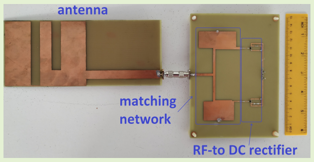
Smart Irrigation System for Precision Agriculture - The AREThOU5A IoT Platform

Achilles D. Boursianis, *Member, IEEE*, Maria S. Papadopoulou, Antonis Gotsis, Shaouha Wan, *Senior Member, IEEE*, Panagiotis Sarigiannidis, *Member, IEEE*, Spyridon Nikolaidis, *Senior Member, IEEE* and Sotirios K. Goudos, *Senior Member, IEEE*

***Abstract*—Agriculture 4.0, as the future of farming technology, includes several key enabling technologies towards sustainable agriculture. The use of state-of-the-art technologies, such as the Internet of Things, transform traditional cultivation practices, like irrigation, to modern solutions of precision agriculture. In this paper, we present in detail the subsystems and the architecture of an intelligent irrigation system for precision agriculture, the AREThOU5A IoT platform. We describe the operation of the IoT node that is utilized in the platform. Moreover, we apply the radiofrequency energy harvesting technique to the presented IoT platform, as an alternative technique to deliver power to the IoT node of the platform. To this end, we fabricate and validate a rectenna module for radiofrequency energy harvesting. Experimental results of the fabricated rectenna exhibit a satisfactory performance as a harvester of ambient sources in an outdoor environment.**



***Index Terms*—IoT technology, precision agriculture, radio frequency energy harvesting, smart irrigation**

I. INTRODUCTION

THE environmental footprint of agriculture has increased rapidly over the last decades, causing several environmental changes, including water scarcity, climate change, land degradation, etc, [1], [2]. To this end, the fourth revolution of agriculture is taking into consideration all the primary aspects of sustainable agriculture by incorporating Information and Communications Technologies (ICT) into traditional farming practices [3], [4]. Precision agriculture is a farming system approach to quantify the crop (or livestock) production by observing, measuring, and responding to field metrics towards a low-input, high-efficiency, sustainable agriculture [5], [6].

Irrigation is one of the fundamental sources of agricultural productivity. It has been a central feature of agriculture for thousands of years. It requires almost 85% of the available freshwater resources [7]. During the last decades, climate change and over-consumption of resources have strongly affected the water resources globally [8]. The lack of freshwater, the reduction of water quality, as well as the water salinity, are some of the main reasons that agricultural community needs to take into consideration for water management in irrigation practices [8], [9]. Smart irrigation is a farming approach by applying water management (and aiming to reduce water usage) in cultivation. Smart irrigation systems usually apply wireless technology (e.g. Wireless Sensor Networks - WSNs) and Internet of Things (IoT) technology in their implementations [8], [10].

For the farming digitalization, as the fourth revolution of agriculture clarifies, the cornerstone is connectivity [3]. Thus, the key enabling technology for the next step in farming is IoT [11]. IoT technology, by adapting various enabling techniques, such as wireless sensor networks, big data, communication protocols, edge computing, and web services [12], can be applied in various sectors of farming including irrigation, fertilization, plant growth, weed management, etc. [13]. It is expected that the IoT will be one of the leading technologies that will transform traditional cultivation and livestock practices into a new aspect of intelligence in precision agriculture [13], [14].

During the last years, a new well-promising technique that can be applied in wireless sensor networking has emerged, the so-called Radio Frequency (RF) Energy Harvesting (EH). It can be utilized as an alternative way to deliver energy in low-power electronic systems, e.g. wireless and IoT sensors [15]. RF EH, as an emerging technology, is expected to play a pivotal role in next-generation energy-constrained wireless networks [16]. In outdoor environments, mobile communication networks provide one of the dominant ambient sources for energy harvesting [17].

In this paper, a smart irrigation system, the so-called AREThOU5A, that adopts several state-of-the-art technolo-

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A. D. Boursianis, M. S. Papadopoulou, S. Nikolaidis, and S. K. Goudos are with the ELEDIA@AUTH Research Group, School of Physics, Aristotle University of Thessaloniki, Thessaloniki, 54124, Greece (e-mail: {bachi, mpapa, snikolaid, sgoudo}@physics.auth.gr).

A. Gotsis is with Feron Technologies, 15126 Maroussi, Athens, Greece (e-mail: antonis.gotsis@feron-tech.com).

S. Wan serves as an associate professor at School of Information and Safety Engineering, Zhongnan University of Economics and Law, Wuhan, Hubei 430073, China (e-mail: shwanhust@gmail.com).

P. Sarigiannidis serves as an associate professor at the Department of Electrical and Computer Engineering, University of Western Macedonia, Kozani, Greece (e-mail: psarigiannidis@uowm.gr).

gies, such as IoT and machine learning, is presented for water management in various agricultural fields. The AREThOU5A IoT platform will provide a smart irrigation system that exploits the specific capabilities of 5G networks. Moreover, it will support an alternative way of delivering energy to the IoT sensors of its wireless sensor network, by utilizing the RF EH technology. To the best of the authors' knowledge, this is the first time that a smart irrigation system adopts these two key-enabling technologies (5G and RF EH) in the field.

This paper is organized as follows. In Section II, we perform an outline of the existing smart irrigation systems that have been published in the literature. It is noteworthy that in the literature review, we have taken into consideration the variability of these irrigation systems demonstrated in various geographical zones, including harsh environments (extreme meteorological conditions), as well as the various communication technologies that acquire. In Section III, we describe in detail the AREThOU5A smart irrigation system, by analyzing its main subsystems, its layered architecture stack, as well as its processes and methods that each layer includes. Moreover, in Section IV, the experimental validation of the RF EH module that is included in the measurement subsystem is demonstrated. Finally, Section V draws some concluding comments and remarks.

II. RELATED WORK

In this section, we briefly describe the smart irrigation systems of the literature that present different techniques in water management, by notating the origin of the demonstrations of these systems in the field, the adopted technologies, as well as the various communication protocols that include in their implementations.

There are several water management models or platforms presented in the literature that combine various technologies to deliver smart irrigation systems in agriculture. The authors in [7] proposed a smart sensor for automatic drip irrigation that was applied for paddy cultivation in India. The wireless sensor connectivity was based on Global System for Mobile Communications (GSM) protocol to transfer the measured data from the field to farmer's mobile terminal. In a similar way, the authors in [18] developed a system of wireless sensors architecture for irrigation water management in Spain. The proposed architecture was based on various wireless nodes that were equipped with General Packet Radio Services (GPRS) protocol for the communication with their database. A more sophisticated approach has been applied in [19]. The authors proposed a novel architecture for smart agriculture by utilizing cognitive radio technology in the IoT driven system. They used two different data types to model the various conditions of crops, especially in countries with limited resources. In [20], the authors demonstrated a new platform for precision agriculture, including smart irrigation and fertilization management techniques. Their objective was to develop a precision agriculture platform based on open-source software technologies and open communication protocols. A quite interesting solution describing an ecosystem of interconnected was presented in [21]. The authors analyzed their IoT agnostic architecture as an IoT platform and they validated it in a smart farming scenario.

Various smart irrigation platforms (or systems) have been introduced in the literature, which their experimental validation fields origins from different geographical zones. In [22], the authors developed a dynamic model to establish a water management system for irrigation in Central Taiwan, by confronting a rather harsh environment, including typhoons and uneven rainfalls in an annual period. A real-time model was introduced in [23] to synchronize the available power from a photovoltaic system with the required energy to operate an irrigation system. Their model was applied in a real olive orchard in Southern Spain. The authors in [24] developed an IoT-based smart irrigation platform for precision agriculture and validated in four different experimental pilots in Brazil, Spain, and Italy. Their findings revealed the specific on-site requirements of these systems and, in some cases, the designed re-configurations that required.

In the literature, the issue of water management in environments with extreme meteorological conditions has been addressed, indicating the significance of the topic. The authors in [25] discussed the problem of water management in several parts of Africa. They presented a smart irrigation system based on an Arduino microcontroller for algorithm control configuration to manage the water availability in an effective way. Another interesting work has been presented in [26]. The authors created an irrigation tool to assist cultivators in water management for their fields by taking into consideration the El Niño Southern Oscillation (ENSO) phenomenon that affects the climate in Mozambique and, consequently, the water requirements for agricultural crop growth of tomato in the same area.

There are a couple of smart irrigation systems for precision agriculture that utilize fuzzy logic in their scheduling algorithms to deliver efficient water management. In [27], the authors demonstrated a scalable smart irrigation system applied to precision agriculture by integrating a fuzzy logic strategy. Their objective was to optimize the volumetric water content in the soil by reducing water usage and improving the quality of products. Moreover, the authors in [28] presented an IoT enabled WSN framework for precision agriculture by automating the various cultivation processes. They combined neural network prediction and structural similarity techniques to optimize water usage in soil. Based on these two techniques, they applied valve control in a smart irrigation system by utilizing a fuzzy logic-based weather condition modeling system. Finally, the architecture of a smart irrigation system using monitoring and actuating capabilities by including the fuzzy logic as a decision support tool was demonstrated in [29].

Several intelligent irrigation systems engage key enabling technologies, such as thermal imaging, big data, and machine learning. The authors in [30] combined the use of thermal images from the field to provide information about the soil moisture, of an IoT sensor network to measure temperature and humidity, and the cloud, to collect and process all the acquired data in a cost effective way, to develop a smart irrigation system for precision agriculture. Moreover, the authors in [31] demonstrated and validated a decision support system for automatic smart irrigation that utilizes two different machine

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learning techniques (Partial Least Square Regression - PLSR and Adaptive Neuro Fuzzy inference System - ANFIS) as reasoning engines against decisions taken by a cultivator expert. In a similar way, the authors in [32] combined the open source technologies and the machine learning techniques to present and test a smart irrigation system that predicts the irrigation requirements of the field. Finally, a water and fertilizer smart system using big data was integrated in [33].

During the last years, several emerging technologies have been applied in smart irrigation systems, such as the Message Queue Telemetry Transport Protocol (MQTT) and the LoRa (Low Range) protocol. MQTT is a lightweight network messaging protocol for small sensors in WSNs, suitable for the deployment of various applications of IoT networks, including agriculture and livestock [34]. MQTT has been successfully utilized in several smart irrigation systems to exchange information between the sensors and the central unit (server) [35], [36], [37], [38]. Moreover, the LoRa is a low-power wide-area network protocol (LPWAN) that uses sub-GHz frequencies enabling long-range transmissions with low-power consumption. LoRa is one of the key solutions to deploy IoT sensor networks in agriculture, especially in cases of open fields that usually cover large areas [38], [39].

Various experimental prototypes of smart irrigation systems for water management that utilize commercial electronics have been proposed in the literature. Their implementations were based on microcontrollers with ultra-low-power technology [40], [41], [42], [43], single-board computers [44], [45], or wireless connectivity modules [46], [47].

Smart irrigation techniques are applicable not only to cultivation fields, which are usually open areas, but in greenhouses and tunnel farming as well. In [48], the authors used a smart irrigation system to study the effects of greenhouse water management in tomato plants. Moreover, the authors in [49] utilized a prototype-cloud connected sensor-based irrigation system in greenhouse soil-less cultivation for basil production. Finally, an intelligent approach for efficient plant irrigation in tunnel farming has been proposed and validated in [50].

III. THE ARETHOU5A IOT PLATFORM

In this section, we describe in detail the system overview of the ARETHOU5A IoT platform, including its subsystems, the layered architecture approach of the platform, including the processes and methods applied at each layer, as well as the rectenna (rectifier + antenna) module that has been designed and fabricated to deliver energy to the IoT wireless sensor nodes of the system from ambient sources in an outdoor environment.

A. Smart Irrigation IoT Platform Overview

The main objective of the ARETHOU5A is to exploit state-of-the-art technologies towards the design and fabrication of a fully integrated IoT platform to manage the irrigated water in cultivation as a precision agriculture application. To this end, it combines wireless sensor network data, collected from the field, and satellite data, provided by international weather forecast services, to provide efficient water usage strategies for cultivators. Moreover, it adopts several enabling technologies, such as LPWAN, RF energy harvesting, and machine learning, to enhance solutions and practices towards sustainable agriculture.

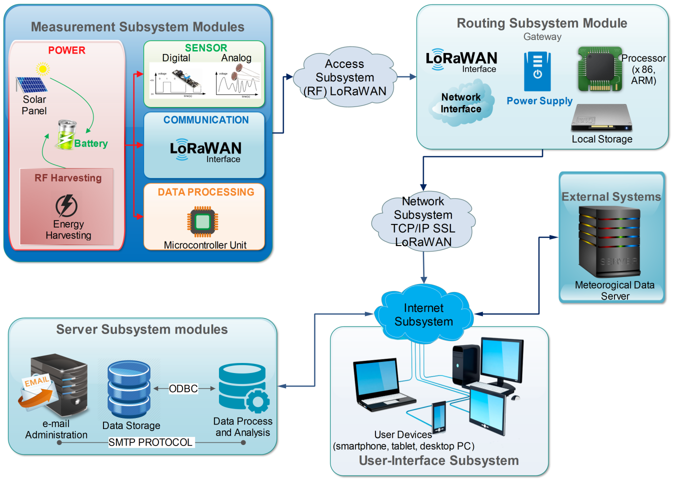

Fig. 1. The ARETHOU5A smart irrigation IoT platform and its subsystems.

ARETHOU5A IoT platform consists of four independent, yet fully functional primary subsystems; the measurement subsystem, the routing subsystem, the user-interface subsystem, and the server subsystem (Fig. 1). Several other secondary subsystems exist within the platform; the external systems, which are connected through the Internet using cloud applications, the access subsystem, for the interconnection between the IoT end-nodes and the IoT gateway, the network subsystem, providing connection between the IoT gateway and the Internet subsystem, and the Internet subsystem, for the interconnection between the IoT sensor network with the server subsystem, the user-interface subsystem, and the external systems (Fig. 1).

- *Measurement subsystem*: The measurement subsystem collects all the required data to operate the IoT platform efficiently. The heart of the sensor network is the IoT end-node (Fig. 2). It comprises of the following modules (a) a LoPy4 microcontroller (Pycom © 2020) for handling the IoT sensors of the module and pre-processing the measurement data. The microcontroller is equipped with various state-of-the-art communication protocols, such as LoRa (LoRaWAN) and SigFox, (b) two different IoT sensors for measuring the temperature (DS18B20 Programmable Resolution 1-Wire Digital Thermometer, © 2020 Maxim Integrated) and the soil moisture (ECH$_2$O EC-5 Moisture Sensor, Meter Environment, © 2017-2020 METER Group, Inc.) on the field, (c) a sensor driving circuit, and (d) a proper power supply (Fig. 2 omits the photovoltaic module and/or the RF energy harvesting module of the subsystem). Fig. 3 displays a photograph of the ARETHOU5A IoT end-node installed on a perennial olive field in southeast Greece (Petas village, Achaia).
- *Routing subsystem*: The routing subsystem controls and routes all the information of the ARETHOU5A IoT platform between its subsystems. To this end, it is equipped

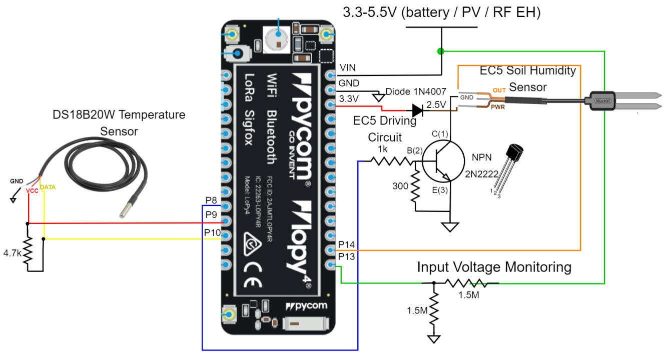

Fig. 2. The IoT end-node of the AREThOU5A platform (The RF energy harvesting circuit is omitted).

with both LoRaWAN and Transmission Control Protocol/Internet Protocol (TCP/IP) Secure Sockets Layer (SSL) network interface. From the LoRa network, it operates as an IoT gateway, collecting all the information from the IoT end-nodes and performing administration processes. On the other hand, from the TCP/IP SSL network, it operates as a bridge to the rest of the network architecture within the IoT platform.

- *User-interface subsystem*: The user-interface subsystem provides a user-friendly environment for the rest of the IoT platform. It is based on an open-source LoRaWAN network server stack (The ChirpStack project, available at https://www.chirpstack.io/project/), which supports several components (LoRaWAN devices, LoRa gateways and gateway bridges, network and application servers, and an end-application) communicating with the MQTT protocol.
- *Server subsystem*: The server subsystem includes e-mail administration services and database services to support the user-interface subsystem, as well as the measurement subsystem since it stores all the pre- and meta-processed data to a dedicated database management system.

B. Layered Architecture Approach

AREThOU5A IoT platform for water management in smart irrigation is deployed in a five-layered architecture approach (Fig. 4). Looking at the Fig. 4 from the bottom to the top, the following layers are stacked:

Fig. 3. Installation of the AREThOU5A IoT end-node in a perennial olive field.

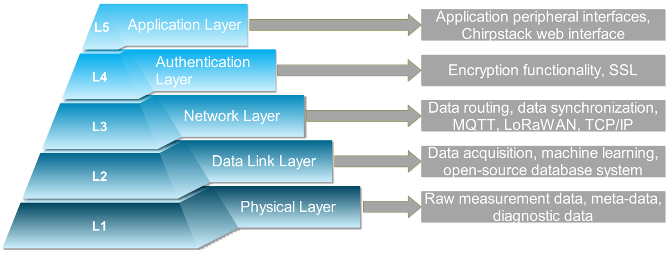

Fig. 4. AREThOU5A layered architecture stack.

- *Physical Layer (L1)*: The physical layer concentrates all the required processes and methods related to the measurements on the field. Among others, it is responsible for the collection of raw measurement data, the copy of data in the server storage, and the diagnostic information retrieved from the sensors of the platform.
- *Data Link Layer (L2)*: In the data link layer, as the next layer in the hierarchy to the physical layer, the processes performed are related to the data acquisition and analysis upon request from the user-interface subsystem. Some of the methods applied in this layer are the machine learning and the open-source database management system utilized in the platform.
- *Network Layer (L3)*: The third layer in AREThOU5A architecture stack is the network layer. Several processes of protocol functions operate within this layer, i.e. routing data, data synchronization between user-interface and server subsystem, data transfer through IoT protocol, etc. The main protocols involved in this layer are the LoRaWAN, the MQTT, and the TCP/IP.
- *Authentication Layer (L4)*: The authentication layer adds an encryption interface to the communication protocols between the subsystems of the IoT platform to ensure data integrity and credibility. The utilized technology that establishes encrypted links in this layer is the SSL.
- *Application Layer (L5)*: The top layer in the AREThOU5A architecture stack is the application layer. As the definition implies, it contains all the application peripheral interfaces (APIs) designed and developed for the functional operation of the IoT platform. The Chirpstack web interface is one of the primary applications included in this layer. Among others, the machine learning API, the e-mail API, and the data storage API are also included here.

C. Radio Frequency Energy Harvesting Module

The AREThOU5A IoT platform combines several key-enabling technologies, such as RF energy harvesting. As previously stated, to the best of the authors' knowledge, this is the first time that a smart irrigation system incorporates the wireless power transfer (WPT) technique to deliver energy to the sensor nodes of the IoT network (in our case to the IoT end-node of the AREThOU5A platform), which are usually require small amounts of power to operate.

The cornerstone module for wireless power transfer is a rectenna. Fig. 5 displays the main components of a rectenna

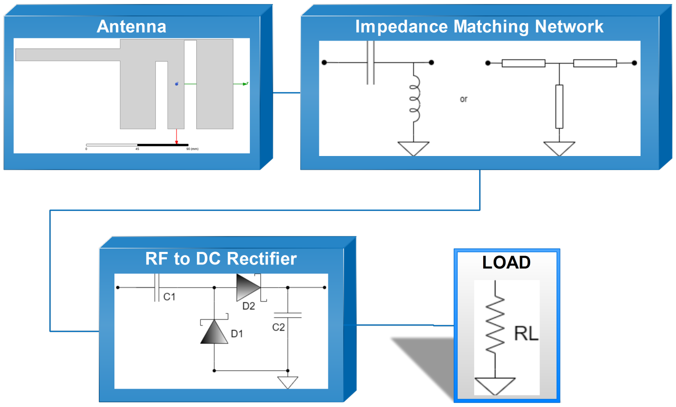

Fig. 5. Typical block diagram of a rectenna module (the main parts in each sub-module of the rectenna module are demonstrated; the voltage management and storage circuit is omitted).

module. It consists of an antenna, an impedance matching network, an RF-to-DC rectifier, and a load. The operation of a rectenna is summarized as follows. The antenna in a rectenna module operates as a receiver of the electromagnetic radiation from ambient RF sources (e.g. FM/TV broadcasting, mobile communication networks, etc.). The matching network adjusts the input impedance of the antenna to the input impedance of the RF-to-DC rectifier, so a maximum RF-to-DC power conversion is achieved by the module (maximization of the RF-to-DC efficiency). The RF-to-DC rectifier transforms the RF power that has been received from the antenna to DC voltage. Finally, the load completes the rectenna module. In various application solutions, a voltage management and energy storage circuit is added between the RF-to-DC rectifier and the load, to adjust the DC voltage for energy storage to a capacitor or a battery.

IV. EXPERIMENTAL EVALUATION

Within the context of the AREThOU5A IoT platform, an experimental setup of the RF energy harvesting module is fabricated. The antenna component is a dual E-shaped patch antenna, operating in the frequency bands of LoRaWAN and EGSM-900 mobile communication networks (tuning frequencies 866 MHz and 937 MHz). The choice of a patch antenna as the receiving component of the rectenna module is adopted based on the comparative advantages that this type of antenna presents (ease of fabrication, low to medium design complexity, and low cost). The E-shaped patch antenna is made of copper material (conductivity = 5.80E+07 Siemens/m, relative permeability = 1). It is fabricated on an FR-4 substrate (relative permittivity = 4.4, substrate thickness = 1.6 mm, dielectric loss tangent = 0.02); a microstrip line is properly attached to the patch antenna to forward the harvesting energy to the RF-to-DC rectifier. The length of the microstrip line is selected to adjust the input impedance of the antenna to the impedance of 50 Ω to the input impedance of the RF-to-DC rectifier, achieving a maximum power transfer. Details about the design method of the antenna component, the population-based algorithm that was selected to optimize the antenna parameters on the desired tuning frequencies, the overall optimization process, as well as the numerical results obtained by the antenna design can be found in [51]. Fig. 6 illustrates the fabricated E-shaped patch antenna for the RF EH module of the AREThOU5A IoT platform.

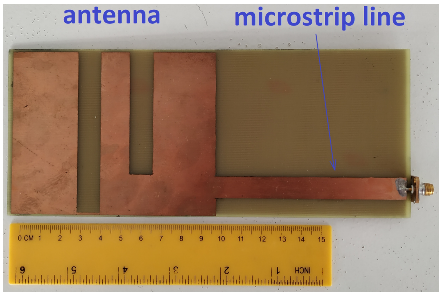

Fig. 6. Photo of the fabricated E-shaped patch antenna for the RF EH module of the AREThOU5A IoT platform.

The RF-to-DC rectifier component of the RF energy harvesting module in the AREThOU5A IoT platform is a two-stage rectifier circuit based on the Greinacher voltage doubler, operating in the frequency bands of LoRaWAN and EGSM-900 mobile communication networks as well, as the operating frequency bands of the antenna component. Fig. 7 depicts the schematic diagram of the proposed two-stage rectifier circuit. It consists of four zero bias Schottky surface-mount Avago HSMS-285C diodes (D_1 - D_4), four AVX capacitors of 100 pF (C_1 - C_4), and an output load resistor (R_L). The input impedance of the rectifier is adjusted to the impedance of 50 Ω by the use of a matching network. Thus, the input impedance of the antenna is matched to the input impedance of the rectifier to achieve maximum power conversion. The RF-to-DC rectifier is made of copper material and it is fabricated on an FR-4 substrate as well the antenna component of the RF EH module. Details about the rectifier design, tuning operation, and its performance can be found in [52]. Fig. 8 illustrates the fabricated RF-to-DC rectifier for the RF EH module of the AREThOU5A IoT platform. The RF input signal (P_{in}) is converted to DC voltage using the Schottky diodes. The matching network adjusts the input impedance of the rectifier to the input impedance of the antenna and the microstrip line, thus minimizing the reflected wave of the component. The capacitors of the fabricated rectifier perform a smoothness of the obtained DC output. Finally, the output power supplies the load resistor R_L.

Fig. 9 portrays the reflection coefficient versus frequency

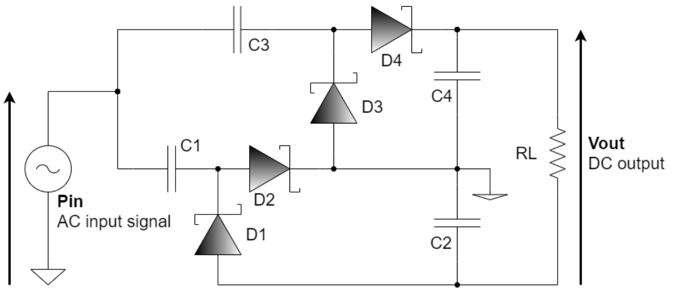

Fig. 7. Schematic diagram of the proposed dual-band rectifier.

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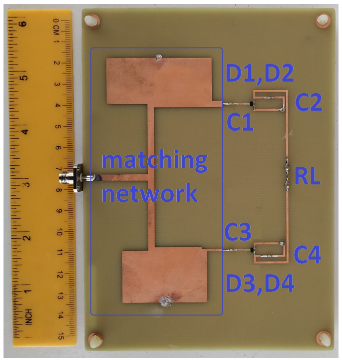

Fig. 8. Photo of the fabricated RF-to-DC rectifier for the RF EH module of the ARETHOU5A IoT platform.

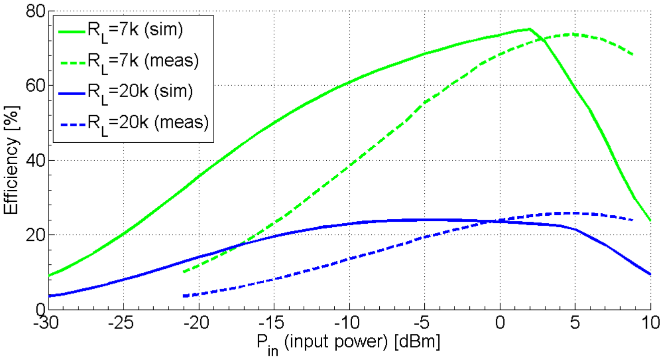

Fig. 10. Efficiency versus RF input power of the RF-to-DC rectifier for the RF EH module of the ARETHOU5A IoT platform (solid lines: simulated results (green color: $\boldsymbol{R_L}$ = 7 kOhms, blue color: $\boldsymbol{R_L}$ = 20 kOhms) [52], dash lines: measured results (green color: $\boldsymbol{R_L}$ = 7 kOhms, blue color: $\boldsymbol{R_L}$ = 20 kOhms)).

of the dual-band E-shaped patch antenna. The green solid line represents the computed by a numerical method (Finite Element Method - FEM) reflection coefficient (S_{11}) of the designed (and optimized) antenna [51], whereas the blue dash line displays the measured reflection coefficient of the fabricated antenna. From the presented results, we can easily derive that simulated and measured results are in good agreement. The fabricated antenna is satisfactorily tuned at two different frequency bands with minimum values of S_{11} equal to -31.18 dB at 870 MHz and -27.84 dB at 937.5 MHz, which are close to the tuned frequencies of the designed antenna (-34.31 dB at 865.1 MHz and -32.06 dB at 935.8 MHz) presented in [51]. Moreover, the -10 dB measured bandwidth of the fabricated antenna at the previously mentioned frequency bands (847.5 MHz - 895 MHz, 922.5 MHz - 950 MHz) practically covers both the European LoRaWAN frequency band (863 MHz - 870 MHz) and the EGSM-900 mobile communication frequency band (925 MHz - 960 MHz). Finally, the dual-band E-shaped patch antenna exhibits acceptable values of gain (5.0 dBi at 870 MHz and 4.8 dBi at 937.5 MHz) and satisfactory values of efficiency (81% at 870 MHz and 78% at 937.5 MHz) in the frequency bands of interest.

Fig. 10 illustrates the efficiency versus RF input power of the RF-to-DC rectifier for two different values of the load resistor R_L.The green color (solid line: computed results, dash line: measured results) corresponds to the efficiency for R_L = 7 kOhms, whereas the blue color (solid line: computed results, dash line: measured results) presents the efficiency for R_L = 20 kOhms. From the presented results, we can easily extract that, for P_{in} = 0 dBm and R_L = 20 kOhms, both computed and measured efficiency of the RF-to-DC rectifier are equal to 23.4%. Moreover, for P_{in} = 0 dBm and R_L = 7 kOhms, the obtained efficiency is 73.5% and 68%, respectively. The maximum simulated and measured efficiency of 75% and 73.6% are achieved for P_{in} = 2 dBm and 4.8 dBm, accordingly. Considering Fig. 10, we can also notice that the measured power conversion efficiency varies from 56% to 72% (R_L = 7 kOhms), when the RF power signals are bounded between -5 dBm and 5 dBm, respectively. In most cases, the circuit's performance does not exceed 50%, if we take into account the given operating frequencies [53], [54]. Furthermore, it is also noteworthy that, for an input power equal to -15 dBm, the measured efficiency is above 20%, which confirms the system's acceptable performance.

Fig.11 portrays the relation between the DC voltage and the AC input power for R_L = 7 kOhms. Once again, the green solid line represents the computed result of the output voltage, whereas the blue dash line corresponds to its measured result. From the presented graph, we can derive that, for P_{in} = 0 dBm, the computed and measured values of DC output

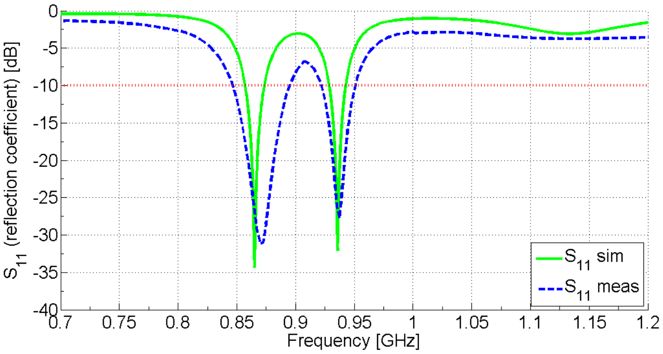

Fig. 9. Reflection coefficient ($\boldsymbol{S_{11}}$) of the E-shaped patch antenna for the RF EH module of the ARETHOU5A IoT platform (green solid line: simulated results [51], blue dash line: measured results, red dot line: -10 dB limit).

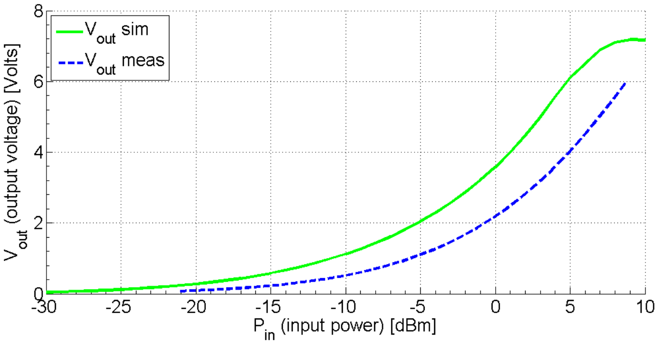

Fig. 11. DC output voltage versus the AC input power ($\boldsymbol{R_L}$ = 7 kOhms) of the RF-to-DC rectifier for the RF EH module of the ARETHOU5A IoT platform (green solid line: simulated results [52], blue dash line: measured results).

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voltage V_{out} across the load resistor R_L are 3.5 V and 2.2 V, accordingly. Finally, for P_{in} = - 10 dBm, these values are 1.2 V and 0.6 V, respectively. Considering the application point of view, the proposed rectifier facilitates the advantage of feasibility, as the voltage of the two operating frequencies is good enough to supply a sensor (e.g. a temperature sensor). These metrics allow us to furthermore investigate the circuit's performance by applying a DC-to-DC booster, to enhance the output voltage and to power supply a wireless sensor network. The DC-to-DC booster could include a storage element, while at the same time, a set of measurements on the sensors' energy consumption could be performed.

V. CONCLUSION

In this paper, we have described and analyzed the AREThOU5A platform, an IoT platform that is developed to perform intelligent irrigation practices and policies in water irrigation management of a perennial olive field. We have presented and discussed the AREThOU5A IoT platform subsystems, along with their main operations, as well as the layered architecture stack that has been deployed. Within the context of the AREThOU5A IoT platform, an innovative approach for delivering power to the IoT nodes of the platform has been utilized. To this end, a rectenna module of the AREThOU5A IoT platform measurement subsystem has been fabricated. Experimental validation of the fabricated rectenna demonstrates an acceptable performance both for antenna and RF-to-DC rectifier in an outdoor environment. Measured results show satisfactory values of the antenna's reflection coefficient (-31.18 dB at 870 MHz and -27.84 dB at 937.5 MHz), as well as of the rectifier's efficiency (68% for P_{in} = 0 dBm). Future work includes the installation of the rectenna module in various IoT nodes within a cultivation field to assess its performance.

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Achilles D. Boursianis (M’19) has received the Ph.D. degree from the School of Physics, Aristotle University of Thessaloniki (AUTh). Since 2019, he has been a postdoctoral researcher with the School of Physics, AUTh. He is also a member of the ELEDIA@AUTH research group. His research interests include wireless sensor networks, Internet of Things (IoT), RF energy harvesting, antenna design and optimization, 5G communication networks, and artificial intelligence. He has authored or co-authored several referred journals and conference papers. Dr. Achilles D. Boursianis is a member of the Institute of Electrical and Electronics Engineers (IEEE) and the Hellenic Physical Society.

Maria S. Papadopoulou has received the Ph.D. degree from the School of Physics, Aristotle University of Thessaloniki (AUTh). Since 2014, she serves as a visiting Lecturer in the Department of Information and Electronic Engineering of International Hellenic University. She is a senior researcher at the School of Physics, AUTh and she holds a postdoctoral research scholarship. She is also a member of the ELEDIA@AUTH research group. Her research interests include non-linear dynamics, chaotic cryptography, RF energy harvesting, wireless sensor networks, Internet of Things (IoT), and electronic design and optimization. She has authored or co-authored several peer-reviewed journals and conferences. Dr. Maria S. Papadopoulou is a member of the Hellenic Physical Society.

Antonis Gotsis is the Co-Founder, Co-Owner and Chief Executive Officer of FERON TECHNOLOGIES P.C. (FERON), as well as an Adjunct Lecturer in the Department of Digital Systems, University of Piraeus. Dr. Gotsis has more than 15 years' experience in conducting research and innovation in physical and medium access control sublayer technologies for 4G and 5G wireless access networks, and in the software development of radio standards and applications for custom communication systems. Dr. Gotsis received the Ph.D. degree in Wireless Communications from NTUA in 2010. He has more than 30 publications in journals, magazines, book chapters and conferences articles. His research interests include the design and prototyping of autonomous IoT systems and customized communication solutions based on in-house SDR and commercial equipment.

Shaohua Wan (SM'19) received the joint Ph.D. degree from the School of Computer, Wuhan University and the Department of Electrical Engineering and Computer Science, Northwestern University, USA in 2010. Since 2015, he has been holding a post-doctoral position at the State Key Laboratory of Digital Manufacturing Equipment and Technology, Huazhong University of Science and Technology. From 2016 to 2017, he was a visiting professor at the Department of Electrical and Computer Engineering, Technical University of Munich, Germany. He is currently an associate professor at School of Information and Safety Engineering, Zhongnan University of Economics and Law. His main research interests include deep learning for the Internet of Things and edge computing. He is an author of over 100 peer-reviewed research papers and books. He had served as the lead Guest Editor of several SCI indexed Journals.

Panagiotis Sarigannidis is an Associate Professor in the Department of Electrical and Computer Engineering in the University of Western Macedonia, Kozani, Greece since 2016. He received the B.Sc. and Ph.D. degrees in computer science from the Aristotle University of Thessaloniki, Thessaloniki, Greece, in 2001 and 2007, respectively. He has published over 170 papers in international journals, conferences and book chapters.He has been involved in several national, European and international projects. His research interests include telecommunication networks, internet of things and network security. He is an IEEE member and participates in the Editorial Boards of various journals, including International Journal of Communication Systems and EURASIP Journal on Wireless Communications and Networking.

Spyridon Nikolaidis received the Diploma and PhD degrees in electrical engineering from Patras University, Greece, in 1988 and 1994 respectively. Since September 1996 he has been with the Department of Physics of the Aristotle University of Thessaloniki, Greece where he is currently a full professor. His current research interests include: design of high speed and low power digital circuits and embedded systems, modeling the operations of basic CMOS structures, development of analytical expressions for the propagation delay and the power consumption of logic gates, modeling the power consumption of embedded processors. He is author and co-author in about 200 scientific articles in international journals and conference proceedings. He was member of the organization committee of three international conferences. He is the founder and organizes from 2012 the annual International Conference on Modern Circuit and System Technologies (MOCAST) while he has organized the 27th International Symposium on Power and Timing Modeling, Optimization and Simulation (PATMOS) for 2017. He also contributes to a number of research projects funded by European Union and Greek Government where in many of that he has the scientific responsibility. He is a Senior member of IEEE.

Sotirios K. Goudos (S'01-M'05-SM'14) received the B.Sc. degree in Physics in 1991 and the M.Sc. of Postgraduate Studies in Electronics in 1994 both from the Aristotle University of Thessaloniki. In 2001, he received the Ph.D. degree in Physics from the Aristotle University of Thessaloniki and in 2005 the Master in Information Systems from the University of Macedonia, Greece. In 2011, he obtained the Diploma degree in Electrical and Computer Engineering from the Aristotle University of Thessaloniki. He joined the Department of Physics, Aristotle University of Thessaloniki in 2013, where he is currently an Associate Professor. His research interests include antenna and microwave structures design, evolutionary algorithms, wireless communications, and semantic web technologies. Dr. Goudos is the director of the ELEDIA@AUTH lab member of the ELEDIA Research Center Network. Prof. Goudos is the founding Editor-in-Chief of the Telecom open access journal (MDPI publishing). Prof. Goudos is currently serving as Associate Editor for IEEE ACCESS and IEEE open journal of the communication society. He is also member of the Editorial Board of the International Journal of Antennas and Propagation (IJAP), the EURASIP Journal on Wireless Communications and Networking and the International Journal on Advances on Intelligent Systems.