A UHF Radio Frequency Identification (RFID) System for Healthcare: Design and Implementation

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Abstract. This paper presents a customized design of a UHF Radio Frequency Identification (RFID) system to be installed at the Bank of Cyprus Oncology Center (BOCOC) in Cyprus. This is a pilot project that aims at evaluating the effectiveness and overall benefits of UHF RFID technology in the healthcare sector. The purpose of the project is threefold: a) Error-free identification of in-hospital patients through the use of RFID wristbands/cards; b) drug inventory control and monitoring; c) Real Time Location Service (RTLS) capable of locating tagged objects within the premises of the hospital. For the three main pillars of the project, a Graphical User Interface (GUI) was developed in order to run on light-weight medical tablet PCs. The application can access data from a secured central database hosting sensitive information regarding patients, drugs, medical assets, and high-value equipment. The communication between the server and the medical tablet PCs is done over an encrypted wireless local access network.

Keywords: RFID, e-health, patient identification, drug inventory control, RTLS, smart labels.

1 Introduction

RFID technology uses radio frequency signals to identify objects that are equipped with RFID tags. The RFID tags utilized in this project are passive UHF tags composed of a printed antenna and an integrated chip hosting a unique 96-bit identification code. The technology is based on the UHF-band EPC C1 Gen2 data exchange protocol between the tag and the reader (interrogator). The interrogator launches a UHF signal (30dBm) which impinges on a number of RFID tags in its vicinity and, from the modulated backscattered field, the reader is able to read and identify hundreds of these tags per second. Identification of objects is possible when the tagged objects are located within the area of coverage of the interrogator's antenna, even when there is no direct line-of-sight between the two. This is a major advantage of RFID technology over the well-accepted and widely-used barcode technology where

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the reader must be in contact with the barcode label. The maximum distance between the interrogator and an RFID tag, in order to allow readability, depends on the total link budget between the two devices, which in turn depends on the sensitivities of the interrogator and the tag, the gain of the reader's antenna in the direction of the tag, the sensitivity and input impedance of the chip, the propagation loss, the cable losses, the communication protocol, etc. Our primary objective in this pilot project was to optimize our design in order to achieve maximum RFID coverage in the premises of the hospital at minimum cost. For this purpose, we used ray-tracing algorithms, optimization tools, and electromagnetic simulation software, where several parameters have been taken into consideration, in order to properly design the RFID system. The number of antennas placed in each of the hospital's patient rooms and the precise location and orientation of these antennas were judiciously chosen in order to maximize RFID coverage and reduce the probability of "fail-to-read" a tag.

This project was designed to help medical personnel overcome major problems that are nowadays present in a hospital environment. Routine hospital tasks, like drug prescription or drug administration, are based on paper-bound processes that are prone to human errors thus putting patients in great danger on an everyday basis. The US Institute of Medicine estimates that more than 44,000 deaths occur each year in the US due to in-hospital medication errors [1]. The US Food and Drug Administration (FDA) estimates that medical errors approach 40% in paper-based environments. Simply stated, there are patient mix-up errors due to paper-bound processes which often end up in serious health problems for the hospitalized people. With the launch of an RFID system, in-hospital patients will be given a unique identification code, in the form of an RFID wristband or a plastic card, which will be automatically identified by a handheld UHF RFID reader attached to a light-weight medical tablet PC in the hands of a medical doctor or nurse. Once the patient is uniquely identified, the tablet will upload from the central database the patient's medical profile and relevant information. This is the first major pillar of the pilot RFID project.

The second pillar of the project is drug inventory control and monitoring. Drugs are usually stored in inventory rooms which are extremely difficult to monitor on a daily basis. Drugs may expire without noticing; drugs are sometimes removed from the inventory room without authorization; in other cases, drugs run out without the pharmacist being aware of it. It is estimated that approximately 10% of the inventory drugs are lost every year [2]. Unavailability of certain drugs may certainly put patients in great danger. Tagging each drug with a unique RFID allows the pharmacist to monitor drug inventory at all times.

The third pillar of the project is locating and tracking tagged objects in the premises of the hospital. Such objects may include patient files, infusion pumps, wheelchairs, walkers, expensive medical equipment, and even medical personnel. It is estimated that hospital employees spend approximately 25-33% of their time searching for medical equipment [2]. This translates to a waste of valuable time, inefficiency, and low productivity at workplace. The problem can be effectively solved by tagging objects or equipment with passive RFIDs, and by using the RTLS system with a network of antennas and stationary readers, these objects can be located and tracked everywhere in the premises of the hospital. Of course, a successful implementation of this idea mandates a careful design of the RFID system taking into account all possible factors ranging from the current needs of the medical personnel at workplace to major engineering issues such as electromagnetic coverage, tag readability, electromagnetic interference with other devices, security, privacy of sensitive data, etc. All these have been considered and carefully studied in order to be able to design and implement a system that meets all the specifications and expectations of the research team involved – including, of course, the medical personnel of the hospital.

2 RFID System Design and Implementation

The RFID system under development will be installed in one of the two hospital wards (Ward A) of the Bank of Cyprus Oncology Center in Nicosia, Cyprus. The top view of the hospital ward is shown in Fig. 1. Due to limitations in research funds, the system will provide electromagnetic (EM) coverage only for three patient rooms (Rooms 33-35) and for a drug inventory cabinet sitting in the area of the nurse station (indicated as 14-15 in Fig. 1). Nevertheless, this small-scale installation is deemed sufficient for the purpose of the project as our primary goal is to evaluate the designed RFID system in a realistic hospital environment and to draw valuable conclusions as to the effectiveness and the overall benefits of this technology for the patient and the healthcare system in general. At the time when this paper is being written, the RFID system has been only partially installed at the BOCOC. No measurements or testing has been performed, yet. The only measurements and testing of the system was carried out in a laboratory setting. A number of meetings have been organized between the developers/designers of the system and the medical personnel of the BOCOC in order to obtain feedback and valuable suggestions that can be used toward improving and perfecting the capabilities of the application.

For the design and implementation of the system, the following major devices were acquired: a) Handheld and stationary readers supporting the UHF ETSI (EN 302 208) band of frequencies together with the EPC Class 1 Generation 2 protocol which is characterized by a better anti-collision scheme as compared to previous generation protocols and, therefore, higher percentage of tag readability; b) A network based RFID printer that can support a wide variety of passive inlay tags. This type of printer can program RFID tags before they are attached to objects. The printer communicates with the front application via a local area network (LAN/WLAN) in order to, first, record a specific tag ID to the SQL database and, second, associate this unique ID number to a specific object; c) Tablet PCs for medical applications having specific characteristics including Wi-Fi capabilities, light weight, long-lasting batteries, ease of charging, USB ports, ability to disinfect; d) Wireless Access Points (APs) that will provide adequate coverage at high bit rates everywhere in the hospital ward; e) RFID antennas that are circularly polarized, with low Voltage Standing Wave Ratio (VSWR), high gain, moderate beamwidth, etc.; f) Low-loss coaxial cables to allow transmission and reception without significant attenuation due to cable loss; g) Computer server to host a secured central database housing sensitive information regarding patients, medical personnel, assets, drugs, patient files, etc.; h) Effective RFID tags that can be used for asset tracking as well as drug inventory control. The tags must provide high enough sensitivity in order to support long-range reading capabilities. Fig. 2 illustrates a block diagram of the RFID system design for hospital applications along with the interconnectivity of the devices involved. For example, the RFID printer will be installed at the pharmacy of the hospital and will be networked. Through the use of the application, the pharmacist will be able to access the printer, read an unused RFID label, obtain the corresponding unique EPC code, assign this code to a drug or asset, type his/her comments and/or associated expiration date, and store this information onto the secured database. The label can then be attached to the particular drug or asset and sent to its final destination. Once in the database, the tagged object can be uniquely identified or located if seen by the networked antennas.

In achieving a good RFID system design for a healthcare environment, the research team carefully examined the suggestions and recommendations of the medical personnel of the hospital. A network of highly efficient antennas was designed in order to provide maximum RF coverage inside the patient room, thus allowing a high degree of tag identification. The antenna gain is 7 dBi and the corresponding elevation and azimuth beamwidths are approximately 72 degrees. They exhibit VSWR below 1.3 within the band of interest (865-870 MHz) and the Front-to-Back (F/B) ratio is below -17 dB. They are all Right Hand Circularly Polarized (RHCP) antennas and their physical dimensions are 19cm x 19cm. Even though we could have chosen antennas with higher gain, in order to further improve EM coverage, we decided to use the antennas with 7 dBi gain because of the smaller physical size. The antennas were connected to the ports of the stationary RFID reader using low-loss coaxial cables. As most of the ordinary coaxial cables are characterized by high losses, and since the distance between the antenna and the reader's port was approximately 10 meters, it was important to incorporate into the design coaxial cables that have very low losses, otherwise the system would fail to provide sufficient coverage within the room. The coaxial cables used in the system design are characterized by 1.3 dB/10m attenuation. Cables with lower attenuation may now be found in the market, which can certainly help further improve the performance of the system.

A number of computer simulations using electromagnetic software and ray-tracing models [3] were conducted in order to optimize antenna position and orientation as a function of RF coverage inside a typical room. Measurements were conducted in a laboratory setting in order to verify the simulation results. Tag identification was improved by using spatial and polarization diversity at the expense of using multiple tags per object. This was necessary in cases where the sensitivity of the tags used was not very low. Initially, we were using tags with -14dBm sensitivity, whereas recently we introduced tags with -17dBm sensitivity, thus allowing us to improve readability and system performance. Alternatively, we used a pair of antennas per room, instead of a single antenna, in conjunction with a two-way power splitter/combiner. The position and orientation of the antennas inside the room was optimized using a ray-tracing code [3]. Fig. 3(a) shows the field distribution inside a typical patient room when using a pair of antennas whose position was optimized in order to have maximum EM coverage. As seen in the figure, the two antennas were placed at a close proximity to each other with a certain elevation/azimuth tilt. Using this configuration and assuming tag sensitivity of -14dBm and 3dB power reduction due to the bi-directional power splitter/combiner, we can achieve 93% RF coverage inside the room. In case the two antennas are placed apart from each other, at arbitrary locations/orientations, one may observe in Fig. 3(b) the nulls of the field that are created due to destructive interference between the radiated fields by the two antennas. Thus, a judicious choice of the antenna position and orientation is necessary in order to have constructive interference between the two radiated fields and the surroundings, thus improving EM coverage and tag readability.

The benefits of using the highly sensitive tags were obvious during an experiment we recently performed at the laboratory just before we launched the installation at the BOCOC. We used a room that resembles a patient's room at the hospital and we positioned more than 130 RFID tags (-17dBm sensitivity) inside the room at different locations and heights. The tags were oriented in all different directions. The system was using a pair of antennas with 7 dBi gain along with low-attenuation cables (10m long); the antennas were positioned 2 meters high at an optimized location obtained through multiple numerical simulations using ray-tracing codes. The transmitted power was 30dBm, according to the EU directive. Allowing the stationary reader to scan the room for a maximum of 3 seconds, the system was able to identify 100% of the tags. Consequently, tag diversity may not be necessary in the case of using highly sensitive RFID tags. Note that tag sensitivity improves significantly year after year. Note also that the tags used in the experiment were attached onto a paper type of material. From other experiments performed, it was observed that a tag behaves differently when attached to a bottle filled with liquid or to a metallic container. These are issues that will be addressed at a later stage.

A user-friendly GUI was developed, according to the needs and suggestions provided by the medical staff of the BoC Oncology Center. The GUI has numerous functionalities including adding/deleting patients to/from the system database, interfacing with the handheld RFID reader attached to the USB port of the medical tablet PC, identifying patients equipped with a passive RFID tag, loading patient's medical history and profile, assigning tasks to the nurses and monitoring their tasks, allowing doctors to prescribe drugs to in-hospital patients, allowing pharmacists to monitor drug flow in and out of the inventory room, locating and tracking medical assets everywhere in the hospital ward, and more. Fig. 4(a) illustrates a front view of the GUI with an account icon for nurses, doctors, and pharmacists, an icon for inventory control and monitoring, an icon for medical asset locating and tracking, an icon for printing RFID tags for assets, and an account icon for hospital administrators. Each of the accounts has different capabilities and privileges. For example, the doctor's account allows access to prescription of drugs, whereas all other accounts do not. In addition, the administrator's account has the privilege of adding and removing accounts from the system; however, he/she cannot access patient data as these are encrypted on the database. Fig. 4(b) depicts the top view of the hospital ward indicating all medical assets/equipment that were located. This is part of the RTLS component of the project. As shown in the figure, the system of networked antennas was able to locate 1 wheelchair in room 33 and 2 wheelchairs in room 35. The application card is able to search for other type of equipment or assets such as infusion pumps, walkers, patient files, and medical/surgical equipment. It is very easy to use but very powerful, and that is exactly what makes this application suitable for the healthcare environment. A similar card can be shown for the inventory control and monitoring which tabulates all drugs found in the cabinet or inventory room (see Fig 5 (a)). By double-clicking on a particular item, more information about the drug can be shown, e.g., expiration date, type of drug, etc. Another card, shown in Fig. 5(b), depicts the profile of a patient who was uniquely identified by the system through the use of a wireless tablet PC and a handheld RFID reader. Once the patient is identified, depending on the account, his/her medical history and profile are automatically uploaded onto the screen of the tablet.

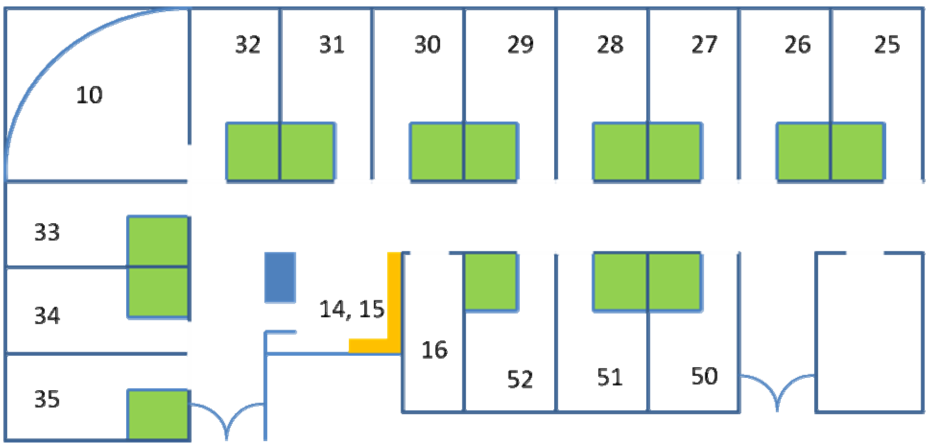


Fig. 1. The top view of the hospital Ward "A" of the Bank of Cyprus Oncology Center. The RTLS system will be installed, on a pilot basis, in rooms 33-35 and around the nurse station (14-15).

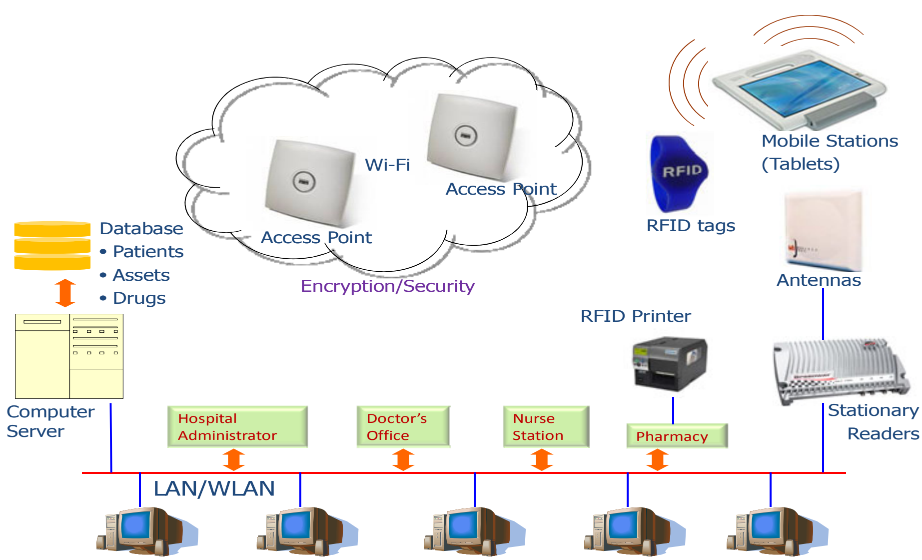
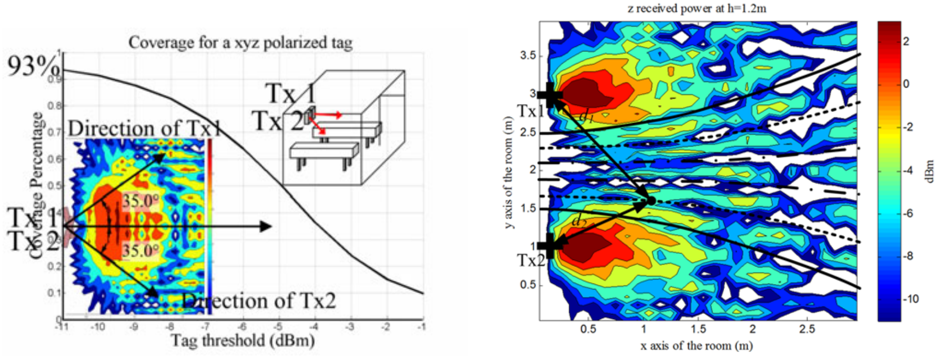


Fig. 2. Block diagram of the RFID system design that is being installed at the Bank of Cyprus Oncology Center



(a) (b)

Fig. 3. RF coverage inside a typical patient room using: (a) optimized two-antenna configuration at close proximity to each other; (b) a pair of antennas spaced apart

(a) (b)

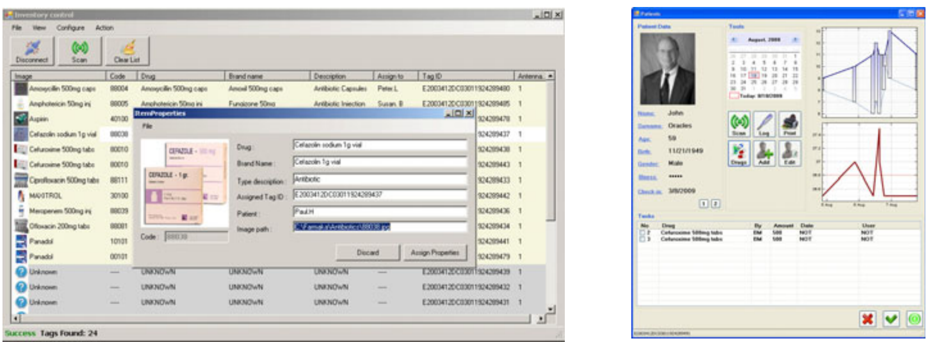
Fig. 4. (a) The Login card of the GUI; (b) The RTLS card where it is shown that 1 wheelchair was found in room 33 and 2 wheelchairs in room 35

It should be emphasized that fundamental antenna theory and propagation models were used in the design of the proposed RFID system. For example, considering only the line-of-sight path between the reader antenna and the RFID tag, one may use the well-known Friis equation [4] to calculate the maximum possible range that will allow data exchange between the reader and the tag (chip). This is the maximum possible forward link budget that corresponds to the minimum power at the terminals of the chip that is required for it to be energized. When the available power is lower than this threshold, the chip cannot be energized and, therefore, there is no modulated backscattered signal toward the reader antenna. This maximum forward link budget is given by

$$r_{\max} = \left(\frac{\lambda}{4\pi}\right)\sqrt{\frac{P_{tx}G_{tx}G_{tag}\left(PLF\right)\left(1-|\Gamma|^{2}\right)}{L_{c}P_{chip}(\min)}} \qquad (1)$$

where P_{tx} is the Effective Radiated Power (ERP=2W for Europe), G_{tx}, G_{tag} are the gains of the transmitting and tag antennas, respectively, PLF is the Polarization Loss Factor between the incident field and the tag antenna, Γ is the complex reflection coefficient at the terminals of the tag antenna for a given chip input impedance, L_c is cable loss factor due to attenuation, and $P_{chip}(\min)$ is the minimum power required by the chip (chip sensitivity). The power of the backscattered ASK-modulated signal by the tag is proportional to the differential RCS ($\Delta\sigma$) of the tag antenna terminated to a given chip impedance [5]:

$$P_{received} = \frac{P_{tx} G_{tx}^2 (PLF)}{L_c^2} \left(\frac{\lambda}{4\pi r^2} \right)^2 \frac{\Delta\sigma}{4\pi} \qquad (2)$$



(a) (b)

Fig. 5. (a) Application card indicating all drugs located in the inventory room/cabinet; (b) patient identification card depicting medical history, patient profile, and routine task icons

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References

1. Institute of Medicine: To Err is Human: Building a Safer Health System. National Academy Press, Washington, D.C. (1999)
2. Glabman, M.: Room for tracking: RFID technology finds the way. Materials Management in Health Care (2004)
3. Saunders, S.R.: Antennas and Propagation for Wireless Communication Systems. John Wiley and Sons, Chichester (1999)
4. Balanis, A.C.: Antenna Theory: Analysis and Design. John Wiley and Sons, Chichester (2005)
5. Nikitin, P.V., Rao, K.V.S., Martinez, R.D.: Differential RCS of RFID tag. Electronics Letters 43(8) (2007)