# Towards a Hybrid UHF RFID and NFC Platform for the Security of Medical Data from a Point of Care

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***Abstract*—In recent years, body-worn RFID and NFC (near field communication) devices have become one of the principal technologies concurring to the rise of healthcare internet of thing (H-IoT) systems. Similarly, points of care (PoCs) moved increasingly closer to patients to reduce the costs while supporting precision medicine and improving chronic illness management, thanks to timely and frequent feedback from the patients themselves. A typical PoC involves medical sensing devices capable of sampling human health, personal equipment with communications and computing capabilities (smartphone or tablet) and a secure software environment for data transmission to medical centers. Hybrid platforms simultaneously employing NFC and ultra-high frequency (UHF) RFID could be successfully developed for the first sensing layer. An application example of the proposed hybrid system for the monitoring of acute myocardial infarction (AMI) survivors details how the combined use of NFC and UHF-RFID in the same PoC can support the multifaceted need of AMI survivors while protecting the sensitive data on the patient's health.**

***Index Terms*—Body-area internet of things, cybersecurity, electrochemical sensor, H-IoT system, Near Field Communication, Radiofrequency Identification.**

## I. Introduction

Systems exploiting RFID (radiofrequency identification) and NFC (near field communication) have quickly arisen among the most advanced and versatile internet of things (IoT) solutions for healthcare in the last years, increasing the efficiency of processes and enabling completely new approaches [1]–[3]. Hospitals are adopting radiofrequency identification for inventory management together with barcodes, and regulations worldwide are fostering this trend [4] while advanced sensing application as breath monitoring [5] or wound healing monitoring [6] are under research. The wireless sensors for healthcare could be crucial for points of care (PoCs). The latest generation of PoCs provides feedback on the health status of patients while avoiding hospitals and large clinics for the sake of timeliness and personalized care [7] (Fig. 1). Hence, they are crucial for the latest paradigms of medicine, ranging from *homespitals* [8] to the *expert patient* [9]. Accordingly, PoC systems reduce cost and increase the quality of the treatment [10]. Smartphones can gather a myriad of data on the user's health status and are primary candidates for enabling points of care to monitor the user continuously, thanks to the NFC protocol [11], [12].

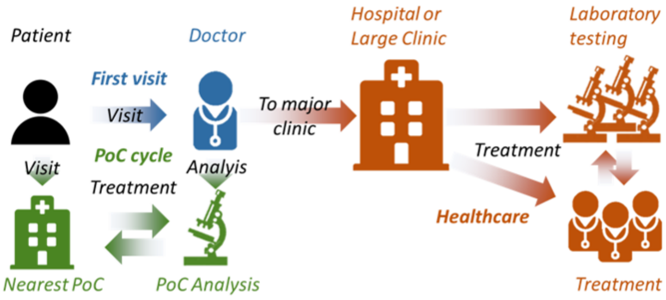

Fig. 1. Concept of a *PoC cycle* timely treating the patient while avoiding hospitals and large clinics.

Although many RFID and NFC for medical applications were proposed, a system architecture for implementing PoC while considering the security of the gathered medical data [13] has never been investigated. Therefore, this contribution focuses on the combined use of UHF-RFID and NFC in the same PoC platform to meet the needs of patients suffering from chronic health issues while fostering the secure transmission of the medical data through proxy re-encryption (PRE). Firstly, the system architecture is introduced, including the hardware components and data encryption exploiting a public cloud service; afterwards, an application example of a domestic PoC system for acute myocardial infarction (AMI) survivors is introduced as an example of the discussed hybrid platform.

## II. Architecture of the PoC System

### A. PoC Scenario

We consider a scenario in which a patient collects data on their own health condition using the PoC and wants to share this information with her doctor in a privacy-preserving way using a public file sharing service. Furthermore, if necessary, these data must also be accessible to other healthcare entities who could request them.

### B. RFID/NFC Hardware

Wearable or even epidermal RFID and NFC devices [1], [10] connected to electrochemical sensors [3] according to

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the patient's needs are exploited by the system to perform the required sensing. The UHF RFID boards allow for reading distances of a few tens of centimeters up to a few meters [14]; thanks to the long reading distances, such boards can continuously monitor even multiple patients while they are moving freely in a limited area. Their main limitations are the proneness to eavesdropping attacks [15] and that they could need batteries to perform electrochemical sensing [16]. NFC devices, instead, can perform electrochemical biosensing without the aid of any battery at the cost of shorter read distances [17]. Even if continuous monitoring is not possible through NFC transponders, since common smartphones can be used as readers, such transponders are suitable for monitoring slow varying biosignals such as the cortisol level [18] during the whole day. Therefore, NFC and UHF RFID can be used together to maximize the effectiveness of the PoC.

### C. Secure Transmission of the Medical Data

The data gathered by the body-worn sensors are afterwards protected and managed by proxy re-encryption.

*1) Actors:* According to §II-A, we consider the following actors: *i*) the *Cloud Provider*, which offers the file storage, sharing and synchronisation service; *ii*) the *Patient* who has to be able to share data with the Medical Staff; *iii*) the *Medical Personnel* who has to be able to access data shared by the Patients; *iv*) the *Medical System* that manages the access authorisations.

*2) Proxy Re-Encryption:* PRE is a cryptographic technique that allows a third party (*proxy*) to transform an encrypted message (*ciphertext*) that initially has been encrypted for a party into a new ciphertext, so that it can be decrypted by another one. The most important property of PRE is that this alteration occurs without data leakage because it does not require firstly decrypting the data, but the operation is directly executed on the original ciphertext. So, the decryption key is not compromised and can be used in the future. PRE has been extensively studied in the literature due to the underlying characteristics related to trying to provide a transformation function that is unidirectional and transitive [19]. More advanced solutions have been presented later. For instance, a lattice-based scheme is presented in [20].

The primary motivation for using PRE, particularly in the considered scenario, is to relieve Patients or the Medical System of the burden of encrypting the data specifically for each member of the Medical Personnel. PRE allows Patients to encrypt their own data without the need to know its recipients because the re-encryption process will make the ciphertext accessible to each one of them. Using conventional public-key encryption schemes (e.g. Rivest-Shamir-Adleman encryption), instead, Patients have to know the public-key of the recipients of their medical data at the time they are encrypting the data. Moreover, the PRE operation makes the ciphertext *specific* to each recipient, so nobody but the target recipient will be able to access the related content. Another important advantage introduced by the use of PRE is that the storage/sharing service becomes an *oblivious* data transfer service. Indeed, because of the properties of PRE, an *honest-but-curious* Cloud Provider has no way to learn any information about the content of the ciphertexts during the re-encryption process.

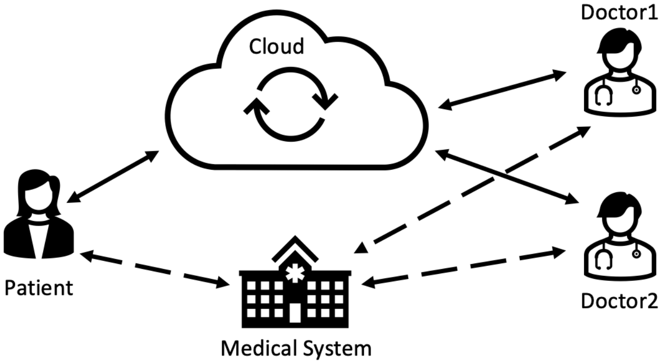


Fig. 2. A simplified example of the data-sharing architecture

*3) Data-Sharing Architecture:* The data-sharing architecture consists of the following four components:

- a *Key Management Service* (KMS), run by the Medical System, provides keys for encryption, decryption and re-encryption operations to Patients and Medical Personnel's members;
- a public *File Storage/Sharing* service (FSS), offered by an honest-but-curious Cloud Service Provider (e.g., Dropbox), used to store and share data by performing PRE operations;
- the *Data Owner* (DO), i.e. a Patient, generates sensitive data and saves them in an encrypted form on the FSS;
- the *Data Processor* (DP), i.e. a Medical Personnel's member (e.g., a doctor), has to access the encrypted data on the FSS and process them.

Fig. 2 shows a simplified example of the architecture for data-sharing and the interaction between the different components.

### D. Protected Data-Sharing Workflow

The data-sharing workflow follows the two phases next.

*1) Data encryption and storage in the cloud:* Patient uploads their own data to the FSS by encrypting the related files using a public-key provided by the KMS.

*2) Data access of Medical Personnel:* A Medical Personnel's member asks the KMS for a private key and asks the FSS service to access a specific file. The FSS service applies a PRE operation and re-encrypts the file so that the Medical Personnel's member can access it by decrypting it using the private key.

## III. Hybrid PoC System for AMI Survivors

### A. Needs of AMI Survivors

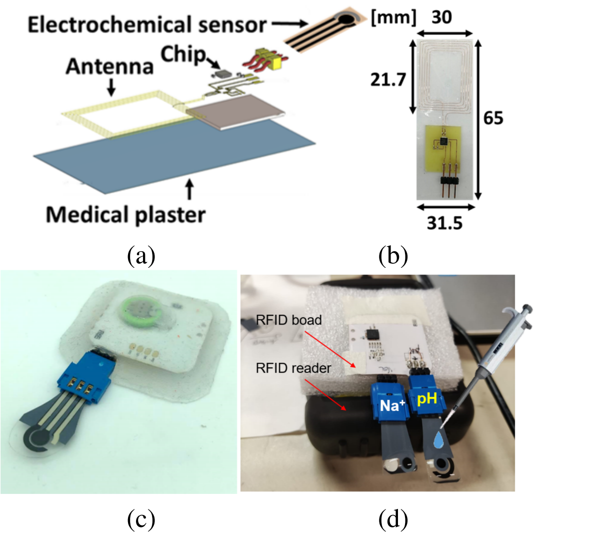
The hybrid platform conceptualized above must be tailored to meet the needs of the actual patients to be monitored. As an example, let us consider the survivors of acute myocardial infarction. The survivors can suffer from further major adverse cardiovascular events (MACEs). To avoid MACEs is essential to keep the cortisol, a precursor of stress, level low in blood and sweat [21], [22]. Stress can be effectively reduced by physical activity [23], but exercise could compromise the body-fluid balance of AMI survivors [24]. Consequently, both stress and exercise must be properly considered by an ad-hoc domestic PoC to heighten the patient's quality of life significantly.

### *B. Hardware Selection*

Physical exercise can be monitored by measuring sodium and pH of sweat thanks to the reading distance achieved by battery-assisted epidermal UHF RFID boards [25] by installing a fixed RFID reader in an exercise room. Instead, it is possible to check the stress level of the patient from the cortisol level in sweat which is highly correlated with cortisol in blood [22]. Given that stress is a sensitive indicator of mental health [26], and cortisol level is a slow-varying biosignal [18], the use of NFC can avoid the use of any battery thanks to the high power transferred by the interrogating smartphone. The low read distance of an NFC board can prevent eavesdropping altogether, and it is suitable for checking stress levels a few times during the day through a smartphone regardless of where the patient is.

The NFC device in [27] and the epidermal RFID tag in [16] can be used as body-worn tags (Fig. 3). They can be worn for a long time and connected to low-cost, ad-hoc electrochemical sensors [25] for the monitoring of cortisol, sodium, and pH in the sweat. The NFC spiral antenna is made of copper wires thick 40 $\mu$m posed on a medical-grade plaster (Tegaderm by 3M$^{\text{TM}}$), and it is connected to the SIC 4341 (from Silicon Craft Technology) IC, which is compatible with electrochemical sensing and can be read by smartphones through the ISO/IEC 14443A protocol. Tegaderm ensures the adhesion, breathability, and flexibility needed for long-term wear-time. The SIC 4341 and plug&play connectors are instead soldered to an FR-4 pad for the sake of robustness. The multi-sensing UHF RFID, instead, exploits the sensor-oriented SL900A (by AMS OSRAM) IC used in battery-assisted passive mode to bring down the chip sensitivity to $-15$ dBm. The electromagnetic interface is an open-loop antenna having $-15$ dBi as maximum antenna gain so as to allow for a maximum read distance higher than 1 m when reading the board with 3.2 W of equivalent isotropic radiated power (EIRP). Hence, the board can support indoor physical activity like exercising with a stationary bicycle or a treadmill. The boards can be attached to the right and left ventral mid-forearms, which are among the optimal positions for the targeted sweat sensing [28]; afterwards, the proper electrochemical sensors for cortisol [27] or pH and sodium [16] sensing can be connected. Fig. 4 shows how the AMI survivor can wear both the NFC and UHF RFID sensors.

For the sake of completeness, sensory measurements utilizing the integrated circuits are reported, too. Fig. 5 shows the output current of the electrochemical sensor when it is wet with a given concentration of cortisol as returned by a bench potentiostat (Emstat Blue, by Palmsense) and the SIC4341 IC, proving the fidelity of the sensory data communicated through NFC. Fig. 6 instead depicts a measurement of pH and temperature carried out by the UHF RFID board worn by a volunteer during 40 minutes of jumping rope. The pH measurements report decreased pH after 30 minutes, suggesting a temporary loss of salts [29] that should be compensated, for instance, by drinking energy drinks.



(a) (b)

(c) (d)

Fig. 3. Hardware selected for the implementation of the system. (a) Simulated model of the NFC epidermal responder and (b) one realized prototype. (c) One realized prototype of the UHF RFID board embedded in the silicone shell and (d) bench testing of the board connected to the pH and the sodium electrochemical sensors. Images adapted from [16], [27]

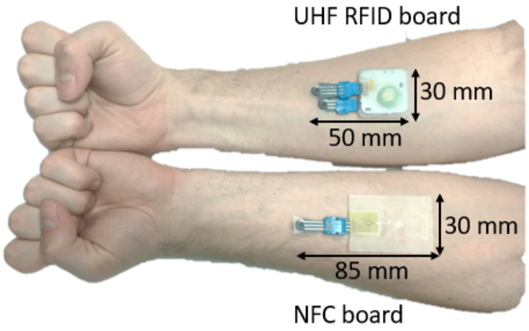


Fig. 4. The NFC and UHF RFID boards worn at the application points to monitor the physical exercise and the cortisol level simultaneously.

### *C. Use of the PoC Platform*

With the selected hardware, the AMI survivor can monitor their stress level during the day to check if a break or some relaxing activity is required. The medic can also prescribe monitoring the stress level along some days to verify if the patient is conducting a proper way of life to avoid abrupt deterioration of their health condition. When a physical activity has to be performed, the UHF RFID board can be worn to ensure the exercise is not excessively demanding for the patient. The medical record created through the wireless sensors is then shared with the medical personnel through the cloud and the proxy re-encryption.

## IV. Conclusion

A hybrid NFC and RFID-UHF system architecture was proposed in this contribution. Despite their increasing importance,

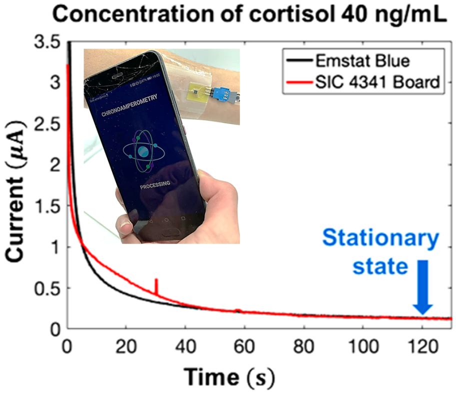


Fig. 5. Electric current vs time returned by the NFC board when the sensor is wet by a cortisol concentration of 40 ng/mL. The concept of the data retrieved by a smartphone is illustrated in the inset. Image from [27].

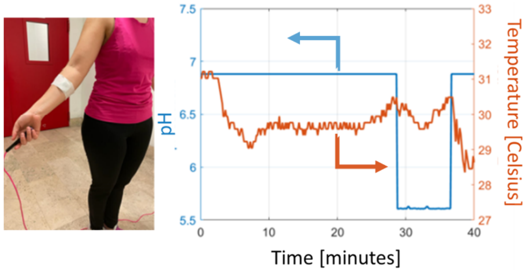


Fig. 6. Measurement of pH and temperature during physical exercise indoors.

the security of medical data gathered by current devices for points of care is still an open issue. Therefore, after reviewing some techniques for increasing the security of data transmission after the retrieval from the body-worn boards, an example of a high-level system design to meet the multifaceted needs of survivors from acute myocardial infarction is summarized, detailing the NFC and RFID hardware and the advantage of their simultaneous use.

Currently, we are developing and implementing the PoC for AMI survivors described in the pages above, including the sensors for cortisol and an ad-hoc application and server for ensuring secure transmission. After the implementation, the system will be preliminarily tested on healthy volunteers.

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