Design and implementation of a children safety system based on IoT technologies

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***Abstract*—In this paper a system for increasing children's safety is proposed. The focus is on the daily route from home to school and vice versa, assuming the use of school buses. IoT paradigm is exploited together with different localization techniques i.e. RFID and GPS, in order to design a solution for parents willing to make certain of their child's following the main steps to school or home, i.e. taking the school bus and entering school or leaving school and entering the school bus. In this paper the applicability of RFID technology efficient tracking capabilities is tested in children's tracking and monitoring during their trip to and from school by school buses. The proposed solution is discussed in terms of technologies and architecture and the first prototype is presented. Finally a test phase is planned to verify the correct operation of the system.**

***Index Terms*—IoT, RFID, GPS, security, mobile, children, school**

I. Introduction

Children's security has always been a priority problem whose solution must constantly be improved, [1] [2]. The Smart Cities paradigm clearly takes into account the need of providing a more favourable environment for children's living and learning, but focusing on this aspect it has also to deal with challenges due to cities complex environments, e.g. many construction sites, a large number of running vehicles, crowded meeting places and complex personnel structures. Such an environment indeed is generally lacking of safety conditions for children, which are inherently curious, active, and unaware (or incautious) of surrounding dangers.

According to the incomplete statistics of news reports, [3], the school-age children security accidents in recent years can be classified into four types: 34.7% of accidents happening outside the schools, 11.7% of children's misconnections, 29.8% of school bus drivers carelessness and 23.8% of children's losses. Safety oriented projects are addressed to use ICT services to build secure ways of reducing accidents probability.

For parents the safety of their children is vital and a low cost technology may give a big contribution to improve it.

L'Aquila municipality is moving in that direction, exploiting University innovative researches, trying to offer a more efficient service aimed to solve children's security issues. One line of experimentation is related to the monitoring of child's movements through a system involving both GPS (Global Positioning System) and RFID (Radio Frequency IDentification) technologies. The first solution is exploited for school buses localization, while the second to gather informations about children's entering and exiting the school bus. This paper is especially focused on children's movements from home to school entrance, trying to solve a little part of the school-age children's security problem.

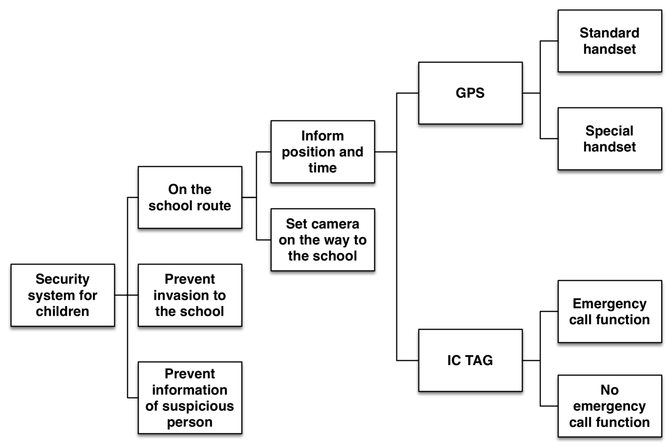

Figure 1. Categories of security system for children

A possible categorisation of security system for children is displayed in Figure 1, [4].

During the past few years, in the area of wireless communications and networking, a novel paradigm named the Internet of Things (IoT) which was first introduced by Kevin Ashton in the year 1998, has gained increasing attention both in the academia and industry, [7]. In recent times, researchers have used the term "Internet of Things" to refer to the general idea of things, especially everyday objects that are readable, recognizable, addressable, and/or controllable via the Internet, whether via RFID, wireless LAN (Local Area Network), WAN (Wide Area Network), or other means.

Combining different developments will build an "Internet of Things" that enables interaction of intelligent systems with the real world. Based on IoT, RFID, and cloud computing technologies, our project is designed to guarantee the children security protection, focusing on the *security on the school route* category in figure 1.

We built a system that uses such types of information to alert parents when their child is moving by school bus. The system generates alert, managed by a backend system, when the child enters and exits the school bus. The same mechanism is followed when the child leaves the school, taking the school bus and approaching home. With this information the system can inform parents about their child's movements and definitely his security. In this paper we only present the children tracking process while they are in the school bus, indeed the children's movements prior to entering and after exiting the school bus is not covered. Nevertheless, the same monitoring solution can be exploited for children's entering and exiting the school, allowing for a better safety check. It is worth noting that the chosen technology is also dependent on the idea of maintaining as low as possible the overall costs in order to make the solution affordable for municipalities and parents.

The paper is organized as follows: in section II related works are reviewed, section III presents the overall system architecture by detailing each subsystem, advances of the prototype are discussed in section IV, while in section V we offer concluding remarks.

II. Related works

The combination of GPS and RFID technologies is widely used in goodies monitoring, [8] [9] [10].

Many positioning technologies should be used to get context-aware information, such as 802.11, [11], RFID, [12], and GPS.

A possible exploitation of these monitoring technologies is clearly given by children's monitoring for safety purposes, [1], [2]. With respect to the architectures already presented in literature, we want to reduce the costs as much as possible in order to allow the spread of our solution. For this reason the project implementation is achieved through the exploitation of a smartphone and a mobile reader which make the solution not only cheaper but also more versatile and scalable. Particularly referrig to paper [2], it is worth noting that our solution also allows to switch on the reader only when doors are opened, thus reducing the duration children are exposed to an electromagnetic field. Moreover we plan to extend the architecture to other aspects such as the school lunch service (e.g. it may allow to precisely evaluate how many meals to be prepared) or the electronic school register (e.g. integration of children movements in the existings school registers).

With this paper we want to move over the results of another project, called KHESTO, [14], where University of L'Aquila and L'Aquila Municipality worked together in a conceptual similar environment.

The specific objectives of KHESTO were:

- to increase the use of public transportation
- to decrease the burden on the environment
- to reduce the isolation and the feeling of abandon in people living in marginal areas
- to reduce the depopulation of areas where isolation prevents the full exploitation of their potentialities
- to enhance the social cohesion
- to carry out pilot actions showing different possibilities of application in the transport systems of the tools developed as examples for policy makers.

These topics are clearly strongly related to the children's transport safety issue tackled in this paper.

III. Technolgies

GPS is a navigation system used to provide time and location information by the use of GPS satellites in all weather conditions. Each GPS satellite continually sends a signal (carrier frequency with modulation) which includes a pseudo random code (sequence of zeros and ones) that is generally known at the receiver side. By aligning with time a receiver generated version of the code and receiver measured version of the code, the time of arrival of a defined point called an epoch, is found in the receiver clock time scale. Time of transmission of the code epoch is included in the message (in GPS time scale) and satellite position at that time.

RFID technology is an advancement of the barcode, [16]. The main difference between RFID and barcode is that RFID can scan a large number of items at the same time whereas the barcode can scan only one item at a time. RFID is an automatic identification system consisting of two types of elements: readers and tags. A tag has an identification number (ID) and a reader recognizes an object through consecutive communications with the tag attached to it, [12]. RFID has the potential to enable machines to identify objects, understand their status, and communicate and take action if necessary, to create "real time awareness".

In comparison with low frequency (LF) and high frequency (HF) bands, ultra high frequency (UHF) RFID systems provide fast reading, enhanced information storage ability, superior read range, and especially low cost, [12]. For these reasons, and especially giving the fact that a long range reading is required in our application (indeed no actions are required to children or drivers), the Ultra High Frequency (UHF) RFID readers (868-870 MHz) have been selected.

In Europe, the allowed UHF frequency range is between 865.5 and 867.6 MHz. Due to the limited operating range, RFID systems are mainly used indoors. The main problem of such communication is multi-path propagation, which results in dead zones within the range of the system incurred by destructive interference, [6].

IV. System architecture

Based on modular ideology [17], with the application of RFID and GPS, the system designed in this paper can be divided into two subsystems. This top-down design reduces the complexity of the system and improves the possibility to expand and upgrade it.

Figure 2 shows the system architecture. It involves two parts: the *bus-subsystem* and the *server-subsystem*. Globally, the entire system should be considered as a classical three-tier architecture where the client tier is given by the *school bus*

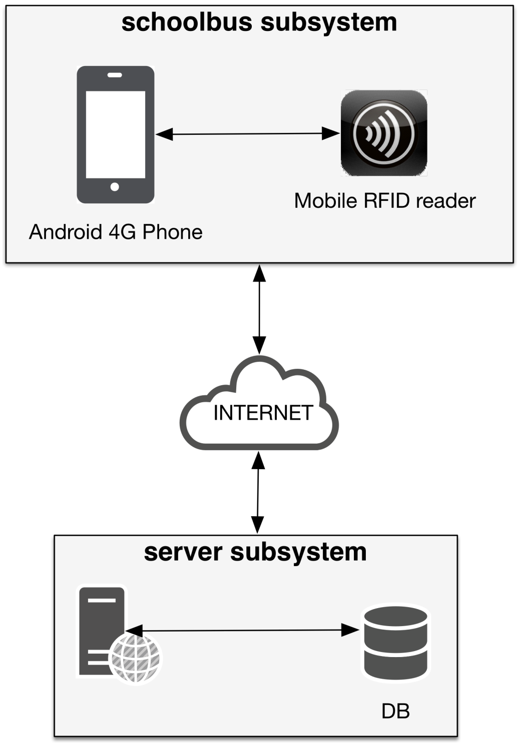

Figure 2. System architecture

subsystem while the application and data tiers belong to the *server subsystem*.

The proposed flexible architecture is based on the use of a mobile device equipped with GPS and radio interface (4G), joined to a mobile RFID reader, that provides the connectivity to a server application.

The *school bus subsystem* is responsible for child's identification on the bus through RFID and GPS localization. It communicates with the RFID reader to acquire the children tags when they enter and exit the school bus and it uses the smartphone connectivity to send these data to the *server subsystem*. In particular, as the tag is detected by the reader installed in the school bus upon entering or leaving the bus, the time, date and location is logged and transmitted to a secure database. The system also uses the smartphone GPS to localise the school bus and continuously sends the acquired coordinates to the *server subsystem*.

The *server subsystem* manages the data sent by the *school bus subsystem* and is responsible of parents alerting when a monitored event happens. It stores all the data received from the *school bus subsystem* (events and coordinates) and also communicates with mobile notification services.

The children's monitoring process is completely automatic and it does not require any action on the part of drivers or students, other than to carry the card. Indeed the system satisfies the required performance without impeding the normal loading and unloading process: this ensures that the

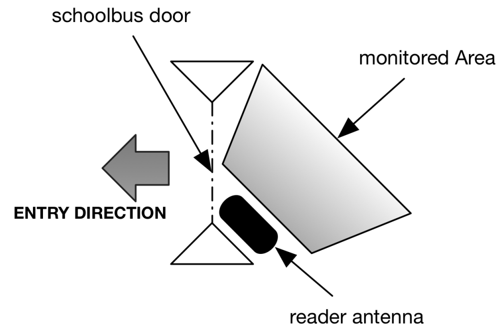

Figure 3. The school bus access control system

system has great usability. As mentioned before, the proposed system is an extension of the system developed for the KHESTO project, this proves the high scalability of the proposed solution and that the change of operating conditions do not affect it. Moreover the planned phase of the extension of the system ensures a great interoperability of the system: the generated data of child's movements can be easily used in other systems like the proposed meal planning or digital school register. Data security will be ensured by encrypted communications with the server subsystem.

A. The school bus subsystem

To be certain that the school bus localisation is representative of the children's movements it must be ensured that a single child is on the school bus. To do this and to ensure the privacy of the child, the RFID technology has been chosen. Comparing with the traditional bar code technology, RFID is a non-contacted automatic identification technology, which can recognize multi-targets movement and obtain related data through radio frequency signals. It can work in severe environments without manual operation. It has outstanding advantages of high-speed identification, long service life, high data security, huge storage and rewritable. For children's monitoring, tags are packaged in keychains that are tied to each child's bag. The tags store representative information for each child. RFID reader can read and identify the digital data in tags when they are in proximity of the school bus door and, when the door is open, the RFID reader sends wireless signals through the radio frequency antenna at a certain frequency, and tags within the magnetic field of antenna will produce internal inductive current. With this energy, tags could return the data information to the reader.

GPS technology is used here for the exact localization of the school bus that is equipped with a smartphone supplied with GPS connectivity.

At the entrance door the *school bus subsystem* fires the RFID reader to identify the child. Every tag detected entrance (for morning travel from home to school) or exit (for afternoon travel from school to home) to the bus is sent to the *server subsystem*. Figure 3 shows that the RFID should be oriented toward the door area because, when a child enters

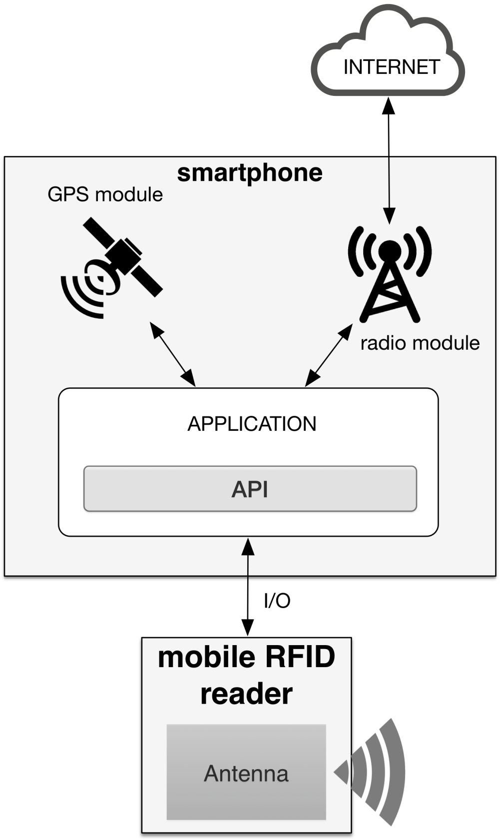

Figure 4. *school bus subsystem* architecture

the monitored area, the RFID reader can check his tag and RFID tags can be automatically matched to the identity of the child. Definitely every kind of event generated by the *school bus subsystem* is sent to the *server subsystem*. Figure 4 shows the *school bus subsystem* architecture.

To avoid high Electromagnetic (EM) Radiation on the school bus and therefore to reduce children's exposure to it, our prototype use a system, based on a magnetic switch installed on the door of the school bus, that notifies the smartphone when the door is opening or when it is closing in order to activate or deactivate the RFID respectively. In this way we can be sure that the RFID antenna is active only when necessary.

B. The server subsystem

Subsequently, the *server subsystem* has been designed and implemented to handle the data received by the *school bus subsystem*. Depending on the type of the data received, it executes the specific function. Furthermore all the data received by the *server subsystem* are stored into a database in order to be analysed if necessary. In more detail the *server subsystem* operates as shown by the chart in Figure 5, i.e. when the received data is an event, this is notified to interested persons and stored in the DB, while when it is about the bus coordinated it is just stored.

Finally Figure 6 shows the *server subsystem* architecture.

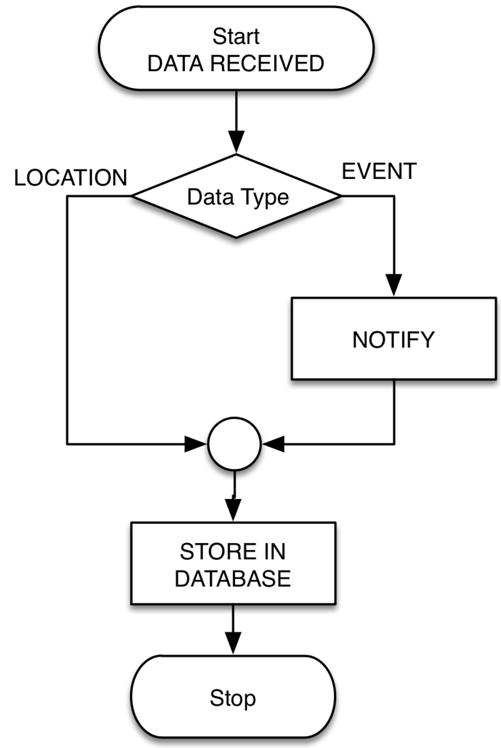

Figure 5. *server subsystem* flowchart

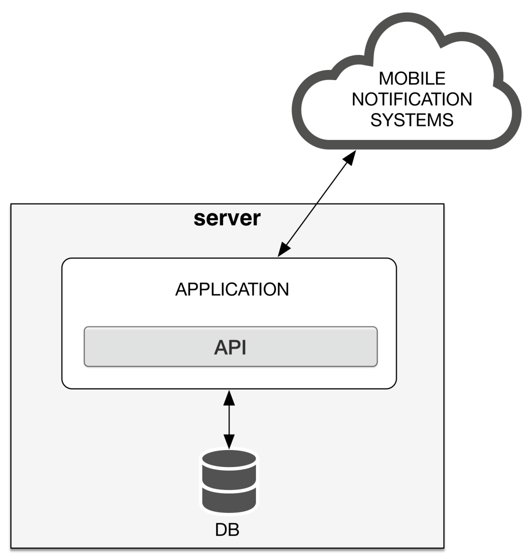

Figure 6. *server subsystem* architecture

Table I
U Grok it SPECIFICATIONS

Air Interface Protocol	UHF Class 1 Gen2 (ISO 18000-6C)
Operating Frequency	865-928MHz, customizable by region
Output Power	5-30 dBm (programmable)
Antenna Type	Proprietary
Read Range	2-3m general use, 7m optimal
Power	Rechargeable Li-Ion 1800mAh
Drop Spec	1.5m to concrete
Operating Temperature	-10¡C to 55¡C
Size	153mm x 95mm x 38mm
Weight	170g
Host Interface	Proprietary, via audio port
Host Compatibility	iOS and Android phones & tablets
Software Development	iOS, Android and other SDKs

Figure 7. School bus hardware

V. Prototype

This section describes the infrastructure prototype detailing methodologies and technologies. It is organized as a typical distributed multi-tier system where it is possible to recognize the network communication tier, a client application tier, represented by a mobile app running on Android, and the services tier.

A. School bus

The *school bus subsystem* is implemented by an Android device that also provides the GPS and communication technologies, on which a native mobile application implementing the system is developed. The school bus is also equipped with a mobile RFID reader manufactured by *U Grok it* (i.e. Grokker), [18]. *U Grok it* is cheap, moreover battery-less tags works with it. During the experience of KHE-STO Project, a project by the Cross-border Cooperation Programme Adriatic IPA, [15], we have noticed that equipping vehicles with intrusive technology should be problematic. Indeed, in order to achieve the same goal of reading RFID tags in proximity of a vehicle door, we have used a more complex RFID reader, [19], which has an external antenna and communicate with the host via TCP/IP. The biggest problem in that implementation is the size of the system. So, for this work where users are school-age children, a smaller system is exploited that can be easily hidden on the school bus.

Table I shows the *U Grok it* mobile RFID reader specifications.

While the system that equips the school bus is represented by the hardware in Figure 7.

The smartphone employed to develop and evaluate the system is based on Android 7.0 Nougat, [20]. *U Grok it* provides a native Android SDK to interact with it. The *U Grok it* API enables applications to easily use the Grokker's RFID functionality whose implementation on the existing app is pretty straightforward. The API layer communicates with the Grokker to perform the various operations, and communicates data back to the application. While inventory is being run, the API tracks which tags have been found and when. This functionality is common to almost all RFID applications; having it in the API makes RFID applications quicker and simpler to write. The API layer also manages connection status, and makes it easy for applications to elegantly handle the Grokker being connected and disconnected. In addition, the API layer also provides information about the Grokker and its capabilities. Under the hood, the API layer implements a communications stack to talk with the Grokker (connections, bits, bytes, packets and so on). This stack is highly optimized to provide robust performance over the audio port connection.

The EM exposure reduction is implemented through the exploitation of a magnetic contact sensor, that is installed on the top of the bus door. When the bus door opens, the sensor allows the closing of the connected circuit thus enabling a Bluetooth Low Energy (BLE) module. The BLE module is configured to transmit a beacon with a certain payload. The Android device, installed inside the bus, switches on the RFID reader when it detects the beacon and it maintains it on until no beacon is sensed within its timeout interval.

B. Server

The core of this tier is a NoSQL database, [21], used to store all the information related to this application. At the server side we built a J2EE, [22], application based on Spring Framework, [23]. The NoSQL database chosen to implement the *server subsystem* is MongoDB, [25].

JavaScript Object Notation (JSON) format was selected as the data-interchange format between the client and server, [24].

A REpresen-tational State Transfer (REST) interface, [26], has been designed to communicate with the server. The reason of choosing REST resides on the great advantages that it can provide for mobile applications, indeed many of them use REST integrations to interact with the backend as in this case. REST is based on HTTP, it can be either directly managed or managed by using frameworks in several languages. REST is broadly used to provide services (e.g. Google maps) and simplify their integration in the web. So we have developed a web application to support the *server subsystem*: it provides an endpoint for the mobile app and also communicates with the notification systems provided by Apple and Google to send notifications to parents' mobile devices.

VI. Conclusion & Future Work

In this paper, we propose a solution to the security issue of children on their way to school, with the main objective to improve the municipality service of children transportation.

After the analysis of the problem, considering L'Aquila as the scenario, we developed a technological solution comprising various types of elements. Firstly we equipped the school bus with GPS technology for tracking and RFID technology to ensure children's presence onboard. Using a native Android application that interact with a mobile RFID reader, data are sent to a server that keeps in touch with child parents. We also designed the server application to interact with mobile vendors notifications services.

We did not yet tested the system since the prototype is still on its very first phase and we still have to make agreements with children's parents to start the first tests. Basing on the good results we gathered from the KHE-STO project experience, we are very positive about the possibility of achieving good results also in this case. We think that our target might be satisfied.

Concerning tests operations it is worth noting that special attention will be given to the mobile reader behaviour inside the metallic structure of the bus, with the opportunity of also setting up a multireader/multiantenna system, similar to [2], in case of poor performance results of the basic solution. The behaviour of the low-power tag proposed in the system will be discussed also in comparison to the solution proposed in the KHE-STO project (i.e. Impinj reader).

Future works are also focused toward the development of a web application allowing parents to interact with the system and also toward the integration of the proposed system with other municipality services related to schools, like cafateria or school digital register.

We are also planning to apply the same RFID based access control system for school entrance monitoring.

Acknowledgment

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