Smart Tracking System for School Buses Using Passive RFID Technology to Enhance Child Safety

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***Abstract*—Millions of children need to be moved from home to school and vice versa every day. For parents, obtaining a safe transport for their children is a critical issue. Many children find themselves locked in a school bus in the bus parking lot after falling asleep on their way to school, miss the bus, step into the wrong bus, or leave at the wrong station with no method to track them. This research tested the applicability of radio frequency identification (RFID) technology in tracking and monitoring children during their trip to and from school on school busses. The child safety system developed in this research utilized the passive RFID tracking technology due to its efficient tracking capabilities, low cost, and easy maintenance. To explore the technical feasibility of the proposed system, a set of tests were performed in the lab and with the public. These experiments showed that the RFID tags were effective and stable enough to be used for successfully tracking and monitoring children using the bus. When asked to give their feedback of the solution through a questionnaire, more than 95% of the parents see that such a solution will take their anxiety and worry away and will provide them a tool to track their kids during commuting to and from their schools.**

***Index Terms*—School buses, passive RFID, child safety, tracking system.**

I. Introduction

Millions of children need to be moved from home to school and vice versa every day. For parents, obtaining a safe transport for their children is a crucial issue. The students ride their bicycles, take buses, and arrive in vehicles with one purpose getting to and from school safely. A research undertaken by the Scottish Executive Central Research Unit with the purpose of increasing the proportion of non-car travel to school reveals that travelling by bus or coach appears to be by far the safest mode. Statistics suggest that a child travelling by car is seven times more likely to take part or be involved in a road traffic casualty than a child travelling by bus [1].

Statistics from USA, Canada and Australia also confirm that public transport (and school transport in particular) has a high level of safety, just as in Europe. For instance, the Australian College of Road Safety notes that bus travel is the safest form of road transport, at least 14 times safer than the private car, and that the record for school bus travel in particular is very good [2]. Also, the research undertaken by National Highway Traffic Safety Administration in USA notes that when comparing the number of fatalities of children aged 5 to 18 years during normal school transportation hours, from 1989 to 1999 (school years), school buses are 87 times safer than private cars [3].

However, headlines like "Girl dies in bus tragedy" from the May 18, 2010 issue of the Peninsula newspaper in Qatar seems to be repeated several times every year in different places of the world [4]. Many children find themselves locked in a school bus in the bus parking lot after falling asleep on their way to school. To help avoid frightening and potentially costly mistakes like these, this paper investigates an RFID-enabled solution to help monitor children when they are traveling to and from school on school busses.

II. Literature Review

A. RFID Technology

RFID technology relies on communication between an applied tag and a reader. Two types of RFID tags are in common usage: passive tags, which have no internal power supply and emit a radio frequency signal only in response to a query from a transponder, and active tags which are internally powered and which continuously emit a radio frequency signal. While passive tags are less expensive, active tags have higher reliability and transmission power. Active tags can be read from distances of several tens of meters, while passive tags have a range between tens of centimeters and a few meters. Furthermore, active tags contain more memory and can be integrated with additional sensors, for

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example, for checking temperature or humidity, and are able to store the history of sensor data. Passive tags, on the other hand, have longer life time, and its cost is significantly lower. The information contained in the signal of either type of tag can be a unique identifier that is then linked to a database (similar to barcode technology), or can include sample data that is programmed into the tag and then broadcast in the signal [5]-[6]-[7]. The technology consists of two basic elements: RFID tags (or transponder) and RFID readers (or interrogator). The tag exchanges data with the reader using radio waves that are tuned to the same frequency as the reader and within the reading range of the reader. Figure 1 shows a typical passive RFID system configuration and examples of the RFID tags.

The RFID reader consists of an antenna, transceiver, processor, power supply, and an interface for connecting it to a host computer (i.e. via serial port, or Ethernet). The RFID tag has an antenna, a transceiver, and an Integrated Circuit (IC) with memory. The performance of the RFID tag is determined by factors such as IC technology used, the read/write capability, the radio frequency, the read range, and external factors such as the environment and packaging.

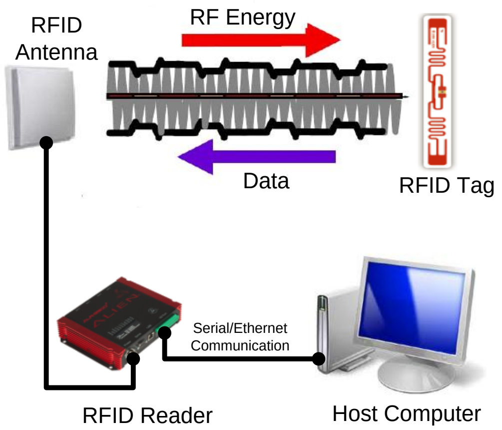

Figure 1. Typical Passive RFID System

Based on the functionality provided by each technology, active and passive RFID address different, but often complementary, aspects of asset/people visibility. Until now, the attention was focused on people tracking based on active devices transmitting beacon-like signals. In the proposed child safety system, passive RFID tags will be used for the children to carry. Since passive RFID tags are inactive unless powered by the energy radiated by the reader when they are close, the tags pose no harm to the children. Although the operating distance is limited to the reader's range, this will be an advantage for the proposed system to know who are onboard the school bus, and thus filters the detected outlier tags easily. Moreover, passive tags are low cost and do not need battery replacement. The Ultra High Frequency (UHF) RFID readers (868-870 MHz) were mainly selected due to having a longer read range (>3 meter). Moreover, UHF RFID readers have a faster reading speed and a larger memory size.

B. *RFID Application in the Transportation Field*

RFID tags have also been used in the transportation field for different reasons. Rajbhandari and Villa designed and deployed an RFID technology based system to measure wait times, and crossing times of U.S. bound commercial vehicles at the Pharr-Reynosa International Bridge in Pharr, Texas [8]. Araujo and Araujo designed a self-positioning system using RFID tags, smart phones and smartcards, as well as real time image and ID recognition. Trucks, drivers and even cargo content are managed by a control center which provides scheduling commands, visual and ID monitoring, and real time incident avoidance [9]. Ergen and Akinci provided a vision of tracking intelligent transportation infrastructure components and materials through knowing their identities and locations. The authors proposed streamlining information flow through a supply chain by utilizing RFID tags [10]. Rajbhandari and Villa used an RFID system at one of the major land border-crossings, in El Paso, Texas to automatically and accurately collect, archive and disseminate crossing times for commercial vehicles [11]. Schwartz. C. and J. Khan used the RFID technology to implement a practical way to record truckload of hot-mix asphalt leaving the production plant and eventually deposited along the roadway [12]. Ross et al. tested the applicability RFID technology to track the progress of construction materials being tested within the Georgia Department of Transportation's Office of Materials and Research (OMR) to track thousands of construction samples each year that used to be tracked with a paper-based system [13]. The main objective of this research is to investigate the applicability of the RFID technology in a new area of the transportation field, which is the tracking and monitoring of school children during their trip to and from school on school busses.

III. System Capabilities

The system will be designed to monitor children ridership in a safe and non-intrusive way. It will use a combination of RFID, GPS (Global Positioning System), and GPRS (General Packet Radio Service) technologies. Each student is issued one or more unique RFID card(s) to carry. The card will be embedded in the school bag for each student. As the student's 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. It will requires no action on the part of drivers or students, other than to carry the card and will deliver the required performance without impeding the normal loading and unloading process.

The system will enable parents to receive instant SMS alerts when bus is within 10 minutes of the designated pick up and drop off points reducing the time the child spends on the street. The system will also notify parents via SMS when the child boards and alights from the bus or enters/leaves the school. Parents will take the appropriate action because they have precise answers to boarding status and times. If a child is still inside the bus for a predefined time after the vehicle's engine is turned off, and doors are closed, an SMS message will be sent to the school authorities. This is critical especially in a country like Qatar where temperatures can reach 50 º degrees Celsius (122 ºFahrenheit) during summer time. In addition, the system will display the real-time location of the bus and the student inside the bus at any point in time.

In addition, the system will include a Web-Based Reporting that makes it fast and easy to access accurate information, a student report, which provides time and date for all loading and unloading activities by student and bus report that provides all students ridership data by bus. In summary, the system will enable school authorities, fleet owners and parents to keep track of the bus online, help transporters and authorities to plan and manage the bus routes better, saving money and ensuring smooth and quick rides to the destinations.

IV. System Architecture

The full system architecture includes four main components: 1) the on-board/in-school RFID Tracking System; 2) the on-board/in-school Smart Gateway (RFID system, GPS, and GPRS); 3) the Backend Server; and finally 4) the end-users applications, as shown in Figure 2.

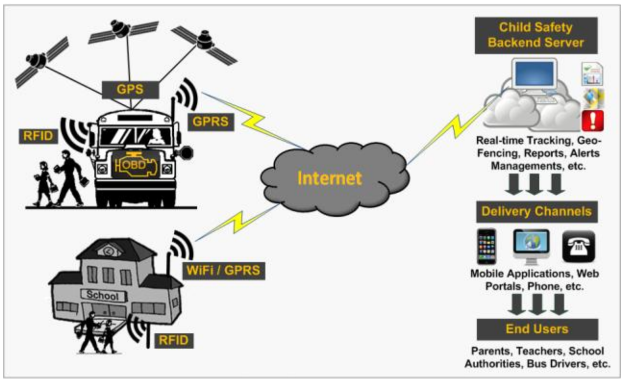

Figure 2. Overall System Architecture

A. Overview of the on-board / in-school RFID Tracking System

The main task of this module is to identify the children tags that are onboard the bus and retrieve the data stored using two RFID antennas. Each school bus will be equipped by an RFID reader. The details of the RFID detection algorithms and design considerations are listed in details in the paper. This module is one of the two modules completed so far as part of this project.

B. Overview of the on-board / in-school Smart Gateway

The Smart Gateways module is in charge of managing the different SBC hardware components and aim at: 1) providing local intelligence for the RFID Tracking system (i.e. implementation of the RFID tracking algorithms); 2) tracking the school buses and driving behaviors; and 3) providing network connectivity through GPRS or WiFi to Internet. This smart gateway is able to collect various and useful information, such as to the current bus location, the vehicle health information, the bus driving behaviors and the list of children who left or stepped into the bus. All this information are then processed and filtered by the local smart gateway and are transmitted wirelessly to the remote Child Safety Back-end servers for post-data analysis and decision making. The details of this module are listed in details in the paper. This module is one of the two modules completed so far as part of this project.

C. Overview of the Backend Server Design

The Backend Server represents the core of the Child Safety solution and is responsible for translating the received data from the Smart Gateways into useful and comprehensive high level services. More specifically, the Backend Server will filter and analyze the received data, track in real-time the current locations of children and school buses, check these locations against defined geo-fences areas, generate comprehensive alerts, notifications and reports, and so on. It will mainly help the operator (e.g. school authorities) to make decisions, and optimize crisis and emergency management.

D. Overview of the End-Users Applications Design

Depending on the considered end users, i.e. school authorities, teachers, and/or parents, the Child Safety Backend System will deliver high level applications through three main delivery channels: web portals, mobile applications, and phone calls/SMS.

V. On-board/In-School RFID Tracking System

As mentioned before, this module is the only module completed so far as part of this project. The system testing included only the RFID detection and tracking with a gateway. The evaluation of the end-to-end child safety solution, including the backend server and the end user applications is work underway and beyond the scope of this paper. The main task of this module is to identify the children tags that are onboard the bus and retrieve the data stored using two RFID antennas. The system capabilities are shown in Figure 3. Each school bus will be equipped by an RFID reader, and two RFID antennas mounted on the bus door. A passive RFID card will be issued to each child, which contains his personal information. Thus, whenever a child that has a tag is within an RFID reader's read range, the reader can detect the child instantly and retrieve the ID from the tag.

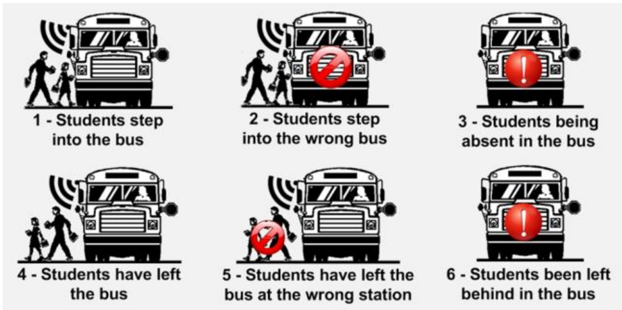

Figure 3. System Capabilities

In many ways, the received signal strength indication (RSSI) is considered as an appealing modality for RFID tags tracking, mostly because RSSI information can be obtained at almost no additional cost with each radio message sent or received [14]-[15]. However, the greatest challenge is that the RSSI is so unpredictable, making the location estimation (i.e. in-bus/school, outside bus/school) of the tag a challenging task. Usually, in the indoor environment the RSSI suffers from a random fluctuation and null spots (i.e. tag data cannot be read within the reader interrogation zone), due to the tag's antenna orientation and polarization, radio wave absorption and reflection, and human shadowing. In the proposed scenario, the random fluctuation of the RSSI and the null spots cause sometimes wrong detection of the children whether they are inside or outside the bus.

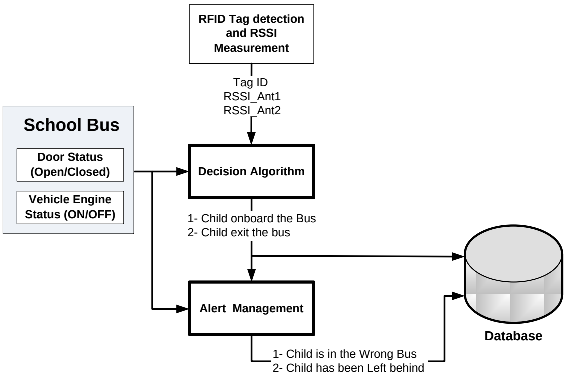

Figure 4. Children Tracking Module Block Diagram

The Children Tracking module consists of three main algorithms as shown in Figure 4:

1. RFID tags detection and RSSI measurement algorithm: This algorithm detects the students (RFID tags ID) who are preparing to get on/get off the bus, and measures the tags RSSI received by both antennas. This data will be used later to identify students who are onboard/left the bus. The main challenge of the passive system is the random behavior of the tags RSSI in indoor harsh environment like a school bus. For better performance, an adjustment of the radiation pattern and reading range of both RFID Antennas is needed. This process can be done only the first time with some regular check.

2. Decision algorithm: The main purpose of this system is to enable tracking and locating children, and to know whether they are inside or outside the bus. Let's assume at position **x**, the measured received RSSI at each RFID antenna are *RSSI_Ant1(**x**)* and *RSSI_Ant2(**x**)*. As illustrated in Figure 5, the proposed decision algorithm is based on the comparison between the two processed and filtered RSSI values where their difference has to be higher or lower to a pre-defined Threshold value *DTh*. Therefore, we can define two separate zones as follows:

Zone-1= {x, where (RSSI_Ant1(x)- RSSI_Ant2(x))> DTh}
Zone-2= {x, where (RSSI_Ant1(x)- RSSI_Ant2(x))< DTh}

Assuming that the school bus has only one boarding and exiting door, the Zone-1 and Zone-2 can be considered as inside and outside the bus, respectively. The merit of this method is that the boarding and exiting directions of each tag can be estimated independently. Using the sensors data about the bus engine status (i.e. ON or OFF) and the bus door status (i.e. open or closed), the system will be able define the final list of the children who are onboard the bus.

3. Alert Management Algorithm: This algorithm is responsible for generating different alert cases, such as the kid get on the wrong bus, get off the wrong place or left behind in the bus.

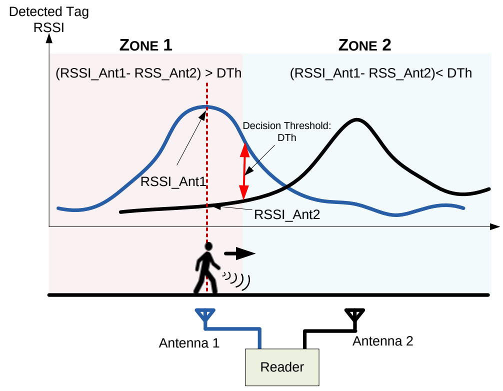

Figure 5. Decision Algorithm Scheme

VI. On-Board / In-School Smart Gateway

The Smart Gateway consists of a single board computer (SBC) running the Linux operating system (OS) as well as the related Child Safety software modules as shown in Figure 6. The smart gateway is in charge of managing the different SBC hardware components, and providing common services and standardized interfaces for the high level software programs. The smart gateway comprises five main software programs to operate the Child Safety System:

A. RFID Tracking Module

This module is responsible for reading raw RFID measurements from the RFID reader and antennas and to detect in real-time the RFID tags, and thus the children, that have left or step into the bus or the school.

B. Bus Monitoring Module

This module is responsible for tracking in real-time the current bus location as well as the bus driving behaviors. In particular, the following driving events are continuously monitored, and the related alerts are automatically sent to the Child Safety Backend Server: bus over-speeding, hard acceleration, and hard braking.

C. Over-The-Air (OTA) Gateway Protocol

This module is mainly responsible for the configuration and management of the Smart Gateways. In particular, this OTA protocol will enable the Bus Operator to remotely manage the deployed in-bus and/or in-school smart gateways by sending new configuration parameters, firmware versions and commands through SMS messages. Moreover, this module will allow the smart gateways to send urgent alerts and notifications to the Child Safety Backend Server, in particular in case of unavailable or stable Internet connectivity.

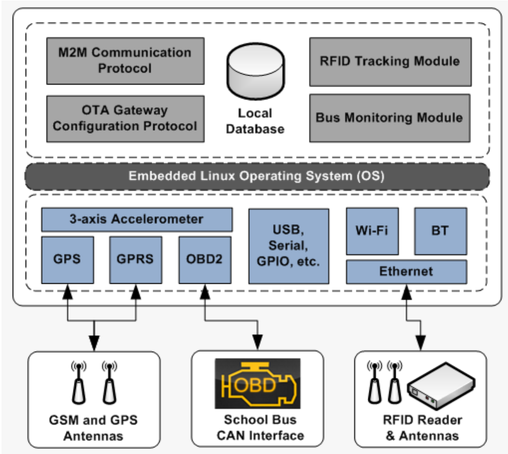

Figure 6. Smart Gateway Hardware and Software Components

D. Machine-to-Machine (M2M) Communication Protocol

This module is responsible for connecting wirelessly the smart gateways to the Internet and thus to the remote Child Safety Backend Servers. This module implements a two-way M2M communication protocol which will be in charge of 1) sending all tracking and sensors information, notifications and alerts to the remote Servers; and 2) receiving all the gateway parameters (e.g. firmware, software modules configuration parameters, etc.) and assigned tasks (e.g. list of assigned children, list of RFID tag IDs to detect, etc.) from the same servers.

E. Local Database

This module is responsible for buffering all the related smart gateway configuration parameters, software modules inputs and outputs and tracking information.

VII. System Testing

A demo of the proposed system has been deployed and tested in a lab environment. The demo consisted of one RFID reader, two UHF antennas, a Gateway running the Linus operating system, and few RFID tags. The antennas were installed at the main entrance of the lab and the RFID reader was connected to the laptop through Ethernet cable. A program was developed to apply the reading algorithm and show the results to the user. The lab testing started with adjusting the two antennas based on their polarization in such a way to maximize the reading probability of the tags inside and outside the lab, which mimics detecting the tags inside and outside the school bus. Many tag reading trails have been carried out under controlled tag orientation and elevation from the ground. This was essential in order to understand the detection behavior of the RFID reader.

The next step was to test the detection algorithm shown in Figure 5 when the RFID tags are installed in various locations (i.e. on the body, inside the pocket, or hanged on the bag. Testing results showed that successful tag detection depends on the location of the RFID tag. In general, there are two main issues that limit the successful detection of the RFID tag: 1) the nature of Omni-directional antenna of the tags, and 2) the human body shadowing. The RFID reader fails to detect the RFID tag when the direction of the tag is exactly perpendicular on the reader antenna. This causes null areas in which the reader cannot detect the tag. However, this happens for a short time duration because the student moves towards or far away from the antenna. The second issue is the body shadowing that affects the detection rate of tag.

Many trials have been carried out to study the percentage of successful detection of the tags in different installations: inside the pocket, hanged on the nick, hanged on the bag’s handle, and inside the bag. The detection rate when the tag was placed in the pocket was between 70% - 75%. The detection rate was improved when the tag was hanged on the nick, between 75% and 80%. However, this detection accuracy is not acceptable in such application. The third testing scenario was when the tag is placed inside the bag. The detection rate was improved to the range of 85% to 90%. The last scenario was to test the detection algorithm when the tag is hanged to the bag’s handle. This scenario gave high success rate in the range of 98% to 100%. Therefore, the conclusion was to place the RFID tag to the bag’s handle. To increase the probability of tag detection and due to the low price of each tag (about five cents), it is possible to issue two RFID tags for each student. This step has led to accurate detection of all people who participated in these trails.

The next step was to show the results of the detection algorithm on a graphical user interface (GUI) and send SMS to a certain phone number based on the current status of a specific tag that was assigned to this phone number. The GUI was developed to show the map of the bus route and a list of students’ names. The scenarios to be tested included detecting a student when he/she enters or leaves the bus, detecting when a student leaves the bus at the wrong address, detecting a student when he/she is left behind, and the engine is off and the door is closed, and detecting when a student enters a wrong bus. The system was tested, and all scenarios were fulfilled.

VIII. Conclusions and Future Research

This research showed that RFID tracking technology is a practical option for monitoring and tracking the children during their trip to and from school on school busses.. Lab and field trials confirmed that the RFID tags functioned well under different conditions. The readings were consistent and resulted read ranges that were acceptable within the constraints of locating children stepped into the bus, stepped into the wrong bus, left the bus, and left behind in the bus. In addition, the cost associated with tagging of materials is relatively low. It should be noted that the work completed in this research is the first phase of the project. Future work including combining RFID tracking with an information management system will result in detailed children tracking that will provide different application to the users. Once the next phases are complete, the system will be capable of notifying parents via SMS when the child enters/leaves the school, enabling school authorities, fleet owners and parents to keep track of the bus online, helping transporters and authorities to plan and manage the bus routes better, saving money and ensuring smooth and quick rides to the different destinations.

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