An Innovative Cloud-based RFID Traceability Architecture and Service

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***Abstract*—Today, several sectors are demanding the track of their objects to improve the efficiency and reliability of the system. RFID technology enables an automatic identification of objects attached to RFID tags via radio waves and allows reading or writing data without physical contact between an RFID reader and a tag. The main engine of RFID development is the need for traceability in order to ensure the authenticity of objects, avoid counterfeiting and track all events in the system. So, RFID technology adds intelligence to the process of identification and traceability and it is the best choice to create tracking systems. Our work aims to provide a secure RFID track and trace architecture which can be implemented in many areas and to design an RFID multi-frequency HF/UHF reader able to interact with HF or UHF tags. Moreover, to ensure and complete the historization of all sector events, we propose to enrich our traceability system with enforceable proofs through an electronic safe Cloud-based platform in a secure manner. The integration of RFID technology with a Cloud platform allows to link RFID objects to the Internet. Consequently, this network of networks represents the concept of the Internet of Things which is the key enabler for our traceability system. The present article is a report of our current research effort and our planned future work.**

***Index Terms*—RFID, Internet of Things, traceability, Cloud-based, multi-frequency HF/UHF, RFID tag, RFID reader, tracking.**

I. Introduction

Traceability is defined in [1] as the ability to trace the history, application or location of an entity by means of recorded identifications. The need for traceability of inert or living products is present in many economic sectors (for example: medical, food industry, aeronautics, luxury, supply chain, etc.) in a perspective of improving security, safety and efficiency. RFID (Radio Frequency IDentification) technology allows automatic identification and tracking of objects where each one is attached to an RFID tag which contains information that are stored electronically. This technology uses radio waves to ensure communication between an RFID reader and tags: the reader transmits electromagnetic waves, and each tag responds to the reader by sending its stored data [2]. Thus, by using RFID technology, we can collect, track, and manage object information in an efficient way. This technology is certainly a revolution in the field of traceability: it adds intelligence to the process of identification and traceability and it is the best choice to create tracking systems [3] [4].

Nowadays, many industries require an accurate and efficient traceability solution which must be enriched with enforceable proofs to ensure and complete the historization of the system events. Hence, to achieve this goal with RFID technology and enhance the tracking process, an increased development of RFID systems is remarkable today to integrate them with other systems. This integration opens a new era: the *Internet of Things*. Thus, the *Internet of Things* is a network of networks which allows, through standardized and wireless electronic systems, the identification and digital communication with objects in order to measure and exchange data between physical and virtual worlds in a secure way. The Internet of Things is a system of systems: interoperability between these systems and their integration with other components induces high complexity [5]. So, the enrichment of the tracking procedure with enforceable proofs using RFID technology, requires linking RFID objects to the Internet through other components such as: an information server, wireless network, mobile device, etc.

Our aim is to build a *Cloud-based RFID traceability architecture* which can be used in several sectors. The concept of the *Internet of Things* is the key enabler for our solution: using RFID technology enriched by storing proofs in a platform Cloud-based so as to complete the RFID tags information. Also, to enjoy the benefits provided by both HF and UHF frequencies, we propose to develop an RFID multi-frequency HF/UHF reader able to interact with HF or UHF tags.

This paper is a report of our current effort, which is still under development, and our planned future work. It is organized as follows. In section II, we introduce an overview of related works whereas section III describes the proposed traceability system. Section IV presents the software design and functional description of our system. The last section provides a brief conclusion and outlines future work.

II. Background and Related Work

RFID solutions enable to identify objects, to capture, store, process, and transfer data in physical environments and virtual worlds. RFID technology covers a range of very different applications that depend on several parameters (scope, frequency band, price, size, power consumption, etc.) [5]. Hence, it is necessary to differentiate between types of RFID systems. Generally, there are two categories of RFID tags, active and passive, depending on their power source. An active RFID tag uses an internal power source (battery), whereas a passive RFID tag relies on RF energy received from the reader (by electromagnetic induction). In addition, RFID systems are standardized at various frequencies, including LF (125-134 KHz), HF (13.56 MHz), UHF (860-960 MHz) and microwave (2.5 GHz and above). An UHF RFID system ensures a rapid exchange rate on a large reading range, allows to identify several objects simultaneously and it is widely used for tracking purposes. However, an HF RFID system only allows a short reading range and it is widely used in transportation and identity applications [6] [7].

Today, several research projects have considered RFID technology for different needs as a primary factor in the development of their systems. In [8], authors proposed an RFID solution for the counterfeiting problems of products which enables maintaining partners and the end consumers supply chain. Thus, other research works have considered the need for traceability of objects in many areas and proposed different systems based on RFID technology to satisfy this requirement. Hence, to have an accurate RFID traceability solution, the organization of the data architecture is essential action. Consequently, research efforts have used different design methods to get an efficient data architecture, either based only on an RFID classical model (reader, tags, etc.), or based on a combination between an RFID classical model and another platform.

So, a meat tracking solution that integrates RFID technology with GIS system is presented in [4]. It aims to improve meat quality and safety level and enhance customers confidence in meat consumption. A wine traceability system combining RFID and WSN technologies is discussed in [2] and enables the automatic collection of data along all the steps of wine elaboration. Also, authors proposed in [9] an RFID system integrated with a platform Cloud-based which permits the identification and tracking of objects through the supply chain management life cycle. In addition, a new solution using both RFID and GPS technologies is proposed in [10] and allows tracking for the logistics supply chain. Also, other traceability solutions for supply chain management are proposed in [11] and [12]. In [13], authors presented a solution to track animals in zoos, based on RFID, GPS and sensors. This allows to provide real-time information for animals such as their current location.

In order to trace food production and allow customers to have access to full food production information (in order to choose their food safety), cheese and chicken RFID traceability solutions are respectively discussed in [14] and [15]. In the field of aquatic product, an RFID traceability system is proposed in [3] and [16]. Also, authors presented in [17] an RFID traceability system for pork supply chain which helps consumers to trust in pork safety and encourages the development of the pork industry.

All works cited previously have built their RFID traceability systems using only one frequency (HF or UHF) for communication between the reader and tags. However, the idea for developing an RFID multi-frequency HF/UHF system (antenna, reader, etc.) has been studied in several research articles such as [18] and [19], where the goal was to enjoy the benefits offered by both HF and UHF frequencies. So, we have based our work on the architecture proposed in [9] *"combining RFID and Cloud technologies"*, taking into consideration multiple levels of security and proposing an RFID multi-frequency HF/UHF reader.

III. Proposed Traceability Architecture

Nowadays, we see in several fields of activity an increased complexity of operations (maintenance, supply, etc.) performed on objects (material, product, etc.) by the sector operators. So, it is necessary to control and trace all operations made in order to ensure the confidence in the sector environment. Our proposed system is a generic and an interoperable solution that can be used in many areas to allow object traceability by taking into consideration the operators existing in the system and their authentication. Therefore, the concept of the Internet of Things is our choice to construct this solution where we suggest to combine RFID technology with a Cloud-based platform. Our traceability model aims to ensure a secure end-to-end communication with different security levels and user rights. So, we can define all parts of our architecture as shown in Fig-1.

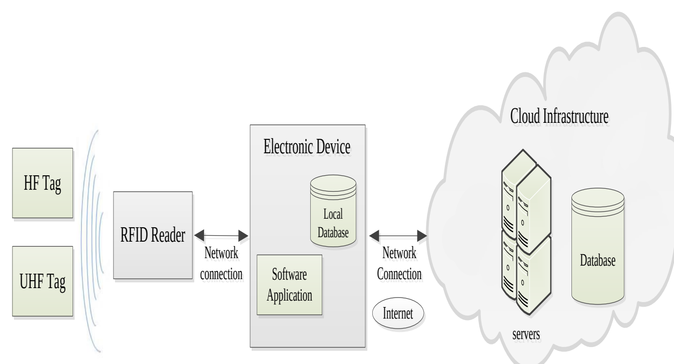

Fig. 1. Cloud-based RFID traceability architecture

A. HF/UHF RFID tags

To trace who performs which operation on which object, we propose to supply our traceability architecture with RFID identifications (tags) for the object and the operator. We suggest to use passive tags without cryptographic capabilities at two frequencies: HF and UHF. An HF RFID tag (or NFC badge) serves to identify and authenticate the operator who wants to perform an operation on an object, and an UHF RFID tag serves to identify and trace the object (write information about all events objects for traceability purposes). These passive tags will be powered through the magnetic field of the RFID reader proposed in our work and they are able to exchange data with this reader (receive commands and send responses). As well, an RFID tag can be seen as a simple storage device on which we can write or read data. For our traceability system, typically each tag (HF or UHF) contains the following information:

- Identifier (ID): is used to identify the tag in accordance with the standard (HF or UHF). It is attributed to the tag during its manufacture.
- Other information (INFO): are used to complete the role of the tag. Necessary information either to authenticate the operator (HF tag) or to ensure the object traceability thereafter (UHF tag).

B. RFID multi-frequency HF/UHF reader

We propose to develop a new type of RFID reader: *RFID Multi-Frequency HF/UHF Reader* which is able to interact with HF or UHF tags, and it relies on the trusted services offered by the Cloud infrastructure allowing high security functions. For the hardware design of this type of reader, we typically suggest to use two RFID modules and a microcontroller as illustrated in Fig-2:

- HF module: allows to read/write HF tags, it is composed of an HF card and an HF antenna. The HF card is composed of an HF microcontroller, an HF modulator and an HF demodulator.
- UHF module: allows to read/write UHF tags, it is composed of an UHF card and an UHF antenna. The UHF card is composed of an UHF microcontroller, an UHF modulator and an UHF demodulator.
- HF and UHF antennas: allow to radiate (transmitter) or capture (receiver) the electromagnetic waves.
- Microcontroller: contains a binary program allowing the management of frequencies. It is used to control the RFID modules based on a specific algorithm (see section IV) in order to enable the reading (or writing) of information from HF and UHF tags without interference.

Our proposed reader also permits the control of all its internal components and the feeding of tags through its magnetic field. Thus, we propose another electronic device which permits, via a secure network connection (for example: Bluetooth), the reader piloting. As a result, the reader can send the information read from a tag to this electronic device and it can receive commands or responses from this unit.

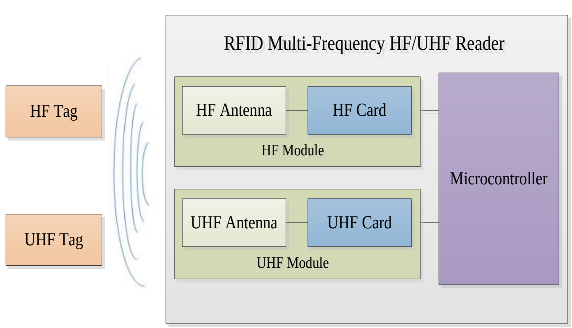

Fig. 2. RFID Multi-Frequency HF/UHF Reader

C. The reader controller

The controller is an electronic device (laptop, smartphone, tablet, etc.) able to drive the RFID reader using a software application. It is a medium of exchange between the Cloud infrastructure and the reader, and it includes a local database. It is connected to the RFID reader and the Cloud platform through a network connection where several software components are developed to ensure a secure interaction between them. It should be noted that these software components are based on an architecture consisting of recognized and validated standards in terms of safety. An operator can use this device to display the data read from tags and to send a writing request to the reader. This electronic device ensures the synchronization of the local and remote databases (remote database is located in the Cloud platform). The operator authentication procedure is made by this unit using share confidence information with the Cloud infrastructure after the reception of the HF tag content (see section IV).

D. Cloud Infrastructure

The Cloud infrastructure is a *Software as a Service* (SaaS) platform of an electronic safe server with the deployment of several software components that are specific to our architecture. This infrastructure is an emerging technology which uses resources (hardware and software) to provide services over the Internet. Thus, it represents a set of servers exposing trust functions and includes a global database for our traceability system. This infrastructure provides a high level of availability, it stores enforceable proofs to complete the information of RFID tags. The identification, authentication of operators and traceability of objects are ensured via the Cloud database in any time and locations around the world. In addition, a regular synchronization is made between the Cloud infrastructure and the reader controller.

IV. Software Design and Functional Description

In the previous section, we have described the different parts of our solution by briefly introducing their roles. In this section, we present a generic functionality of our architecture by detailing the software system design. Therefore, our implementation aims to satisfy: the establishment of traceability enforceable proofs of all operations (events) performed on the objects equipped with UHF tags, by relying on electronic signatures Cloud-based produced for the objects and the operators. So, our traceability system permits:

- Frequency management HF/UHF: an initial authentication of the operator with his HF tag (bagde) and then the reading of UHF tags.
- Combination the operator authentication with an electronic signature process Cloud-based.
- Generation of proofs stamped for different events that the system has traced.
- Writing information on an UHF tag.
- Synchronization of the databases (local and remote) to ensure consistency.

In addition, to improve our system security, we propose to identify rights of reading and writing on HF/UHF tags for the operators:

- All operators have the right to read the identifiers (ID) of HF or UHF tags.
- The operators can have the following rights on the information (INFO) of UHF tags: no reading and no writing, only reading, reading and writing.
- For operators which have the right to read the information (INFO) of UHF tags, we propose a reading security classification (top secret, secret, confidential, etc.).

Therefore, we can define three use cases as illustrated in Fig-3: authentication, consultation and writing. A use case expresses the interaction between an actor and the system. An actor represents a role played by an external entity and interacts directly with the system. So, in our traceability system, we have a single actor which is the operator. The latter can perform an operation on an object and he owns the electronic device (controller) that he can use it to send (or receive) commands (or responses) to the reader:

- Case 1 'Authentication': the operator possesses an HF badge, he presents it to the reader to authenticate itself.
- Case 2 'Consultation': the operator can use the electronic device to display UHF tags information (depending on security rights), or to consult the list of UHF tags present in the reader magnetic field.
- Case 3 'Writing': the operator can enter data, using the electronic device, in order to write information in an UHF tag.

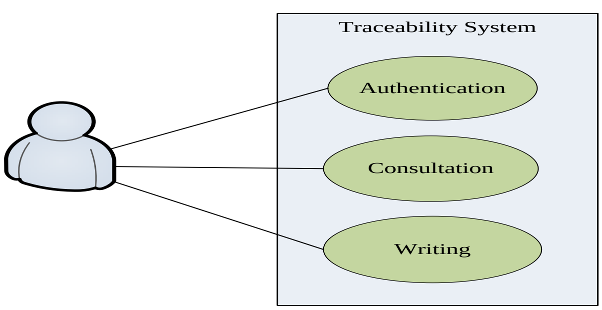

Fig. 3. Use cases diagram

A. Frequency management

The RFID reader is able to interact with HF or UHF tags using two antennas (HF and UHF). The control of these antennas (so as to enable the reading of HF and UHF tags without interference) is provided by the application (firmware) implemented in the microcontroller of the reader and executed in real time (hardware design explained in section III). This firmware is an orchestration algorithm allowing the management of frequencies. Thus, our proposed idea, as shown in Fig-4, is "allowing the reading of UHF tags only if the operator owning his HF badge has been well authenticated":

- Initially, the microcontroller puts ON the HF antenna and OFF the UHF antenna. In this case, the reader can read only HF tags.
- The reader waits until the operator presents his HF badge for authentication.
- If the operator presents his HF badge, then the reader reads the information contained in this tag and transmits them to the electronic device (controller of the reader).
- After the receipt of information by the controller, the latter performs an authentication procedure based on proofs obtained from the Cloud infrastructure.
- If the reader receives a message about successful authentication from the electronic device, the microcontroller puts ON the UHF antenna and OFF the HF antenna. In this case, the reader will be able to read only UHF tags.
- Otherwise, if the reader receives an authentication failure message, it asks for another operator authentication.
- The microcontroller may also put OFF the UHF antenna after a period of non-use DT. Then, the reader asks for operator authentication.

B. Consultation and writing procedures

After the previous step, if the operator is well authenticated, he can use the reader and controller for a consultation or a writing procedure:

- When the reading of UHF tags starts, the reader sends the list of UHF tags detected in its magnetic field to the electronic device.
- The operator can then view this list, and according to his security rights, he may have the right to read and write for example, where he can send a writing request about an UHF tag (if he made a particular operation on this tag) from the electronic device to the reader by entering the necessary information.
- In the case of successful writing, the reader locks the UHF tag to prohibit modifications.
- The electronic device which is connected to the Cloud infrastructure updates the databases (local and remote).
- Thus, time-stamped proofs are generated by the Cloud service for all events that have been doing in the system.

V. Conclusion and Future Work

RFID technology plays an important role in satisfying the need for traceability with the development of the Internet of Things. In this paper, we introduced a Cloud-based RFID traceability system which is compatible and adaptable to many sectors. We proposed to base our traceability architecture on the concept of the Internet of Things: using RFID technology enriched by storing proofs in a platform Cloud-based in order to complete the RFID tags information. Also, we proposed to construct an RFID multi-frequency HF/UHF reader able to interact with HF or UHF tags in order to enjoy the benefits provided by both HF and UHF frequencies. Therefore, for our next work, we will implement our tracking solution in a secure

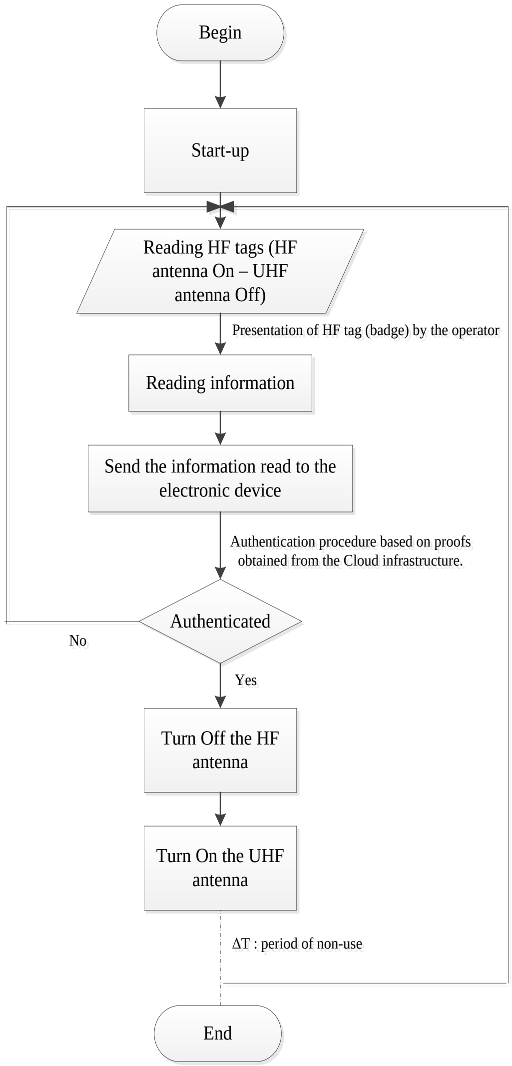

Fig. 4. Frequency management algorithm

real environment to have results tested, and develop the RFID multi-frequency reader. In addition, we will introduce other execution scenarios in the system, and more details on the use cases and their implementation. Thus, we will improve our research by proposing a new security protocol between the tags (HF/UHF) and the reader.

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