

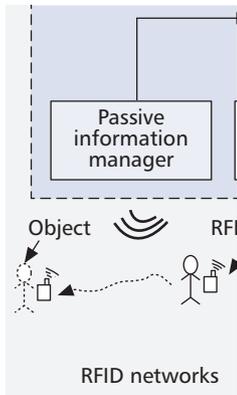
A 2G-RFID-BASED E-HEALTHCARE SYSTEM

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The authors propose an evolution into second-generation RFID systems characterized by the introduction of encoded rules that are dynamically stored in the RFID tags.

ABSTRACT

Radio frequency identification technology has received an increasing amount of attention in the past few years as an important emerging technology. However, the intrinsically passive features of existing RFID systems, to which we refer as first-generation RFID systems, render their adaptation to real-world dynamics in order to efficiently comply with up-to-date application-specific requirements difficult. To address this challenging issue, we propose an evolution to second-generation RFID systems characterized by the introduction of encoded rules that are dynamically stored in RFID tags. This novel approach facilitates the systems' operation to perform actions on demand for different objects in different situations, and enables improved scalability. Based on 2G-RFID-Sys, we propose a novel e-healthcare management system, and explain how it can be employed to leverage the effectiveness of existing ones. It is foreseeable that the flexibility and scalability of 2G-RFID-Sys will support more automatic and intelligent applications in the future.

INTRODUCTION

Radio frequency identification (RFID) [1] is an RF electronic technology that allows automatic identification or locating of objects, people, and animals in a wide variety of deployment settings. In the past decade RFID systems have been incorporated into a wide range of industrial and commercial systems, including manufacturing and logistics, retail, item tracking and tracing, inventory monitoring, asset management, anti-theft, electronic payment, anti-tampering, transport ticketing, and supply-chain management [2]. In this article we refer to them as first-generation RFID systems (1G-RFID-Sys). 1G-RFID-Sys designs treat the information contained in the corresponding tags as passive data that provides a simple description of its bearer (e.g., a simple identification number), and any action applied to the bearer object is obtained from an existing rule database [3]. Basically, rules are constructed based on three pieces of information:

- The object's identification and/or description (e.g., type, color, shape, and weight)

- Conditions and associated environmental parameters, which are used to determine whether a rule is satisfied
- An action directive that guides the system in order to provide the required service to the object when the rule is satisfied.

Obviously, the main functionality of 1G-RFID-Sys' backend processes is searching the rule database and determining a suitable action based on the tag's associated rule. However, 1G-RFID-Sys exhibits the following undesirable features:

- The rule database must be populated in advance. Otherwise, the system does not know how to proceed based solely on contextless information provided by the tag.
- The size of the rule database will constantly grow where the number of applications involved is increased, or one or more parameters associated with the deployment setting changes frequently, raising scalability issues.
- It may be impractical or undesirable to update the rule database manually as needed, since this introduces an error-prone *human operation delay*.

Also, we have seen a great increase in the demand for e-healthcare management system in recent years. According to the U.S. Census Bureau, the population aged 65 and older is projected to more than double from 2000 to 2030, from 35 million to 70 million. It is thus reasonable to expect that this circumstance will only contribute to an ongoing decline in the quality of services provided by an overloaded healthcare system. With RFID technology, it is now possible to design new systems that help collect and monitor patients' health conditions, and to issue diagnoses based on both medical history and real-time information. However, the above issues with 1G-RFID-Sys impede its seamless adoption for supporting efficient, automated and intelligent operations of next-generation e-healthcare management systems.

To address this issue, we propose an evolution from 1G-RFID-Sys to second-generation RFID systems¹ (2G-RFID-Sys), whose main dis-

¹ This is not to be confused with the Generation 2 (GEN 2) RFID tag, which is a standard for the current generation of RFID tags.

Compared to 1G-RFID-Sys, tags in 2G-RFID-Sys would store not only passive but also active information encoded in the form of mobile codes reflecting the up-to-date service requirements. Thus, the regular rule-searching process and its associated issues seen in 1G-RFID-Sys can be averted.

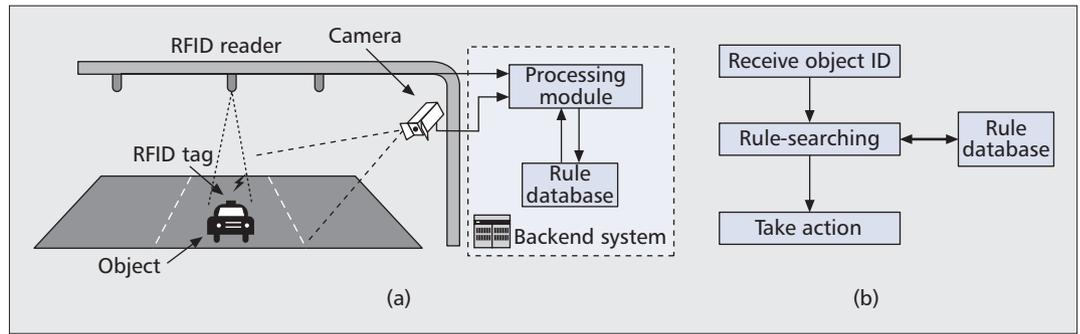


Figure 1. A typical example of a 1G-RFID system: a) basic elements; b) operation flow.

tinctive feature is the introduction of dynamic rule encoding stored in RFID tags, instead of placing them in databases as is currently done in 1G-RFID-Sys. Based on this novel idea, we propose an advanced design of a 2G-RFID-Sys. Our proposed architecture facilitates the system's operations to perform actions on demand for different objects in different situations, and improves scalability. Then we propose a 2G-RFID-Sys for e-healthcare, which integrates diverse wireless networking technologies, such as wireless body area networks and wireless LANs. The core idea proposed in this article is to use body sensors to collect patient information while deploying 2G-RFID-Sys for enhanced diagnosis assistance and action handling. We claim that the effectiveness of future e-healthcare technology can be significantly enhanced with this new system.

The rest of the article is organized as follows. An overview of 1G-RFID-Sys is given in the next section. The architecture and design issues of 2G-RFID-Sys are then presented. Based on 2G-RFID-Sys, a novel e-healthcare management system is then described. Finally, we present our conclusions in the final section.

AN OVERVIEW OF THE 1G-RFID SYSTEM

A typical RFID application consists of an RFID tag, an RFID reader, and a backend system. With a simple RF chip and an antenna, an RFID tag can store information that identifies the object to which it is attached. There are three types of RFID tags: passive tags, active tags, and semi-active tags. A passive tag obtains energy through RF signals from the reader, while an active tag is powered by an embedded battery, which enables larger memory or more functionalities. Although a semi-active tag communicates with RFID readers like a passive tag, additional modules can be supported through an internal battery. When it comes within proximity of an RFID reader, the information stored in the tag is transferred to the reader and onto a backend system, which can be a computer employed for processing this information and controlling the operation of other subsystem(s). Current 1G-RFID-Sys is designed to retrieve and process passive information about the RFID tag's bearer. An RFID tag associated with an object does not directly convey instructions on how to handle the object, or what action should be applied to it if a certain event occurs.

Assume that a vehicle carrying an RFID tag is moving on a highway. When it passes a check point equipped with an RFID reader, the identification data of the vehicle is transmitted to the RFID reader and backend system, which associates the vehicle's ID with a pre-existing rule database entry. This database maintains a list of identifications and their associated rules, which are matched against the conditions required to issue an action for a specific object's ID. After obtaining the corresponding rule from the database, the system checks whether the required condition is satisfied in order to initiate the appropriate action. In our example the vehicle is being monitored by a camera to measure its speed. If the speed limit is exceeded, assume that the condition is satisfied. Based on the rule, some actions will be triggered, such as issuing a penalty ticket to the vehicle driver (associated with the vehicle's identification data). Alternatively, the vehicle may be chased by a police car, for instance, if the vehicle travels at an extremely high speed. As observed in the operation flow shown in Fig. 1b, the rule searching process is the key operation performed by 1G-RFID-Sys.

THE 2G-RFID SYSTEM

EVOLUTION TO 2G-RFID-SYS

Compared to 1G-RFID-Sys, tags in 2G-RFID-Sys would store not only passive but also *active* information encoded in the form of *mobile codes* reflecting the up-to-date service requirements. Thus, the regular rule searching process and its associated issues seen in 1G-RFID-Sys can be averted. Here, the term *mobile codes* is employed to refer to encoded procedural directives stored in the RFID tag, which are intrinsically mobile with the object's bearer. The basic format of these mobile codes can consist of a simple conditional statement and a series of action codes:

```
if {condition (environmental parameters)}
then {<action1 (parameter1)>, <action2
(parameter2)>...},
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where *environmental parameters* (e.g., temperature or humidity sensed by some sensors) are used to determine whether the *condition* of a rule is satisfied, and *action* represents the operation/service the system can provide for the

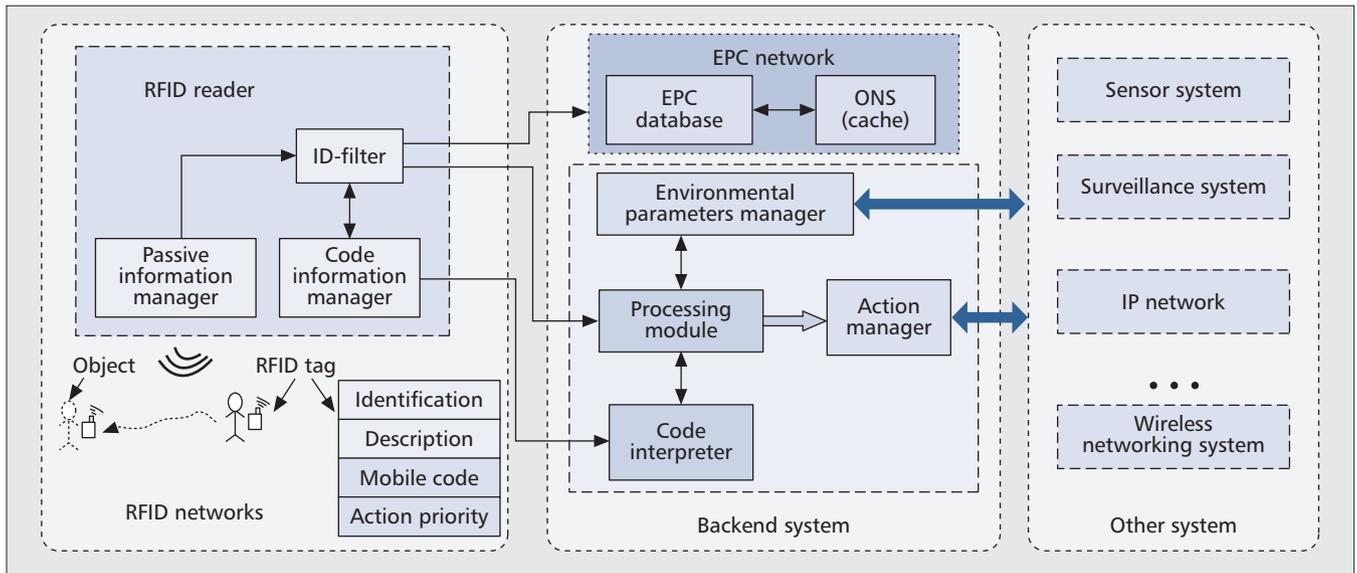


Figure 2. Functional components of 2G-RFID-Sys.

object. Given the example in Fig. 1a, the mobile code stored in the tag of 2G-RFID-Sys can be

if {Speed >80km/hr} then {notify_police()}.

However, a speeding car situation can be justified in special cases. For instance, the vehicle's driver may be subject to an emergency situation while transporting a severely ill patient, a pregnant woman, or someone previously involved in a car accident to a hospital. In such medical emergency cases the driver needs to get to the hospital as quickly as possible. However, being unaware of the situation, a police car that relies on a 1G-RFID-Sys would still initiate pursuit if the purported speeding vehicle (i.e., the emergency situation of a regular vehicle) is not proactively sent from the RFID tag to the backend system. Conversely, in the 2G-RFID-Sys, when an emergency situation signal is detected or given by the driver, an emergency code request is sent to an emergency station for emergency status permission. If the emergency situation is verified, the permission code is approved to be remotely written into the 2G-RFID tag. In this case the code stored in the tag of a 2G-RFID-Sys is simply changed to

emergency: "on"

Thus, when the RFID reader receives this mobile code, the backend system becomes aware of the developing situation, and the detailed emergency response actions are interpreted by distributed code interpreters for enabling the ambulance's siren, raising the maximum speed limit, giving all possible assistance on the road, and so on.

As illustrated in the previous example, 2G-RFID-Sys provides more flexibility and scalability, and supports various applications in an on-demand manner. 2G-RFID-Sys, designed with functions of mobile code and action priority, makes adaptation to changing situations possible. If the capacity of RFID tags is very limited, the mobile code can only store some abstract

codes, such as "emergency: on," "accident: car crash," "operation: yes," and "transfusion: yes." Thus, there is a need for an intelligent processing system to support the functionality of the mobile code. In the backend system the mobile code can be interpreted corresponding to an intelligence entity (IE), which can be retrieved from an IE pool system proposed by Runhe Huang *et al.* [4]. Compared to 1G-RFID-Sys, 2G-RFID-Sys has the following features:

- It provides a new dimension of freedom for backend systems, and can be effective in relieving the processing, communication, and storage load from the backend system.
- Based on the current application's context and its environmental assumptions, the architecture can be designed more easily to provide the flexibility and intelligence to accommodate various functions with specific requirements.
- By transferring the action specification from the backend system to the object itself, information on the object's requirements is always available as needed.
- The introduction of mobile code in an RFID tag eliminates the need to set up and update the rule database and the corresponding rule-querying interactions at the backend system. When encountering a dynamic environment, the tag's mobile code is simply updated according to the user's requirements (e.g., using a portable RFID tag writer), and not by means of the backend system. It is thus conceivable to realize a much more scalable system that can accommodate a significantly larger number of applications without having to perform many changes to the existing infrastructure.

ARCHITECTURE FOR 2G-RFID-SYS

Figure 2 shows the functional components of our proposed 2G-RFID-Sys, which mainly includes a predefined tag message format, a code information manager, an identification filter (ID-filter), a code interpreter, an environmental parameters

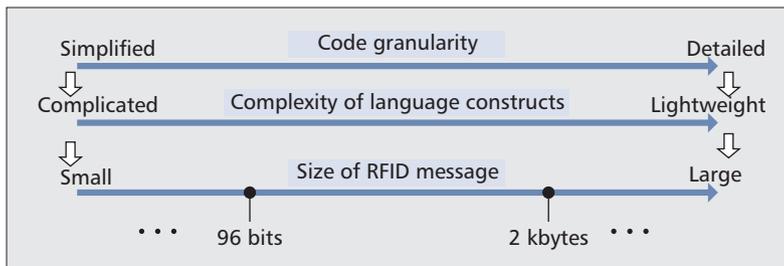


Figure 3. Design trade-off of the language constructs in 2G-RFID-Sys.

manager, a processing module, and an action manager, as detailed next.

Tag Message Format — With the latest developments in RFID technology, tags can be rewritten millions of times [5], and the amount of memory they possess is much larger than before. For instance, Fujitsu's model MB89R118 RFID tag provides 2 kbytes of user-defined memory [6], which is suitable to incorporate an extended message format that supports the realization of 2G-RFID-Sys. As shown in Fig. 2, the message format contains four fields: identification, description, mobile codes' space, and action priority. The identification and description information is passive, and usually unchanging. By comparison, the mobile codes and action priority can be updated dynamically according to application requirements. Since the memory size of RFID tags is still limited, mobile codes need to be abstracted as compact action scripts based on a high-level language system. The action priority is used to provide differentiated services when the corresponding processing resources are limited and/or multiple objects compete for the same type of service.

Code Information Manager — When the tag's content is received by the RFID reader, the data is first fragmented into its passive information and codes information fields. The codes information will be forwarded to the code information manager. However, if an ID-filter is employed by the reader, the codes are held until the object's identity clears, and they are subsequently forwarded to the codes interpreter. Otherwise, the codes are discarded by the code information manager.

Codes Interpreter — The codes interpreter comprises an incoming codes queue and a codes parser. If there are multiple requests in the codes queue, the codes with higher action priority will be forwarded to the codes parser first. Since the codes are associated with a specific object/user, such priority provisioning can be referred to as object-oriented differentiated service provisioning. Later on, the codes are sent to the processing module.

ID-Filter — The ID-filter is an optional module. If it is present, the ID information is first checked by the ID-filter, which has two main functionalities:

- It decreases unnecessary system load by discarding the tag information read by the RFID reader when unknown/unassociated objects appear in its proximity.

- It provides enhanced security by maintaining a list of IDs that represents either the approved or unapproved tags. However, the security supported by such a simple ID-filter is limited. An enhanced authentication mechanism can be designed to further enhance the security capabilities in the backend system.

EPC Network — The Electronic Product Code (EPC), which was designed by the EPC Global Network [7], is a set of global technical standards aimed at enabling automatic and instant identification of items in the supply chain and sharing the information throughout the supply chain. The EPC is a unique identifier of a physical object stored in an RFID tag. The EPC network has three main components: Object Naming Service (ONS), EPC Information Service (EPCIS), and EPC Discovery Service (EPCDS).

Environmental Parameters Manager — This module is used to retrieve the environmental parameters that facilitate the processing module's decision making task. For example, in order to get the environmental temperature and humidity, a notification is sent to the sensor nodes in the region of interest to sense the environment in advance.

Action Manager — The action manager carries out the desired tasks in accordance with the decision made. If an action/service is requested, the action manager executes the necessary processes to perform such an action. The output of an action can vary according to the different types of systems.

DESIGN ISSUES FOR 2G-RFID-SYS

In this section we describe the aspects related to efficient design of the language constructs of the codes interpreter module.

Language constructs: The first step in realizing a 2G-RFID-Sys is to identify all of the possible actions that might be needed. In addition, the maximum memory space available in the RFID tags must be considered. As seen in Fig. 3, a good design should simplify the complexity of such language constructs as much as possible, while considering the capabilities of the backend system. If the available memory size of RFID tags is large enough, a more detailed text-based action script scheme can be realized. However, the degree of code granularity used in these language constructs should be selected carefully based on the actions to be taken. If the tag size is small, the code granularity should be simplified, as indicated on the left side of Fig. 3. As a result, an efficient 2G-RFID-Sys design should realize a suitable compromise between the degree of functionality incorporated into the code interpreter, and the complexity incorporated in the language constructs employed in programs stored in a tag's memory.

Middleware design: In 2G-RFID-Sys, a corresponding middleware layer is needed to integrate the RFID system with other system(s) seamlessly, and to interface different RFID devices with targeted applications. Also, the RFID middleware layer incorporates the aforementioned high-level text-based language system

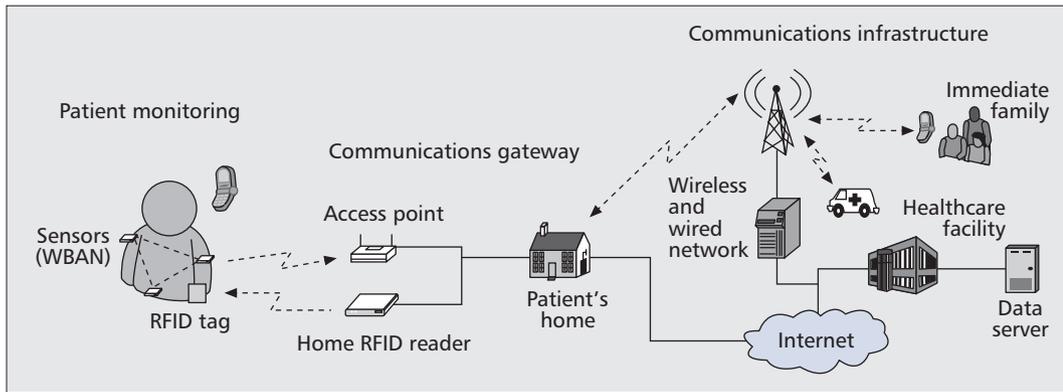


Figure 4. 2G-RFID-based e-healthcare system.

that acts as a compact action script. In [8] we outlined the most important characteristics for middleware design in wireless sensor networks, which are formed by devices with severe memory and data processing limitations. It is straightforward to see that these same limitations exist in the proposed 2G-RFID-Sys, where an event-driven scheme prompts the deployment and execution of compact mobile codes with a sufficient degree of flexibility to support a variety of applications.

A 2G-RFID-SYS-BASED E-HEALTHCARE SYSTEM

We propose a 2G-RFID-Sys-based e-healthcare system. In this system the medical conditions of a patient can be monitored as determined by the corresponding healthcare system, and subsequently updated in the database by means of a cell phone, a Wi-Fi connection, or something similar, depending on the patient's location. Any abnormalities that do not require immediate treatment may be logged into the database and registered by the patient's RFID tag for future reference. If necessary, doctors or other caregivers can communicate with patients directly by videoconference via the Internet. In fact, it might be possible for the doctor to remotely diagnose a problem by relying on both video communications with the patient and the patient's physiological data information retrieved by a wireless body area network (WBAN) hosted by the patient. If needed, the patient can then be asked to visit the healthcare facility. When the doctor arrives, the doctor uses his/her RFID reader to read the information from the patient's RFID tag, such as recent medical history and pharmaceutical history. Then the doctor writes diagnosis information, medical methods, and prescription information into the mobile code in the patient's RFID tag after the current operation for the patient, which will improve patient care quality by eliminating human errors and ambiguity presented in patient-physician and physician-physician interactions.

2G-RFID-Sys finds its unique effectiveness in information collection and transformation for handling medical emergencies. For example, an ambulatory patient traveling to a loca-

tion outside his/her hometown might experience a critical situation due to a medical condition that requires immediate attention. Using a 1G-RFID-Sys here would imply that emergency medics could read the patient's ID embedded in the tag, and attempt to remotely retrieve the patient's medical history from his/her home hospital. This approach has the shortcoming that if the corresponding database is unavailable or the necessary security clearances and/or data access protocols have not been pre-established, the patient might not be aptly treated according to his/her existing medical conditions (of which other doctors might be unaware), especially for a patient who is unable to verbally communicate with healthcare providers.

ARCHITECTURE

Figure 4 shows the architecture of the proposed 2G-RFID-based e-healthcare system. This architecture makes use of existing telecommunications infrastructure to improve its effectiveness, and relies on the following key components: RFID tag, WBAN, cell phone, and healthcare database, as explained next.

RFID Tag — The tag grants users access to the corresponding medical facilities as needed. Different tags can be associated with different categories of services and different action priorities. After being admitted to a healthcare facility, the user's profile information is sent to the database, and the user is assigned a tag. The information embedded in the tag will vary depending on the patient's health conditions. However, under 2G-RFID-Sys it is reasonable to designate the respective mobile codes for the doctor and the users. For instance, the doctor's mobile codes would encompass the required directives related to up-to-date diagnosis and necessary medical treatment. Similarly, the patient's mobile codes can specify the level of service expected (e.g., low, medium, or high priority), access permissions, and so on. This makes it easier for the local RFID readers to determine whether a patient is receiving the service he/she needs, whether the patient is in the correct location within the medical facility, and so on, without having to rely on the central database (i.e., decisions are made locally).

WBAN — In the particular case of e-healthcare systems, physiological signals (e.g., body temper-

If necessary, doctors or other care-givers can communicate with patients directly by video conference via the Internet. In fact, it might be possible for the doctor to remotely diagnose a problem.

2G-RFID-Sys can enable a number of automated processes to be supported in order to improve the effectiveness of E-healthcare. One example is given by the possibility of a new healthcare facility being deployed in an area closer to the patient's residence.

ature, blood pressure, heart rate) conveys useful health condition information on a person who needs to be remotely monitored on a constant basis by a qualified healthcare practitioner. These signals are obtained by means of tiny sensors attached to his/her body (arms, legs, etc.) to form a WBAN. In addition, ultra-low-power Zigbee [9] technology (also known as IEEE 802.15.4) is a perfect candidate for linking sensors and other types of devices with a WBAN to realize external communications, explained below. Ultimately, the data collected by a WBAN can readily be examined at a healthcare facility to ensure that the patient receives the appropriate treatment as needed.

Cell Phone and Communications Gateway — The effectiveness of future e-healthcare systems can be greatly leveraged by means of commercially available personal communications devices, which can be particularly helpful as the means to link the user's monitoring subsystem, realized by a WBAN, with different components of the e-healthcare system through one or more communication interfaces. For example, a Zigbee-enabled WBAN can readily send the patient's physiological signals to a cell phone, which can in turn forward this along with GPS information to locate the patient in an emergency situation as needed.

Healthcare Database — As explained before, the database maintains the user's profile and medical history. According to a user's service priority and/or doctor's availability, the doctor may access the user's information as needed. At the same time, automated notifications can be issued to his/her relatives based on this data via various means of telecommunications.

PILOT SERVICES

Based on the proposed 2G-RFID-based e-healthcare system, the following pilot services can conceivably be realized.

Automated Services — 2G-RFID-Sys can enable a number of automated processes to be supported in order to improve the effectiveness of e-healthcare. One example is given by the possibility of a new healthcare facility being deployed in an area closer to the patient's residence. In this case the new facility can negotiate with the original one to transfer the service provision in order to reduce their current patient load. This process can be highly convenient for patients, as it automates the handover of their hospital paperwork without their interaction with medical/administrative personnel. For the service providers, this approach reduces their deployment cost and provides improved convenience for future extension. A second example is portrayed by a new pharmacy opening in a patient's residential neighborhood. In this case key information regarding a drug prescription issued by a doctor, previous purchases, and so on can be attached to the RFID tag as well, thus providing a way for medical personnel to interact with the pharmacy. In addition, pharmacy personnel may match the medical data encoded into the patient's RFID tag to ensure that no abuse is being attempted.

Medical Emergency Response Service — During an unforeseen circumstance, a savvy patient may determine that she is experiencing a serious medical condition. The detected information is sent to notify/alarm medical personnel, and an ambulance may be dispatched. If an ambulance comes, the patient is loaded onto the ambulance and transported to a hospital. From the location where the patient is put into the ambulance to the hospital, the paramedic in the ambulance can put some diagnostic information and other strategic medical methods into the patient's RFID tag.

2G-RFID-Sys enables RFID tags to be written by mobile code information while the ambulance is approaching the hospital. When the ambulance arrives at the hospital, the patient's ID along with mobile code information is transferred to the emergency room personnel without further registration. Based on the mobile code information, preparation can immediately begin in the operating room, as well as related medical personnel notified to go to the operating room. Thus, the chance of the patient staying alive is increased because the amount of time used to access a rule database and/or process a document in 1G-RFID-Sys is eliminated, along with possible errors caused by human input. Such precious time saving improves the quality of medical service.

CONCLUSIONS

We have presented a novel concept for the second-generation RFID system and qualitatively demonstrated the value of its application in future e-healthcare systems. We have discussed the many benefits that our proposed 2G-RFID-Sys can provide, including improvements in system scalability, information availability, automated monitoring and processing of sensitive information, and access control. We claim that these benefits can be achieved by employing RFID tags with more memory to encode information-rich data along with action scripts that can be interpreted by the corresponding subsystems to automate a number of processes. While such RFID tags are available, their high costs mainly confine their applications to high-valued objects, such as human beings. We believe that our proposed solution can be a key element of intrinsically complicated e-healthcare systems that are being planned and developed, whose deployments are already being considered in order to cope with the aging population and increasingly stressed healthcare infrastructure. A number of issues remain to be examined, especially those that deal with security and internet-working between varied technologies.

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BIOGRAPHIES

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We believe that our proposed solution can be a key element of intrinsically complicated E-healthcare systems that are being planned and developed, whose deployments are already being considered.