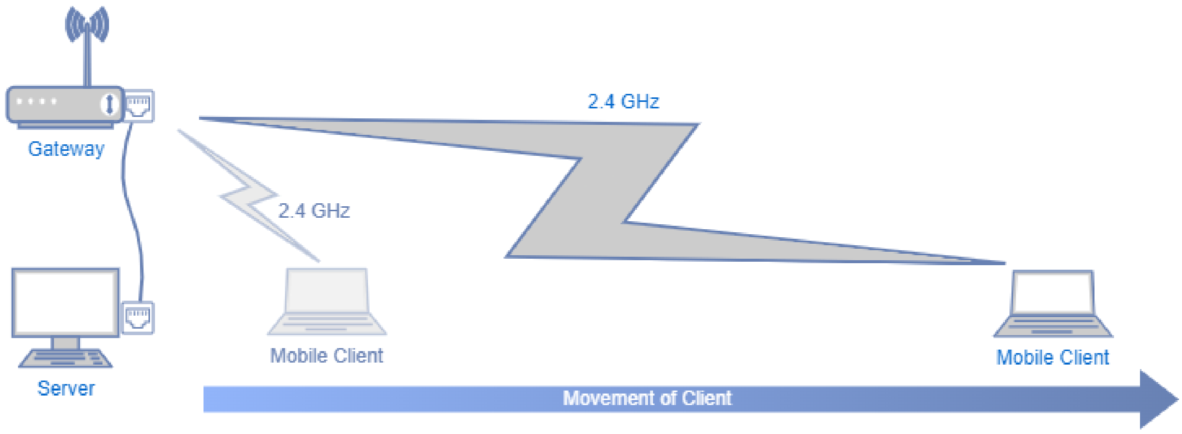


Figure 4
Wireless connection between a stationary Server and a mobile Client.

Figure 4 illustrates the connection between a stationary server, connected with the Gateway via a UTP link (for stability reasons described before), and a mobile client connected wirelessly to the network and in active communication with the server. During the communication, the client starts physically close to the server and after approximately one minute it will have moved away from the Gateway to approximately thirty meters.

This communication scenario will serve as a baseline for the degradation of the quality of the connection with the increase in distance between a client and the Gateway.

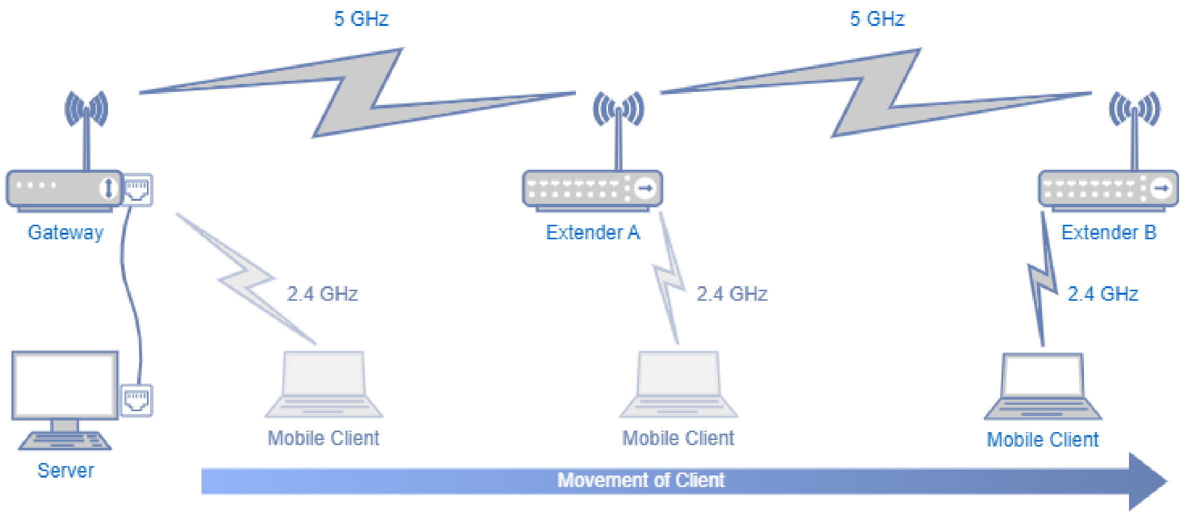
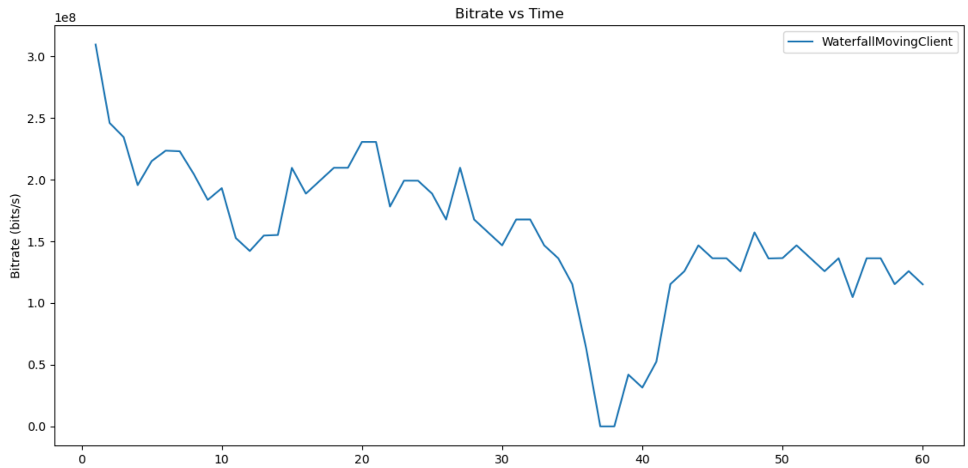


Figure 5
Wireless connection between a stationary Server and a mobile Client with a mesh network.

Being that mesh networks are specially designed for large area coverage, it has also been previously mentioned that the addition of nodes in a connection negatively affects the bitrate of the connection. Knowing this, the experiment intends to observe if a single but long-distance 2.4 GHz connection is preferable to a combination of a single and short-distance 2.4 GHz connection, combined with one, or more, medium-distance 5 GHz connections. The procedures for testing with this new topology are the same as with the previous one.

4.2.1 Results



Graph 3
Bitrate over time of a client moving away from the Gateway

As we can see in Graph 3, it is evident the moments in time when the handover of the Client connection occurs between access points (APs). The first handover is particularly important; it occurs approximately twelve seconds after the beginning of the test, between the Gateway and the first Extender in the daisy chain. It is important to note that, before the handover, the connection between the Gateway and the Client is handled by a single wireless connection in the band of 2.4GHz, and after the handover, it will then occur is two separate links, one in the band of 5 GHz, between the Extender and the Gateway, and the other in the band of 2.4 GHz between the Extender and the Client.

After the handover, the bitrate improves significantly to levels only comparable to the ones when the Client was near the Gateway, what this shows is that the bitrate degradation per unit of distance is much lower in 5 GHz connections. Also proving this observation is the fact that when trying to find comparable measurements of bitrate to compare with the lowest bitrate observed in the single 2.4 GHz connection (moment of the first handover), these will be found in sections where the client was further away from the Gateway, which again, makes the point that for the same bitrate, a higher distance is possible, if the connection is made by a combination of 5 GHz and 2.4 GHz links, instead of a single long-distance 2.4 GHz link.

For the second handover, we can observe the improvement in bitrate, but contrary to the first one, the improvement is not as pronounced, which argues the case for the obvious: although the extenders with their 5 GHz connection do improve the connection, the cumulative effect of the latency of each node, for increasingly larger distances, will neutralize the benefits of a new and faster link in the connection, thus imposing a limitation in the usefulness of this type of topology for the escalation of the physical infrastructure. (Although, it is important to note that this will depend on the potency of the hardware used, which does not fall within the scope of this experiment.)

5. Conclusion

From the experiments conducted for this project, the benefits of mesh networks are clear when dealing with networks of a larger scale and the deployment of these in intricate physical spaces.

It was observed that with careful placement, the connection improvement by the routing between Extenders will avoid most obstacles in order to better the connection with the Client, and although latency does increase slightly, the faster connection in 5 GHz between Extenders more than compensates for this complication.

Some other experiments for this project were also conceived for this project, unfortunately, they were not possible to be conducted. The capture and analysis of packets transmitted between APs would be quite useful and enlightening, but the fact that the connection between the hardware provided is encrypted makes this impossible. The team did try to capture them nonetheless, being that the only observable packets during a TCP connection were request-to-send (RTS) and clear-to-send (CTS), which do not offer any relevant information for our use case.

Some tests for network behaviour and performance were also intended to be conceived, but since these relied on our ability to use the application MEO Smart WiFi developed by Altice, we never managed to get these ideas off the ground. Simply because we were unsuccessful in using the application to set up the network in the first place: for an unknown reason, we were unable to successfully connect the Extenders to the Gateway in order to perform the tests. Wired connection allowed us to use the app, but since our tests were intended for wireless connections, we dropped this avenue of testing altogether.