5G-Cognitive Drone System for Preventive Maintenance in Energy Infrastructures

Experience in 5G-PPP NRG-5 project

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***Abstract*— Targeting the Smart Energy vertical domain, an energy infrastructure Preventive Maintenance as a Service (PMaaS) application is being implemented within 5G-PPP Phase 2 NRG-5 project. This service relies on semi-autonomous swarms of drones to run such a complex, bandwidth demanding, computationally heavy and time critical application, at the same time all operational, communication and mission requirements are met. The use case presented in this paper is supported by the definition NFV concepts within a 5G communication network architecture and the integration of application specific logic with a complex forwarding graph of VNFs for virtual Media Processing & Analysis (vMPA) and virtual Drones Flight Control (vDFC); VNFs able to perform respectively real time video streams processing and analysis and autonomous flight control of drones. This paper addresses the 5G advances at the edge network and develops these VNFs to support low-delay 5G-enabled cognitive surveillance using drones leading to more efficient operation of energy networks, resulting in a reduction of maintenance costs and an increment of the QoE offered by the utilities to the citizens.**

***Keywords*— swarm of drones; 5G; smart energy; surveillance;**

I. Introduction

Drones are becoming nowadays popular and affordable. The Global Drones market is expected to cross USD 7.0 Billion by 2022 [1]. Taking advantage of this progress, the Energy industry started to adopt manually driven drones to perform visual inspections, but special flight control certification has been necessary, and the time required for such operations is, still, hindering wide adoption. To overcome with these limitations, intelligent drone-based systems are being increasingly proposed for its usage in aerial preventive maintenance of critical infrastructures (e.g. energy generation and distribution plants and the corresponding assets of either electricity or gas scenarios), context that can benefit from automated video surveillance in terms of: (1) accident prevention and safety by reducing risks of working at dangerous environments (due to height, poisons, etc.) and reducing interventions; (2) enhancing quality of work; and (3) solutions environmental friendly by avoiding damage to land; at the same time maintenance costs are reduced and the reliability of the power network increases. However, high power consumption, flight coverage range and weight are some of the limitations future drone-based systems need to deal with.

Furthermore, the new mission critical related "as a Service" business models that relying on drone-based technology can be offered for critical infrastructures is demanding a next generation 5G communication network able to match expectations at least in terms of optimal deployment, scalable, fast response, less energy consumption and improved security.

This paper targets a novel application that exploits the possibilities that performing data processing at the edge of the network offers in a 5G-ready communications environment. It is the result of further research on the project idea presented in [2]. By means of the offloading of drone's flight control and visual media processing and analysis functionalities the provision of a low-delay, 5G-enabled Preventive Maintenance as a Service (PMaaS) in the energy domain using swarm of drones is possible.

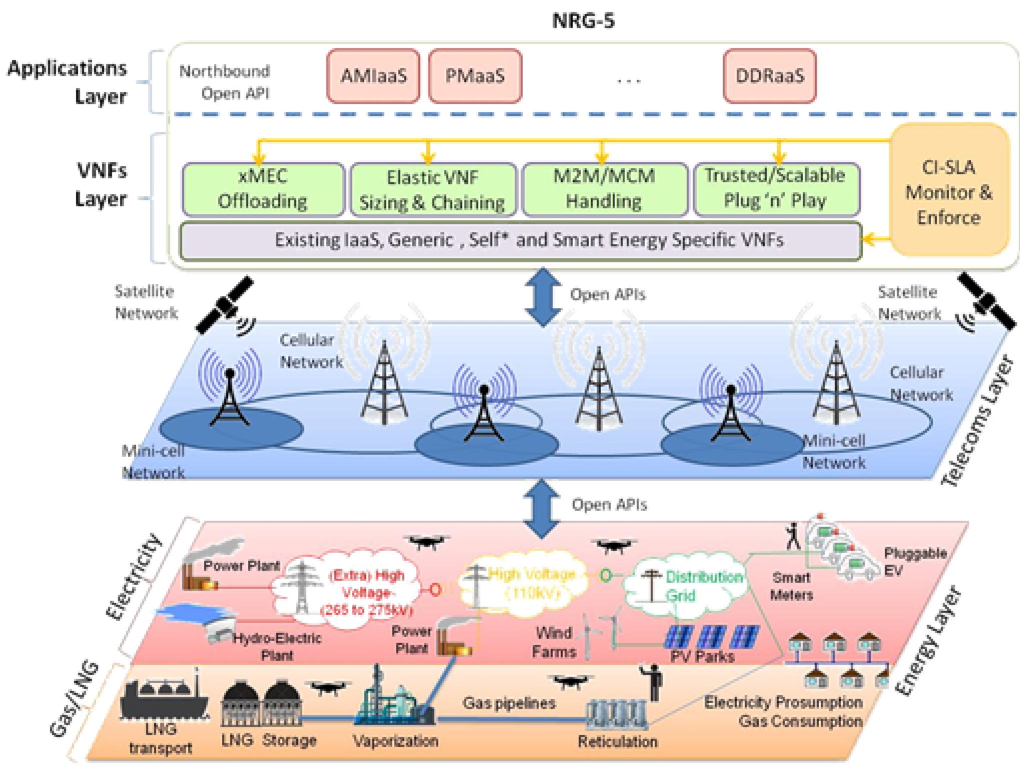

Fig. 1. NRG-5 High-level architecture

II. System Architecture

Controlling a swarm of drones is a quite complex and processing intensive task. The automatic surveillance of the network needs of extensive video processing. However, the benefits of counting on with 5G-ready cognitive drones are manifold as it will be demonstrated in subsequent sections.

In order to realize the PMaaS scenario, a 5G Network Architecture as shown in Fig. 1 is proposed as part of NRG-5 project [3]. At the lower level, the energy layer, composed of varying energy infrastructure assets is represented. It covers the complete energy scenario, being the scenario presented in this paper specifically focused on the gas network of pipes and related critical assets used for its generation, storage and distribution. Over this layer, the telecommunications network, including a satellite backhaul. Finally at the higher level, the architectural and application layers.

Following the 5G Architecture vision, a number of Virtual Network Functions (VNFs) offering Infrastructure as a Service (IaaS), Self* functions (such as self-discovery, self-configuration, self-healing etc.) and smart energy specific VNFs are provided. At the higher layer, we introduce mechanisms such as extended Mobile Edge Computing (xMEC) routers for offloading computationally heavy functions from hardware constrained devices to the edge-cloud infrastructure [4], elastic VNF sizing and chaining, M2M/MCM communications and additional trusted functions. Thus, services such as the one for Authentication, Authorization and Accounting (vAAA) is considered really important for the provision of 5G based services. The work presented in this paper is focused on two VNF that support the PMaaS service within NRG-5 project: a virtual Drone Flight Control (vDFC) and a virtual Media Processing and Analysis (vMPA), respectively.

III. PMaaS in NRG-5 Project

The scenario proposed for predictive maintenance of critical infrastructures in NRG-5 project is based on the use of a single drone or swarm drones equipped with visible HD/thermal image acquisition and GPS positioning capabilities to proceed with performing standard monitoring activities as follows:

- flight over pre-designated areas containing critical infrastructure allowing for regular survey missions;
- specific local checks/incident detection in sensitive modules;
- security oversight: predefined round circuit, to check site boundary limits;
- monitoring of worksite areas for activity support;
- remote third-party inspection: drone flights over non-accessible structures for inspection, to avoid process disruption.

Apart from these mission requirements that will guide the intelligent video analysis and inspection other requirements need to be met: a) operational requirements, such as to define the flight plan for each drone in a swarm, so that they have optimal coverage with minimal resources, taking into account the flight capability of each drone and the remaining energy, b) communication requirements, either by cellular or satellite links controlling the drones flight and uploading captured video that will be further processed.

Figure 2 shows an initial design of the proposed PMaaS that will be implemented on top of the envisaged 5G network architecture to address above mentioned issues. Both the drone GPS/Flight Control and the Remote-Control module will be modified so that computing complexity tasks to be offloaded to the xMEC, while vMPA and vDFC VNFs will also run on this device so that applications hosted on drones may migrate tasks from their embedded processor to the edge cloud accelerator [5], sense the traffic demand and the mobility/distribution of the drone swarms.

This solution provides a large area coverage only limited by drone battery as we are using machine-type communications over 5G systems: a) Extreme/Enhanced Mobile Broadband xMBB/eMBB communications via the vMPA VNF for video streaming from the drones and analysis to the xMEC and the utilities control centre, and b) Ultra-Reliable Machine Type Communications (uMTC), also called Ultra-Reliable and Low Latency Communications (URLLC), via the vDFC VNF for controlling the flight of drones.

Additional vMPA and vDFC instances may be deployed and/or their resources may be dynamically scaled-up in locations where there is an increased traffic processing demand. In this way, the access and especially the backhaul network capacity is preserved, thus offering the capability to the network infrastructure to allow remote control and conserve more users/terminals, while mobile operators monetize on their access/edge resources.

The solution proposed in this paper helps to overcome limitations current drone technology is affected by: low range flying control, low camera quality, onboard storage of data, no encryption mechanisms and data transmission bandwidth limited to 10Mb/s in the best case. The NRG-5 benefits are: very low latency able to secure the flight control and the transmission of real time HD videos, simultaneous control and data transmission and registration of events in a secure and non-disputable fashion.

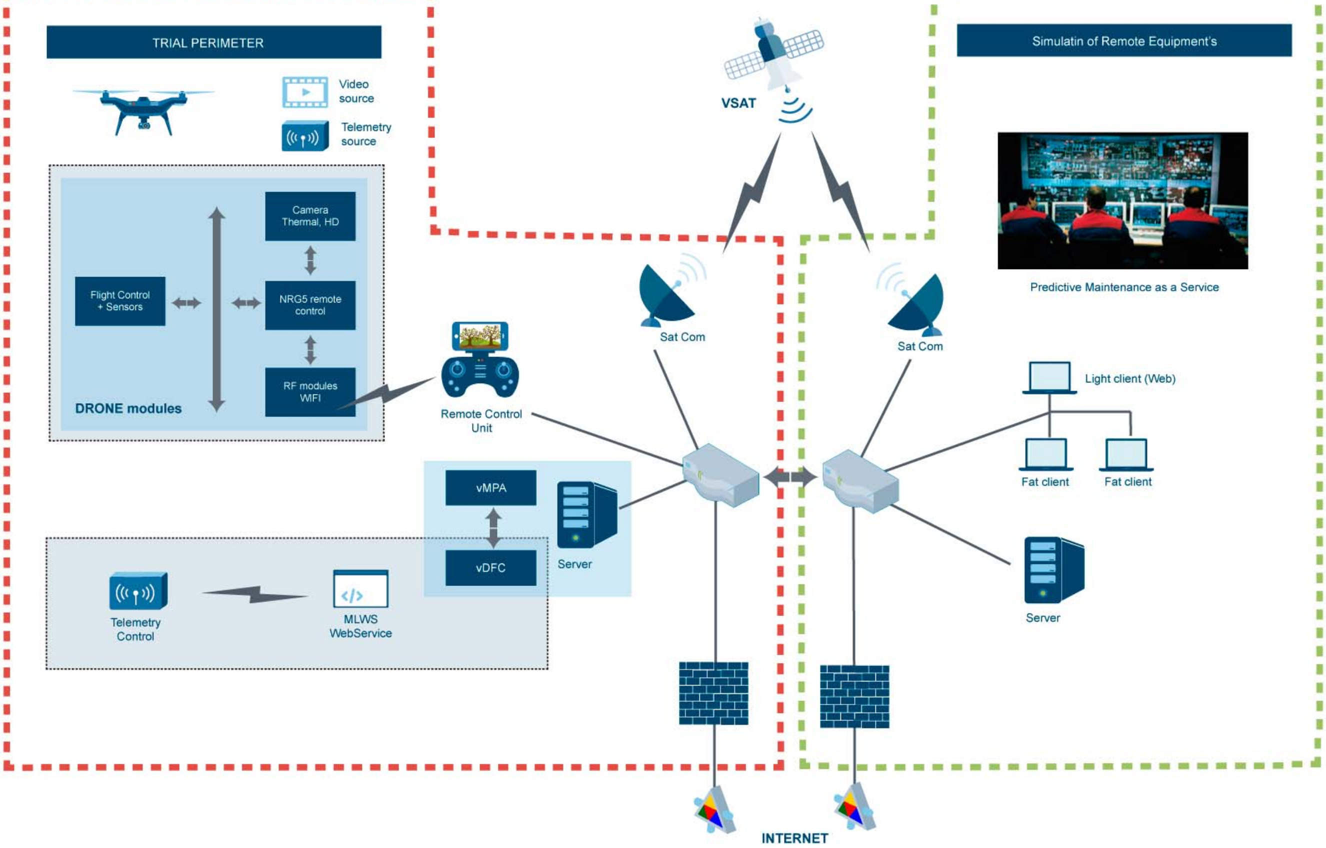

Fig. 2. NRG-5 Initial design of the Preventive Maintenance as a Service (PMaaS) for energy infrastructures

Table 1. NRG-5 UC requirements matching 5G expectations

Drone use case requests			
Item	Actual in use	Future requests	5G objectives
Broadband	10 to 30 Mb/S (5Ghz Wifi-WiMax, public 4G)	50 to 60 Mb/s (future camera capacity)	10Gbps to share
Latency of Radio transmission, without vMEC	2 seconds via VSAT 50 to 200 ms local 4G, 5Ghz Wifi-WiMax	20 ms	1 ms handover guaranty without disconnection
Registration time	2 seconds	2 seconds	less than 1 second
Q.o.S	5Ghz: 99.98 4G:Operator QoS	5Ghz: 99.98 4G:Operator QoS	99.99 5% of picture quality
handover	20 ms	20 ms	handover guaranty 5ms with preselection

IV. IMPLEMENTATION

It has been showcased the capability for a drone to sense the surrounding, compute its trajectory that avoids nearby obstacles while flying towards the original destination using a real-time trajectory generation layer based on model predictive control schemes. We will continue to take on the challenging topics by providing solutions to real world problems that require more than one autonomous system to perform their missions with minimal human intervention. Such goals require the capability of the autonomous systems to sense, reason, and act in a highly intelligent manner. Moreover, the formation flight is the primary movement technique for the drone teams: it establishes a coordinated formation to achieve flight integrity with less power consumption, increasing the possibility of a mission's success [6][7]. Finally, system identification techniques have not been exploited for drone flight guidance [8]. Yet, these techniques are quite complex leading to significant energy consumption and quite expensive CPUs on the drones. Autonomous navigation, obstacle avoidance, landing, and flight guidance in the context of PMaaS should be considered from several factors: accurate positioning, sensor fusion, sensing arbitrary terrain, and real-time operation.

The objective of this paper is not to report on these areas, but instead to focus on the off-loading of drone’s on-board computer, migrate the visual analysis at the MEC using relevant media Processing and Analysis VNFs (vMPA), continually evaluate the scenario to enhance situation awareness, requiring the remote operation of the Drone Flight Control (vDFC) in any case.

A. virtual Media Processing Analysis (vMPA)

The virtual Media Processing & Analysis (vMPA) is a VNF able to perform real time video streams processing and analysis. By exploiting data coming from onboard camera sensors, cognitive capabilities on the edge let drone-based system understand what is happening in the scene under surveillance [8][9]. This requires not only drones able to transmit their captured video streams and high-resolution images in real time to the vMPA, but also this virtual function able to automatically and with the lowest possible delay processed, transform data into contextual intel and semantically enhanced in a semi-supervised way. For automated tasks, vMPA would raise any alert to the control center for a video review by inspectors or to the drones themselves for self-reconfigure the flight plan. During manual operation, vMPA aids maintenance operations as well. Though this VNF is specialized for energy infrastructures-related video processing, it will be generic enough to be used for generic video processing and analysis in similar scenarios.

B. virtual Drones Flight Control (vDFC)

A virtual Drones Flight Control (vDFC), also part of the xMEC, is a VNF able to perform real time autonomous control of drones so that drones and particularly swarms of drones should be able to be coordinated in either an automated or a remote-operated manner. vDFC is being prepared to take control of the drones not only in a real time manual mode, to drive the drone as a pilot would do it, but also in an automatic mode by predefining surveillance routes or semi-automatic and setting a map point, by an operator or by alert system, and letting the drone to reach it without human interaction. This evidently involves ultra-low latency for acquiring the proper drone driving directives, as well as accurate positioning of drones and minimal base stations handover, when these are deemed necessary by the relevant infrastructure.

This VNF will also be quite generic, as it may be used for applications such as precision agriculture, security monitoring of critical infrastructures and crown management. The vDFC is remotely accessible to let secure remote control of the drone, moving all control functions to wherever the user is.

V. RESULTS

Figure 3 shows preliminary results corresponding to intrusion related events (i.e. people and vehicle not expected but detected close to the main entrance) after processing sequence of visible range images acquired by drone type DJI Inspire 1 with a Zenmuse X3 Camera and a FLIR Zenmuse XT IR camera for thermal images, available at the critical energy infrastructure.

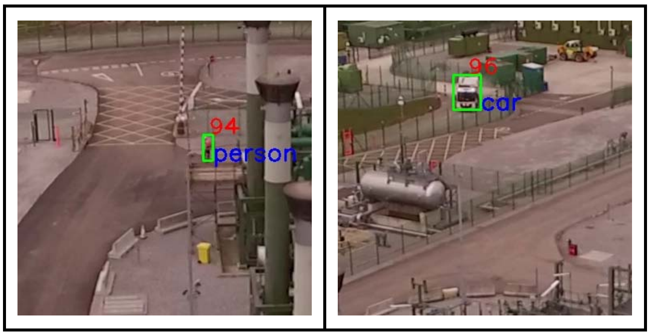

Fig. 3. Intrusion Detection at the critical infrastructure processing sequence of visible range images

In the same way, images from thermal cameras are processed to provide an early warning response to hot spots. The temperature at which an alarm signal is generated can be set, and multiple target spots and alarms can be used. Some initial results are shown in Figure 4.

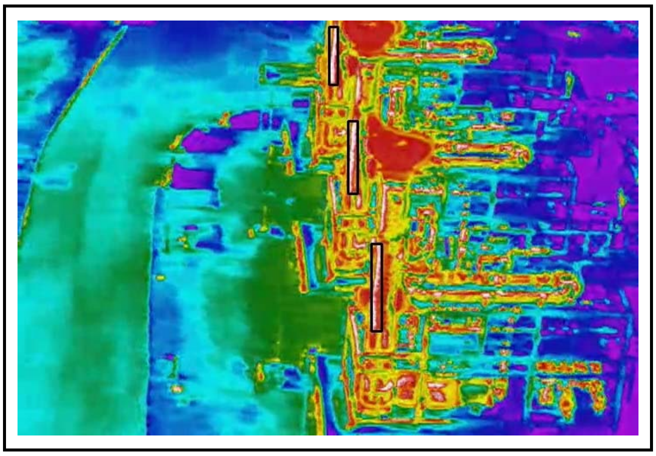

Fig. 4. Thermal image from a gas storage area in the critical infrastructure highlighting three spots where temperature is abnormally high causing an alarm to go off

When an alarm occurs, visual information is provided to the operator for verification of the problem and its exact location in an extremely early stage. Further development in the framework of NRG-5 will allow feedback to be directly provided to the cognitive drones so that their flight plan can be modified for double-check inspection.

Thermal image analysis uses to generate fewer unwanted alarms, which are a common problem with visible range images, allowing the detection of intruders like the ones highlighted in Fig. 3 in the event of total darkness.

VI. Conclusions

This paper proposes a use case related to PMaaS that can be instantiated in form of VNFs running on top of xMEC NFV architectures, utilizing drones remote control, processes offloading and advanced media processing techniques. The complete framework will be validated in laboratory environment but under real life situations where failure (in whole or in part) may have a significant impact on security, the economy and basic human needs.

Integration with vDFC is still required. First tests will be using the automatic mode with a pre-selected flight plan. This will include the classical predefined predictive maintenance checks and the specific missions in a gas plant selected for the experiments (e.g. process alarm, intrusion detection, thickness measurement, landscape movements, etc.). Further, a second flight plan can be added to control the borders around each critical site. It will deal with emergency/unscheduled activities, caused by no expected events. Indicatively, in the case of an alert, the use of drones operating in manual mode should allow for the incident localization, support of the active team on their activities (construction phase or repair) and participation to human search and rescue operations (e.g. people lost, injured or intruder).

The proposed PMaaS on top of an innovative virtualized 5G architecture able to simplify 5G coverage extension and centralized applications, fully integrated in the 5G architecture layers will save time in energy maintenance operations by increasing efficiency inspections exploiting the capabilities of vMPA/vDFC to automate routine inspection. On the other hand, will avoid personal risks due to poisoned areas in case of poison products leakage and gives easy access to heights avoiding climbing just for a visual inspection. This way, the staff can be prepared to face any issue by having real time images and plan how to solve it more precisely. KPI evaluation will be carried out in terms of: time and cost savings, reduction of the risk of injury for operators, performance incensement as it will permit to survey non-accessible zones regularly, frequency of control incensement for early detection of risks, and no service breakdown as replacements of defect elements can be anticipated.

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