# Cloud to the edge computing continuum exploiting the third spatial dimension: A practical approach


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***Abstract*—The requirements imposed when supporting ubiquitous communications, both in time and space, drives to the research community to conceive new approaches aiming at fitting service and user demands. It is becoming more usual to provide support to spontaneous communication needs raised by a community of IoT devices, crowds or even to cope with the consequences, in terms of infrastructure communications, of a natural disaster. In this context, the availability of agile network management techniques boosted by the artificial intelligence as well as exploiting the third spatial dimension can provide key assets matching the corresponding requirements. Hence, this paper presents drone-based solutions which embed the eNodeB and the Evolved Packet Core infrastructure to support such spontaneous communication needs as well as a monitoring system of critical infrastructure.**



***Index Terms*—UAV, 5G, NVF, MEC, computing continuum**


## I. Introduction

The mobile communication networks have experienced a rapid growth during the last years, bringing together a complex technology deployment, which usually hinders its optimization. Indeed, the deployment of new network elements, or upgrading of existing ones, with most innovative solutions may be not affordable in some cases. As for innovative services, Artificial Intelligence (AI) is expected to play a relevant role in mobile networks since it will improve the operations and performance as well as reducing costs and decreasing the network management vulnerability [1]. AI techniques are adopted to analyze faults and generate alarms. Some methods are based on Machine Learning (ML) algorithms aimed at predicting the status according to past experiences, this is the case of probabilistic networks and neural networks. The advantages of using AI/ML algorithms, commonly called data driven algorithms, has been studied intensely in the recent past [2].

Additionally, the development of software-defined networking (SDN) and network function virtualization (NFV) constitutes the fundaments of software/programmable networking. These technologies are boosting 4G/5G mobile networks to provide optimized solutions for services with diverse functionalities within mobile edge computing being able to achieve low latency communications. Future networks will be strongly software-defined and they will be deployed considering the third spatial dimension. In this sense, unmanned aerial vehicles (UAV), such as drones, are being considered [3] for adding new network infrastructure, which will be deployed ad-hoc to offer mobile advanced capabilities in those areas where it is required, and to react immediately to events which could overload the terrestrial network infrastructure. Furthermore, drones can perform inspection and monitoring tasks in multiple areas during their flights by using the video captured from their cameras, detecting the presence of intruders or other issues. To accomplish this, the use of artificial intelligence is required. However, the algorithms typically used for this purpose are developed for images captured by stationary cameras, so it is necessary to adapt them for the type of images obtained by drones.

In spite of the consensus regarding the play of drones as network infrastructure [3], [4], it is still necessary to perform in-the-field experiments to analyze their capabilities and requirements to exploit new network and services paradigms. In this context, this paper describes the ongoing tasks that are being carried out on IMMINENCE project to exploit drones for advanced communications and services.

The rest of the paper is structured as follows. Section II describes the current situation and technological challenges that motivate IMMINENCE project. Then, section III provides an overarching view of the project highlighting its main objectives and use cases. Later on, two complementary in-the-field use cases developed in the project are described in Section IV. Finally, Section V concludes the paper outlining the main future work.

## II. State of the art

Network management has become more flexible with the current deployment of 5G, allowing the introduction of new businesses into the market within a matter of hours instead of weeks. However, 5G does not accept autonomous management and it is still in an immature state when it comes to implementing self-adaptation based on network conditions. Additionally, the current model-based approach to mobile network management is insufficient for future networks with diverse technologies broad applications and dense deployments [5], [6]. In this context, alternative scenarios where ad-hoc deployments could be carried out even relying on drones and UAVs can be considered. This complexity on future networks will go beyond models and exploit available data for achieving an optimal design, enhancing situational awareness and overall network operation. The introduction of AI technologies allows analysing vast data from heterogeneous sources like wireless channel measurements, sensors, drones and surveillance images to generate a complete map of network devices.

Then, the processes of fault management can benefit from AI in order to improve filtering events and diagnosis of the network status. Since next-generation networks produce a high number of alarms it is necessary to filter them efficiently. In this sense, AI can help to manage them, reducing the number of the alarms created by the same event and classifying them according to their priority level thanks to correlation processes.

Additionally, by leveraging application aware networks, which enable access to cross-layer metrics, there is a potential to employ data-driven methods based on cross layer metrics in order to optimize multiple objectives for different applications with diverse quality of service (QoS) [7] and quality of experience (QoE) requirements [8], [9].

Another relevant field for next generation networks is the analysis and control of QoE. Since new deployments will be characterized by supporting high bandwidth and low latency communication, introducing large-scale low-latency and distributed immersive environments, understanding user experience issues related to these environments is crucial. Therefore, increased efforts are needed to comprehend QoE and ensure that the new technology does not result in negative user experiences. This control can be considered in professional and leisure activities, for instance, interactive services like remote control of professional equipment or gaming.

Finally, the maturity of the Telco sector is leading it to a strong competition that brings urgent needs to explore new business models. As an example, operators are divesting assets to improve their economic accounts. Maintaining sites is challenging due to variable energy costs, diverse site requirements, limited locations in cities, and complex licensing processes. In this sense, co-locating sites with multiple operators is a common practice. The primary focus to cut expenses lies in reducing operational and maintenance costs. Therefore, the potential to optimize operational and maintenance processes is crucial and can be achieved through the utilization of technology, implementation of effective business processes, and adoption of tools to target new customer segments and maximize asset capacity.

## III. General objectives of the project

IMMINENCE project is focused on three main ecosystems: Intelligent business analytics capabilities, Intelligent network management and new mechanisms for future mobile networks, considering the interconnection between them. Therefore, the project is aimed at developing intelligent network management methods and control functions techniques such as, application aware and self-configuration networks, artificial intelligence mechanisms for future mobile networks as well as advanced business intelligence and analytics. For this purpose, the project conceives multiple use cases and scenarios, which are exploited by the corresponding ecosystem. Figure 1 summarizes the ecosystems considered in IMMINENCE, so as to complete the intelligent network management and control functions. The main building blocks of such architecture are: i) New mechanisms for future mobile networks which include techniques such virtualization and resource slicing, the integration of AI in the edge part of the network and the use of drones for monitoring the infrastructure and facing spontaneous demands, improving coverage or coping with natural disaster which drive terrestrial infrastructure out of order; ii) Intelligent network management subsystem which encompasses a variety of techniques for improving network performance. Some examples are the use of machine learning algorithms for enabling the autonomous operation of the network, as well as for fault and security management. iii) Intelligent business data analytics which leveraging on the previous components provides information related to key performance indicators (KPIs) for further monitoring, business data analytics and quality of experience among others.

The project also includes several use cases in which the technology proposals are being integrated. We can highlight the following cases:

*a) KPIs in 5G networks:* Considering the radio level component in 5G networks, this use case aims to generate and improve existing algorithms based on AI for the determination of KPIs in 5G networks. The objective of adopting these algorithms is to achieve more efficient techniques for determining such indicators, by means of realistic estimations and alternative approaches from those traditionally adopted.

*b) Application-aware mobile networks:* This use case is focused on the analysis and design of intelligent network mobile management based on the domain-knowledge of the under-control processes as well as ML models in the network for predicting performance outcomes.

*c) QoE for 5G:* this case focuses on applying AI algorithms to make realistic estimations of Quality of Experience for 5G networks in real time, as well as correlating them with radio and network parameters so as to offer fast predictions in the future.

*d) Autonomous management for moving vehicles:* Based on vehicles that can move in a complete autonomous manner it is necessary to establish the interaction between automatic and human operator. Therefore, the use case analyses such a multi-modal environment in order to exchange the necessary information for supporting remote driving.

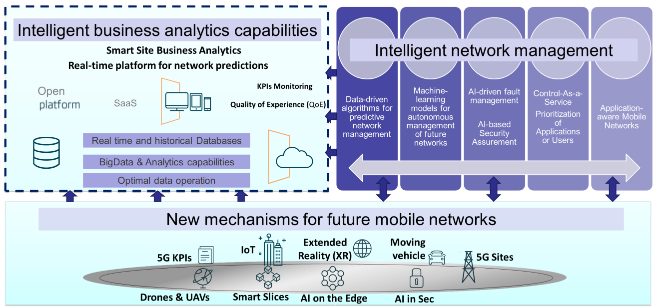


Fig. 1: IMMINENCE ecosystems

*e) Prioritization of applications or users:* Usually not all the applications, even for a single user, have the same priority. Therefore, since there are different scenarios in which the communication, computation and other resources might be limited, it is crucial to have clear priorities for accessing them. This use case focuses on the integration of new components able to establish these priorities for resource management allocation.

*f) Data-driven algorithms for predictive network management:* Since automation is essential for scaling and developing services, in this scenario are being developed data-driven algorithms for predicting degradation in end-user performance based on early predictors in network metrics. Moreover, it is also being developed data-driven learning approaches aimed at management scalability and distributing computation over edge and cloud effectively.

*g) Smart grid security:* Smart Grid technologies allow people to connect and disconnect from the main grid and generate and deliver electricity locally. IoT enable backup generators as photovoltaic panels, electric vehicle charging stations are integrated in the grid edge architecture. Unfortunately, these devices can be the objective of malicious actors so as to change the load. To avoid this, the project is working on gathering telemetry data from smart grid infrastructure and correlating it with the performance outcomes of the feedback controllers, using machine learning models.

*h) Smart site business analytics:* Building a big data architecture based on an open source solution is required to easily develop heterogeneous use cases for communication companies with the objective to prescribe specific improvement actions. Therefore, intelligent analytics are being designed as an accelerator of business use cases in order to track and improve key indicators of the next generation network management

In addition to the use cases presented above, the project integrates two additional use cases drone-based, for the development of new services that will be described in section IV.

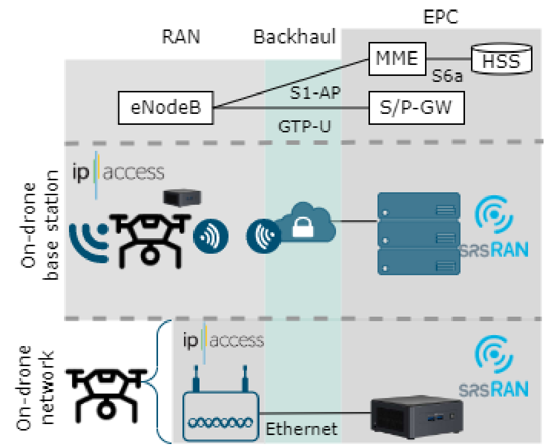


Fig. 2: Envisioned scenario for the ad-hoc RAN use case

## IV. Use cases around the drone IoT+4G embedded platform

Considering the new mechanisms for future mobile networks ecosystem integrated in the project, two complementary use cases are being developed. Both use cases are using drones and advanced wireless communications, however the developments are taking different work lines as they are described in the following section. The first use case tackles ad-hoc cellular network deployments, while the second one focuses on drone-based mobile edge computing (MEC).

### A. Use case 1- Drone based ad-hoc network

Future mobile solutions will consider on-demand network deployments to cover the user needs offering optimized systems for different services that require diverse functionalities. That kind of network deployment cannot rely on traditional models and must be deployed in an ad-hoc manner. When terrestrial infrastructure is damaged or it is not offering an adequate quality of service level for specific high-quality demanding services, the use of UAVs, such as drones, can help to deploy additional capabilities in a specific location. Additionally, artificial intelligence mechanisms can be deployed for analyzing data or images from this concrete area to support those services that were not responding properly.

This use case aims to demonstrate the possibilities brought by UAVs to ensure connectivity, even upon unavailability of terrestrial infrastructure. To that end, the use case will leverage the virtualization of network functions and services. It is implemented by embedding an LTE eNodeB and communication capabilities on a drone DJI Matrice 300 able to load 2,7 kg. In particular, the base station is the ip-access S60z AP which supports LTE FDD and LTE TDD operation. Additionally, the processing unit is a mini PC Intel NUC, with an i7 processor and 32 GB RAM Memory. From a networking perspective, the eNodeB is connected to an Evolved Packet Core (EPC) instance. At the time being, we are using the srsRAN [10] EPC implementation due to its lightweight and simple configuration.

Figure 2 depicts the overall use case setup. As can be observed at the top, it implements a simple end-to-end LTE network. In a first configuration (middle), the drone acts as a simple base station aiming to increase the cellular capacity in a specific area or to bring connectivity to a coverage gap. Although other alternatives could be possible, the backhaul connectivity between the drone and on-ground services is being implemented with WiFi. Hence, data information fed by ground sensors are sent to the base station embedded in the drone for overcoming radio coverage constraints. Note that this situation may happen when trying to read the parking sensor status in areas in which cellular coverage is limited demanding the third communications dimension.

Then, in the use case we will emulate lack of connectivity with the on-ground EPC; for instance, because of a natural disaster, such as earthquake. On detecting the disconnection, the processing unit will deploy a local EPC instance and redirect the traffic from the eNodeB, both control and user planes, to the new EPC instance. In addition, an instance of the IoT service will be also deployed within the processing unit. The use-case architecture resembles the ones defined by the 3GPP for 5G [11, Clause 4.2]. In this sense, in the on-board configuration the processing unit will host both the EPC and the local part of the Data Network.

### B. *Use case 2 - Mobile network and edge cloud resources for drone video analytics*

Within this use case, the available cellular network connectivity (5G/4G) and edge-cloud computing resources open up new possibilities for the efficient data transfer required by a drone during an unmanned aerial mission and for the flexible analytics of the data acquired by the drone (sensors, cameras, etc.).

We mainly focus in this use case on capturing, transferring and analyzing video, however a similar solution can also be applied to other types of data, such as RGB and thermal images, multispectral imaging or air quality data. The described scenario is meant to demonstrate the value of the proposed system in a specific application that requires monitoring safety or security on protected areas like telecommunication company critical infrastructure facilities and large construction sites. Buildings and technical installations on a fairly large area of land must be supervised by security guards. They are in charge to prevent security incidents such as intrusion of a person or entry of an unauthorized vehicle into the premises. Similarly on constructions sites we need to monitor intrusions and safety of workers. We propose within this use case to support security procedures with a dedicated, automated Information and Communication Technology (ICT) system consisting of cameras on drones, cellular data transfer, advanced AI video analytics and event notification system. Such security scenario can be easily adapted and applied to many other scenarios, such as search and rescue missions, inspection of railroads, pipelines or monitoring large gatherings of people.

The proposed system will be implemented using edge based architecture, as shown in Figure 3. The video stream from the

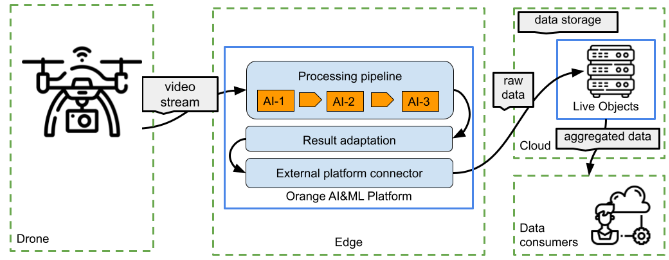


Fig. 3: System architecture for drone video analytics system

drone camera will be sent using 5G/4G network to the installed on edge premises AI/ML Platform [12]. Using dedicated, YOLOX based algorithms[1] implemented in the platform we are able to detect objects such as people, people in helmets, vehicles, animals etc. Raw data containing information about discovered objects is sent to the IoT Live Objects platform[2]. This cloud platform enables the storage and aggregation of data and makes them available using APIs for further use. Finally, information on the detection of unauthorized persons and vehicles in the supervised area is sent to the system operator.

In our preliminary experiments a Parrot Anafi Ai drone is used, equipped with 4G LTE connectivity for both command and control link and payload data transmission. The second drone with 5G connectivity is under preparation. In the presented use case we focus on the examples:

1) Detection of people, animals and vehicles in the restricted area.
2) Detection of people and helmets in the construction site.

The proposed architecture, where the video analytics platform is implemented in the cloud, is much more flexible, in terms of modification of the algorithm (e.g. adding new objects for detection or certain patterns for recognition), than if the algorithm would be implemented directly on the camera. In this way an introduction of a new scenario – e.g. not a facility security monitoring, but detection of flood embankment damage – requires uploading a specific AI model to the platform (which is simpler and cheaper), and not implementing a new camera board for the drone during the manufacturing process (which is more complex, time-consuming and expensive).

The camera set on a drone, which is performing and aerial mission, produces different type of image (different frame) than a typical fixed camera usually positioned at a height of up to several meters. Most of the AI model used for image detection and recognition are based on typical datasets (fixed camera positioned on the level of a few meters). We anticipate the potential need to adapt AI video analytics models to recognize aerial imagery. Preliminary results of people and vehicles detection in public areas from drone video stream are shown in Figure 4, where people and vehicles are correctly detected.

[1]https://github.com/Megvii-BaseDetection/YOLOX
[2]https://liveobjects.orange-business.com

Fig. 4: Preliminary results of people and vehicles detection

Fig. 5: Preliminary results of helmet detection

Also, preliminary results of the helmet detection in case of safety of workers on the construction site is promising and Figure 5 shows how people with and without helmets are detected. The raw images were taken from public data set[3].

## V. Conclusion and future work

The massive deployment of IoT infrastructure and new paradigms such edge to cloud computing continuum are becoming key drivers in conceiving new approaches in wireless network infrastructures. Furthermore, the requirements imposed by data analytic based services tend to approach computational capacities closer to the collecting data sites. Hence, it is in this context that, in the framework of IMMINENCE initiative, we propose a drone embedded architecture able to cope with several use cases characterized by low latency and high IoT density.

The first solution is based on embedding a 4G/5G eNodeB/gNodeB on drones aiming at collecting/detecting heterogeneous information which is sent to the terrestrial infrastructure for further processing. However, when such an approach is not yet valid, due to extreme requirements in terms of latency reduction, or because a natural disaster, such infrastructure is running out of order, besides the xNodeB also the packet core infrastructure is embedded in the drone which enables to carry out data processing on it. Initial promises results have shown improvement in terms of service provision and resource saving.

The second use case leverages the drone capabilities to develop an ICT monitoring system of critical infrastructure. While the first use case pays attention to the access network architecture, this one focuses on the service provision. In particular, the use case provides a video monitoring service and exploits ML/AI in the edge for image recognition. Preliminary results shown in the paper demonstrate the potential for infrastructure monitoring from images captured by drones.

In our immediate future work, both use cases will be validated in-the-field, using the described equipment and devices. Once independently validated, we will analyze the potential integration of both use cases to ensure service continuity for critical infrastructure or emergencies. Thus, in a combined scenario the AI/ML image recognition in the second use case will be placed in the drone along with the cellular core upon disconnection from the terrestrial network. In turn, the deployment of the combined scenario will require analysis of the complexity of the AI/ML algorithms to ensure that can be embedded in the drone while keeping the required accuracy.


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