Comments and changes done to the paper "Automated deployment of an IP telephony service on Unmanned Aerial Vehicles using Network Functions Virtualization"

We would like to take this opportunity to thank the feedback from the reviewers. By providing valuable comments and highlighting the issues with our paper, we were able to improve its value. We hope that the enhancements and modifications are able to satisfy the reviewer's comments.

We present below the detailed comments provided by each reviewer, followed by our answer, making references to the changes done to the paper. In the online submission system, we have uploaded the updated paper with the main changes highlighted in red color.

Yours sincerely, the authors.

Editorial #E

Comment E.1. Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues.

Answer E.1. *Following the editorial suggestion, we have done a detailed proofread of the whole paper.*

Comment E.2. JoVE cannot publish manuscripts containing commercial language. This includes trademark symbols (™), registered symbols (®), and company names before an instrument or reagent. Please limit the use of commercial language from your manuscript and use generic terms instead. All commercial products should be sufficiently referenced in the Table of Materials and Reagents. For example: ZyXEL (although, note that Ubuntu is OK).

Answer E.2. *Attending to the editorial comment, the new version of the manuscript limits the use of the commercial language. In addition, we have elaborated the suggested Table of Materials, which includes the proper references to the commercial equipment utilized to carry out the experiment described in the manuscript.*

Comment E.3 Please ensure every protocol step/substep has at least one action written in the imperative.

Answer E.3. *Taking into account the editorial suggestion, we have done the corresponding modifications to the "Protocol" section to ensure the imperative voice in every step/substep of this section.*

Comment E.4 For each protocol step/substep, please ensure you answer the "how" question, i.e., how is the step performed? Alternatively, add references to published material specifying how to perform the protocol action. If revisions cause a step to have more than 2-3 actions and 4 sentences per step, please split into separate steps or substeps.

Answer E.4. *According to the editor's comment, we have reviewed the "Protocol" section to ensure that the procedure to perform every step is properly reflected. To this purpose, we have enhanced the text including additional links in which this information is presented in detail.*

Comment E.5. Please ensure the Table of Materials has information on all materials and equipment used (e.g., computers, software, UAVs), especially those mentioned in the Protocol.

Answer E.5. *The elaboration of the suggested Table of Materials, including the equipment used in the experiment, has been addressed in the comment E.2. Taking into account the editorial comment, the "Protocol" section has been modified to better comply with the manuscript instructions.*

Reviewer #1

Comment 1.1. The protocol was evaluated under emulation and also using a real UAV cluster. The authors were very clear stating that the performance results were achieved with fixed/non-flying UAVs. Although the reviewer acknowledges that the protocol's explanation does not depend on the flying status of each UAV, the link quality in a flying procedure, and its impact on the management of the VNFs and on the selected application/use case, might be of critical importance for the execution of the presented protocol

Answer 1.1. *We agree with the reviewer that the quality of the wireless link is a relevant aspect in our work as a whole. Nevertheless, this protocol has a main focus on describing the specific methodology that allows the automated deployment of moderately complex network services on UAVs, using NFV standard technologies to that end. For this reason, the flight procedure is considered as optional within the manuscript, and the performance results have been obtained with the devices on the ground. This way, the results could be easily replicated by third-parties, using SBCs in a controlled laboratory environment.*

Regardless, our work takes into account the aspects related to the wireless links quality. In this context, the protocol includes an optional section ("Validate the functionality of the softwarization units via Emulation"), which aims at demonstrating the appropriate operation of the deployed network services under realistic wireless communication link conditions. To this end, we have developed an emulation platform that allows emulating the multi-hop aerial links and to define the characteristics of those links (e.g., length of the wireless communication links, pattern of data packet losses, the radio technology used in the wireless communications, etc.).

In any case, we agree that the scope of the article may have not been properly stated. We have enhanced section "Introduction" to better reflect the main focus of the protocol, i.e., to enable the reproducibility of a protocol that integrates the UAVs into an NFV environment, to allow the automated deployment of network services on the UAVs.

Reviewer #2

Comment 2.1 The study consists of significant amount of work and trials in order to provide NFV platform on top an aerial network. However, it lacks certain elements regarding the challenges which an aerial/UAV network may pose. In the submitted version, it is hard to grasp what the critical challenges are when we specifically target UAV-platform, since it looks like this framework may be migrated to any mobile or immobile environment which can carry a RPi. The authors should emphasize the unique challenges (in a UAV network) and their unique decisions/solutions which are designed to address these challenges.

Answer 2.1. *Our work aims at providing the UAVs with the capacity to flexibly adapt their functionalities to different mission objectives, through the use of the standard NFV technologies. In addition, the integration of the UAVs into the NFV environment makes possible the coordinated operation of the UAVs to allow the deployment of moderately complex services and applications. Notwithstanding the benefits, the realization of this view presents a set of fundamental challenges that needs to be carefully addressed, such as: the integration of these devices as part of an NFV infrastructure, using an existing NFV software stack, so that an NFV orchestration service can deploy virtual functions on the UAVs; the constraints in terms of the computational resources provided by the UAV, which may present limitations in terms of the the size, weight and computing capacity of payload equipment; the proper placement of the virtual functions onto UAVs, i.e., selecting the best UAV candidate to deploy a particular virtual function; the maintenance of the control communications with the UAVs, in order to manage the lifecycle of the VNFs despite of the potentially intermittent availability of network communications with them (e.g., caused by mobility and battery constraints); the limited operation time of the UAVs, due to their battery consumption; and, related to the latest, the migration of the virtual functions when a UAV needs to be replaced due to battery exhaustion. These benefits and challenges are detailed in our previous work [1, 2], which include the design of an NFV system capable of supporting the automated deployment of network functions and services on UAV platforms, as well as the validation of the practical feasibility of this design.*

Attending to the reviewer's comment, we have highlighted these benefits and challenges in the section "Introduction" of the manuscript, with the appropriate references to our prior work.

In addition, we agree with the reviewer that our solution could potentially be exported to other environments, where resource-constrained hardware platforms might be available with the needed capacity to execute virtualization containers (e.g., Internet of Things, or IoT, environments). Of course, the applicability of our solution to different environments and its potential adaptations will require a carefully study in a case-by-case basis. We have updated *the "Discussion" section of the paper to include this aspect of exporting our solution to other environments as a future application of the method.*

Comment 2.2. The authors stated that NS-3 simulation has been used to emulate multi-hop aerial links and provided results based on simple topology which consists of grounded drones. It is hard to clear (considering Figure 1) which parts of the described system actually physically implemented and which parts are just emulated via NS-3. I suggest the authors to improve the distinction between these two parts.

Answer 2.2. *The article has a main focus on describing a specific procedure to enable the automated deployment of network services over a network of UAVs, using the NFV standards and open source technologies. In this specific work, real flight is considered as optional, and performance results are obtained with the devices on the ground, as highlighted by the reviewer. This will facilitate interested readers to replicate and validate the execution of this procedure even in a controlled laboratory environment.*

Regarding the physical implementation, we have developed all the components of the network service depicted in the Figure 1 (i.e., the VNFs described in the manuscript composing the IP telephony service) using Linux Containers. Hence, these components can be automatically deployed by the MANO platform.

On the other hand, our work also considers operational and real deployment aspects, such as wireless link quality. To address these aspects, we have used a purpose-specific emulator, based on ns-3, which allows emulating multi-hop aerial links and defining the characteristics of those links (e.g., length of the wireless communication links, pattern of data packet losses, the radio technology used in the wireless communications, etc.). This emulator is under development as one of our current research works. The protocol specified in the paper includes an optional section ("Validate the functionality of the softwarization units via Emulation") that uses this emulator, aiming to demonstrate the appropriate operation of the deployed network services under realistic wireless communication link conditions.

For the emulation, we created Linux containers to represent the different physical components of the testbed, i.e., the SBCs and the fixed compute server for the UAV cloud platform, and the compute server for the core cloud platform. The functions provided by the different VNFs of the IP telephony service (i.e., access points, routers, DNS server, and IP telephony server) were also deployed as Linux containers over their corresponding emulated SBCs and compute servers. With this setup, our ns-3 based emulator is able to provide the realistic wireless communications that take place in our scenario (i.e., the Wi-Fi ad-hoc network, which enables the data exchange among the nodes of the UAV cloud platform; and the wireless networks offered by the two Wi-Fi access points provided in the service). The emulation platform, along with all the aforementioned components, is provided as a virtual machine in the public repository, and it is used in the section "Validate the functionality of the softwarization units via Emulation".

In any case, we agree with the reviewer that this distinction, between the physical implementation and the components implemented for the emulation, can be improved in the manuscript. To address this issue, we have modified "Protocol" section (in particular, the *information included in the step "2. Validate the functionality of the softwarization units via Emulation") in order to better clarify all these aspects, according to our answer to this comment.*

Comment 2.3. The detailed information about attaching RPi on drones (Parrot AR Drone 2.0 or Parrot Bebop 2) is missing. Is there any additional connection between drone and RPi besides the power link which enables to integrate flight and communication/network data?

Answer 2.3. *Following the reviewer's comment, we have modified the explanatory note of the step 1.5 and the step 1.5 itself of the "Protocol" section, to better clarify how the SBCs are attached to the UAVs.*

In our prototype implementation, the role of the UAVs is only to transport the RPis (which provide the compute/network/storage resources needed to execute network services, as payload. Each RPi is attached to a UAV through a fixing accessory, without requiring any other connection between the RPi and the UAV (e.g., ethernet, USB, etc.). Additionally, the RPis are provided with a battery-power supply HAT (Hardware Attached on Top) that ensures the operation of the RPis, independently of the UAV they are attached to.

Besides, in our prototype we assume that control communications with the UAVs (e.g., commands to remotely manage the operations of the UAV, read the information about the status of the battery, or the verification of the proper operation of the rotors), if needed, could be done through the integrated Wi-Fi interface of each UAV. Hence, UAVs can be controlled from a ground control station using the Wi-Fi Ad-hoc network built by all the UAVs. In addition, a flight-control VNF running at each UAV could be used to aid control operations [1, 2].

Comment 2.4 The submitted manuscript has a 87 percent similarity score with another publication authored by the same researcher. However, this manuscript has not been cited in this manuscript. If there are certain similarities, please make sure to remove them or at least cite that publication to avoid any self-plagiarism.

Answer 2.4. *The manuscript has been written without including text or content extracted from any other of our publications. However, we understand that there might be certain degree of similarity with our previous work, since the developed experiment is a re-elaboration of the one described in [2]. In any case, the submitted paper is a unique manuscript, which the bulk of itself is a step-by-step methods section, aiming at enabling the reproducibility of the mentioned experiment. Nevertheless, to verify the similarity of our paper with the existing literature, we have utilized the Turnitin tool (a well-known plagiarism detection solution) in order to verify the similarity degree with our previous work. According to the report originated by Turnitin, which is attached to this rebuttal letter for convenience, the similarity percentage obtained is 7% (as is reasonable, excluding the references section of the manuscript).*

In any case, and following the reviewer's suggestion, we have modified the "Introduction" section to better emphasize that the experiment is a re-elaboration of the one described in [2].

Comment 2.5. Given public repository is not accessible (http://vm-images.netcom.it.uc3m.es/jove/).

Answer 2.5. *We appreciate the reviewer has notified this spelling mistake. We have corrected in the paper the erroneous URL of the public repository, which is: http://vm-images.netcom.it.uc3m.es/JoVE/*

Comment 2.6. I suggest the authors to improve the Figure 1. In the given form, it is hard to understand the hierarchy in the system and mapping between the physical entities and the deployed functions. Please also include more detail about the links (rather than just Physical and Virtual), what are the access technologies utilized between devices to create the described platform.

Answer 2.6. *Following the reviewer's suggestion, we have updated the particular figure to better clarify the mapping between the physical entities and the deployed functions. We agree with the reviewer that this information was not conveniently presented in the previous figure, especially in the case of the UAV cloud platform where not all the UAVs have a secondary wireless interface that enable the execution of the wireless access point functions. Finally, and taking into account the reviewer's comment, we have included in the figure the access technologies used to provide the VoIP service over the network of UAVs.*

References

1. Nogales, B., Sanchez-Aguero, V., Vidal, I., Valera, F., & Garcia-Reinoso, J. A NFV system to support configurable and automated multi-UAV service deployments. In Proceedings of the 4th ACM Workshop on Micro Aerial Vehicle Networks, Systems, and Applications (pp. 39-44). ACM (2018, June).
2. Nogales, B., Sanchez-Aguero, V., Vidal, I., & Valera, F. Adaptable and automated small UAV deployments via virtualization. *Sensors*, 18(12), 4116 (2018).