Radio Frequency Energy Harvesting System and the Utilization of Blockchain Technologies in Agriculture

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Abstract

Modern agriculture and livestock breeding look for sustainable models that improve the efficiency of their ecosystem, while providing a secure and privacy-preserving IoT ecosystem. Multi-collected and heterogeneous data coming from crops, livestock, or even better from mixed farming systems that are coupled with AI capabilities is a promising approach that enhances agriculture systems. Such technologies aim at transforming farmers everyday live, promising accessibility, personalization and precision to the users, but they also suffer from significant issues. In particular, security, integrity and auditability have been major issues that need to be addressed, and one way of dealing with the aforementioned is by using Distributed Ledger Technologies (DLT), such as blockchain.

Keywords

IoT, blockchain, harvesting, radio frequency, sensors, sustainability

1. Introduction

The Internet of Things (IoT) is enabled by heterogeneous technologies, devices, and platforms, where they work together towards providing sensing, collecting, acting, processing, managing and analysing data. Within the IoT concept, intelligent embedded devices, such as smart sensors, wearable devices, and autonomous vehicles, are connected to each other and they are able to communicate without human intervention. The emergence of the IoT concept has led to the pervasive interconnection of people, services, and devices. However, new systems in the IoT domain that employ smart solutions having embedded intelligence, connectivity and processing capabilities for edge devices rely on real time processing at the edge of the IoT network near the end user. Current, traditional cloud computing and IoT solutions are not able to support real time applications since they are designed to offer non real time services, e.g., stress detection in IoT smart farming applications, while they are offered in high cost The computation remains at the cloud, i.e., at the provider datacenter, while heavy analytics, visualisations, and user aware services need long times, they are high cost, and they pose privacy issues since personal information is stored and processed in the backbone centralized servers. However, new generation systems and solutions require low latency and ultrafast analytics, given that they bring advanced smart technologies and applications with embedded intelligence, connectivity, and processing capabilities. A new cost-effective approach is needed, where these new IoT systems could be closer to

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the data source; low latency services and applications are viable, while the d at privacy could be increased. The vision of TERMINET project is to provide a novel next generation reference architecture based on cutting-edge technologies such as SDN, multiple-access edge computing, and virtualisation for next generation IoT, while introducing new, intelligent IoT devices for low-latency, market-oriented use cases. The User Centric Devices in Smart Farming use case is one of the six cases that TERMINET uitilises and is used to validate, demonstrate and assesse key aspects of the TERMINET platform in one of the most popular IoT ecosystems, smart farming. Two of the elements used for the implementation are presented in this paper.

2. Radio Frequency Energy Harvesting System

Radio Frequency (RF) Harvesting (EH) has attracted significant interest during the last years since it is one of the most promising techniques to self-power systems that require small amounts of energy to operate [1]. Although it can be applied as an alternative technique, it is expected to play a pivotal role in wireless networking and bring several transformative changes [2]. Wireless sensor networks, by the deployment of the Internet of Things (IoT) and Cyber-Physical systems, will be the dominant field of RF EH applications [3]. Beyond self-power and perpetual operation, RF energy harvesting in wireless networks can significantly reduce the demand for conventional energy and the associated carbon footprint, as well as the requirement of mobility to recharge conventional batteries [4]. The 24-hour availability and the spatial coverage of wirelessly transmitted power, specifically in urban areas, are the most comparative characteristics of RF EH against other widely used EH techniques [5].

The advent of the Fifth Generation (5G) network has brought several requirements to the characteristics of cellular communications. Among them, the increase in system capacity by 1000 times, the increase in spectral efficiency by 10 times, the higher energy efficiency, and data rate (i.e., 1 Gb/s in high mobility and 10 Gb/s in low mobility), and the improvement of the average cell throughput by a term of 25 times, are some of the key performance indicators that present a significant improvement in 5G cellular networks. 5G network is the first cellular communication system that combines micro- and millimeter-wave frequency bands of operation for outdoor and indoor coverage, accordingly [6]. Within the 5G ecosystem, various key-enabling technologies have emerged. One of the most representative examples of a technology that is combined with 5G is the Internet of Things (IoT) [7]. IoT has brought a breakthrough to wireless communication systems and artificial intelligence technologies, having applicability to many different fields and applications [8]. The deployment of billions of sensors in IoT networks will create vast amounts of data to be processed. So, the next generation of IoT, which combines artificial intelligence and the capabilities of 5G networks, will be emerged.

Typical RF energy harvesting systems are characterized by specific key performance numbers. These include the power conversion efficiency (PCE) of the rectenna (rectifier + antenna), the average and maximum output voltage of the rectifier, the rectifying antenna reflection coefficient, efficiency, and gain, and the proper impedance matching between the antenna and the rectifying circuit. These key performance numbers, if we consider that the RF energy harvesting systems operate in the ultra-high (300 MHz - 3 GHz) or the sub-6 GHz frequency band, are ultimately affected by a series of factors including, (a) the rectenna profile (i.e., the overall physical size of the rectenna compared to the wavelength of the operating frequency), (b) the type of the rectifying antenna (dipole, monopole, patch, E-shaped, slot, inverted-F, bow-tie, etc.), (c) the type of the impedance matching network (Π-, L-, T-network, etc.), (d) the type of the rectifying circuit (full-wave or bridge rectifier, Villard, Dickson or Greinacher topology, etc.), and (e) the maximum harvested energy that can be achieved [9]. As a result, rectenna systems that operate in the ultra-high or the sub-6 GHz frequency band usually require relatively high values of input power (>-20 dBm) to achieve an acceptable power conversion efficiency (20% - 40%) [10]. They usually occupy a significant board area compared to the wavelength of the operating frequency and they achieve relatively low values of efficiency in the rectifying antenna module. The implementation of a rectifying antenna and the corresponding rectifier circuit that operates in a dual-, triple- or multi-frequency band improves the maximum values of harvested energy against the overall size occupied by the rectenna in the substrate. Finally, the polarization of the rectifying antenna is of great importance to the maximum harvested energy [11].

Within the TERMINET project, a Radio-Frequency Energy Harvesting transceiver as a prototype system will be designed, optimized, and fabricated. The prototype system will operate in the licensed-free frequency bands of the Internet of Things (IoT) and/or Wi-Fi 2.4 GHz. Figure 1 portrays a generic block diagram of the prototype system. In detail, the prototype system will include a transmitting antenna, where its design will focus on the wireless power transfer of electromagnetic radiation. To this end, the prototype transmitter will be optimized by utilizing modern evolutionary (EAs) or Swarm Intelligence (SI) algorithms. Specific system metrics, such as impedance matching, directivity, and gain, will be considered in the optimization process to obtain the optimal solution of the derived antenna design. Moreover, the prototype system will include a receiving module, i.e., a rectenna (antenna + rectifier), to harvest the electromagnetic radiation and convert it to DC power. In this context, the prototype rectenna will also be optimized to obtain a feasible solution to the optimization problem. Both prototype modules (transmitting antenna, rectenna) will be designed and optimized to operate in the licensed-free radio frequency bands of IoT (EU863-870 (863-870/873 MHz) in Europe and/or Wi-Fi 2.4 GHz).

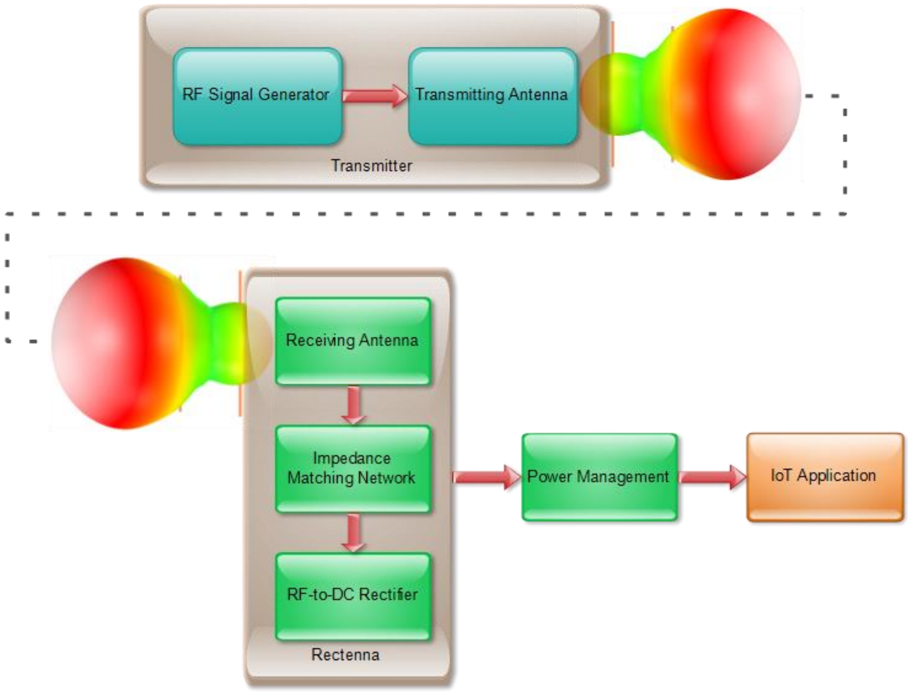

Figure 1: Generic block diagram of the RF EH Tx – Rx prototype system.

3. Blockchain Technologies in Agricultural Use Cases

With the rise of technologies such as IoT and Cloud Computing, there has been an ongoing digital revolution attempting to utilize the aforementioned technologies. Such technologies aim at transforming our everyday lives, promising accessibility, personalization and precision to the users, but they also suffer from significant issues. In particular, security, integrity and auditability have been major issues that need to be addressed, and one way of dealing with the aforementioned is by using Distributed Ledger Technologies (DLT), such as blockchain [12]

Blockchain is a highly regarded technology that has a potentially huge untapped potential in its use and could further revolutionize our lives. As a consequence, there has been a looming interest in this technology, with many applications ranging in different fields, similar to the IoT revolution, thus it is natural to try and combine IoT and Blockchain in order to leverage their capabilities, while minimizing their shortcomings. Many different fields have been on the receiving end of blockchain's benefits, most importantly financing, supply chain management, healthcare, smart farming and many more.

Blockchain is capable of providing a trustworthy and fault-tolerant system that has no single point of failure and trusted third parties. It also provides an immutable record of transactions thus increasing data security and integrity, which can also be used for logging and auditing.

Given the aforementioned information for IoT and Blockchain technologies, one can understand that combining the two can bring further breakthroughs. That is because blockchain technology can provide IoT systems with enhanced security and trust among devices, both critical for IoT applications, while safeguarding privacy, as compromising risks are reduced and finally providing further reliability [12], [13]. Another aspect that has been underappreciated when combining blockchain with IoT is the access control capabilities blockchain possesses. Access control is particularly important, since IoT devices can contain sensitive data, ranging from personal to business related data, which obviously need to remain away from unintended viewers [14].

Specifically, for agricultural IoT applications, the addition of blockchain is deemed as quite unique and is projected to improve the supervision and management of agriculture, as well as improve the entire supply chain and potentially introduce product traceability and transparency. In general, there are several categories in which blockchain can support the agricultural IoT applications. Those are: Supply chain management, Farm overseeing, Trust Management, Agricultural products tracking and Agri-food supply chain, all with different applications [15]. Finally, a more indirect support to agriculture is to combine drones and authentication/key management capabilities, backed up with a private blockchain solution can limit the insecure communication and subsequently limit attack vectors [16].

Within the TERMINET project, a permissioned blockchain network will be designed, along with the respective smart contracts in order to provide supply chain management functionalities. More specifically, the use of blockchain will be to be able to keep a full log and ultimately trace a product from the start of its production all the way to the market. As a supplementary functionality, some form of access control via blockchain will also be implemented, since sensitive business data will be the focal point of the entire procedure, allowing only certain entities to access the data. By doing the aforementioned, one can ensure that the entire trace of the product will be correct, as blockchain consists of an immutable ledger and will also act as an audit mechanism, especially useful for faulty products, but also safeguarding the confidential information of every farm to its respective trusted parties. Finally, further optimizations for performance and particular business needs will also be implemented if needed.

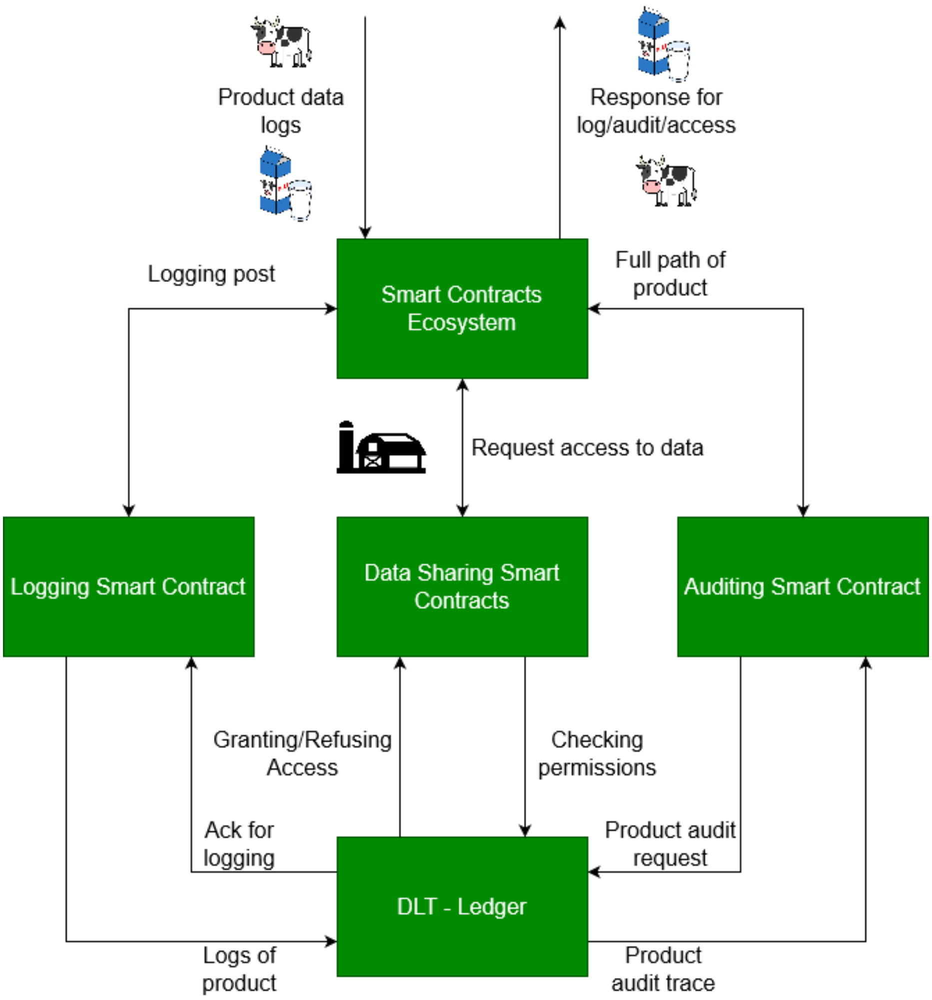

Figure 2: Reference diagram of the smart contracts functionalities with reference to agricultural use cases.

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