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WiFi NETWORKS ON DRONES

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ABSTRACT

The huge growth in the number of connected wireless devices leads to an increasing demand for network connectivity. In this context, aerial networks may play an important role by widening the concept of access networks. This paper describes and analyzes one of the most promising applications of Unmanned Aerial Vehicles, commonly known as drones, in the field of communications: Extending the capacity or coverage of wireless systems through the deployment of aerial communication networks. We present a comprehensive characterization study of an experimental system to deploy an aerial WiFi network. To do so, an Intel Galileo development board is appropriately configured and equipped as a WiFi node playing either the role of an access point in the infrastructure mode or of an intermediate hop in the ad-hoc operational mode. This device is then integrated onboard a drone. We compare both WiFi modes in terms of coverage area, throughput, and energy efficiency. Preliminary results reveal that there is a trade-off between coverage and data rates, for which the infrastructure mode performs better, and energy efficiency, where the ad-hoc mode is more responsive.

Keywords— Aerial network, UAV, drones, WiFi, low altitude platform, network access.

1. INTRODUCTION

Initially seen as an optional commodity, network connectivity has come to be considered an essential utility. There is not only a growing number of devices (e.g., smart phones, bracelets, wearables, different-nature sensors, etc.) that need to be almost continuously connected because of the advent of the Internet of Things (IoT) paradigm, but societal changes are also posing new challenges into the telecommunications arena. As a surprising example, it has been recently published in the news the need of Internet access that refugees request when they get to the refugees' camps. Among their first questions asked when they arrive was "when will we get WiFi?", and far from frivolous, this is a need for them as important as being fed [1]. Therefore, we face a world scenario with a tremendous growth of connected devices and redoubling demand of network access or connectivity.

On the other hand, UAV (Unmanned Aerial Vehicles) have recently drawn the interest of the research community. Due to the strong efforts made to improve their performance, e.g., miniaturization, energy efficiency, etc., UAV have become a useful tool widespread in different disciplines. These devices, also known as drones, provide disruptive applications in areas such as military, logistics, environmental monitoring [2], or rescue activities. For instance, drones eliminate the need of human presence to accomplish dangerous tasks and hence the risks that some of these activities entail are dramatically reduced. In the telecommunications field, one of the most promising applications of UAV is to use them as support equipment, aimed at extending the capacity or coverage of wireless systems through the deployment of an aerial communication network [3]. An interesting strategy used to achieve this goal is to assemble a light development board, e.g., Raspberry Pi [4], Intel Galileo [5], etc., onboard a UAV. Their low power consumption and the high number of connectivity elements that they support (communication chips, antennas, etc.) are among the most valuable features that these cheap single-board computers offer to perform this task. Thus, these devices are able to deploy a wireless network acting as network nodes within the system architecture, and allowing the end-users/things to gain connectivity through them. WiFi is so far the most widespread access network for providing connectivity to end-users' wireless devices. As specified by the standard (IEEE 802.11), it provides two different modes of operation: the infrastructure mode and the ad-hoc mode, with their corresponding pros and cons depending on the application scenario. Both modes are provided by all versions of the WiFi standard family (IEEE 802.11a/b/g/n/ac), which has increased its maximum transmission rate almost exponentially, using the 2.4 GHz (802.11b/g/n) as well as the 5 GHz (802.11a/ac) Industrial, Scientific, and Medical (ISM) radio bands.

In this paper, we present a complete characterization study of an experimental system for deploying an aerial WiFi network. To this purpose, we use the Intel Galileo development board integrated into a UAV. First, we conduct a theoretical coverage study by means of two suitable radio propagation models for the scenario under consideration. Second, we carry out an experimental deployment of the aerial network and explore both, the infrastructure or access point-based (AP) and the ad-hoc

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modes. Then, we compare the maximum transmission rates and the coverage achieved for each operational mode and discuss which one better fits considering the system requirements. Results attained from the working system in a real flying experiment are included and compared with those obtained theoretically and from a controlled lab test-bench. Finally, we present an experimental study regarding the energy efficiency of the development board. To this end, the instantaneous current consumption obtained for the different modes of operation, in both idle state and transmitting under different-rate data flows is measured.

The rest of the paper is organized as follows. In Section 2, we review the most prominent works regarding the deployment of aerial networks using UAV. The methodology and equipment used in this work is described in Section 3. Section 4 presents and comparatively discusses the results obtained from both theoretical and experimental studies. Finally, Section 5 concludes.

2. RELATED WORK

According to recent estimates of EUROCONTROL (the European Organization for the safety of air navigation) [6], we are already living with some two million UAV around the world considering all their types, from toys to large military vehicles. Taking into account that there are around 200,000 manned aircraft, and the fact that the safety of these last aircrafts is a must, the European Aviation Safety Agency (EASA) is still trying to reach the objective established in December 2013 by the European Council in order to develop a strategy to support the progressive development of the UAV market in Europe. This regulatory framework stated a common regulation within all the EU countries for UAV with an operating mass of 150 Kg or more. However, the use of civil UAV below this weight should be regulated by individual Member States of the EU. In this last scenario, the Spanish Government has been doing its homework and can be considered as a pioneer: AESA (the Spanish National Agency for Air Security) published in April 2014 a regulation draft for the use of UAV [7] and it is expected to be updated shortly. The reasons that explain this leading position are varied: UAV technology is available in Spain, the aeronautic industry is well positioned, and there are appropriate weather and population conditions (low density, large extensions, etc.), among other factors.

Focusing on communications, UAV have been used to deploy air networks in different fields of action [8, 9], and research in this area is increasing. Drones usually operate on the ISM, IEEE-S, and IEEE-L bands. Due to the proliferation of wireless devices that also work in these bands, Saleem *et al.* suggested in [10] the possibility of using Cognitive Radio technology in UAV communications as a way to solve the spectrum scarcity problem. Nevertheless, using cognitive radio results in additional challenges to be solved at upper layers of the communication architecture, as indicated by the authors. Routing in aerial ad-hoc networks is addressed in [11]. Routing is challenging in this scenario mainly because of UAV high mobility and the fact that most ad-hoc routing protocols have been studied following planar graph-based techniques not suitable in 3D (as it would be the case of UAV networks). Their routing proposal seems effective in this environment, although as the authors stated, it still needs some refinement to improve its performance. UAV networks have been also tackled from the perspective of Delay Tolerant Networks. The work in [12] introduced a so-called Autonomous Flight Wireless Node to deliver data under poor network conditions from one location to another using an epidemic delay-tolerant routing approach. Other research focus has been flying planning [13, 14]. For instance, in [14], authors proposed to leverage public wireless communication infrastructures to connect UAV. They included a planning method so that UAV only fly within a 3G coverage area, i.e., avoiding non-signal zones, with interesting results.

Similarly, several initiatives have been announced using UAV to provide broadband connectivity. For instance, the European projects ABSOLUTE, ANCHORS, and AVIGLE. When a UAV is exploited with this aim, the term Low Altitude Platform (LAP) can be also employed. The work done by Säe *et al.* [15] studied the coverage of temporary WiFi networks built using drones as access points. The authors only used computer simulation to theoretically evaluate the coverage area by applying a deterministic radio propagation model called the Dominant Path Prediction Model. As we will discuss in next sections, the lack of experimental results in Säe *et al.*'s work is a notable shortcoming since their results will likely not match with real measurements. Likewise, the work in [16] presented results about the use of the IEEE 802.11n and 802.11ac standards in aerial WiFi networks. These protocols were used for communication among UAV, between a UAV and a ground station, and to provide terrestrial coverage. They operated drones flying at an altitude of 50 m and the ground station was located at a height of 2 m. Their experimental results revealed that greater throughputs can be achieved by using 802.11ac when compared to IEEE802.11n, although different performances are achieved for 802.11 depending on the used driver, so further experimental research is needed to better understand this behavior. Please note that in addition to use different versions of the WiFi standard, in our work we will use the UAV as an intermediate node between two ground communication endpoints, whereas in [16] the communication endpoints were the UAV and the ground station. As we will see in the results section, this detail has an important impact on the measured performance metrics.

The trend of mixing cellular communications with UAV networks to extend connectivity has been also recently addressed. For example, authors proposed in [17] to transform the UAV into a 5G base station, so that a heterogeneous network (known as HetNet in 5G terminology) can be formed. By means of computer simulation authors showed that it is possible to improve coverage and capacity by deploying this system. Nevertheless, further experimental work is needed to corroborate these promising results. Finally, the energy efficiency of these systems was evaluated in [18]. With an extensive analytical study, authors demonstrated that the use of passive scanning for the mobiles and the periodic beaconing for UAV is possible to optimize the drones' energy consumption maintaining high connectivity.

3. METHODOLOGY AND EQUIPMENT

In this section, we describe the methodology and the main features of the devices employed to perform this study. The Intel Galileo board was used as the central element of the system. This development board is based on the Quark SoC X1000 Intel 32-bit processor at 400MHz. Specifically, the Intel Galileo Generation 1 was used in the experiments conducted. This board ran a well-suited version of Linux (Linux quark 3.19.8 yocto-standard). This Linux image is based on BSP 1.2.0 [19] (iot-devkit, Intel IoT Development Kit) with Kernel 3.19.8 of Linux and several patches that built a consistent platform to provide the different communication configurations as described in this work. Regarding the Galileo board power supply, an external battery of 10400 mAh was used. This battery allows up to 15 hours of Galileo's working time, depending on the operational mode and the traffic load. More information about the lifetime will be provided in the results section. The Intel Dual Band Wireless-AC 7260 wireless card was connected to the Galileo board through its PCI Express port. This network card allows for connections up to 867 Mbps, supporting several WiFi standard versions, namely, IEEE 802.11a/b/g/n/ac. This wireless card can operate as an access point, or as an ad-hoc node within a mesh network. In addition, we also used two 5 dBi omnidirectional gain external antennas providing large coverage range. The total weight of the board, the battery, and the antennas is approximately 340 g. Then, we illustrate the methodology followed. Our work was divided into three phases. First, we developed a theoretical study of a UAV coverage area equipped with the Intel Galileo board acting as a WiFi node. We assumed an open-air scenario and selected two radio propagation models: Free Space (or Friis) model [20] and the Wireless World Initiative New Radio (WINNER) D1 model [21]. Based on these models, we calculated the maximum expected uplink and downlink radio coverage for several versions of the WiFi standard.

Second, we experimentally tested the performance of the Galileo board as an intermediate node within a WiFi network. These tests were performed first in a controlled lab test-bench (static on-the-ground) and then, in a real aerial deployment. In both cases, we studied the two main operational modes of the IEEE 802.11. The usual mode of operation is the infrastructure mode, which is implemented in most commercial WiFi routers. This mode deploys a network within the coverage area of a central device (the access point, AP), which interconnects all nodes composing the system and acts as a gateway towards an external network (e.g., Internet). Thus, the AP assumes all management tasks of the WiFi network. On the other hand, the ad-hoc mode is a less extended operational mode for WiFi networks. This mode of operation lacks of a central point, so all nodes composing the network connect each-other forming a mesh network. In this case, each node simultaneously assumes both client/host and router tasks, hence network nodes periodically scan for retrieving information about their neighboring nodes. This ad-hoc mode allows the dynamic routing of data-traffic, eliminating the coverage constraint imposed by the access point in the infrastructure mode. In addition, if the ad-hoc network nodes can move, then these networks are called Mobile Ad-hoc NETworks (MANET), which means that links between nodes may be dynamically dropped or created due to nodes movement. An efficient operation of ad-hoc networks strongly relies on the routing algorithm, which is responsible for an effective information delivery towards its destination. Due to the dynamic nature of the network topology, the cost of the links should be periodically evaluated to search new routes and hence choosing the best paths depending on the provided service.

Therefore, in order to test these two WiFi modes, two additional end-devices were included in the system. These nodes were two Linux Ubuntu laptops with wireless cards compatible with the IEEE 802.11 a/b/g/n standard. At the receiving endpoint of the communication, a laptop with the Intel Centrino Advance-N 6230 wireless card was located, and another laptop with the Intel Dual Band 3160 wireless card was employed in the other communication endpoint (transmitter). The Intel Galileo board was always the central point of the system, either working as the AP (infrastructure) or as the intermediate node (ad-hoc) between transmitter and receiver. In the latter, the well-known ad-hoc routing protocol BATMAN [22] was employed. This protocol has already shown a superior performance than other important ad-hoc routing protocols under heavy traffic loads [23]. We used the iPerf3 tool to obtain network metrics. iPerf3 performs active measurements for determining the maximum achievable bandwidth on IP networks, among other metrics such as packet loss or delay. It supports the set-up of several transmission parameters and network protocols. For this study, we used Constant Bit Rate (CBR) transmissions between the communication endpoints with a duration of 30 s, under different bit rates (1, 3, 5, 7, 9, and 11 Mbps), and two different packet sizes (512 and 1024 Bytes).

Regarding the real aerial network, measurements were acquired from the architecture shown in Fig. 1. The two endpoints were progressively separated from each other along the X axis. For the different measurement points (represented as marks in the X axis of Fig. 1), we obtained the maximum available bandwidth using the iPerf3 network tool and the signal level using the Rohde &

Schwarz's FSH3 spectrum analyzer [24]. The UAV was an Idea-Fly IFLY-4S drone, able to carry up to 700 g of payload, positioned at two different heights (10 and 20 m, respectively). It was equipped with the Galileo board, its corresponding battery, and the couple of antennas described above (see Fig. 2).

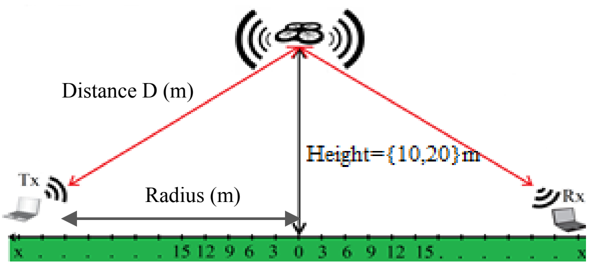
Third (and last), we also conducted a study of the Galileo board's energy consumption. To this end, the instantaneous board's current consumption was measured for the different operating WiFi modes under consideration. The testbed employed for obtaining these measurements is illustrated in Fig. 3. Note that the demanded current is checked at a resistance in series with the power supply feeding the board. By using a data-acquisition card, the board consumption was monitored by means of the Matlab software.

4. RESULTS

Prior to the effective deployment of any network, it is necessary to conduct a performance evaluation of the proposed system. In the following, we specifically explored three key metrics for this type of system: (i) coverage area, (ii) transmission rate, and (iii) energy efficiency.

4.1 Coverage range

In this section, we present both the theoretical study of the coverage area that a UAV can reach with an Intel Galileo onboard and the experimental results obtained. For the theoretical study, it was assumed that the deployed scenario was an open area, without obstacles or any other source of interference, hence existing permanent line-of-sight (LOS) between the intermediate node (UAV) and the communication endpoints. Under these conditions, the analysis of the signal propagation loss was done by means



(a) Diagram

(b) Real snapshot

Figure 1. Experimental test-bench.

Figure 2. Drone used in the experimental aerial WiFi network.

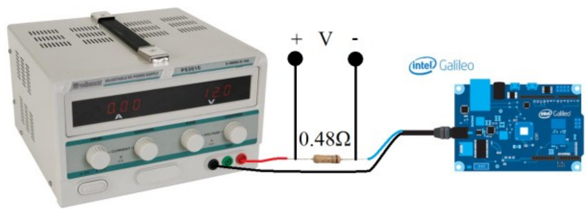


Figure 3. Experimental setup for current consumption measurements.

of two well-known radio propagation models, namely, the Free Space (or Friis) model [20] and the WINNER D1 model [21]. The Free Space model is usually employed to predict the signal strength when there is LOS between transmitter and receiver and there are no nearby objects that might obstruct communication. This model is defined by expression (1). In order to use rigorously this model, it must be applied just under far field conditions. This term is met in the considered environment due to the small size of the used antennas and the long distances covered by the proposed system (please refer to [20] for a more thorough analysis of this concept).

In turn, the WINNER channel model is a stochastic model that predicts channel-introduced losses for different types of environments. The WINNER D1 variation was the specific model chosen for this work due to the aforementioned characteristics of the scenario under study, namely, an open outdoor environment with no obstacles and with the "base station" located at an elevated position; thus, with existence of LOS between the UAV and the other nodes composing the network. The WINNER D1 model is defined by (2), where A = 21.5, B = 44.2, and C = 20.

$$\begin{aligned} L_{PROP} &= 10\log_{10}(4\pi d/\lambda)^2 = \\ &= 20\log_{10}\big(d(m)\big) + 20\log_{10}\big(f(Hz)\big) + 20\log_{10}\left(\frac{4\pi}{c}\right) \\ &= 20\log_{10}\big(d(m)\big) + 20\log_{10}\big(f(MHz)\big) - 27.55 \end{aligned} \quad (1)$$

$$L_{PROP} = A\cdot\log_{10}\big(d(m)\big) + B + C\cdot\log_{10}\left(\frac{f_c[GHz]}{5.0}\right) \quad (2)$$

Therefore, taking into account a transmission power for both the uplink and downlink of 20 dBm (100 mW) and the characteristic gain and sensitivity values of each wireless card as specified in the datasheets, we calculated the maximum coverage distances for the different versions and operating bitrates of the IEEE 802.11 standard. These results are written in Table 1 (downlink) and Table 2 (uplink). Please note that the scenario for these

Table 1. Comparison of radio coverage. Downlink.

Standard		Rate (Mbps)	Prop. Mod	Radius (m)	Max D (m)
2.4 GHz	802.11b	11	Friis	6719	6718,9
			Winner D1	4613	4612,9
	802.11g	54	Friis	950	949,95
			Winner D1	747	746,93
	802.11n	144	Friis	754	753,93
			Winner D1	603	602,92
		300	Friis	534	533,91
			Winner D1	438	437,89
5GHz	802.11a	6	Friis	2562	2561,9
			Winner D1	1882	1881,9
		54	Friis	362	361,86
			Winner D1	305	304,84
	802.11ac	78	Friis	182	181,73
			Winner D1	161	160,69
	802.11n	144	Friis	145	144,65
			Winner D1	130	129,61
		300	Friis	115	114,56
			Winner D1	105	104,52
	802.11ac	200	Friis	102	101,51
			Winner D1	94	93,47
		866	Friis	65	64,23
			Winner D1	62	61,19

calculations is shown in Fig. 1 and we assumed that the drone is located at a height of 10 m. After this theoretical study, the signal strength was also evaluated in the real experiment as described before. Fig. 4 compares the level of received signal in both modes of operation (infrastructure, Fig. 4(a) and Fig. 4(c), and ad-hoc, Fig. 4(b) and Fig. 4(d)) at two drone-flying heights, namely, 10 m and 20 m. Observe the notable difference between the expected theoretical values and the actual attained figures. This can be explained by many elements influencing the real experiment: drone instability, interference caused by the drone's chassis, atmospheric conditions, etc. Comparing both modes of operation, we detect that the level of received signal in the infrastructure mode (Fig. 4(a) and Fig. 4(c)) was significantly higher than in the ad-hoc mode (Fig. 4(b) and Fig. 4(d)). This increase in the signal level for the infrastructure mode was reflected also in a better throughput, as it will be discussed in the next subsection. Please, note that the reduced number of measurement points for the ad-hoc mode (Fig. 4(b) and Fig. 4(d)) can be explained by the fact that only the measurements obtained when the drone acted as an intermediate point between the two communication endpoints were included, ignoring the results gathered when the transmitter and the receiver laptops were directly connected. In other words, while the distance between the communication endpoints was smaller than 60 m (drone flying at a height of 10 m) or 80 m (drone flying at a height of 20 m), the UAV did not act as an intermediate node in the ad-hoc mode.

Table 2. Comparison of radio coverage. Uplink.

Standard		Rate (Mbps)	Prop. Mod	Radius (m)	Max D (m)
2.4 GHz	802.11b	11	Friis	2440	2439,9
			Winner D1	2227	2226,9
	802.11g	54	Friis	487	486,90
			Winner D1	402	401,88
	802.11n	72.2	Friis	274	273,82
			Winner D1	235	234,79
		300	Friis	194	193,74
			Winner D1	171	170,71
5GHz	802.11a	6	Friis	1475	1474,9
			Winner D1	1126	1125,9
		54	Friis	234	233,79
			Winner D1	203	202,75

4.2 Transmission Rates

In order to evaluate the performance of the infrastructure and the ad-hoc modes in terms of throughput, we used iPerf3 for several CBR transmissions lasting 30 s each, between both communication endpoints. We accomplished two experiments in which the Galileo board acted as an intermediate hop between the two communication endpoints (laptops). In the first experiment, which was carried out under lab controlled conditions, four different configurations were explored, namely, infrastructure and ad-hoc with two different packet sizes (512 B and 1024 B). The obtained results are included in Table 3. Observe that the performance in terms of throughput of the infrastructure mode was notably better than that attained by the ad-hoc mode. Furthermore, it was also advantageous to use a larger packet size (1024 B vs. 512 B) in both modes of operation. This behavior was confirmed by a second experiment, which was performed in a real deployment. The results obtained in the experimental aerial WiFi network are depicted in Fig. 5. We observe that the transmission rates achieved for the infrastructure mode were always higher than those obtained using the ad-hoc mode. For these measurements, the experiment was limited to a packet size of 512 B. Please also note that the attained values are far from those measured under controlled conditions, so the drone motion, a possible radio interference caused by the drone's chassis, or the environmental changing conditions seem to have a remarkable impact on the system performance. In the same way, these results are much lower than those obtained in [16], likely because in our experiments the UAV is an intermediate node (either an AP or an intermediate ad-hoc hop), whereas in their work the UAV was a communication endpoint, and because they set the 802.11n version and we allowed the wireless card to auto-select the best version of the 802.11 standard (b/g/n) depending on the link conditions.

Finally, we also investigated the maximum theoretical data rate that the wireless cards could reach, depending on the link conditions during the aerial tests. This maximum data rate is defined by the tabulated values set by the IEEE 802.11 standard. Accordingly, the cards are self-configured to work in a different version of the standard as a function of the link quality, thus employing different modulations, which in turn determines the maximum link transmission speed. In our real experiment, the cards were always alternating the 802.11g and 802.11n versions. The attained results are specified in Table 4. We can observe the expected decrease on the link quality with the distance, which forces the wireless cards to employ more

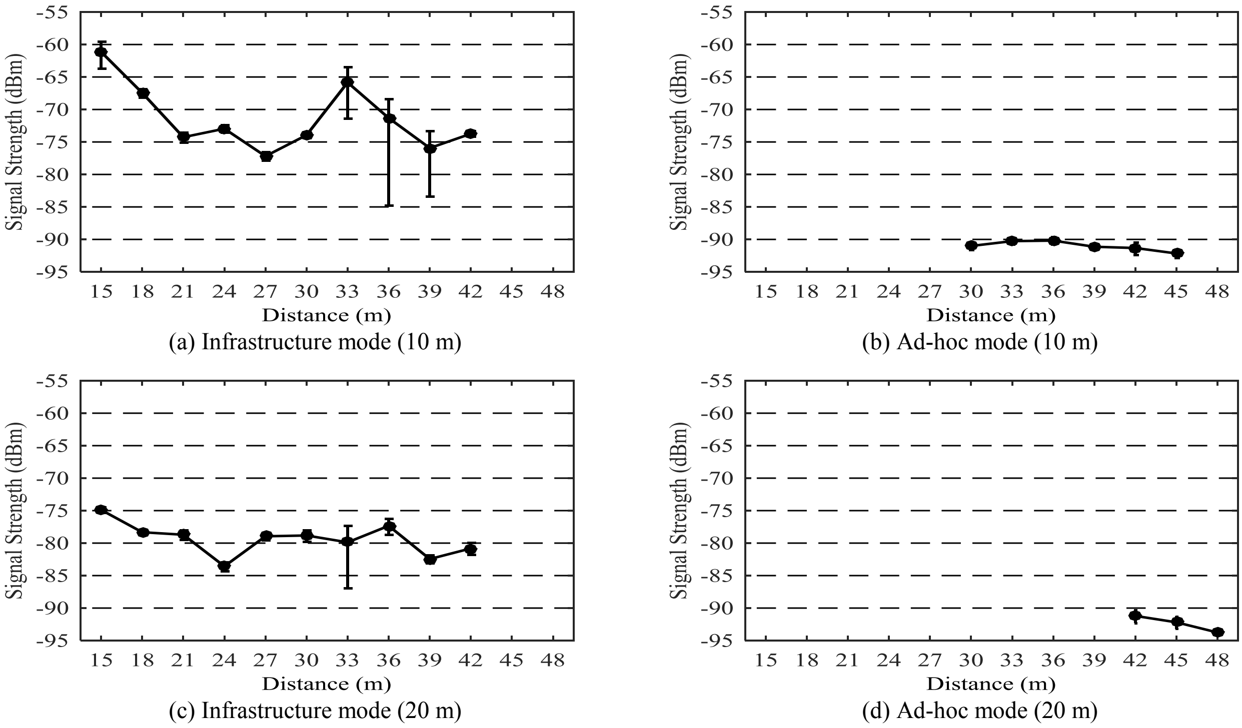


Figure 4. Average signal strength and confidence intervals at the receiver side.

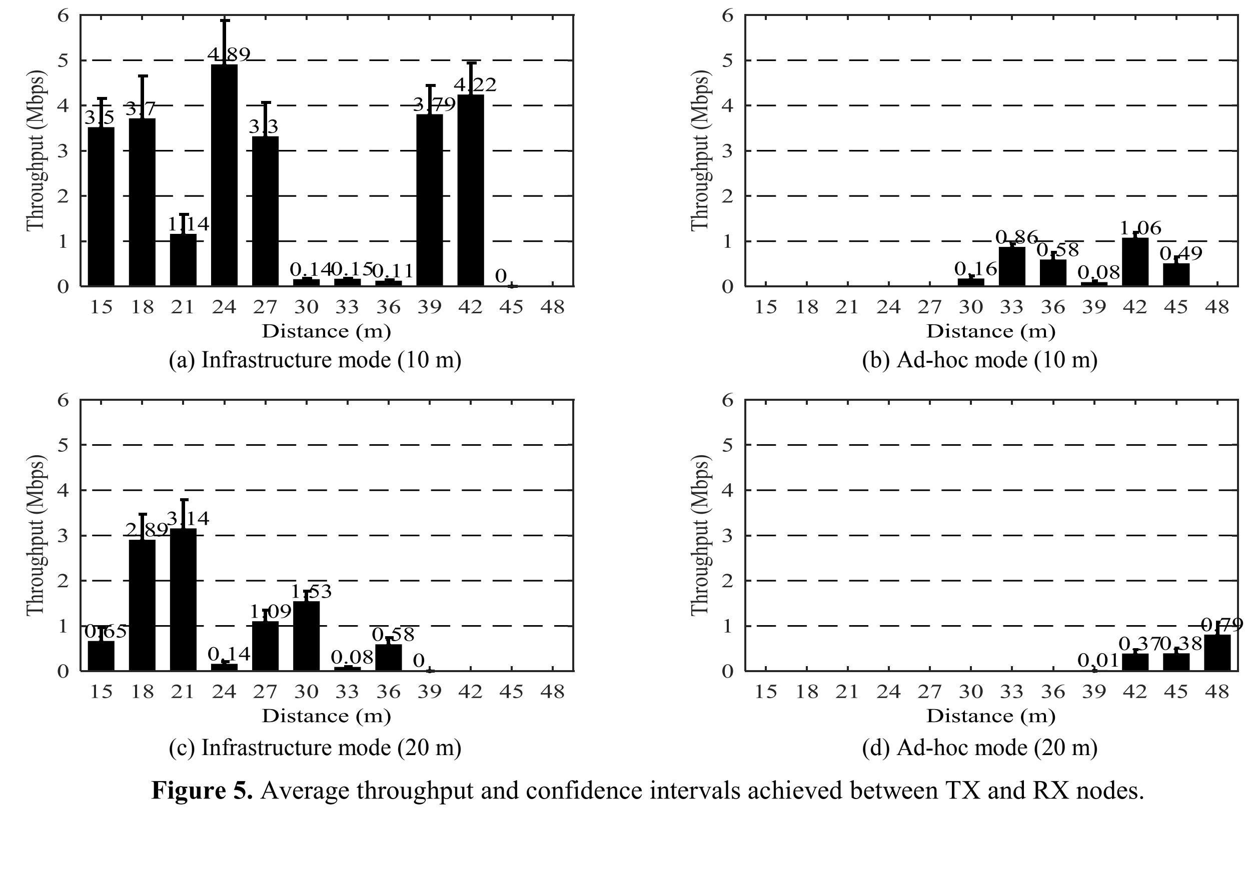


Figure 5. Average throughput and confidence intervals achieved between TX and RX nodes.

Table 3. Comparison of Maximum Transmission Rates.

Operation Mode	Packet Size (Bytes)	Max. Throughput (Mbps)
AP	512	10.5
	1024	11
Ad-hoc	512	4.5
	1024	7.5

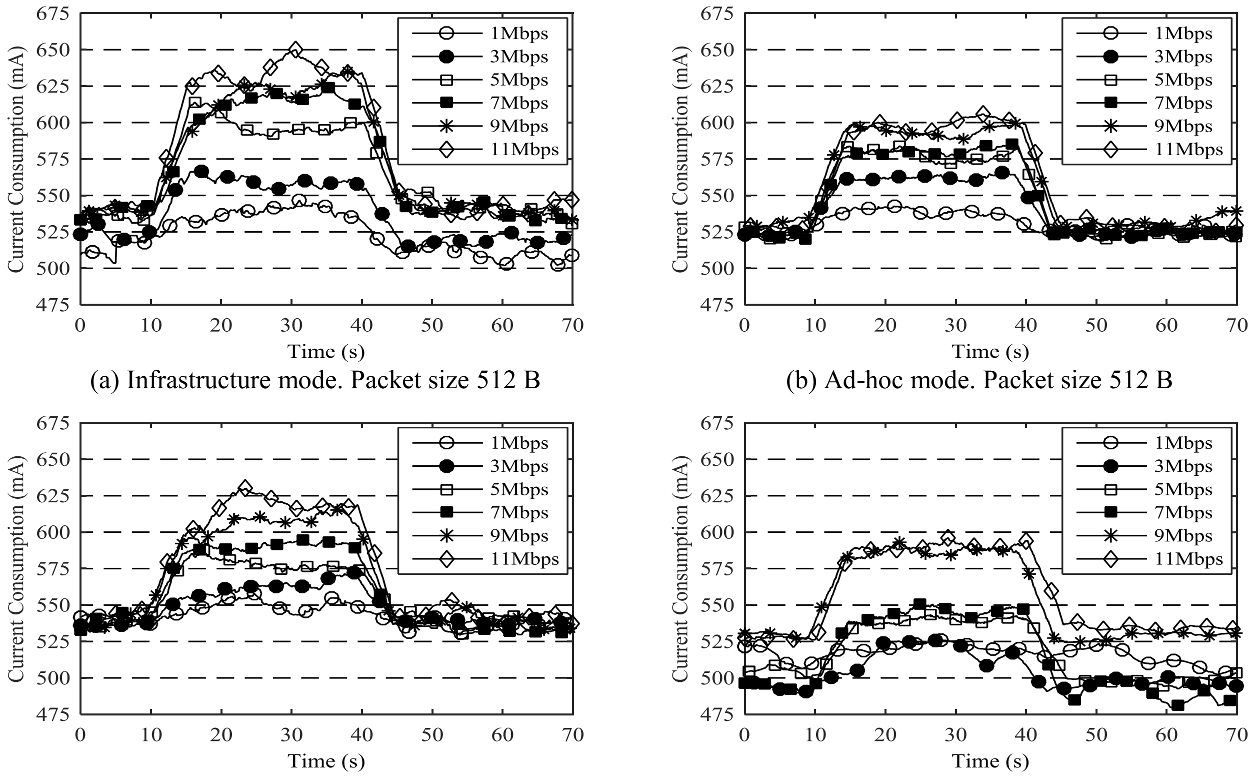
Table 4. 802.11 Operational Bandwidth.

	Drone at 10 m high		Drone at 20 m high	
Distance(m)	**Infrastructure**	**Ad-hoc**	**Infrastructure**	**Ad-hoc**
15	54 Mbps	--	45 Mbps	--
18	60 Mbps	--	135 Mbps	--
21	54 Mbps	--	90 Mbps	--
24	90 Mbps	--	30 Mbps	--
27	81 Mbps	--	54 Mbps	--
30	5 Mbps	6 Mbps	30 Mbps	--
33	5 Mbps	6 Mbps	40 Mbps	--
36	5 Mbps	11Mbps	30 Mbps	--
39	81 Mbps	5.5 Mbps	30 Mbps	5.5 Mbps
42	81 Mbps	11 Mbps	81 Mbps	5.5 Mbps
45	5 Mbps	1 Mbps	5 Mbps	1 Mbps

conservative modulations and hence reducing their maximum data rate. Comparing both modes of operation, please note that, in general, the infrastructure mode allows the use of higher transmission rates than the ad-hoc mode. This behavior matches the results discussed above regarding the level of received signal and the real transmission rate, in which both of them were higher for the infrastructure mode.

4.3 Energy Efficiency

Another important characteristic of the onboard system is its current consumption. By determining the Intel Galileo's current demand under its different operational modes and supporting several traffic loads, its battery can be accurately dimensioned. This is a crucial factor due to the strict load's weight restrictions usually imposed by drones. Consequently, we carried out a study of the instantaneous current consumption of the Intel Galileo board for both the infrastructure and the ad-hoc modes. These measurements were taken at both, idle state and transmitting traffic at a constant bit rate (CBR) using the same controlled lab test-bench as in the previous subsection (i.e., the two laptops as communication endpoints and the on-the-ground board as intermediate device). Each CBR transmission lasted 30 s and we tested several bit rates (1, 3, 5, 7, 9, and 11 Mbps).



(a) Infrastructure mode. Packet size 512 B

(b) Ad-hoc mode. Packet size 512 B

(c) Infrastructure mode. Packet size 1024 B

(d) Ad-hoc mode. Packet size 1024 B

Figure 6. Comparison of WiFi modes in terms of current consumption using 2 different packet sizes (512 B and 1024 B).

Fig. 6 depicts the current-consumption evolution for the different conditions under consideration. The x-axis represents the test duration, starting in an idle state, then transmitting traffic (30 s), and coming back to the idle state. Observe the clear growth in the Intel Galileo board's current demand when the traffic load increases. This behavior was maintained for all the evaluated conditions. In addition, the ad-hoc mode consumes less current than the infrastructure mode (please, compare Fig. 6(a) and Fig. 6(c) with Fig. 6(b) and Fig. 6(d)). Focusing on the ad-hoc mode, observe that it is advantageous to employ a packet size of 1024 B because it allows a notable reduction of the board's current demand. This can be explained as follows. The larger the packet size (1024 B), the lower the number of packet operations (reception and forwarding) are needed to reach a given bandwidth. Finally, we observe the existing tradeoff between both operational modes. Whereas the infrastructure mode offered a superior performance in terms of data rate and coverage, the ad-hoc mode showed better energy efficiency that is also a critical factor for this type of systems.

5. CONCLUSION

This paper explored one of the most promising applications of UAV in the field of communications: The use of aerial networks to increase network connectivity. To this end, we used the Intel Galileo development board, appropriately configured and equipped to work as a WiFi node (either as an AP in the infrastructure mode or as an intermediate hop in the ad-hoc mode) onboard a UAV. We first carried out a theoretical coverage study of the flying WiFi node using the Free Space and the WINNER D1 propagation-loss models, being the latter the most restrictive. Afterwards, we compared the two WiFi operational modes in experimental scenarios in terms of coverage, throughput, and energy efficiency. Results revealed a better performance of the infrastructure mode regarding received signal strength and bandwidth, but a worse behavior in terms of current consumption compared with the ad-hoc mode. As future work, we plan to carry out an extensive performance evaluation of an aerial WiFi network consisting of several drones. To sum up, drones add a new dimension that assists to extend telecommunications beyond their current conventional limits, but the new potential benefits and risks are still an open research area that should be further investigated.

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