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LETTER

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Investigating the deployability of VoIP services over wireless interconnected micro aerial vehicles

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Emerging technological devices, such as Unmanned Aircraft Vehicles (UAV) and Single Board Computers (SBC), are being increasingly employed in recent years, thanks to the advances in electronics and the wide variety of sensors that are endowed. This paper aims at analyzing the viability of deploying multimedia services, focusing on the voice scenario, over wireless interconnected Micro Air Vehicles (MAV), also known as drones. Toward this end, we assessed the performance both of the embedded wireless cards of current drones and also SBCs, which may be carried as payload in existing UAV solutions. Driven by the results obtained in these experiments, we then deployed an operational VoIP service over a network of commercial MAVs, to perform an experimental analysis on the resource capabilities of these devices and demonstrate that this type of service can certainly be used.

KEYWORDS
drone, micro aerial vehicle, single board computer, unmanned aerial vehicle, VoIP, WiFi

1 | INTRODUCTION

In recent years wireless networks have evolved remarkably, optimizing communications between devices and significantly increasing the achievable throughputs, surpassing what wired networks offered a few years ago. For this reason, a plethora of innovative applications have emerged around them.

Nowadays, we are witnessing the development of novel micro aerial vehicle platforms (MAVs), also known as drones, which are obtaining an increasing interest from the research community and the industry. With reduced cost and power consumption, compared with larger tactical UAVs, MAVs open new opportunities. MAV infrastructures can be used for instance in scenarios such as, surveying and mapping, civil infrastructure inspection, or precision agriculture. This paper is focused in disaster situations where the cellular network is unavailable, having the potential to help emergency services increasing the efficiency of their work by deploying a Voice over IP service as contemplated in this paper (the MAV network is instantiated to allow 2 devices on the ground to communicate when the cellular network is unavailable). Another use case could be the use of onboard cameras to accurately inspect the disaster area. The combination of both factors, drones and wireless networks, is of great interest, and it is necessary to carry out studies to be able to analyze their performance.

The main objective of this paper is the study of MAV networks, examining the feasibility of their connection over wireless networks, performing tests in a real environment with drones. Normally, WiFi networks in MAVs are just used to control the aircraft and to receive video and current trends propose to extend their application. Thus, we are presenting a use case where a VoIP call over a MAV network is deployed.

In this context, this paper evaluates wireless networks performance in the 2.4 GHz band, specifically the 802.11n standard.[1] As connection nodes of these networks, 2 types of devices have been used. In the first place, we perform tests using single boards computers (SBC), in particular, Raspberry Pi 3 Model B.* These small computers, with wireless transmission capability, can be carried by drones as light payloads (around 50 g). Secondly, after analyzing the tests performed with the devices discussed above, a deployment is performed on civil MAV, namely Parrot AR Drone 2.0.† Both types of devices are interconnected directly through their wireless interfaces, performing tests to determine the bandwidth and latency.

1.1 | Related work

Small-sized drones open new possibilities to execute mission-oriented collaborative applications,[2] such as search and rescue operations, disaster management and surveillance and law enforcement.

As enablers of these type of applications, MAVs have been proposed to assist in operations of cooperative search,[2,3] in emergency situations, to support the collaborative generation of images[4] or to build aerial sensor networks that aid in disaster management.[5] Besides these applications, other use cases have also been investigated, such as structure building[6] or using autonomous small UAV swarms.[7,8]

In addition, applications that require the coordination and communications between aerial vehicles of heterogeneous sizes and capacities have also been targeted by previous research work. In Reference 9, the authors present a communication scheme where 2 UAVs provide backbone communications to a set of ground mobiles. In Reference 10 the authors present a field demonstration of the integration of UAVs with a ground ad hoc network. In References 11, 12 authors present the use of drones as small cells to provide wireless services to ground users in different scenarios. Additionally, there are different articles evaluating MAVs features.[13]

The main contribution of this paper relies on the experimentation with the possibilities of off-the-shelf MAVs and SBCs. The 2 topologies used in the tests are the most common ones in MAVs networks: full mesh topology based on broadcast distribution (all MAVs are supposed to be 1 hop away from each other) and star topology with a central access point (AP) that helps to route information between the nodes (typical 2-hops architecture). There are obviously many other alternatives since MAVs networks are by definition very flexible (they can act as relays for instance, routing information), but in this study, we will focus in those 2 to set the minimum requirements.

2 | PERFORMANCE EVALUATION IN A CONTROLLED SCENARIO

In this section, we analyze the benefits that can be achieved with MAVs and SBCs. After this evaluation, we can verify if both devices guarantee the minimum requirements for a VoIP service implementation (Section 3), and, at the same time, we make a comparison that will allow us to conclude the most appropriate technology for upcoming studies and developments. For this reason we decide to use very basic devices such as the Parrot AR Drone 2.0 as MAV (total diameter 55 cm including rotors), and Raspberry Pi 3 as SBC (85.60 mm × 56 mm × 21 mm). Drones will remain on the floor since no added value is provided in this type of measurements by flying drones (and since in disaster situations drones will only fly until they reach the desired area where they will land and act as WiFi APs or relays to save battery).

For the evaluation, we are taking into account 4 different metrics. First, we measure the throughput to determine the maximum rate the system can process in a given time. Next, we measure round trip time (RTT) to define the delay among the devices of the network. Then, we measure jitter to check if packets will be sent in a continuous stream. Finally, to measure WiFi transmission power, we have monitored the wireless link quality and the signal level to assess received signal strength, increasing the distance between transmitter and receiver linearly.

Toward this end, we are using an ad hoc wireless network, where the devices form a peer-to-peer network and the participants are clients and AP at the same time. Thanks to ad hoc wireless network features, the topology used in the study, Figure 1, can grow without needing several wireless interfaces per device (as would be required with infrastructure mode), which is essential when working with civil/commercial drones. However, Ad hoc mode has some drawbacks. In fact, wireless systems employing infrastructure mode (at least 1 AP providing infrastructure to network members) provide better performance in terms of achievable throughput than those using ad hoc mode to establish communication.

2.1 | Scenarios definition

For the experimental investigation, we have used 3 drones and 3 SBCs, with a separation of 15 m among them for outdoor measurements, as seen in Figure 2. In order to perform measurements, we directly use these nodes. First, we measure traffic from MAV A to MAV B (1 hop). Second, we measure traffic from MAV A to MAB C adding 1 node (MAV B) with routing capabilities to introduce 1 intermediate hop (2 hops). VoIP service is deployed between MAV A and MAV C too. Measurements have been done in a controlled scenario with ideal conditions, in a WiFi channel without interferences. All tests (1 minute each)

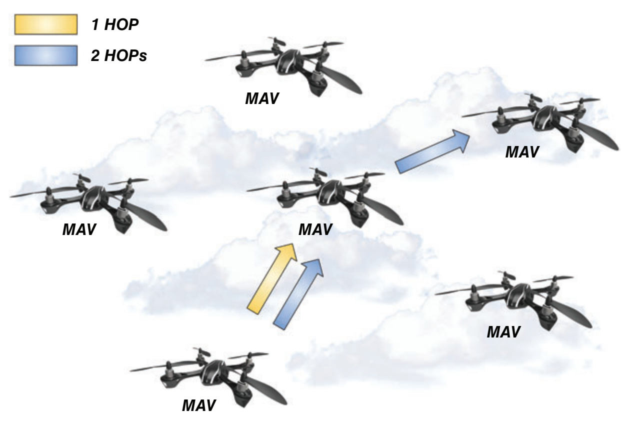

FIGURE 1 MAV Star ad hoc wireless network topology

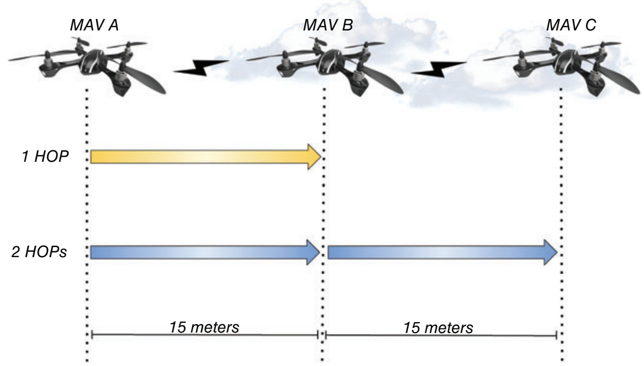

FIGURE 2 MAV scenario used in the experiment

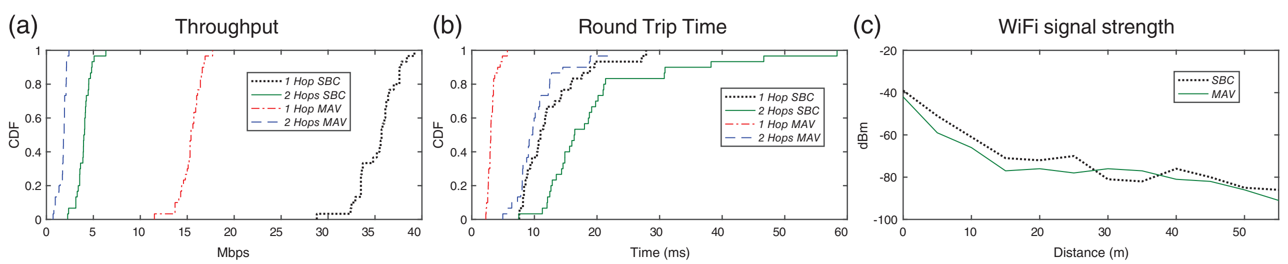

FIGURE 3 Performance evaluation metrics. (A) Throughput, (B) round trip time, (C) WiFi signal strength

have been replicated 30 times to check the system stability over time in a real environment. Figure 3 shows the cumulative distribution functions of the considered metrics.

All the experiments have been performed bearing in mind some considerations: (1) Traffic has been captured in a single direction. (2) The WiFi channels selected before conducting each test were those free or less busy to avoid the possible interferences.

In order to verify the existence of network connectivity between 2 devices and measure the RTT that can be achieved among them we use the *Ping* tool. We perform active measurements on the maximum achievable bandwidth, generating a flow of Transmission Control Protocol/User Datagram Protocol (TCP/UDP) traffic from the client (MAV A) to the server (MAV B or MAV C) using *Iperf*.[‡] VoIP services use different codecs to compress the audio data, allowing to decrease bandwidth usage. For this reason having high capabilities to encode and decode voice data directly impacts audiovisual user experience. Signal quality and signal level (dBm) measured at different distances allows to measure the maximum distance covered by the wireless network.

2.2 | Evaluation results

The quality of experience (QoE) for multimedia services, such as the VoIP application running in the following section, greatly depends on the network performance between the calling parties. To guarantee QoE in a VoIP call, we need to reach not only a bandwidth larger than 100 Kbps but also an RTT smaller than 400 ms.[§,¶]

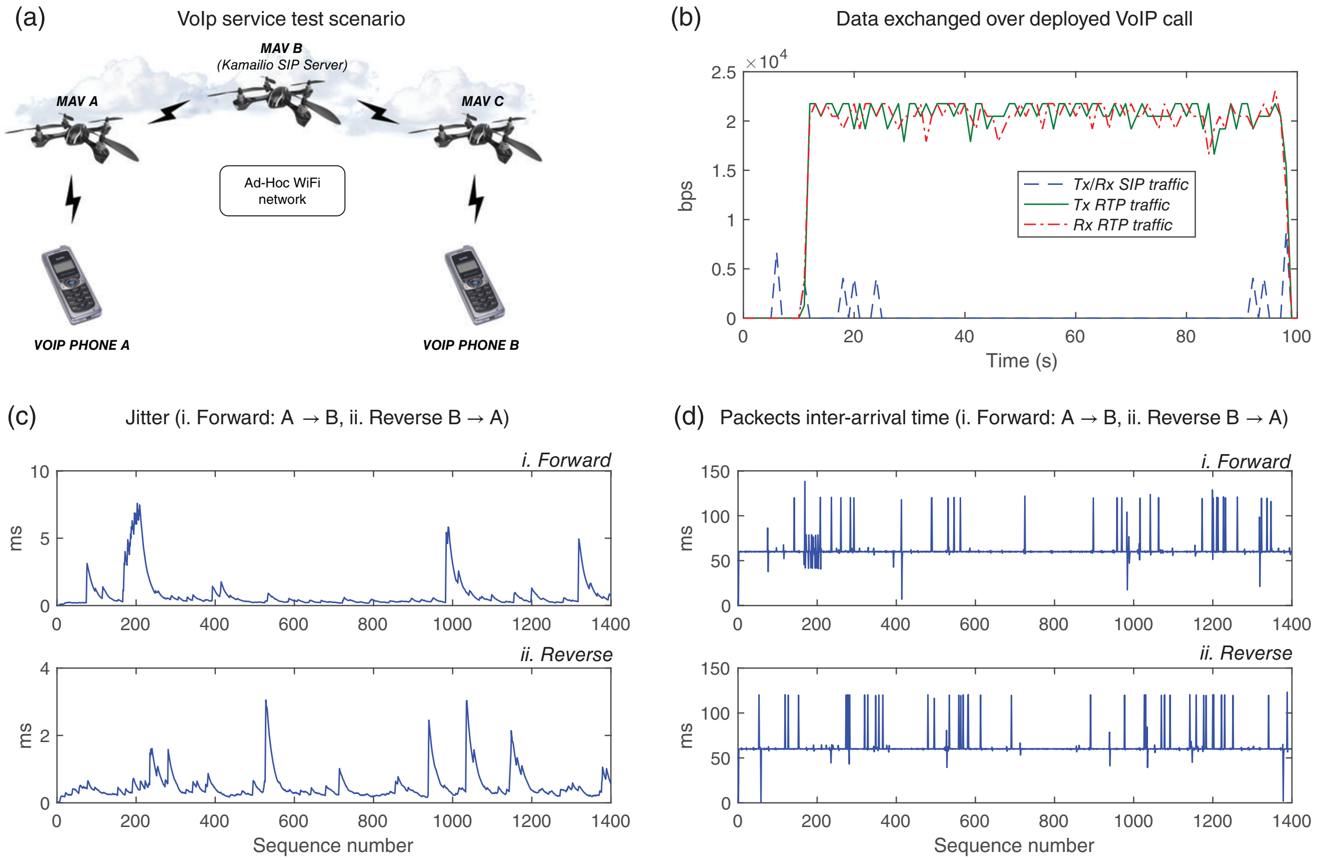

FIGURE 4 VoIP call deployed over MAV infrastructure. (A) VoIp service test scenario, (B) Data exchanged over deployed VoIP call, (C) Jitter (i. Forward: A→B, ii. Reverse B→A), and (D) Packects inter-arrival time (i. Forward: A→B, ii. Reverse B→A)

Regarding the throughput, as seen in Figure 3A incrementing 1 hop significantly deteriorates system performance. The performance of SBC networks is around 2 times better in throughput terms, concluding that SBC is more efficient in terms of throughput than directly using the onboard MAV WiFi. Observe that these results may be due to the low quality of the WiFi devices installed by default in the MAVs we are using in the experiments, as they are not professional devices. The optimal scenario is one that presents a single wireless hop; however, it would mean a decrease in the coverage reach. Examining Figure 3B, we conclude that both technologies accomplish the minimum requirements, even though MAV networks have a better performance regarding the RTT. As opposed to throughput analysis, adding 1 hop does not deteriorate significantly the performance.

To verify the maximum distance to which we can provide network coverage, we have also measured the signal level at different distances. For this analysis, we have configured both SBC and MAV devices as APs to provide connectivity between them and a standard Laptop (Dell Latitude E6330) being the one performing the measurements. Note that these results and conclusions highly depend on the particular WiFi card used for tests and on the requirements set by the applications using the system. The minimum signal strength for applications that require very reliable, timely packet delivery, such as VoIP or video streaming is around −74 dBm,[14] which gives us a maximum distance between Tx and Rx in the range of 20 to 25 m as seen in Figure 3C.

3 | USE CASE: VOIP CALL OVER MAV NETWORK

After the performance evaluation, previous results show that it is possible to deploy a multimedia service in a MAV-based network. We go 1 step further with the implementation of a VoIP call between 2 terminals (VoIP A → VoIP B) as shown in Figure 4A. In this test we can evaluate the capacity of these limited devices to establish voice communication between 2 Wireless VoIP phones ZyXEL Prestige 2000 W. This model supports the IEEE 802.11b standard and the establishment of audio calls using session initiation protocol (SIP) and RTP. All the SBCs are connected in the same network in ad hoc mode. In contrast to previous tests, we have performed this analysis in the Carlos III of Madrid University campus to validate the results in a real environment, where all WiFi channels are massively used. To capture VoIP calls traffic, we are using *Wireshark* tool and a Laptop connected to the WiFi network in promiscuous mode which allows intercept and read each network packet.

To create, modify, and terminate multimedia sessions with 1 or more participants we use session initiation protocol (SIP). The audio packets are transported using real-time protocol for delivering audio and video over IP networks that typically runs over UDP. In the central SBC (MAV B in Figure 4A) we have installed *Kamailio*, an open-source SIP Server supporting the registration of mobile phones and the call control functionality. Then, *Kamailio* SIP Server receives REGISTER requests from SIP phones and updates its database appropriately (ie, SIP:vsaguero@192.168.0.14 → SIP:vsaguero@kamailio.org). With the registrar function, any user can receive calls from any device supporting SIP using its unique SIP URI (ie, SIP:vsaguero@kamailio.org) which brings mobility to the system since every user can change its points of attachment to the network (ie, the MAV used to get network connectivity, and correspondingly its IP address).

3.1 | VoIP call

We completed several audio calls over MAV VoIP service. Figure 4B, represents the data captured in one of the experiments (the traffic is obtained in MAV C that provides connectivity to the phone receiving the call VoIP B). The call starts after 5 seconds. Then *Kamailio* sends the SIP INVITE to VoIP B originated by VoIP A. Approximately at second 10 after SIP ACK the multimedia session start is confirmed. Then the phones start to exchange RTP packet until the end of the call (approximately at second 100) terminating with a SIP BYE message. In the call, the perceived quality of the user experience has been satisfactory. However, we have analyzed the traffic during one of the experiments to quantify the quality of the call.

We are analyzing 2 different RTP Streams: (1) *Forward* stream, that goes from VoIP phone A to VoiP B and (2) *Reverse* stream, that goes in the opposite direction. In such a way, we measure the quality in both directions. Figure 4C shows the Jitter during the deployed VoIP call. In the *Forward* stream, the maximum value was 7.59 ms and the mean value 0.83 ms. On the other hand, in the *Reverse* stream, the maximum value was 3.05 ms and the mean value 0.5 ms. All of them within expected and reasonable values. In Figure 4D we show the Packet interarrival during the deployed VoIP call. Packet interarrival is the difference between the arrival time of the current packet and the arrival time of the previous packet. In the *Forward* stream, mean Packet interarrival value was 61.2928 ms, while the *Reverse* stream had a mean value of 61.6294 ms, both of them really close to the theoretical value. We have also measured Packet Lost. The *Forward* stream suffers a packet loss percentage equal to 2.14%, out whereas in the *Reverse* direction we a measured a packet loss equal to 2.70%.

4 | CONCLUSIONS

The possibilities that MAVs together with single board vomputers are offering nowadays do enable an increasing amount of new services. This paper has performed different tests in order to validate their application in WiFi-based scenarios and in particular in VoIP deployments. The results show that the throughput, RTT and jitter meet the minimum requirements to guarantee QoE when a media service such as a voice call is deployed over off-the-shelf MAV networks.

It is obvious that in depth analysis are required in the future in some other critical fields such as energy consumption, to evaluate the autonomy of these devices and their short-term application in real environments, but these preliminary tests we performed on their communication capabilities have shown to be very promising for emergency scenarios.

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NOTES

- ∗ Raspberry Pi 3 B: https://www.raspberrypi.org/products/raspberry-pi-3-model-b/
- † AR Drone 2.0: https://www.parrot.com/es/drones/parrot-ardrone-20-elite-edition#parrot-ardrone-20-elite-edition-details
- ‡ *iPerf* - The ultimate speed test tool for TCP, UDP and SCTP: https://iperf.fr/
- § Bandwidth requirements: https://www.cisco.com/c/en/us/support/docs/voice/voice-quality/7934-bwidth-consume.html
- ¶ Delay requirements: https://www.cisco.com/c/en/us/support/docs/voice/voice-quality/5125-delay-details.html

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REFERENCES

1. Calhoun P, Montemurro M, Stanley D. Control and provisioning of wireless access points (CAPWAP) protocol binding for IEEE 802.11 (No. RFC 5416), 2009.
2. Quaritsch M, Stojanovski E, Bettstetter C, et al. Collaborative microdrones: applications and research challenges. Paper presented at Proceedings of the 2nd International Conference on Autonomic Computing and Communication Systems (p. 38). ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2008.
3. Waharte S, Trigoni N, Julier S. Coordinated search with a swarm of UAVs. Paper presented at: 6th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks Workshops, 2009. SECON Workshops' 09, 1–3, IEEE, 2009.
4. Quaritsch M, Kuschnig R, Hellwagner H, Rinner B, Adria A, Klagenfurt U. Fast aerial image acquisition and mosaicking for emergency response operations by collaborative UAVs. Paper presented at: Proceedings for the International ISCRAM Conference, 1–5, 2011.
5. Quaritsch M, Kruggl K, Wischounig-Strucl D, Bhattacharya S, Shah M, Rinner B. Networked UAVs as aerial sensor network for disaster management applications. *e & i Elektrotechnik und Informationstechnik*. 2010;*127*(3):56-63.
6. Augugliaro F, Lupashin S, Hamer M, et al. The flight assembled architecture installation: cooperative construction with flying machines. *IEEE Control Systems*. 2014;*34*(4):46-64.
7. Chaumette S, Laplace R, Mazel C, Mirault R, Dunand A, Lecoutre Y, Perbet JN. Carus, an operational retasking application for a swarm of autonomous uavs: first return on experience. In Military Communications Conference, 2011-MILCOM 2011, 2003-2010, IEEE, 2011.
8. Daniel K, Rohde S, Goddemeier N, Wietfeld C. A communication aware steering strategy avoiding self-separation of flying robot swarms. Paper presented at: 2010 5th IEEE International Conference on Intelligent Systems (IS), 254–259, IEEE, 2010.
9. Charlesworth PB. A non-cooperative game to coordinate the coverage of two communications UAVs. Paper presented at: Military Communications Conference, MILCOM 2013-2013, 668–673, IEEE, 2013.
10. Danilov C, Henderson TR, Goff T, et al. Experiment and field demonstration of a 802.11-based ground-UAV mobile ad-hoc network. Paper presented at: Military Communications Conference, 2009. MILCOM 2009, 1–7, IEEE, 2009.
11. Yanmaz E, Costanzo C, Bettstetter C, Elmenreich W. A discrete stochastic process for coverage analysis of autonomous UAV networks. Paper presented at: 2010 IEEE GLOBECOM Workshops (GC Wkshps), 1777–1782, IEEE, 2010.
12. Mozaffari M, Saad W, Bennis M, Debbah M. Drone small cells in the clouds: design, deployment and performance analysis. Paper presented at: Global Communications Conference (GLOBECOM), 1–6, IEEE, 2015.
13. Bristeau PJ, Callou F, Vissiere D, Petit N. The navigation and control technology inside the ar. drone micro uav. *IFAC Proceedings Volumes*. 2011;*44*(1):1477-1484.
14. Mkwawa IH, Jammeh E, Sun L Mapping of received signal strength indicator to QoE in VoIP applications over wlan. Paper presented at: 2012 Fourth International Workshop on Quality of Multimedia Experience (QoMEX), 156–157, IEEE, 2012.
15. Michael N, Mellinger D, Lindsey Q, Kumar V. The grasp multiple micro-uav testbed. *IEEE Robotics & Automation Magazine*. 2010;*17*(3):56-65.

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