

A Novel Smart Farming Architecture Concept: The Insights from the AGRARIAN Project

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Abstract

Achieving effective smart farming is a key target for industry and society in that fulfilling the goals of sustainable agriculture is part of current EC roadmap. To this end, an appropriate and novel multi-disciplinary concept encompassing ICT technologies, data analytics, and support of human factors is a key element to provide stakeholders (e.g., farmers) with a modern platform allowing for automatised monitoring and decision process. In this regard, the design of a new smart farming system architecture is of paramount importance to achieve these goals and to pave the way towards a better quality of experience from a farmer’s point of view in the daily practice. Along these lines, this paper illustrates the view developed by the AGRARIAN project with respect to the design smart farming platform, by discussing at length the general architecture and providing insights to its actual use in real-world pilots.

Keywords: Smart farming, 5G, satellite, edge-cloud continuum, data-driven decision making

Introduction

The agriculture and overall farming sectors represent a key component in today society as part of the overall food supply chain, where they importantly play as the first layer (i.e. production of raw material) in the overall process. In general, the farming process entails several actors and processes, spanning resources production, maintenance (i.e. irrigation), monitoring, and the overall decision making and support process, which all together require interaction with the farmers, technology providers (e.g., ICT, manufacturing sectors, etc.), and eventually with government (local, national, and continental level where applicable) for what concerns regulation and policy reinforcement. Such a complex picture hence requires a proper coordination between all the involved stakeholders and effective integration across all system elements. In particular, the overall smart farming sector demands for a unified approach providing farmers with a platform able to automatise the overall process in a transparent way and to provide a solid decision support concept for guiding the realisation of agriculture services according to best practices, governmental policies, and general adaptation to varying environmental conditions (e.g., climate changes). This eventually calls for the design of a novel concept able to glue communication, computing, and sensing functionalities typically offered by the ICT sector with a proper decision support system, suitably following human factors principles. As such, the definition of future smart farming systems is going to be a complex multi-disciplinary task where diverse stakeholders are expected to cooperate and interface to develop a suitable concept providing farmers with a secure, flexible, powerful, and handy platform.

Such a vision is not completely new and has already attracted the attention from a significant portion of the scientific literature and resulted in industrial developments, especially for what concerns the integration of communication and computation functionalities within the same

platform. For example, [McDonnell24] presented the general requirements for such an evolution and the potential offered by an integrated-network concept to achieve a rural sustainable digitalisation. Likewise, [Vagisha22] evaluated the case of crop monitoring by coming up with specific recommendations towards the deployment of smart farming technology solutions. More specific studies and solution developments have been then carried out by several actors from academia and industry as reported in [Fraunhofer] and [Sateliot]. Interestingly, a special focus has been given in the last 5-10 years to the exploitation of wireless communication and in particular of 5G technology [Damsgaard22], [Rafi26], [Fornes21], where the different network configuration and relevant farming use-cases are addressed mostly of a connectivity standpoint, i.e. with little focus on the data chain and related processing. Then, also the case of UAV has received a large attention [Ghadami23], [Bacco21], for both communication and sensing purposes, by relying on a dedicated ground infrastructure for data elaboration or on remote facilities (e.g., cloud-based) for more powerful and sophisticated data processing. In particular, the aspect of the data acquisition and the corresponding elaboration in the context of the wide farming data acquisition is explored in [Ballestrin26], which provides a possible baseline for current and future smart farming applications. Last but not least, the most recent initiatives also addressed the case of satellite usage for IoT-based smart farming, either in the case of traditional satellite (i.e. proprietary or DVB-bases approached) or also according to the current trend of 3GPP-NTN solutions (i.e. compliant to Rel. 17-19 of 3GPP and the consequent adoption of the NB-IoT NTN waveforms). Preliminary experimentation results have been reported in [Gardikis22], where GEO satellite was considered, while more mature results and discussion based on the use of LEO constellations are available in [Lopez23], where a hybrid access network consisting of both terrestrial and satellite segments was considered. Similar concepts were addressed in [DeSanctis25], where the general adoption of NTN technology for enabling smart agriculture in remote areas is investigated and special note is given to the available connectivity options, while the data processing part was not much emphasised.

Based on this review, key components necessary to evolve current smart farming system and ensure an innovation path relate to the deployment of the corresponding services according to an edge-cloud continuum approach implemented across ground and space infrastructure in order to allow for a ubiquitous connectivity. As such, connectivity service provisioning and overall data distribution have to implement a multi-Radio Access Technology (RAT) concept, whereby diverse communication technologies are employed, acting in isolation or integrated together depending on the specific agriculture use case or on the peculiarities of the target geographical service area (i.e. in remote areas only satellite connectivity might be offered). In this regard, a notable example of such a concept implementation is pursued in the EC-funded AGRARIAN project, which has developed a cohesive system architecture, aligned to the aforementioned building blocks. As such this paper discusses the main pillars of the AGRARIAN system architecture and provides a general view on the developed smart farming platform, by providing horizontal and vertical views on the overall architecture definition.

The remainder of this paper is structured as follows. First, the main concepts and the architecture model will be discussed, then the main findings from the architecture definition will be presented. Finally, the main lessons learnt and the take-home message will be shortly drawn.

Data and Method

As outlined in the previous section, the main contribution of the paper consists in the presentation and discussion of the AGRARIAN system architecture that builds on a multi-disciplinary approach to make sure that the resulting design on the one hand fulfils the users'

requirements and on the other hand aligns to the latest trends and advances from the ICT industry sector. In light of this, the following main elements have been identified in the system engineering exercise aimed at eliciting system requirements on the basis of the collected users' requirements:

- User-friendly access for farmers according to human factor principles: the interaction of the farmers with the platform happens through a dedicated GUI implemented in a dedicated web-portal.
- Data generation, processing, and distribution of in-situ data. Data are sensed by field devices (e.g., IoT and drones), processed through edge-cloud continuum capabilities and distributed through the available communication infrastructure.
- Effective communication infrastructure allowing for seamless connectivity and continuous data path: implementation of a multi-RAT concept building on the availability and integration of satellite and terrestrial connectivity.
- Design modularity to allow new technologies and services to be integrated: external developers can integrate their services and applications through the web-portal. The rest of the architecture is modular, so that different components are integrated by means of well-defined and standardised protocol and software interfaces.
- Overall data management and technology orchestration: central orchestration concept acting as hypervisor and manager of available data path, edge applications, and data repository to support effective communication and computation operations.
- Decision support system to automatise the general information flow and reinforce the necessary actions to be performed on the field: integration of the Agriculture Decision and Support System (ADSS) acting based on the data collected from the field and processed in the end-to-end chain and according to the external data and policies coming from other systems and from governmental entities.

The general system hence results as a multi-composite platform providing different capabilities, as sketched in Fig. 1.

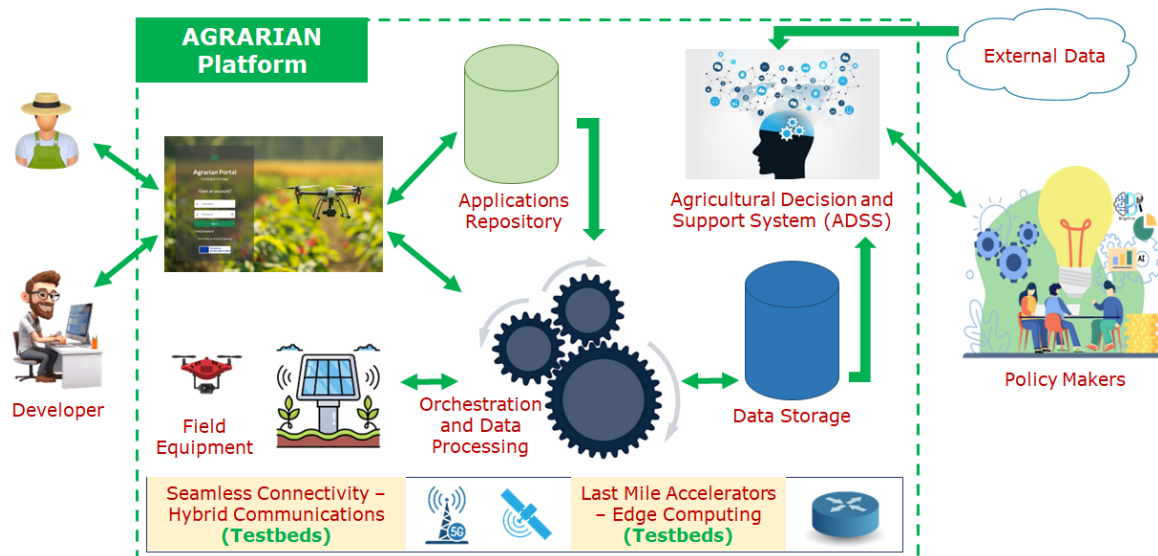


Fig. 1. AGRARIAN platform concept: building blocks and interaction with the stakeholders.

Results

According to the identification and definition of the building blocks illustrated in the previous section in Fig. 1, it is then possible to come with the complete platform architecture, which can be conveniently split into complementary and independent views, i.e. horizontal and vertical. The former is more oriented to the actual deployment through the smart farming field, the telecommunication infrastructure necessary for the data distribution and the edge-cloud continuum functionalities, the orchestration functionalities, and the ADSS integration with the access to the elaborated data. Notably, the edge-cloud continuum is actually split into edge, fog, and cloud to reflect the recent trends in the literature and industry deployment so that the edge segment relates to the computation capabilities directly available in the agriculture field and hence also corresponding to the “extreme edge” classification often used in this context. The fog on the other hand considers the distributed nature of computation performed on ground and space segments, owing to the presence of satellite constellations (GEO/LEO) complementing the terrestrial counterpart. Finally, the cloud part is the traditional cloud computing approach with localised and powerful data centers that may perform the more time- and resources-demanding operations. All intermediate computation steps are supported by AI-dedicated engines leveraged to solve complex data processing problems. The overall horizontal architecture is depicted in Fig. 2.

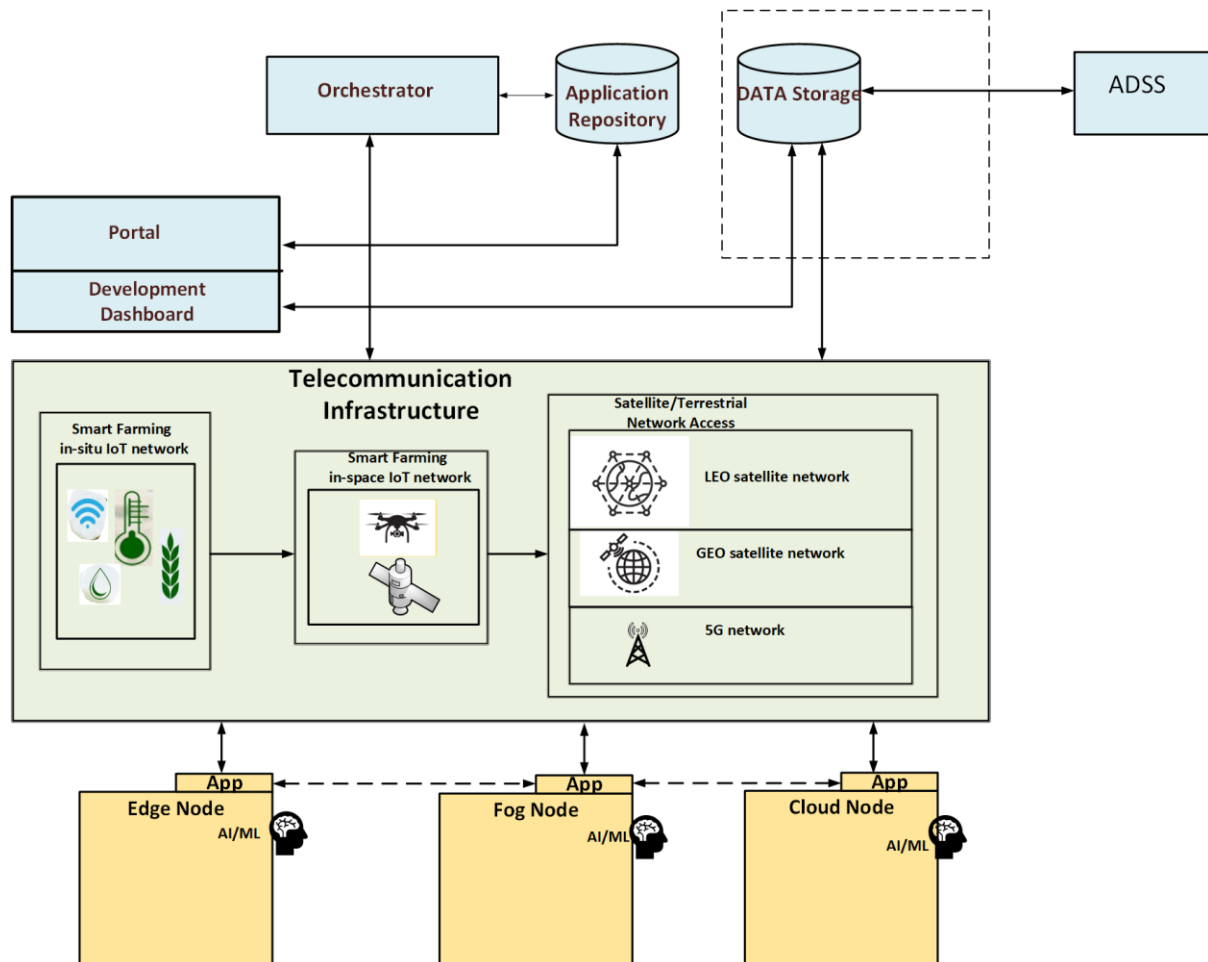


Fig. 2. AGRARIAN platform: horizontal architecture.

On the other hand, the vertical architecture provides the layered view on the system architecture in order to more closely isolate the specific functions in dedicated containers (layers), which is particularly useful for the sake of the software development and overall system integration

across the featured components. More in detail, the following layers are envisaged, which pretty much align with the building blocks shown in the horizontal architecture:

- Application layer: responsible for the specific smart farming services in terms of monitoring and overall management.
- Data processing and orchestration layer: aggregating all the functions related to data processing and consequent orchestration across the so-defined edge-cloud continuum infrastructure.
- Network layer: implementing the multi-RAT concept and hence featuring the various communication technologies used to distribute data, i.e. across 5G and satellite networks.
- Sensor layer: the sensing devices and related functionalities used to generate and collect data to be elaborated later in the processing chain. Notable example of the elements part of this layer are the EO (Earth Observation) satellite, weather stations, IoT devices, drones, etc.

The overall sketch of such a vertical architecture is given in Fig. 3.

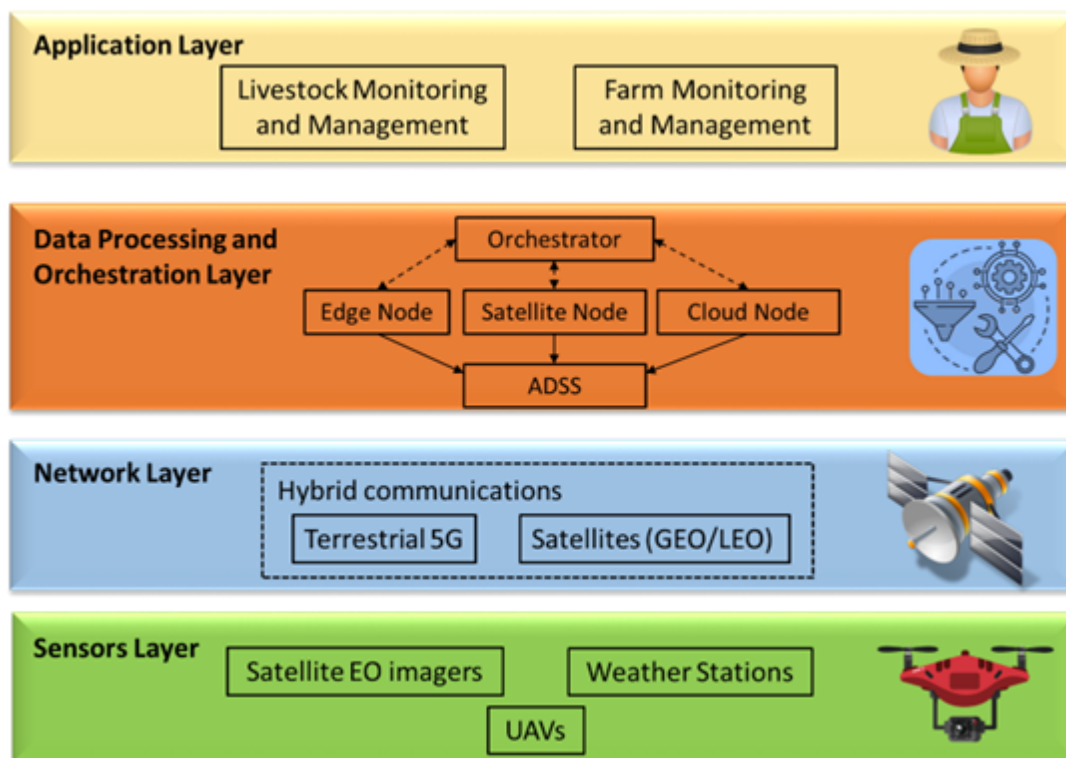


Fig. 3. AGRARIAN platform: vertical architecture.

Conclusion

This paper outlined the main service and technology requirements necessary to bring smart farming to the next level and accordingly introduced the reference system architecture developed in the AGRARIAN project. The main take-home message is that the future of smart farming concepts must build on a multi-composite system platform providing communication, sensing, and computing capabilities through a unified paradigm so as to meet the stakeholders' (e.g., farmers') expectations in terms of effective and timely data processing and distribution as well as an appropriate decision making support system. In more detail, the provided horizontal and vertical views of the developed architecture show how the connectivity and data processing needs have to be properly mapped on a multi-RAT approach suitably integrated into

a space-distributed edge-cloud continuum concept, where the integration of AI functionalities is pivotal to achieve a more effective and sustainable smart farming concepts. As such, the presented architecture from the AGRARIAN project emerges as possible foundation for the future smart farming integrated systems and paves the way towards a more effective alignment between the agriculture sector, society demands, and technology opportunities.

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