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An Integrated LoRa-Based IoT Platform Serving Smart Farming and Agro-Logistics

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***Abstract* — The agri-food value chain is undergoing significant transformation as consumers and various stakeholders in the agro-logistics sector demand enhanced and reliable food safety. Due to the unique characteristics of the agri-food supply chain, which features multiple origin points, various aggregation hubs at different levels, and numerous sales outlets, there is an urgent need for a comprehensive approach to data collection, transmission, and interpretation in an interoperable manner. The advancement of the Internet of Things (IoT) has led to the emergence of smart irrigation systems as a significant trend in agricultural irrigation. This paper introduces the architecture of the traceability platform KalaΘos, along with a smart irrigation system based on LoRa technology and IoT management module, GP CoreIoT. Data from the irrigation node is transmitted to the cloud through LoRa gateways using wireless communication. KalaΘos infrastructure comprises a network of sensor devices located on farms, in equipment, trucks, and at aggregation, processing, and logistics facilities, all connected through a network of LoRa gateways. Its open architecture emphasizes both semantic and syntactic interoperability, facilitating the collaborative use of data collected and managed by other systems with similar objectives.**

Keywords* — *IoT, Platform, LoRa, Smart irrigation, Agri-food

I. Introduction (*Heading 1*)

The agri-food value chain is undergoing significant transformation as consumers and various stakeholders in the agro-logistics sector demand enhanced and reliable food safety. Due to the unique characteristics of the agri-food supply chain, which features multiple origin points, various aggregation hubs at different levels, and numerous sales outlets, there is an urgent need for a comprehensive approach to data collection, transmission, and interpretation in an interoperable manner. This chapter introduces the architecture of the traceability platform KalaΘos, along with its IoT management module, GP CoreIoT. KalaΘos infrastructure comprises a network of sensor devices located on farms, in equipment, trucks, and at aggregation, processing, and logistics facilities, all connected through a network of LoRa gateways. Its open architecture emphasizes both semantic and syntactic interoperability, facilitating the collaborative use of data collected and managed by other systems with similar objectives. This paper aims to examine the present condition of the agri-food value chain, emphasizing its characteristics and particular challenges. It also investigates the potential role of IoT technologies within this value chain. Additionally, the chapter provides a comprehensive overview of IoT telecommunication networks, sensor devices, and data management platforms. An extensive discussion is included regarding the challenges and solutions associated with IoT applications in the agri-food value chain, addressing both primary activities and the logistics that support them.

II. System Architecture

The proposed system architecture of three parts, Device, Cloud and Application.

A. Smart Irrigation System with IoT Based on LoRa

LoRa technology has evolved into a crucial component for Internet of Things (IoT) operations. In a star configuration, LoRa nodes are directly connected to a LoRa gateway, which simplifies the overall system architecture [1]. The distinctive characteristics of LoRa, including low path-loss, excellent sensitivity, and strong interference penetration, position it as a transformative technology that facilitates long-range communication. This technology enables LoRa devices to transmit data wirelessly over considerable distances to remote gateways [2], [3]. Additionally, it operates with significantly low power consumption, allowing IoT device batteries to have an extended lifespan. A single LoRa gateway can support up to 1,000 end devices, and its straightforward setup is attributed to its uncomplicated design. LoRaWAN utilizes a star-network topology for communication between IoT devices and gateways, permitting only a single hop between them. The technology offers extensive coverage, reaching approximately 5 km in urban areas and up to 15 km in suburban regions [4]. Research has shown that a LoRa device can transmit data over distances of up to 15 km in free space, which is suitable for many contemporary long-range IoT applications. However, as the number of IoT devices within a LoRa network increases, the complexity of data transfer among these devices also escalates. Consequently, it is essential to balance data transfer challenges with operational requirements and infrastructure costs [5].

This study employs LoRa wireless communication technology to facilitate data transmission and manage communication among the various modules of the irrigation system. This technology is extensively utilized in the realm of the Internet of Things (IoT). The suggested smart irrigation system aims to enhance water efficiency for agricultural purposes while enabling farmers to monitor their fields in real-time. This system autonomously determines when to open and close solenoid valves to irrigate crops based on soil moisture levels. Additionally, users have the capability to remotely control the irrigation of their fields by selecting the appropriate mode and method of watering. This irrigation solution integrates various hardware and software elements, with its overall architecture. The wireless sensor network is designed to continuously monitor soil moisture levels and manage irrigation to ensure that the water content in the soil meets the needs of crops. A connected weather station collects data at regular intervals, measuring temperature, air humidity, wind speed, solar radiation, and precipitation levels. Additionally, a remote server consolidates all essential information to facilitate informed decision-making from a distance. The selected irrigation method is drip irrigation, which efficiently delivers water directly to the roots, minimizing water loss through deep percolation. The proposed system utilizes LoRa wireless communication technology, which aligns well with the objectives of our research.

Figure 1 illustrates the architecture of the proposed LoRa-based Internet of things smart irrigation control solution with hybrid classifier CNN-SVM. The proposed LoRaWAN combines IoT sensors that are strategically set up over the plantation feld to track the soil parameters. Thus, the agricultural field is split into irrigation zones, with each section charged with air humidity/ temperature sensor and soil temperature/moisture. The solution is targeted at bypassing the weekly irrigation demanded in farming operations in conformity to soil states and climatic variables collected from several sovereign LoRa IoT sensors deployed in the plantation. The direct collection of live reports from the farm area is conceived to reinforce the irrigation activity and present the farmers with sufficient data, like timing for irrigations, and mitigate the overall costs of conservation and water. The tracked soil measurement from the LoRa IoT nodes is delivered to the IoT cloud server for storage and analysis with machine learning algorithms to take up the schedules to implement in the field. Besides assessment of the power consumption of the IoT nodes, we also explore the most suitable machine learning analysis to discern the finest algorithm for scheduling irrigations in consonance with the LoRa IoT sensor data, as well as learn whether a machine learning scheme presents improvements encountering stereotypical or automated irrigation solutions.

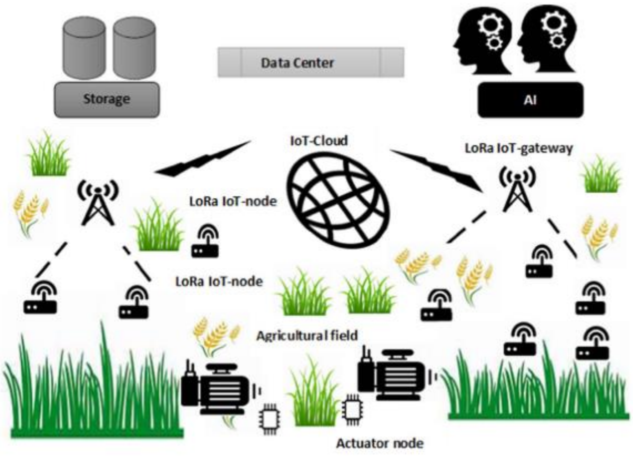

Figure 1. Proposed LoRa IoT-based smart farming solution architecture

III. Proposed Methodology

A. The platform architecture

The solution leverages the traceability platform KalaΘos, along with its IoT management module known as GP CoreIoT. The infrastructure of KalaΘos comprises a network of sensors deployed across farms, equipment, trucks, aggregation points, processing facilities, and logistics centers, all interconnected through a series of LoRa gateway stations. Its open architecture emphasizes both semantic and syntactic interoperability, enabling the collaborative use of data gathered and managed by other systems with similar objectives. KalaΘos Main Platform, along with its supplementary modules, delivers real-time information accessible via IoT devices, web interfaces, smartphones, and tablets. These modules can function autonomously or in tandem with other information systems. The platform employs a Service-Oriented Architecture (SOA) approach, specifically utilizing JSON for implementation. This overall open architecture enhances modularity within KalaΘos and ensures seamless integration with external systems. KalaΘos platform, along with its various modules, comprehensively addresses the entire production and distribution process of fresh fruits and vegetables, from the farm to the wholesaler. Figure 2 illustrates the various information entry points throughout the supply chain at different stages.

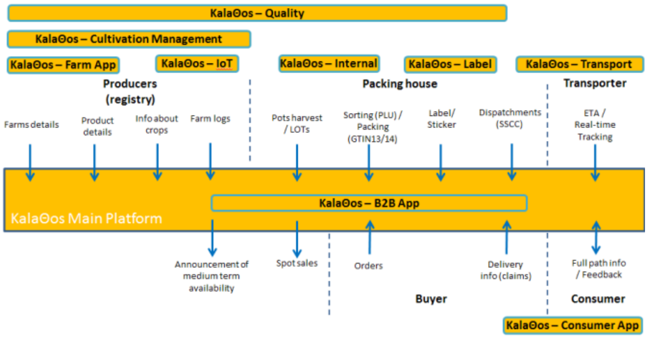

Figure 2. Data flow in KalaΘos platform

The platform not only emphasizes to logistics but also prioritizes consumer food safety by offering comprehensive and reliable information. The KalaΘos Consumer App delivers detailed product insights from production to consumption, utilizing the KalaΘos TraceID, a unique identifier assigned at the batch level.

This capability to furnish such information to consumers is made possible through the "end-to-end" traceability processes within the fresh produce supply chain. This is achieved by integrating both internal and external tracing methods, enabling each operator to identify the immediate source and recipient of every product. The traceability framework of KalaΘos adheres to the "one step up, one step down" principle, ensuring effective tracking throughout the supply chain. Each product is globally recognized in a unique manner, facilitating identification both upstream and downstream. All stakeholders in the distribution network can leverage the system to execute traceability practices, while internal traceability is structured to maintain essential connections between inputs and outputs.

An overview of the processes that facilitate traceability tasks is illustrated in Figure 3. This methodology supports a systematic approach to tracing, tracking, and monitoring agri-food products.

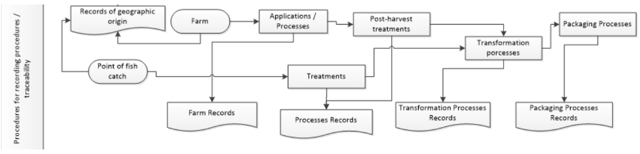

Figure 3. General overview of the processes involved in KalaΘos platform

B. *Platform traceability approach*

Establishing traceability within a supply chain depends on the participants in the distribution channel to gather, document, store, and disseminate essential information for effective traceability. KalaΘos is dedicated to facilitating this process through a structured four-stage approach:

1. Identification: In accordance with GS1 Standards [6], KalaΘos initiates the process by utilizing GS1 Identification Numbers to uniquely identify all fresh products (trade items), logistic units, locations, assets, and relationships throughout the supply chain, from producer to consumer. These identification numbers create connections between the fresh products and their associated information.

2. Capturing: The GS1 System Data Carriers are employed to store varying data volumes, catering to the diverse needs of different products within the supply chain processes.

3. Evaluating: The information collected can be assessed against predetermined targets. Additionally, a blind benchmarking method may be implemented using KalaΘos.

4. Sharing: The interoperability of the KalaΘos Platform and its Modules enables the smooth exchange of information during commercial transactions.

The integration of EPICS, which supports comprehensive traceability throughout the entire supply chain, is a fundamental aspect of the KalaΘos platform. Specifically, EPCIS provides visibility from the farm to all segments of the supply chain. This enhanced visibility not only streamlines business processes but also ensures compliance with regulations and bolsters consumer safety. EPCIS can be utilized to capture and share information regarding all critical business processes in the fresh produce value chain, including cultivation, harvesting, processing, packing, and receiving—along with batch or lot numbers. EPCIS establishes interfaces for sharing visibility event data with other stakeholders in the supply chain. Figure 4 illustrates the tracing of information across various locations (external traceability) and within specific locations (internal traceability).

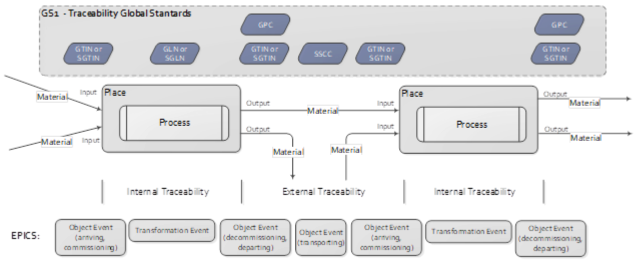

Figure 4. Internal and external traceability in KalaΘos based on EPCIS approach

C. *Platform IoT approach*

An approach to the automatic collection of "big data" directly from farms and other stages of the fresh produce supply chain is facilitated by the KalaΘos infrastructure, which comprises open APIs developed using JSON and REST services as part of a telemetry system. This system leverages libraries provided by sensor device manufacturers. The KalaΘos team has created an efficient telemetric system designed to ensure seamless data collection and transfer from various sources. Its effectiveness can be assessed based on several criteria: (i) ease of installation, (ii) user-friendliness, (iii) minimal maintenance requirements, (iv) extensibility and connectivity, (v) interoperability, and (vi) operational cost. At the core of the IoT infrastructure is the GP IoT Core module, which facilitates data reception and management in the cloud, as well as data visualization and report generation. The development of API services can act as integrators of data within the IoT ecosystem [7], [8]. Additionally, it features both a web application and a mobile application for user interaction. According to mobile architecture, both stationary and mobile nodes are used to provide the necessary information to the users. The latter is used to support for instance precision agriculture applications consisting of mobile farming equipment and stationary field sensors [9], [7]. An integrated telemetric network has been established using the KalaΘos infrastructure, which unites IoT technologies, including meteorological and other sensor devices, along with devices mounted on farm equipment. This telemetry network serves as the hub for gathering, pre-processing, and transmitting data and events from all connected devices through the appropriate APIs. A key component of this telemetric network is the KalaΘos Data Logger, which functions as the intermediary for the data management system. The architecture of the KalaΘos telematics network is illustrated in Figure 5.

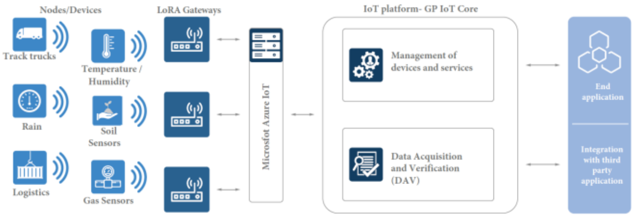

Figure 5. KalaΘos IoT infrastructure architecture (Adapted from LoRa Alliance, 2015)

IV. Conclusions

The research project was successfully implemented in 10 pilot case studies of this system in Greece. More specifically, it was examined in 10 different places, in 8 products of crop origin (table grapes, kiwi fruit, olive oil, oranges, potatoes, carrots, onions and stevia) and in 1 product of animal origin (cows).

This study focused on examining the current landscape of IoT applications within the agro-logistics sector and their relevance to traceability requirements and was implemented in 10 pilot applications of this system in Greece. It addressed the challenges and limitations of IoT technologies in the agri-food industry by showcasing the traceability platform KalaΘos, along with its IoT management module, GP CoreIoT, and their implementation in various pilot projects across Greece. It is essential to emphasize the necessity for large-scale pilot initiatives in agriculture that leverage IoT technologies. A comprehensive architectural framework is suggested, concentrating on interoperability aspects that are vital for the successful adoption of IoT solutions in the agri-food sector.

The primary business model for KalaΘos and its modules is likely to be a combination of three overarching business models for IoT and digital products: (i) physical freemium, which offers basic services for free while charging for advanced features; (ii) digital add-ons, which involve the sale and installation of additional options for products after the initial purchase; and (iii) sensors as a service, where customers pay solely for the operational costs of the infrastructure needed to collect data.

These business models must be assessed regarding their effectiveness in addressing the challenges that may arise during the adoption and implementation of integrated IoT solutions throughout the entire agri-food supply chain. While there are anticipated benefits for various stakeholders, including enhanced processes for tracking, tracing, and monitoring, several challenges were identified during the pilot projects that require attention. These challenges pertain to the devices, network infrastructure, and data management.

Acknowledgment

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