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Review

EPC Class-1 Generation-2 radio frequency Identification (RFID)-based Malaysian University Communities

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Radio frequency identification (RFID) technology has been recently adopted as an automated data management system in many areas, especially in supply chain management systems. However, research and studies on EPC Class-1 Generation-2 (Gen 2) RFID technology-based university communities are relatively few. Ultra high frequency (UHF) RFID technology has outperformed the barcode technology and high frequency (HF) RFID technology in managing heterogeneous and scalable applications. UHF RFID technology is promising a longer detection range, faster detection rate, security and privacy protection, low probability of misread data, and less field distortion and interference problem. Hence, this paper presents the potential of using Gen 2 UHF RFID technology to automate data management system for various applications for Malaysian Universities. A lightweight cryptographic protocol, namely fingerprint-based mutual authentication protocol and a flexible four layer system architecture are used in this paper to increase operational efficiency and create a safe environment in Malaysian university communities.

Key words: Radio frequency identification (RFID), EPC Class1 Generation 2, data management system, multilayer architecture, fingerprint-based mutual authentication protocol, AVISPA.

INTRODUCTION

Radio frequency identification (RFID) has been pervasively adopted in many areas, such as supply chain, library, healthcare management, waste management, etc. An RFID system offers contactless identification, automatic retrieval of data, and wireless data storage. RFID tags do not require line-of-sight communications. Hence, this technology provides a significant improvement in identification, tracking, monitoring, and stocking of objects compared to barcode technology (Ngai et al., 2008). Data reading using RFID also enhances performance and productivity by increasing the accuracy and speed of information communication. A basic RFID system can be operated using three basic components, namely, tag, reader, and backend server. A passive tag stores the object's information in a microchip, and data stored can be read remotely using reader. The reader communicates with the tag in a bidirectional way through the antenna. The tag and reader must work at the same specified frequency and comply with same regulations and protocols to guarantee the compatibility of the communication system (Ngai et al., 2007). The backend server uses middleware to filter and store all the information in the tag. A middleware platform filters input data and emits them to the application.

Based on market lifecycle analysis of 2009, Asia Pacific has the potential to overtake Europe by year 2020 in level of activeness of national RFID programs implemented. Malaysia has a mature RFID market compared to other Asia Pacific countries. Based on market observation, the Malaysian RFID market in 2009 reached approximately $9.5 million. The RFID market is anticipated to further grow to roughly $33.8 million by the end of 2016 with a

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compound annual growth rate (CAGR) of 19.8% (Sebastian, 2010). During the period of 2011 to 2015, several core sectors in Malaysia including government service sector, manufacturing sector, agriculture sector, transport and communication sector and wholesales sector will be granted with a total amount of $1,105 million to develop with RFID technology. Return of investment (ROI) analysis for the five sectors are expected to obtain $5,525.6 million (MCMC, 2010). In addition, with the usage of RFID technology, total factor productivity (TFP) contribution is expected to have an increase of 0.55% and for labor productivity rate is an increase of $0.247 per nominal gross domestic product (GDP) hour in 5 years duration (Sullivan, 2009).

Malaysian Communications and Multimedia Commission (MCMC) govern Malaysia's RFID frequency allocation. The frequency band for RFID in Malaysia is from 919 to 923 MHz, with a total bandwidth of 4 MHz. RFID equipments manufactured in Malaysia shall be certified under the Communications and Multimedia (Technical Standards) regulations (Minan, 2007). In 1997, the first RFID technology was introduced in Malaysia which is Malaysian electronic toll payment system, also known as Touch' n Go system. The first RFID passport (E-passport) in the world was issued by Malaysia in 1998 (Juels et al., 2005).The E-passport contains the information of the holder's travel history including time, date and place of entries and exits from the country. In 2006, the Malaysian Road Transport Department had implemented RFID license plates (Mah, 2008) that contain car owner and vehicle information to enable police officer to detect the location of stolen car. In addition, the world's smallest RFID microchip (MM chip) with the size of 0.4 × 0.4mm is released under the Malaysia Microchip Project in 2007(MIGHT, 2007). Hence, Malaysia is in a leading position in Asia in terms of the growth of implementing RFID technology due to several leading edge applications have been implemented and new RFID microchip is delivered.

The high performance of RFID is a key contributor to the deployment of RFID technology in Malaysian universities. This paper presents a novel concept to improve university management in four areas, namely, car park entrance system, attendance system, library management, and healthcare management. The implementation of UHF RFID technology is needed to improve data management in a faster mode, to have a real time tracking and trace, and to have complete and real-time data accuracy. EPC Class-1 Generation-2 (Gen 2) standards are deployed to develop smart university communities due to the higher reliability, greater read range, and enhanced security and privacy protection offered by the scheme. The Gen 2 protocol operates in the range of 860-960 MHz (UHF band), and data read range can be up to 10 m. The privacy protection of the EPC tag is improved because the EPC tag becomes permanently deactivated once it receives the kill command and a valid 32-bit kill pin. Security of the EPC tag can be guaranteed because reading or writing in the tag's memory is allowed only after receiving the access command with a valid 32-bit access pin (Peris-Lopez et al., 2009).

RELATED WORKS

RFID technology has evolved to transform data management system into more efficient and reliable system. Many studies are conducted to implement RFID system in data managing system. Some of the applications are discussed below.

People management is one of the famous applications of RFID technology. In 2009, a RFID based attendance recording system is applied in C-DAC, Noida (Behera and Kushwaha 2009). The system applies the concept of detecting user id cards, validate and granting access. In terms of hardwares, it uses UHF tags that complies with EPC Class-1 Generation-2 (Gen 2) standards with the frequncy range of 865-867 MHz. The frequency chosen is suitable with Indian regulation and with the reading distance of 3-5 m. UHF antenna was utilized to make people management system completely ubiquitous. On the software side, the application programming interface (API) was designed to become the same core that could be used as a common interface in any middleware application. However, it has limited capability as no database is used. Database system was replaced with creations of text files up to 3 MB only.

Healthcare is another branch of where RFID is widely applied. A research on a couple of study cases had been done in (Najera et al., 2011). A lab testing is performed based on the reliability of passive UHF with tests for medical equipment tracking system in terms of real-time and theft prevention. From the reseach, a few flaws are found and with that, a solution using passive HF RFID is proposed. The proposed solution has two main key. First, it provides a backup data source from patients wristband. Secondly, it allows offline working mode in any case of failure in wireless network. Hence, the proposed system will still be working using local mode to increase application reliability in case of network failure. It uses personal data assistance (PDA) for storing data generated during local mode thus increasing the cost.

Quality management system is a platform for gathering, filtering, monitoring and sharing quality data. A study on an application called the RFID-based Quality, Inspection and Management (RFID-QIM) was done in (Wang, 2008). Basically, the proposed system utilizes RFID to accumulate, manage, monitor and distribute data related to quality. The system has been tested with the information management from concrete specimen quality testing in Taiwan. The concept of this system is it integrated QIM with the web and with RFID technlogy. It has special designated portals that acts on real-time with

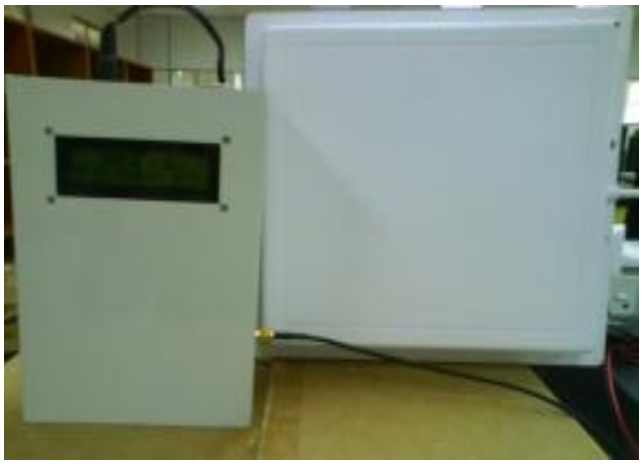

Figure 1. In house built in EPC Class 1 Gen 2 Passive RFID reader and antenna.

mail communicatin channels for participants. Other than that, it could also perform and make quality controls, schedule controls and inventory management based on shared data with suitable emails automatically sent on each update. PDAs are used as the main communicator between participants. For the system to be fully functional, internet access is required and thus if the internet access fails, so will the system.

In RFID based hospitals, complex event processing (CEP) framework is important to ensure efficiency as it extracts meaningful events for context aware applications (Yao et al., 2011). CEP framework maps the objects and behaviours in the physical world into their counterpart by semantically interpreting and transforming data from RFID system and sensors. With the combination of the CEP framework and RFID technology, it is capable to collect events from heterogenus sources and correlate them for situation detection. This proposed system offers sense-and-response capability to a RFID-based hospital, thus resulting a faster reaction. The system is capable to filter basic events and extract meaningful information in order to identify medically significant events. Basically, this system is an add-on to the existing RFID technology and it focuses mainly on the software side only.

The fresh product supply chain has been implementing RFID widely and it increases efficiency mainly in inventory. A research in Spain proves that by adding RFID to a supply chain to provide better value-added service for customers (Martínez-Sala et al., 2009). In this study, active RFID system was added to enhance a system called MT. MT is an innovative and ecological, packaging and transport unit and it is used for the grocery supply chain. Created by a Spanish company, ECOMOVISTAND, the MT unit serves as a packaging to the producer, as a transport unit, as storage to warehouse and as a display at the supermarket stand. By adding active RFID, MT system will add services such as tracking, tracing and cold chain control. The system uses a stateless design where the middleware interfaces as web service. The drawback of the system is high implementation cost due to active RFID is used.

PROPOSED SYSTEM CAPABILITY

The first RFID product of Auto-ID Laboratory, Universiti Sains Malaysia (USM) is a passive RFID reader. The reader, as shown in Figure 1, is designed to support Gen 2 protocol. The reader operating frequency is at UHF 919-923 MHz, offering a 2-3 m reading range. A liquid crystal display (LCD) of 16 x 2 characters is utilized in this product to show the operation message. The reader interfaces with personal computers through RS-232 serial communication link. Transmission Control Protocol/Internet Protocol (TCP/IP) network is integrated with the reader to enable the downloading of data from computer servers through the local area network (LAN). Power consumption of the product can be considered low because only 9-12 V DC and 500 mA is required. The architecture specifications used for the system are 8051 core processor, 32 Kbyte RAM, and 32 Kbyte Flash.

Data management is the main concern of the proposed system. To maintain data security and privacy, all user data are stored in the backend system. Keeping data at the backend system offers more flexibility because data can be changed without the presence of tag. Each tag will only store its unique electronic product code and session key needed for cryptographic algorithm. A lightweight protocol, namely fingerprint-based mutual authentication protocol as shown in Figure 2 is used to secure communication between reader and tag. Simple bitwise Exclusive-OR, cyclic redundancy check, and pseudorandom number generator function are used in the protocol to encrypt the data.

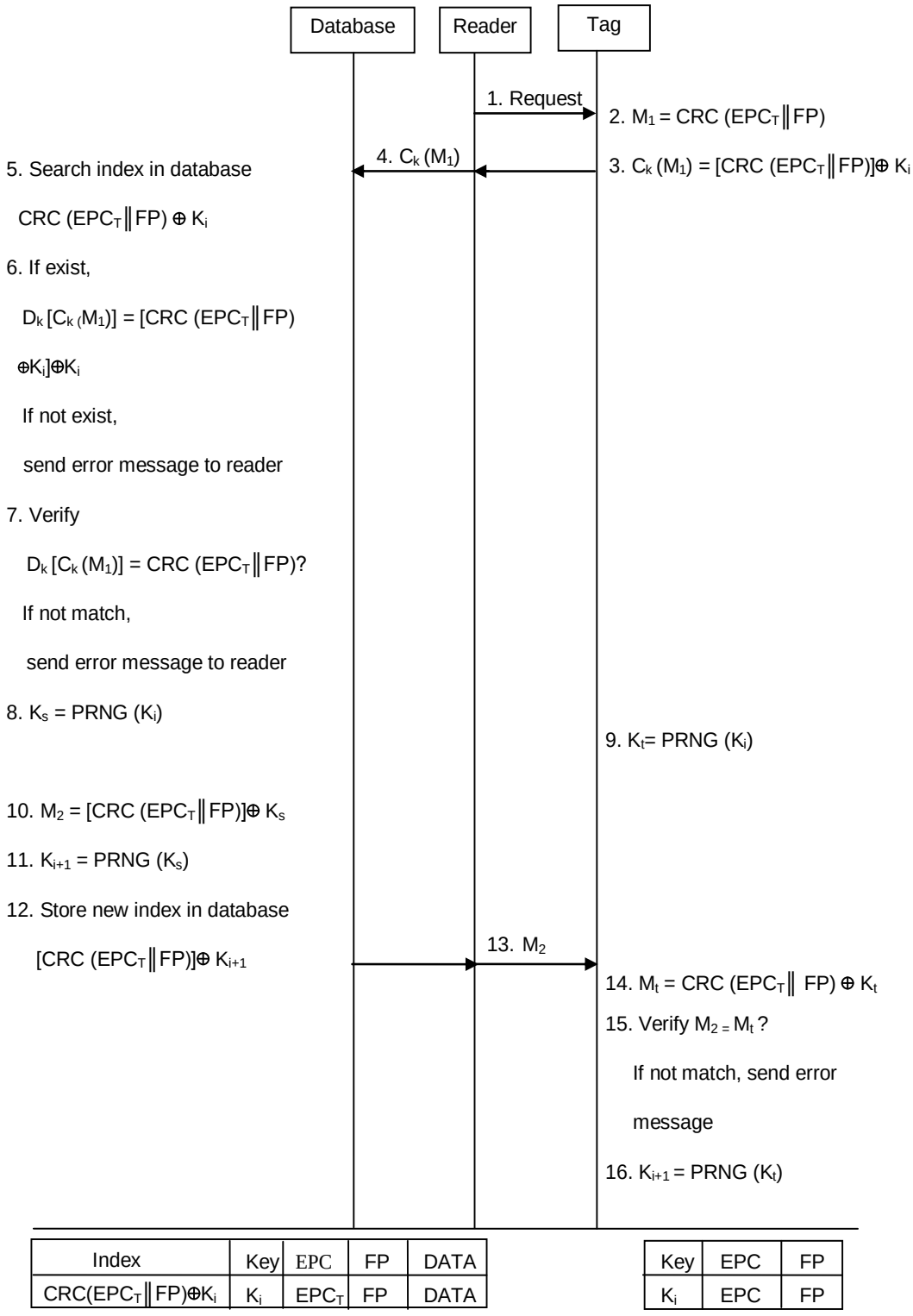

Figure 2. Fingerprint-based mutual authentication protocol.

The protocol is capable to prevent replay attack, denial of service and data leakage issues. In addition, tag's unique electronic fingerprint could be used as a detection method to distinguish counterfeit and legitimate tag (Khor et al., 2010).

The proposed system that is shown in Figure 3 is

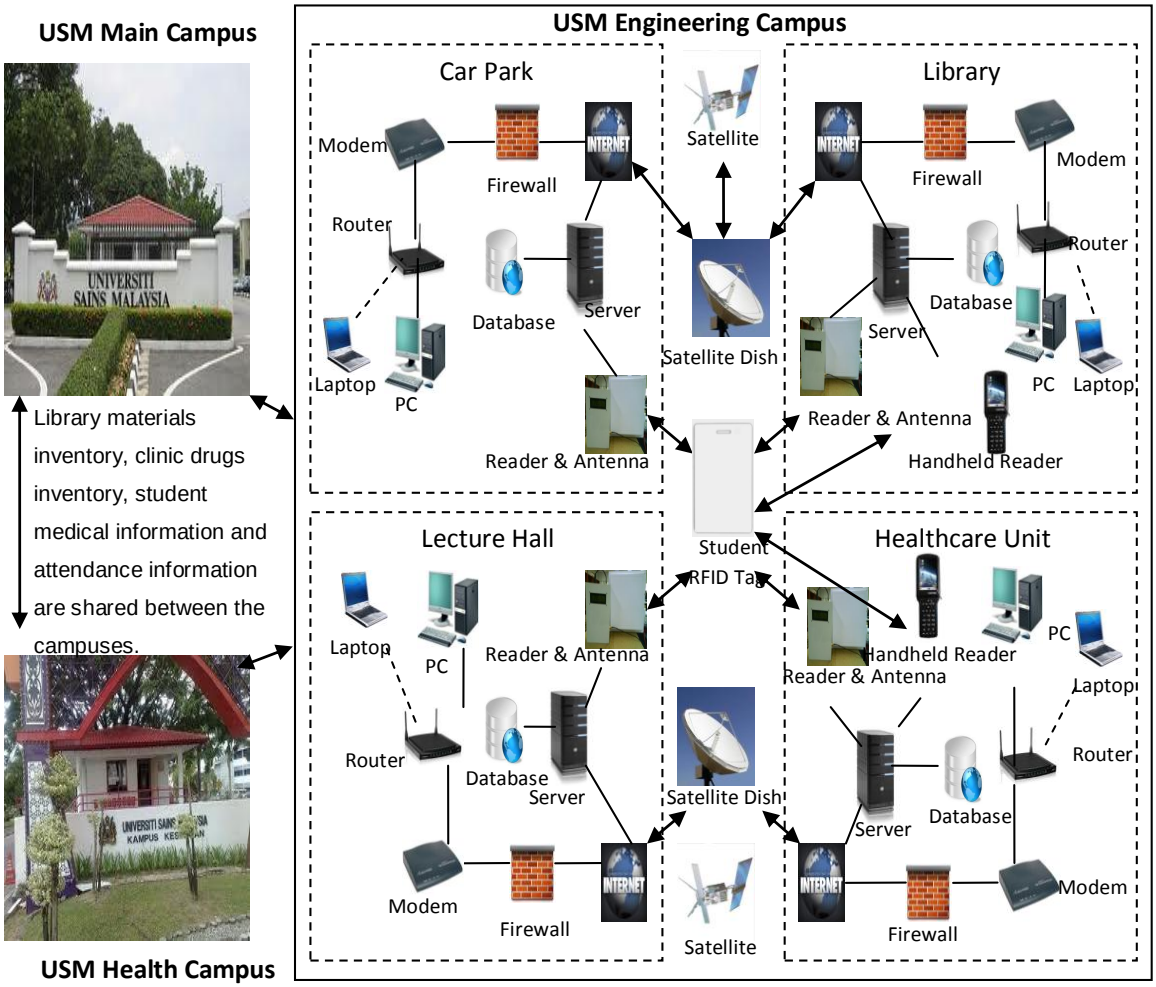

Figure 3. EPC Class-1 Generation-2 RFID-based USM communities.

designed to foster collaboration between USM main campus, engineering campus and health campus that are located at different states. In addition, library materials inventory, clinic drugs inventory, student information including medical treatment and attendance record can be real time updated, tracked and shared to keep the university communities connected.

PROPOSED SYSTEM ARCHITECTURE

The RFID-based university community system architecture as shown in Figure 4 is designed with four layers, namely, physical layer, data capturing layer, process layer, and application layer. The functionality of each layer will be discussed in detail for four different applications namely, car park entrance system, attendance system, library management system, and healthcare management system.

The physical layer outlines the hardware components utilized in the proposed system. The hardware used includes Gen 2 EPC tag, passive RFID reader, and antenna. This layer provides the front-end data-capturing system. Each student RFID tag only stores unique electronic product code. The unique electronic product code is an index that facilitates searching student information in database. The student information that can be obtained in database includes all his academic related data namely, student name, ID, age, faculty, course, grades of attended courses, attendance record, library book transaction record and medical record. The passive RFID reader is capable to detect tags within 2 to s3 m range and operates at 919-923 MHz.

The data capturing layer deals with the communication between tag and reader. This layer makes sure that RFID tags are able to interface with the RFID system that uses different data format and standards. The captured data is converted into system readable data in this layer.
Unwanted and duplicate information is filtered out without human intervention.

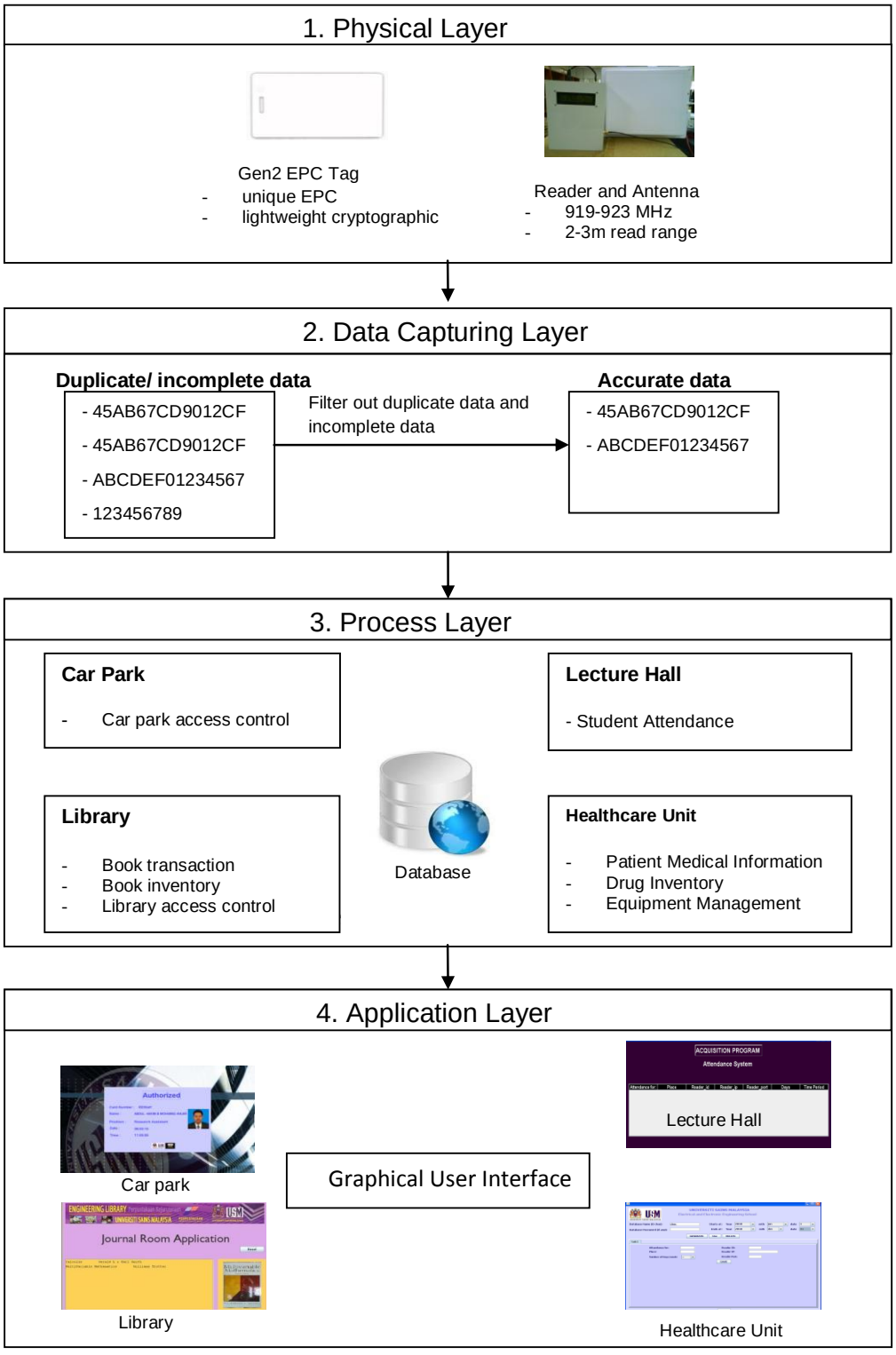

Figure 4. Multi-layer architecture for RFID-based university communities.

The process layer involves manipulating and storing data operation at the backend system. Different databases are used to store and manage the data captured at different areas including car park, lecture hall, library, and healthcare unit. Parking access control database is designed to record the car park entry and exit history.

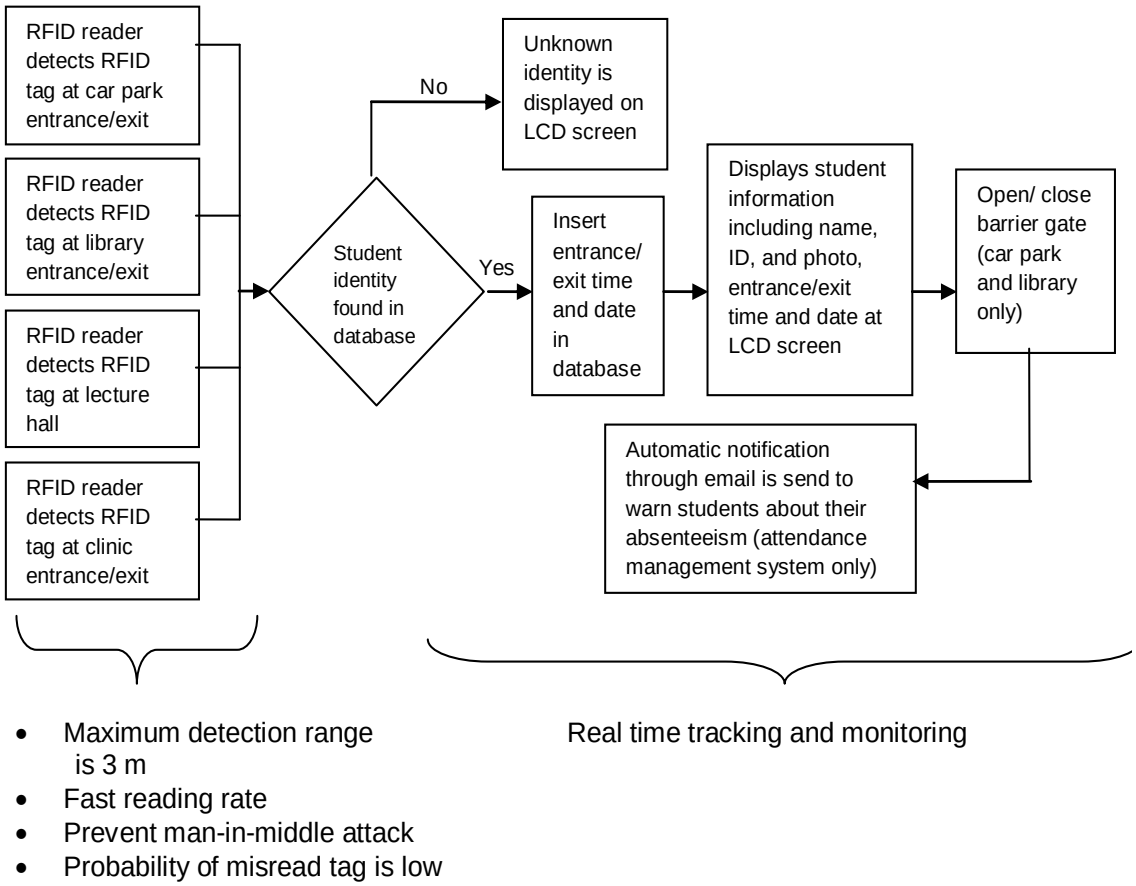

Figure 5. UHF RFID-based access control data management.

Student attendance database that contains student name, ID, lecture class, time, date, venue, and attendance status is used to store the students attendance data history. Three databases are designed for library data management to manage book transaction, book inventory and library access control. In addition, patient medical information, drug inventory and equipment management databases are designed to manage the healthcare unit data management system.

The application layer presents user-friendly graphical user interfaces to allow the students and staffs to use the application seamlessly in a Windows environment. A set of standard application program interface (API) guarantees heterogeneous applications and databases system to interact with each other effectively. A graphical user interface (GUI) program is used to display the specific information on LCD screen to notify the user. The RFID system designed is capable to integrate with the existing barcode and HF software applications.

Figure 5 shows the access control system in car park, lecture hall, library and healthcare unit. The overview of data management in library and healthcare unit using UHF RFID technology is shown in Figures 6 and 7 accordingly.

PROPOSED SYSTEM STRENGTHS

The proposed system outperforms previous works in terms of security protection, cost, variety of applications, multiple architecture layers, and conformation to the Gen 2 standards. The strengths of the system are shown as follows:

Security protection

Previous works did not take consideration on data protection and security issues (Behera and Kushwaha, 2009; Martínez-Sala et al., 2009; Najera et al., 2011; Wang, 2008; Yao et al., 2011). In contrast, a lightweight cryptographic algorithm, namely fingerprint-based mutual authentication protocol which conforms to the Gen 2 standards, is used in our proposed system to raise security level in the RFID communication system. Figure 8 shows that the system's protocol is validated safe from man-in-middle attack (that is, replay attack, denial of service and data leakage problems) in CL-based attack searcher (CLAtSe) back-ends using AVISPA validation tool. Hence, the data secrecy of a tag is protected from eavesdropping and impersonation.

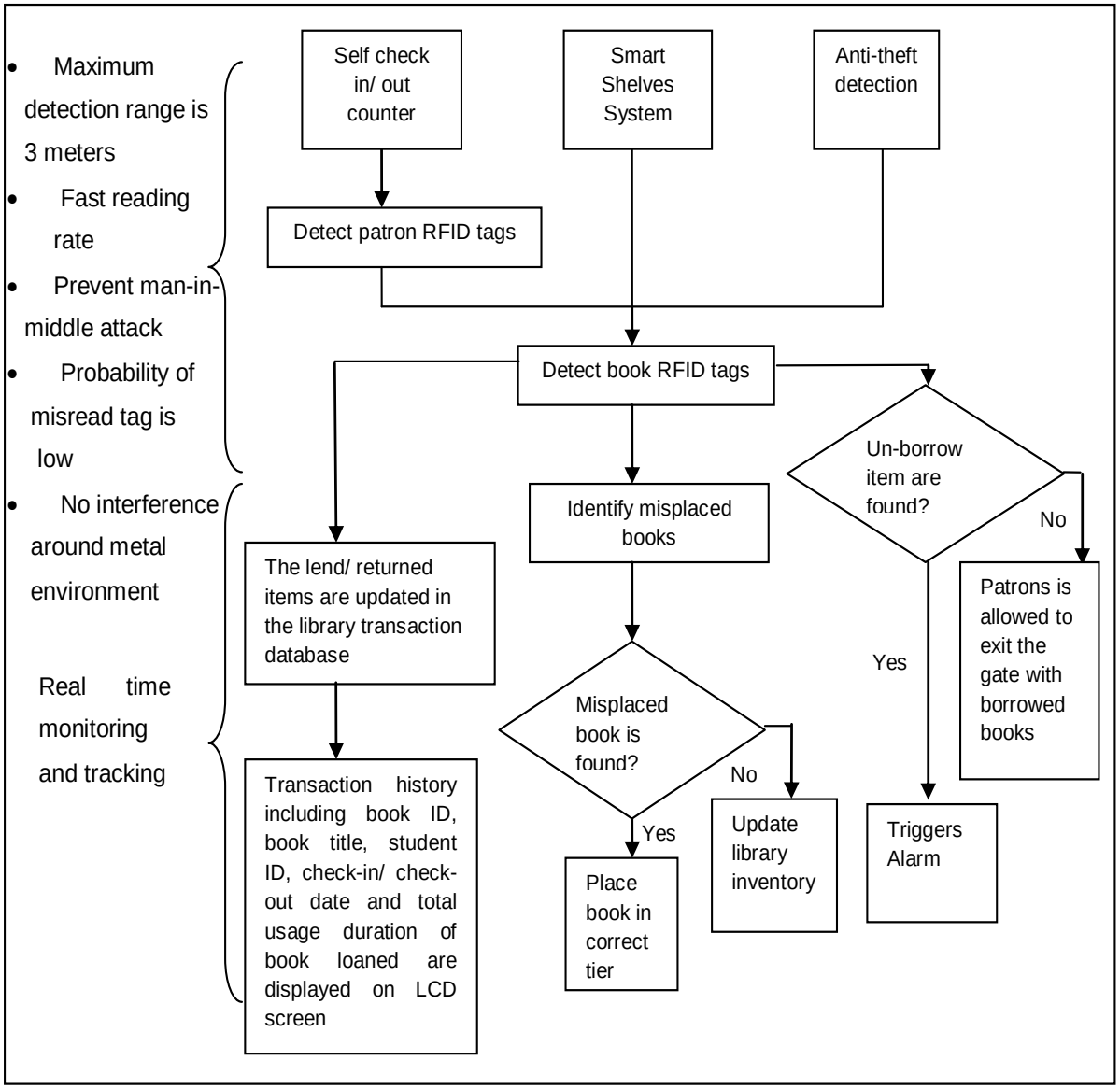

Figure 6. UHF RFID-based library data management system.

Cost

The proposed system is a scalable and custom made system that is able to interface with heterogeneous hardware and software implementation. The UHF RFID system is designed to integrate with existing barcode and high frequency (HF) software applications. Hence, software modification costing can be saved.

Variety of applications

Previous works focused on implementation of RFID technology in certain specific application (that is, healthcare, library, attendance, supply chain, transportation) (Behera and Kushwaha, 2009; Martínez-Sala et al., 2009; Najera et al., 2011; Wang, 2008; Yao et al., 2011). However, the proposed system presented a ubiquitous RFID data management system that consists of a combination of variety applications in order to create smart digital communities in university.

Architecture layer

The proposed system comprises of four architecture layers, including physical layer, data capture layer, process layer and application layer. The four architecture layers are capable to offer a flexible and systematic operation in automated data management system.

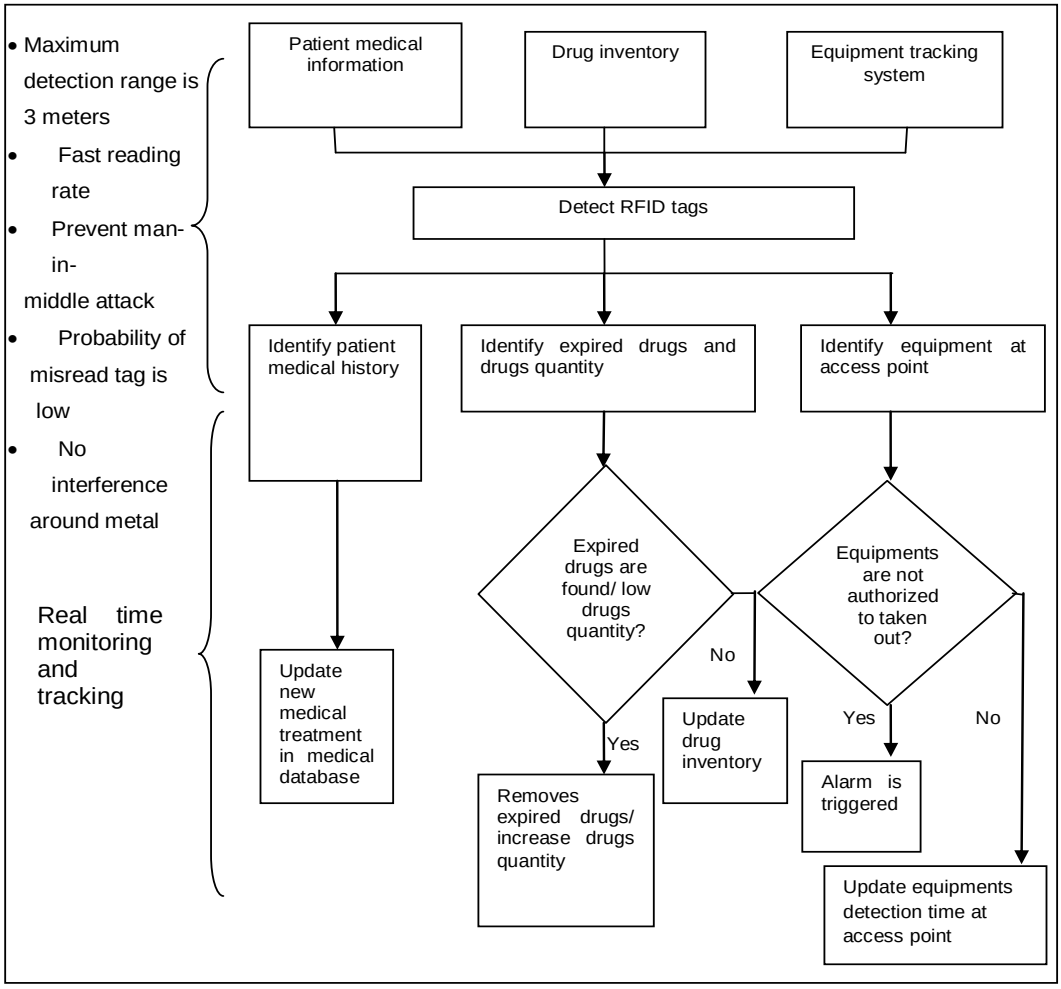

Figure 7. UHF RFID-based healthcare unit data management system.

Conformation of EPC Class-1 Generation-2 standards

Gen 2 standards provide higher reliability and greater read range. Hence, the proposed UHF RFID based system that conforms to Gen 2 standards outperforms previous related works in terms of data collection and data protection. The percentage of misread tags for UHF RFID system is low as shown in Figure 9. In addition, UHF RFID has faster data transfer rate and longer read range as shown in Figure 10. The overall comparison between proposed UHF RFID system with HF and active RFID systems are shown in Table 1.

BENEFITS OF ADOPTING UHF RFID-BASED UNIVERSITY COMMUNITIES

Migration from barcode system and HF RFID system to UHF RFID system promises a more reliable, effective, real time and scalable data management system. UHF RFID system has outperformed barcode system since line of sight requirement is not a need in UHF system. UHF RFID readers are able to detect multiple tags simultaneously. In addition, UHF RFID system offers longer read range and faster read rate than barcode system and HF RFID system. Ubiquitous UHF RFID data management system enables real-time data sharing and tracking for heterogeneous applications between the campuses. RFID application in university communities provides benefits to all people involved in managing and using the facilities. The technology offers a comprehensive route to improve all services and operations.

UHF RFID system has out-performed the closed-circuit television (CCTV) surveillance system to monitor the access control and maintain safety at car park area. UHF RFID system offers real-time access control at car park system without human intervention. However, CCTV surveillance system is dependable on human to observe and monitor the car park area. Hence, security issues can be improved as any unauthorized vehicle breaking in the university premises is easily monitored. Thus, this

Figure 8. Protocol's security validation result.

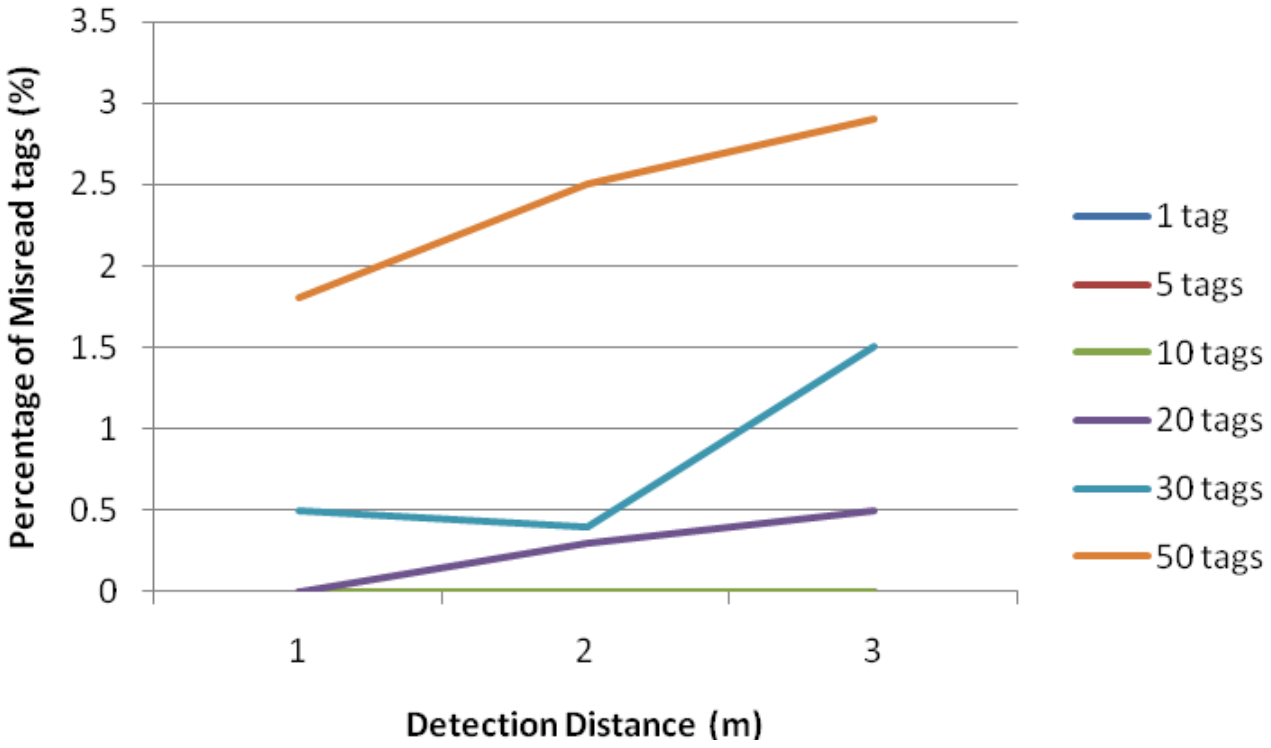

Figure 9. Percentage of misread tags versus distance.

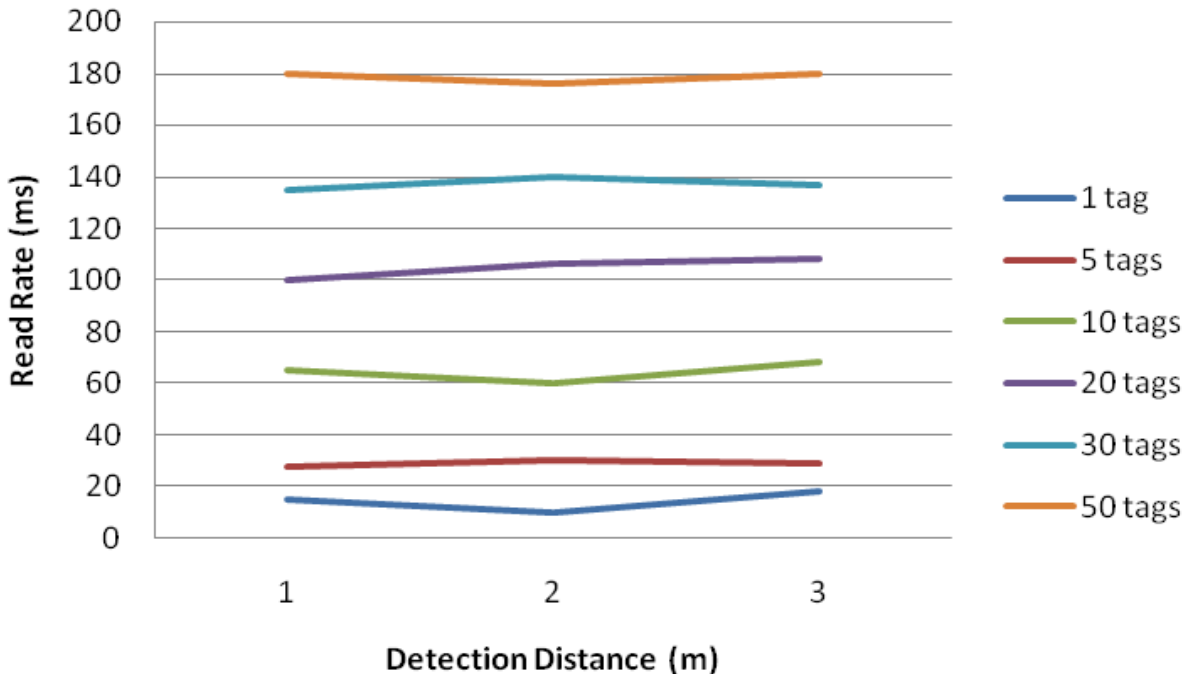

Figure 10. Reader read rate versus distance.

Table 1. RFID systems performance analysis.

Criteria	HF RFID system	Active RFID system	Proposed UHF RFID system
Reader Reading Rate	Less than 100 ms / 64 bits	Less than 1 ms /128 bits	Less than 10 ms / 64 bits
Reader Reading Range	Less than 1 m	Up to 2 km	Within 3 m
Multiple tags Read	Maximum 50 tags/ sec	Maximum 100 tags/sec	Maximum 100 tags /sec
Cost per tag	≈$ 0.20	≈$20	≈$0.15

system guarantees fast and secure vehicle access control and monitoring.

By implementing UHF RFID technology in the attendance system, the attendance registration of students can be automatically updated in the database. The system offers a reliable real time tracking of students' absenteeism. Hence, time for manually checking of attendance during class can be saved. In addition, the paper based attendance system that contributes to global warming can be eliminated.

The implementation of UHF RFID in library enables multiple tags to be read simultaneously. UHF technology is less prone to distortion error caused by tags overlay each other in a stack of books if compared to HF technology. The fast reading speed enables the reader to retry read a misread tag numerous times. Hence, library management system could practice the quick shelving of books to facilitate the books inventory. This allows misplaced books to be detected easily using portable readers to sweep the shelves. The portable reader can immediately detect all books information within the desired range. Books can be directly checked in and checked out by patrons at the library self-service check-in and check-out counter. The books transaction information is updated at the library inventory system instantly. An alarm system will be activated by system if the book ID detected is not stored in the database system.

UHF RFID-based health care unit offers a faster and more efficient drug inventory system than barcode and HF RFID based drug inventory system. The longer UHF RFID reader detection range characteristic guarantees an easier scanning process for tracking equipments at healthcare entrance/exit areas. Healthcare management system using UHF RFID technology enables physicians and nurses to make faster and more accurate decisions on patients' medications. The waiting time of patients can be reduced significantly as patient information and medical history are identified instantly. This system can prevent medical errors and increase management efficiency.

Table 2 shows the comparison between the proposed systems to other related works. The related works

Table 2. Comparison among proposed system and related work.

	Concept	Frequency band	Tag types	Security protection	System architecture	Cost
Proposed system	Custom UHF RFID system with real time mode characteristic that increase operational efficiency and scalability in heterogeneous applications	UHF	Passive	Lightweight cryptographic	4 layers - physical - data capturing - process - application	Low
RFID Based People Management System Using UHF Tags (Behera and Kushwaha, 2009)	Utilization of UHF antenna which makes the attendance recording system ubiquitous	UHF	Passive	Not Specified	Not Specified	Not Specified
Real-time location and inpatient care systems based on passive RFID (Najera et al., 2010)	Provides backup data source from wristband and offline working mode using HF RFID	HF	Passive	Not Specified	5 layers -application -RFID Java Package -wrapper -Native driver -RFID reader/writer	Low
Enhancing Construction Quality Inspection and Management Using RFID Technology (Wang, 2008)	Information sharing platform that integrates QIM (quality inspection and management) with PDAs, web and RFID	Not Specified	Passive	Not Specified	3 layers - presentation - application - database	Low
Leveraging Complex Event Processing for Smart Hospitals Using RFID (Yao et al., 2010)	Utilization of CEP(Complex Event Processing) framework to model surgical events and critical situation	Not Specified	Passive	Not Specified	2 layers -physical -semantic	Not Specified
Tracking of Returnable Packaging and Transport Units with active RFID in the grocery supply chain (Martnez-Sala et al., 2009)	Turns packaging and transport unit into an intelligent product platform by embedding active RFID tags	UHF (2.4 GHz)	Active	Not Specified	3 frameworks - RFID - middleware - customer and control	High

discussed in this section are chosen based on the similarities of the research with the proposed system. The proposed system is superior to the others in terms of data secrecy protection, lower implementation cost, flexible architecture layers, conforming to Gen 2 standards and applicability in wider areas.

CONCLUSION

This paper presents a new concept and system specifications of creating an EPC Class-1 Generation-2 RFID based automated data management system in Malaysian university communities, including car park, lecture hall, library, and healthcare management. UHF reader and tag conforming to EPCglobal Gen 2 standards are utilized to create a reliable automated data management system. Fingerprint-based mutual authentication protocol is applied in UHF tag to protect the data secrecy. Four-layered RFID-based university community architecture is designed to increase efficiency and to enhance the operational system. Ubiquitous UHF RFID data management system for heterogeneous applications is created to foster collaboration between campuses. The implementation of EPC Class-1 Generation-2 RFID based automated data management system in Malaysian university communities is capable to fulfill Malaysian government policies to become a digital smart country.

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