On the interplay between 5G, Mobile Edge Computing and robotics in Smart Agriculture scenarios

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Abstract. The relentless growth of the human population over the time is driving an exceptional rise in food demand. Improving the efficiency of farming processes is the only way to face the so called Malthusian catastrophe. This objective could be pursued by automating production processes in farms. Robots can play a key role in this context, especially when they can execute tasks on collaborative basis. At the same time, low latency communication capabilities are required to translate in reality the robotic-aided smart agriculture vision. This contribution explores the interplay of 5G, Internet of Things (IoT), and Mobile Edge Computing (MEC) as enabling drivers for technology spread in the agriculture domain, based on Industry 4.0 principles. In particular, some key performance indicators have been investigated for a rural-area scenario, exploring different technological configurations.

Keywords: Smart Agriculture, Robotics, 5G, MEC, IoT

1 Introduction

Food security has become a global concern. Governments worldwide are facing an exceptional rise in demand for food, and a significant human population growth. Moreover, limits on the exploitation of natural and human resources cause debates about the actual sustainability of the current economic model [1]. This has led to the rise of precision agriculture methods, which focus on harvest and production maximization, while fully optimizing the available land resources. Just as with any industry, production efficiency requires automation and elimination of human factor issues, which brings great interest in robotics integration into the agriculture supply chain. Many technological and engineering challenges need to be addressed in the context of agriculture mobile robots and precision autonomous farming [2].

The introduction of autonomous agricultural systems fosters a new range of flexible equipments able to reduce waste, improve economic profitability, cut environmental impact and increase food production sustainability [3]. The Agriculture Robots market is expected to rise to more than \$16 billion by 2020 [4], and the use of robotics in this sector will employ a manpower larger than the automotive and aerospace sectors combined [5]. However, costs and technological obstacles to the adoption of such technologies on a large scale could be prohibitive [6]. It is, therefore, necessary to find a new economic and reliable approach to deploy a feasible infrastructure for agricultural robotics.

In this context, IoT and 5G technologies, combined with MEC, can become key drivers. 5G will be the dominant technology providing large area connectivity in the coming years with extremely large throughput coupled with low latency communications [7]. IoT is a definite paradigm for many industrial contexts, widely spread for information sharing and decision coordination [8]. MEC enables the network architecture to move cloud computing capabilities at the edge of a cellular network, reducing network congestion and optimizing applications execution [9]. Combining these technologies makes it possible to take decisions and execute functions more accurately, reliably, and quickly.

In this paper an overview on 5G-MEC and robotics is provided, proposing a use case architecture for precision agriculture environment as an emblematic paradigm for Industry 4.0 applications [10]. In addition, two demonstratives use case examples have been conceived using ground and aerial robots for agricultural operations. Key features of the envisioned domain support many automation improvements for monitoring, harvesting, and remote sensing.

The rest of the paper is structured as follows: Section 2 proposes an overview on Smart Agriculture state of the art, with the current trends in agricultural robotics. Section 3 reports the chosen enabling technologies, focusing on key aspects for the proposed architecture requirements. Section 4 presents the proposed framework focusing on the application areas of the aforementioned technologies. Two representative use cases are described in Section 5. In Section 6, an outline of the work is given, thus envisaging further research activities.

2 Smart Agriculture

The current challenge of agriculture industry is to produce more food to feed a growing population with a smaller rural labor force [11]. As a consequence, in many agriculture-dependent developing countries, the adoption of more efficient and sustainable production methods, and climate change adaptation strategies become mandatory. Within this context, farming technologies will be crucial to the evolution of this industry. Modern agricultural tools have eased the work of many farmers worldwide, and many instruments such as data analysis, detection systems, telecommunication networks, hardware, and software systems are involved into the environment referred to as "Smart Agriculture".

The typical IoT architecture implemented here, entails the deployment of an array of sensors on the field, a gateway that collects information and a cloud-processing service [12].

2.1 Agricultural robotics

The large scale adoption of robotics in agriculture certainly requires the following technological features: navigation tools, image processing, real-time control of physical extensions, and reliable walk on rough terrain [2]. Many works and prototypes have been put in place in recent years: *agricultural robot partners* facilitating harvesting and pest control, remotely controlled by human operator [13]; Controller Area Network (CAN-bus)-based robot using vision positioning systems to identify and locate the fruit to harvest [14]; autonomous Agriculture Robot designed for seed sowing tasks [15]. Moreover, other studies focus on human-machine interaction, regulations, safety, ethics, and human comfort [16].

The aforementioned requirements has led to a growing demand in terms of both tools and connectivity that recent technologies struggle to satisfy. To this end, the rise of 5G and Software Defined Networking (SDN)-based edge computing interplay can be a keystone for effectively boosting robotics adoption in agriculture, even more on a large scale.

3 Enabling technologies and key features

A description of the involved technologies is proposed herein, thus highlighting their most effective features for the proposed environment.

3.1 5G technology

As reported in [17], 5G networks are expected to provide Enhanced Mobile Broadband (eMBB) with a peak data rate up to 20 Gbps, massive Machine Type Communication (mMTC) bringing long range and low data rate capabilities and Ultra Reliable Low Latency Communication (URLLC) for ultra responsive connections offering less than 1 ms air interface latency.

(Figure 1)

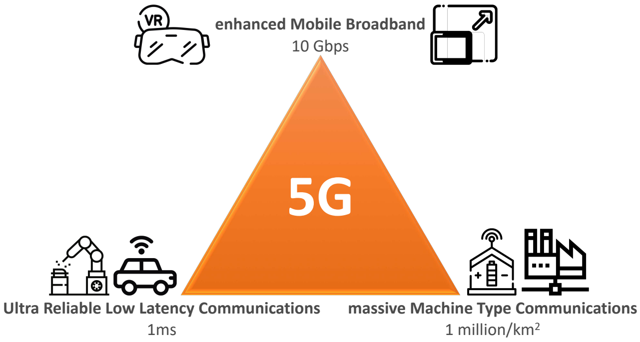

Fig. 1. 5G fundamental pillars and use cases

In addition, 5G technology adopts Cloud based Radio Access Network (CloudRAN) supplying massive connections of multiple standards and deploying on-demand functions of Radio Access Network (RAN) with a simplified core network architecture. Robotics can certainly take advantages from this framework, especially looking at high data rate, for high-definition video streaming, virtual or augmented realit, very low latency (about 1ms) for real-time interaction, and reliability for errors and delays reduction in communication.

Compared to the current 4G standard, 5G connectivity brings higher energy efficiency, more possible connections, higher data volumes, and a lower latency, essential features in the robotics domain [18]. The high number of possible connections provides a mainstay for massive industrial IoT applications where a large sensor network can communicate via 5G modules. 5G also incorporates a direct machine-to-machine mode of communication without the base station as an intermediate waypoint [19]. In Smart Agriculture context, the combination of 5G and Global Positioning System (GPS) will completely unbind robots from manual or near-field control, allowing them to foster innovative farming techniques.

3.2 Mobile Edge Computing

Currently, cloud computing represents an efficient way for data processing, since the computing power on the cloud outclasses the one at the network gateways. However, with the growing quantity of data that IoT and automation systems produce, the network bandwidth has come to an impasse, particularly when compared to the fast developing data processing speed. This represents a bottleneck for the cloud-based computing paradigm [20].

In this context, MEC can represent a step-forward for network design.

The Edge computing model (Figure 2) refers to the capability of moving computation precisely at the *edge* of the network.

MEC servers are implemented on a generic computing platform within the RAN and allow the execution of applications near end devices. This policy can lighten the backhaul enabling low latency, high bandwidth and enhanced mobile services. Specifically, some key performance indicators within peculiar use cases for MEC technological interplay can be highlighted.

The first is about the benefits of using edge nodes in robotics environments for computation offloading over remote processing platforms or local robot controllers. Specifically, computationally expensive robotic Simultaneous Localization and Mapping (SLAM) task can be offloaded. For instance, in [21] a SLAM offloading algorithm in a multi-tier edge+cloud setup is proposed. The proposed scheme outperformed the static offloading strategies thus demonstrating performance enhancement of robotic SLAM using servers at network edge.

The second, highlights the scalability perspectives through edge analysis integration. The growing number of IoT devices is demanding significant cloud input bandwidth for data processing. This can be remarkably lower if data analysis is moved at the edge, uploading only light metadata and information. As shown in [22], the proposed cloudlet-based framework runs computer analytics

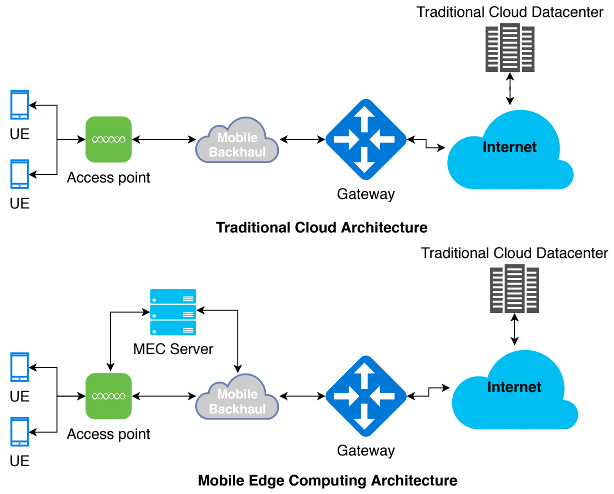

Fig. 2. MEC vs Traditional architecture.

of high-data-rate sensors streams in near real time reducing ingress bandwidth into the cloud by three to six orders of magnitude.

The third considers the adoption of wireless interconnected Virtual Reality (VR) in a 5G/MEC network.

Authors in [23] envisage the migration of computationally intensive activities from VR devices to more resource-rich edge servers, thus increasing the computational capacity of low-cost devices while saving energy. For VR applications, both radio access and computational resources are brought closer to users, taking advantage from small cell base stations near to computing, storage, and memory resources. Experimental results show a 16 percent more immersive experience gains in MEC/FOG configuration compared to other. The immersive experience is defined as the percentage of tasks that are executed and carried out under a specific deadline.

3.3 Key features

Looking at a classic smart agriculture pattern, the leading requirement is to bring automation to the different phases of an agricultural process. However, the full adoption of these solutions on a large scale by precision farming systems is of complex implementation. Farming techniques lacks of actual automation and control in several tasks, still conducted by humans. To this end, robotics certainly represent an enabling technology but unplugging robots from human control requires a strong technological set. As previously mentioned, next generation of 5G networks can meet these needs, ensuring high throughput for bandwidth intensive applications, low latency for real-time control, high scalability to enable a massive number of devices, energy efficiency and ubiquitous connectivity for end-users. Furthermore, considering that IT Infrastructure, data gathering, and Decision Support Systems (DSSs) activities, all access to cloud computing services, the implementation of this pattern into rural areas is often not feasible without a reliable Internet connection and area coverage by local telecommunications infrastructure. As a result, the following topics should be examined to straight out above issues:

- real-time and reliable connections for robotics equipment;
- rural areas coverage by telecommunication networks;
- solid computing capabilities for real-time decision support.

In this paper a Smart Agriculture 5G-robotics architecture is proposed in order to address above queries.

4 Envisioned architecture

The proposed framework is sketched in Figure 3. The involved entities are:

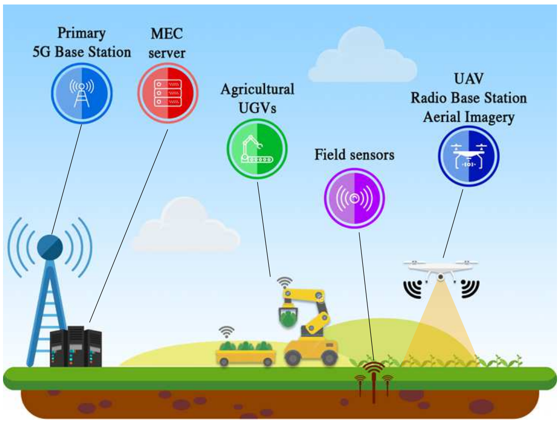

Fig. 3. 5G-MEC-Robotics Smart Agriculture scenario

- Unmanned Aerial Vehicle (UAV)
- Agricultural Unmanned Ground Vehicle (UGV)
- Field sensors
- 5G primary Base Station (BS)
- MEC application server

Thanks to the adoption of these tools, it is possible to accomplish UAV-based monitoring and connectivity, field machineries automation, and MEC-based fast processing. More details are provided in the following subsections.

4.1 UAV-based monitoring and connectivity

The advent of low-cost UAVs will enable a large adoption of remote sensing applications for precision agriculture. Indeed, in the proposed architecture the UAV can carry out two main tasks: area patrolling and analysis through image processing and 5G coverage extension.

The first task is executed through high-resolution image capture by using on-board cameras. This pictures, together with the information gathered from soil sensors, can trigger a more precise crop management. As reported in many studies [24] - [26] and applications [27] a possible alternative to aerial images could be satellite-based captures. On one hand, the accessibility of this type of images is limited and high-priced. On the other hand, open-access multispectral imagery has very low resolution. In this context, aerial imaging campaigns can be convenient even though they require sophisticated camera systems and sturdy hardware. UAV images can address many of the imaging needs of the agriculture context, such as mixed cropping analysis, low area landholding, and variable planting cycles observation.

The second task is fulfilled by the presence of an UAV refers to the need for a 5G platform able to bring rural areas coverage with no infrastructures for Internet connection. To this end, as foreseen in [28], [30] an UAV-aided 5G network architecture can be designed. This solution allows the UAV to carry on a mobile 5G base station, thus providing radio connectivity to the targeted area and connecting itself to a primary base station. In this way, UAV-aided wireless communications can supply ubiquitous coverage, relaying, and data collection. The proposed framework accomplishes the so-called 5G BS offloading through the use of drones.

4.2 Field machineries automation

In the proposed environment, real-time control and autonomous driving capabilities can enable field robots to assist workers by carrying payloads and conduct agricultural operations. Image processing, combined with data gathering from sensors, can be used for instant evaluation of the phenological phases, control weeds, detect the presence of insects, and diagnose diseases. The reported features will increase automation in the field and reduce the reliance on human action in farming management, planning, and decision making.

4.3 MEC application server

All the aforementioned applications, from data gathering to real-time processing, can not be efficiently executed if they are still based on the current cloud-computing paradigm. In autonomous vehicles and robotics systems, gigabytes of data are generated every second, requiring real-time processing to take correct decisions. Classic cloud-computing architecture poses a serious time-response issue in this environment, especially if the use case presents a large number of devices/vehicles to serve in one area. Executing the data processing at the edge can speed up response time, optimize processing, and avoid network congestion [31]. The proposed pattern envisages a MEC server at the edge, in order to manage requests and process information. In particular, it acts as a low-latency aggregation point, allowing applications to respond in real-time. In the following sections some case studies are described where techniques and scenarios are proposed to take advantage of MEC systems, in the smart agriculture environment.

5 Use case configurations

In order to provide examples of how the proposed architecture can be applied, two use case configurations are presented herein.

The first case is about the implementation of an autonomous harvesting robot (Figure 4). The main goal for this type of robot is to execute an unmanned patrolling while having a stable walk on raw terrains and avoiding obstacles. To this end, in the proposed architecture, the robot could employ both real-time processing capabilities and low-latency response to process corrective measures instantly. Moreover, the robot can carry on a high-resolution camera that, powered by MEC high computational capabilities, will be able to process 3D imaging of fruits, vegetables, and plants, thus properly driving a real-time decision policy for the harvesting process based on color detection, dimension, and shape.

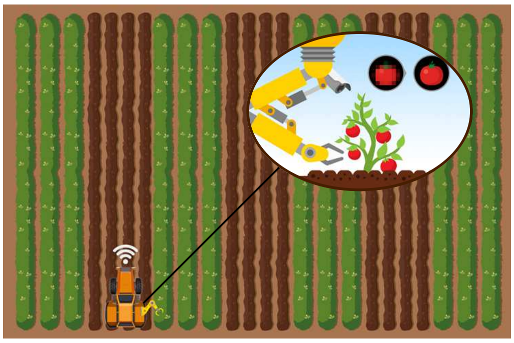

Fig. 4. First use case: Robot patrolling the area and harvesting with image processing-driven decision policy

The second example, reported in Figure 5, concerns the use of the UAV for monitoring purposes. In particular, the drone can periodically execute an unmanned patrolling of the area, providing soil imagery and sensor data. Moreover, thanks to high throughput and bandwidth of the envisioned 5G architecture, farmers can exploit a First Person View (FPV) system for drone navigation through a VR head-mounted display, experiencing immersive teleoperation capabilities. In Table 1 some of the differences for use case requirements are listed. Bandwidth and latency requests, and error tolerance characteristics are highlighted for each task. Despite the advanced applications of the proposed use

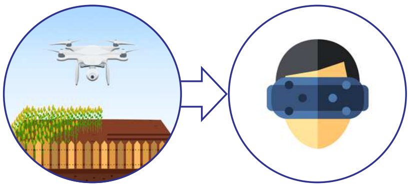

Fig. 5. Second use case: Drone monitoring and VR teleoperation

Table 1. Use case requirements

	Task	Bandwidth	Latency	Error tolerance
UGV	Harvesting	High	Low	Very low
	Patrolling	Low	Low	Low
UAV	Monitoring	High	High	High
	VR Teleoperation	Very high	Very low	Very low

cases, there are some serious drawbacks that have to be investigated. In particular, energy question is primary. An autonomous recharge policy should be provided and UGVs and UAVs have to return periodically to a charge station, thus requiring job scheduling optimization for charging phases. Furthermore, research on robots physical extensions for seeding and harvesting (e.g. extensible arms, prehensile manipulators and automatic drills) still presents many open issues. Indeed, these tools must be reliable and cost-effective to allow a large scale adoption of these solutions.

6 Conclusions and perspectives

This work proposed a reference architecture for Smart Agriculture environments based on 5G, MEC and robotics technologies. The main objective for this solution is to design a system suitable for a large scale adoption of robotics in the agriculture domain. To this end, use case configurations have been provided, highlighting benefits and open issues of employed technologies. The challenge for future research will be to execute modeling and simulations, proving the feasibility of this technological interplay. Moreover, solid business models and attractive pricing strategies can help the wide diffusion of this model. For this reasons, further research activities will consider the application of telecommunication network economics theory within this context.

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