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Radio Frequency Identification Systems: Development and Integration Experiences in Developing Economy

Arulogun, O. T.
Department of Computer Science and Engineering
Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria
otarulogun@lautech.edu.ng;

Olaniyi, O. M.
Computer Engineering Department, Federal University of Technology,
Minna, Niger State, Nigeria
mikail.olaniyi@futminna.edu.ng

Afolabi, O. A.
SanwoTouch2Pay Technology Services Limited, Lagos, Nigeria
oafolabi@sanwo.me

ABSTRACT

Abstract Radio Frequency Identification (RFID) as an inexpensive auto–identification systems have been applied to numerous areas of applications including healthcare, transportation manufacturing and hospitality industry. RFID technology facilitates automatic wireless identification and tracking using passive and active electronic tags with suitable readers. This paper presents an enhancement and expansion to previous student attendance application in [1] to selected industrial applications for successful integration and implementation of RFID auto-identification applications. These industrial applications are Campus and City wide offline RFID based payment, Library book circulation, Cattle tax payment collection Electronic-Thrift collection and Car park control and fee collection. Progresses made so far from these case studies have shown a positive social economic impact in the target communities with formation of a fast-growing startup company named Sanwotouch2Pay limited and direct and indirect value added job creation.; the application records wide acceptance because of its positive user experience.

Keywords: RFID, offline payment, logistics, Passive tag, Reader

1. INTRODUCTION

RFID technology is a ground-breaking technology with many applications in a number of fields that is becoming pervasive and ever-present in our daily activities. Some of the daily activities carried out by humans are typified by production and exchange of goods and services. These activities are usually quantified at some costs or fees. Automation of fees collection in an offline method is a major challenge in most societies especially in locations where there is low telecommunication infrastructure or high digital divides that bring in the high possibilities of low availability rates of online collection service. A technology that can solve this problem and even do more at reduced cost is the Radio Frequency Identification (RFID) Technology. RFID is an automated identification and data collection technology that ensures more accurate and timely data entry. RFID is not actually a new technology; it only quickly gained more attention recently because of its current low cost, miniaturization, tags and readers reusability and advances in other computing fields that open up more application areas [1].

RFID combines radio frequency and microchip technologies to create a smart system that can be used to identify, monitor, and secure object inventory in selected application area. A typical RFID system includes three components: an antenna or coil, a transceiver (with decoder) and a transponder (RF tag) electronically programmed with unique information. There is emission of radio signals by the antenna in order for the tag to be activated and data to be read and written to it [2]. Antennas establish the communication between the tag and the transceiver. The transceiver is responsible for the data acquisition. A more detailed introduction about RFID, transceiver, tag types, and frequencies is provided by [2].

This paper presents summary of further enhancement and expansion of RFID based student attendance application to five related industrial application, detailing application of RFID in some selected developing economy in south western part of Nigeria. These implementations were adaptation and expansion of an existing RFID-based student attendance management system reported in [1]. The remaining section is organized into the following: Section 2 describes the underlying theory of the deployed and integrated passive RFID systems in Section 3, Section 4 describes challenges and solutions in the process of developments and integration of RFID systems in developing economy context; Section 5 presents concludes and provide recommendations for future research endeavor.

2. UNDERLYING THEORY OF DEPLOYED PASSIVE RFID SYSTEM

In most implementation and integration scenarios in Section 3, passive RFID system were applied in the selected industrial applications. Compare to active RFID Systems, tags in passive RFID system do not have their own power source and operates at a frequency range of 13.56Mhz. The underlying principle of communication between the tag/antenna and the transceiver is based on the principle electromagnetism with two regions of far field and near field between the transmission process. The relationship between the RFID reader's power, the power transmitted to the tag, the gain of the reader's antenna and the gain of the tag's antenna could be deduced by considering the far field of the electromagnetic field between the antenna and the transceiver [3]. The far field is the region where the electromagnetic field and the antenna are separated from each other and the field propagates in free space as a plane wave. There exists a constant ratio between the electric field (E) and magnetic field (H), this constant is approximately 377Ω.

The distance where the far field occurs may be approximated for small antenna where D is far less than λ as:

$$r_{nf} = \frac{\lambda}{2\pi} \quad (1)$$

Where, λ is the wavelength of the transmitting tag, D is the maximum dimension of the radiating tag and r_{nf} is the distance from the antenna in the near field. Nevertheless, the far field distance in which D > λ. Equation 1 reduces to:

$$r_{ff} = \frac{2D^2}{\lambda} \quad (2)$$

Where r_{ff} is the distance from the antenna in the far field. Therefore, the transition region (r) is the region between the reactive near field and the far field given by the equation 3:

$$\frac{\lambda}{2\pi} < r < \frac{2D^2}{\lambda} \quad (3)$$

Since most applications towards our enhancement in [1] make use of the passive tag without its power, there exists a relationship between the power transfer to tag (P_T), power on the reader (P_R), the reader antenna gains (G_R), tag antenna gain (G_T), and the electric field strength of the reader at a particular tag position (E). First, there the relationship between the power transfer to the tag and tag antenna gain given by relation (4).

$$P_T = \left(\frac{E^2}{120\pi}\right)\left(\frac{\lambda^2}{4\pi}\right)G_T \quad (4)$$

Also, the relationship between the reader power and the gain of the reader is given by:

$$P_R = \left(\frac{E^2}{120}\right)\left(\frac{r^2}{G_R}\right) \quad (5)$$

Therefore,

$$\frac{E^2}{120} = \frac{P_R G_R}{4r^2} \quad (6)$$

Substituting equation (6) into equation (4) gives:

$$P_T = \frac{P_R G_R \lambda^2 G_T}{(4\pi r)^2} \quad (7)$$

Therefore, the equation 7 represents the relationship between the RFID reader's power, the power transmitted to the tag, the gain of the reader's antenna and the gain of the tag's antenna [3].

3. IMPLEMENTATION AND INTEGRATION OF RFID SYSTEMS

RFID provide a very good solution for offline collection of fees in an organized community of users such as University campus, city, and social clubs, and religious organization, government organization at little or no cost. The five case studies implemented were Campus and City wide offline RFID based payment; Library book Circulation; e-Thrift collection; Car park control and fee collection; Cattle tax payment collection. All the five case studies fall under the same sphere of influence of exchange of goods and service. The choice of selected developing economy in the south-western part of Nigeria was due to high level of acceptance and adoption of innovative ideas by the people living in this area more partly based on more people with high level of educational achievements and relatively low digital divides in this part of country.

The RFID applications in this paper were branded *Sanwo; Sanwo in Yoruba language means Pay money*. Brief description of the individual implementation and integration follows:

4. SELECTED IMPLEMENTATION IN DEVELOPING ECONOMY CONTEXT

(a) Campus and City Wide Offline RFID Based Payment

Cash balance from cash based transactions is a big problem in the campus environment because buyers do not always pay exact fee for items and the merchants also do not have exact amount to pay the cash balance to the buyer. One way or the other, time is wasted, a party is disenfranchised or cheated because developing countries are still fully cash based economy. Small and Medium Enterprises, informal market operators do not embrace online payment due to online payment infrastructural failures, high service charges and cultural belief of most operators. This particular case study was to address these challenges using two Universities A and B as case studies. University A is a public funded university with a population greater than 20,000 students and located in Oyo state, south western Nigeria while University B is privately funded with population of students greater than 5,000 and located in Ogun state, south western Nigeria. The flow process of the campus and city wide offline RFID based payment is shown in Figure 1.

Sanwo cards serves as student official ID card in one of the Universities. Student can credit/top up fund onto the card from credit/Top up agents on campus and it is protected by PIN known to the student alone, and can be used as a payment option with the participating merchants. Real time transactions are available to the student, merchant via web access or after synchronization to the cloud server. Sanwo provides an offline wallet system for the student. The student gets the card, top up the card, and uses it for transactions at participating merchants. The value for the students include:

Secure wallet, No change hassle, Fast and seamless payment, email and/or SMS alert of all transactions. The value for the merchant includes: Seamless payment collection, Transparency, accountability and easy reconciliation that prevent sharp practices by merchant employees, transactions data and Know Your Customer (KYC) details that can be useful in making business decisions.

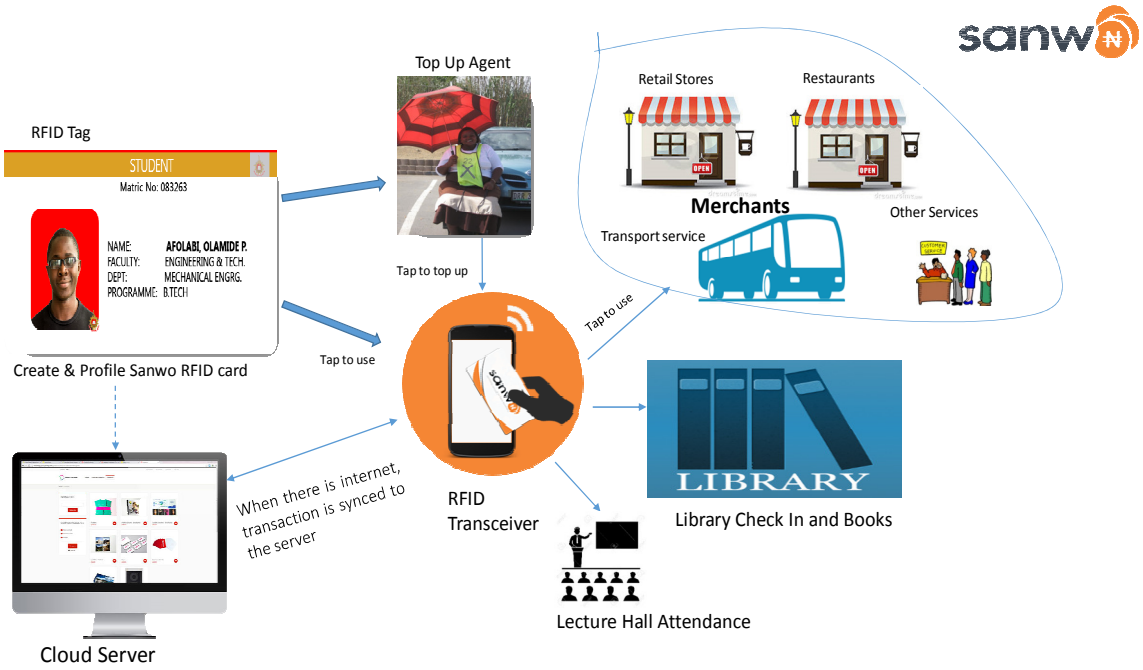

Figure 1: Flow process of the Sanwo's campus and city wide offline RFID based application

(b) Library Book and Patron's Management system

The library system can be a bit complex with the manual task of managing book circulation, security, manage the active library patrons' self-check-in and check-out, and ensure accurate and easy seamless indexing. Sanwo cards for the library automation helps with verifying the library patrons and the library access, then the card also records all outstanding borrows. The card also works with an access control turnstile to revoke or give access to Library users provided they are still active. Sanwo RFID card was used in University A main Library to replace electromagnetic (EM) security system in place, books were tagged with RFID tag in place of EM stripe and barcode. The following benefits were derivable in this specific RFID auto-identification application: The solution allows check-out and check-in of several book items simultaneously, identification and antitheft in one single process, Self Check-in and Check-out with the aid of self check kiosk and book drop machine, speedy and smart inventory taking of library resources. The flow process of the Library and RFID based payment is shown in Figure 2.

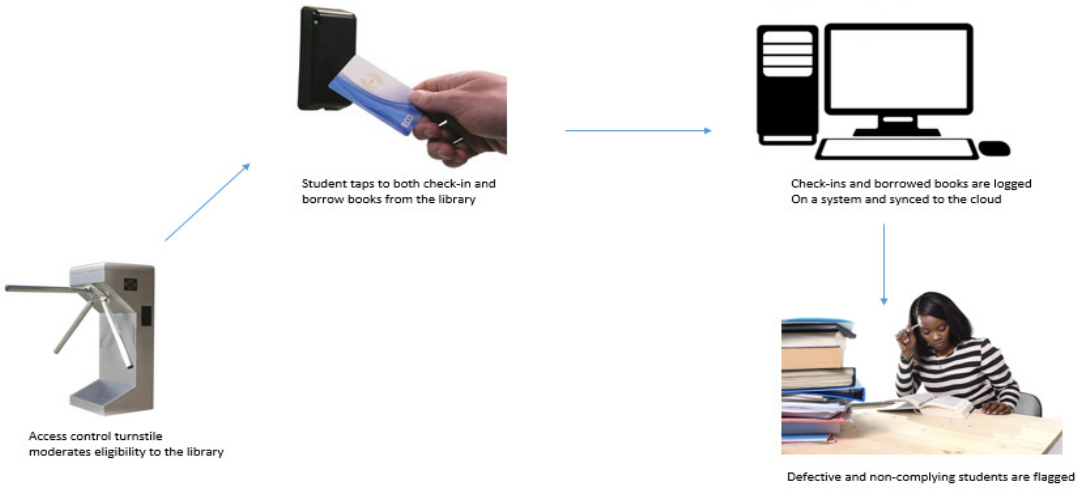

Figure 2: Flow process of the Sanwo's campus and Library RFID based application

(c) Electronic-Thrift Collection

Thrift collection popularly called '*Ajo*' is the earliest form of banking in developing country especially in West Africa. It is a special kind of local business practiced in most neighborhoods and marketplaces where individuals save money to a thrift collector daily, weekly or monthly for keep and future retrieval. Present thrift collection methods in developing economy are not scalable and reliable. With the use of the Sanwo system, thrift collection does not need the use of paper cards for recording of collection and can easily scale and accommodate multiple users. Presently the system helps with thrift collection by easy registration and RFID card issuing, collection, recording and tracking. The simplified flow process is shown in Figure 3. The thrift collector agent's transceiver device is credited with an amount, the maximum cash collection of which the agent can collect by the e-thrift operator. Thereafter, the agent goes to the field, collect cash from the customers and record the unit on the customer Sanwo card by adding the amount collected to the previous balance on the card.

Figure 3: Electronic Thrift Collection Flow process of offline RFID based application

All thrift collection transactions (both credit and debit) happens offline. These transactions are synced online to the cloud server where it can be monitored remotely. Once the transaction is synced, the customer gets SMS alert. The customer can always check the balance on the card from an agent anytime or query the database via Short Message Service (SMS) or web. Customer can always retrieve the full or partial contributed amount from the agent or retrieve to his/her bank account.

(d) Car Park Control and Fee Collection System

Parking fee collection is a form of Internally Generated Revenue (IGR) scheme recently introduced by a State Government in south western Nigeria. The biggest issues with the scheme before the introduction of RFID based collection were: Fraudulent activities of touts, identification and trust of park collection agents, and recording of transaction data. Most motorists could not distinguish a fake ticket from an original one, so motorists do not trust the collection would be remitted to Government covers. Also, when a motorist pays, Government does not know which motorists pays, how consistent the motorist has been paying so as to reward with discounts. With Sanwo, all these problems were solved with the flow process in Figure 4.

The procedure for this RFID application area include:

1. Prior registration of a customer/motorist and tying the plate number with the RFID tag/card.
2. The motorist credits/top up the card with credit/top up agents in any of the parks.
3. The motorist then taps the transceiver to pay for the parking per hour of usage

The transactions are also synced onto the cloud server for remote monitoring, reconciliation and for on-site monitoring of defaulting motorists.

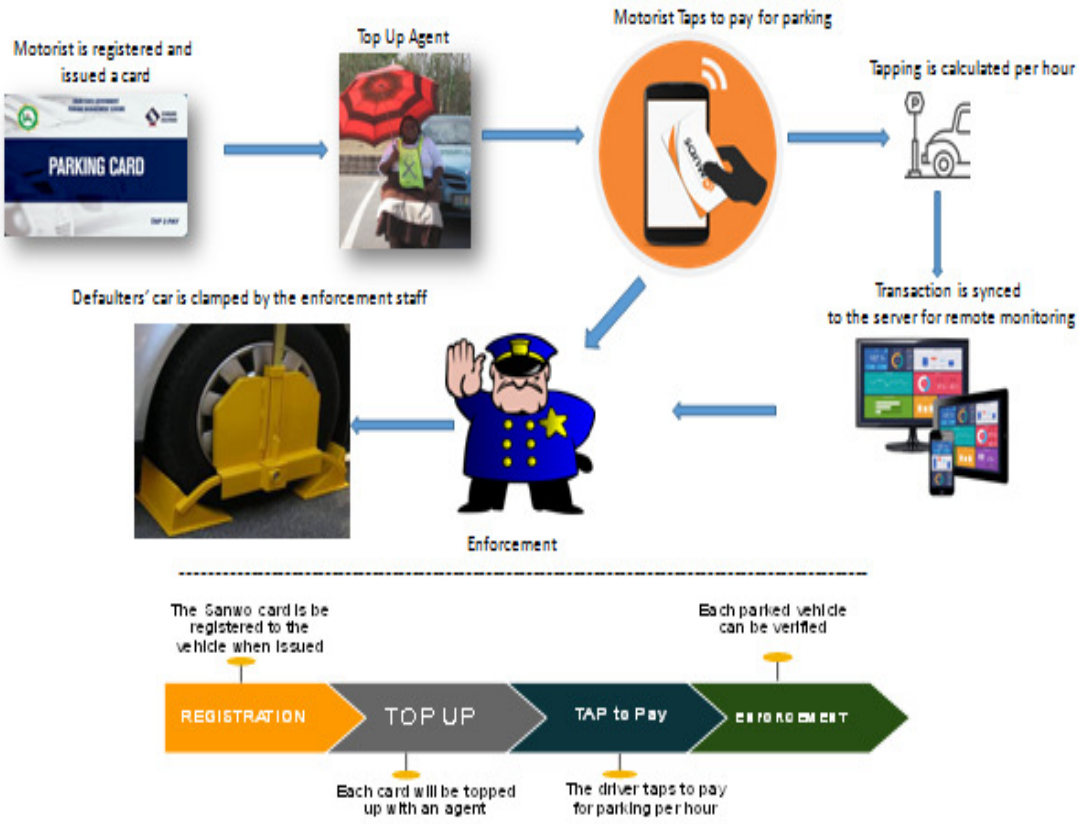

Figure 4: RFID Based Offline Vehicle Parking Fee Collection Flow Process

(e) Cattle Tax Payment Collection

Jangali, otherwise called cattle tax in Kwara state, south western Nigeria, is an area where revenue generation the government is dwindling due to manual tax collection that allows pilfering of cash. The problems with the sector are both technical and cultural. The cattle owners are have some cultural beliefs such as piercing of cattle for identification or tagging is not acceptable, and injecting cattle with a RFID chip is a taboo. Sanwo came up with a solution that put all these into consideration, yet foster financial inclusion while generating revenue for the government. The flow process is shown in Figure 5 where cattle owner is registered, assign an RFID sticker, tail tag all the cattle with a QR code previously assigned to the owner during registration. Record payment on the cattle owner's RFID sticker and verify payment by scanning any of the QR code tagged on the cattle.

The system is very simple, cost effective, more concise and acceptable to Government than existing available methods. Whenever cattle are vaccinated, the information is also recorded against the owner's sticker and synced to the cattle's QR code. The tagged QR code is water-proof for durability.

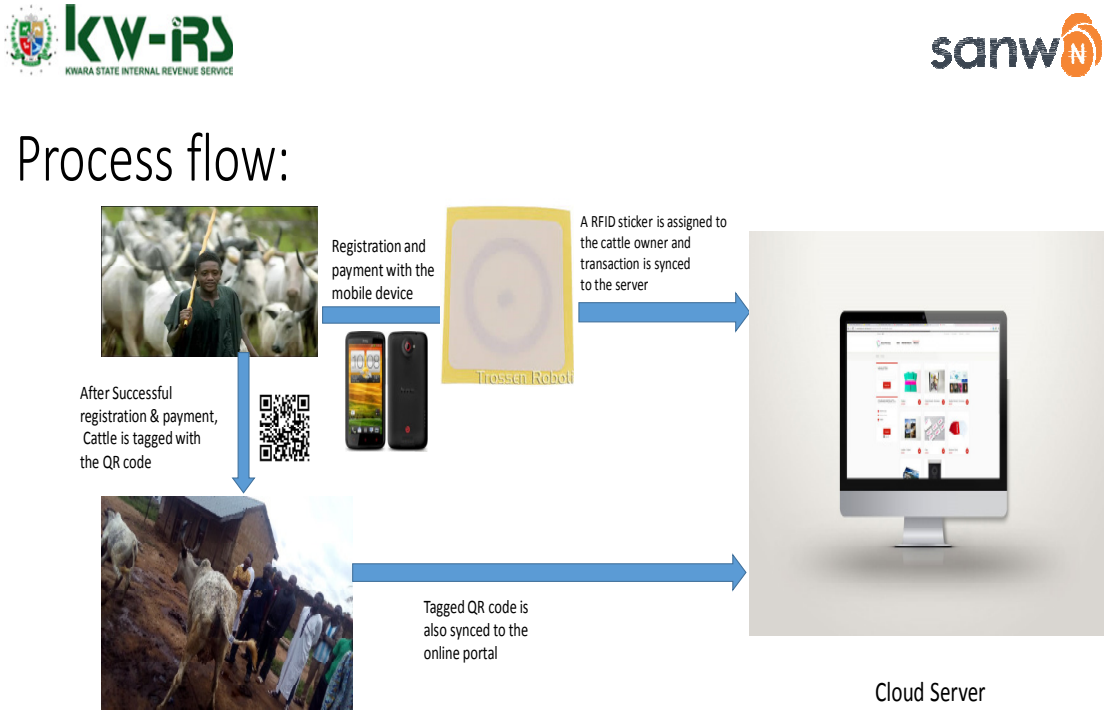

Figure 5: Cattle Tax Flow Process

5. INTEGRATION OF SELECTED RFID APPLICATIONS

The Sanwo RFID implementations in previous section were all integrated to be synchronized to the cloud server for easy monitoring by all the stakeholders such as the card user, top up agents, Merchants, thrift collectors and contributors and Government Agencies. During the creation of Sanwo card, each user is profile with security details such as PIN for using the card and this can be change at any of the mobile and stationary transceivers, Username and Password for accessing the dashboard via the web browser. Assessing the dashboard also require another level of authentication via phone call/SMS. A sample of the dash board is shown in Figure 6 showing basic information about collection in University B with various report generation.

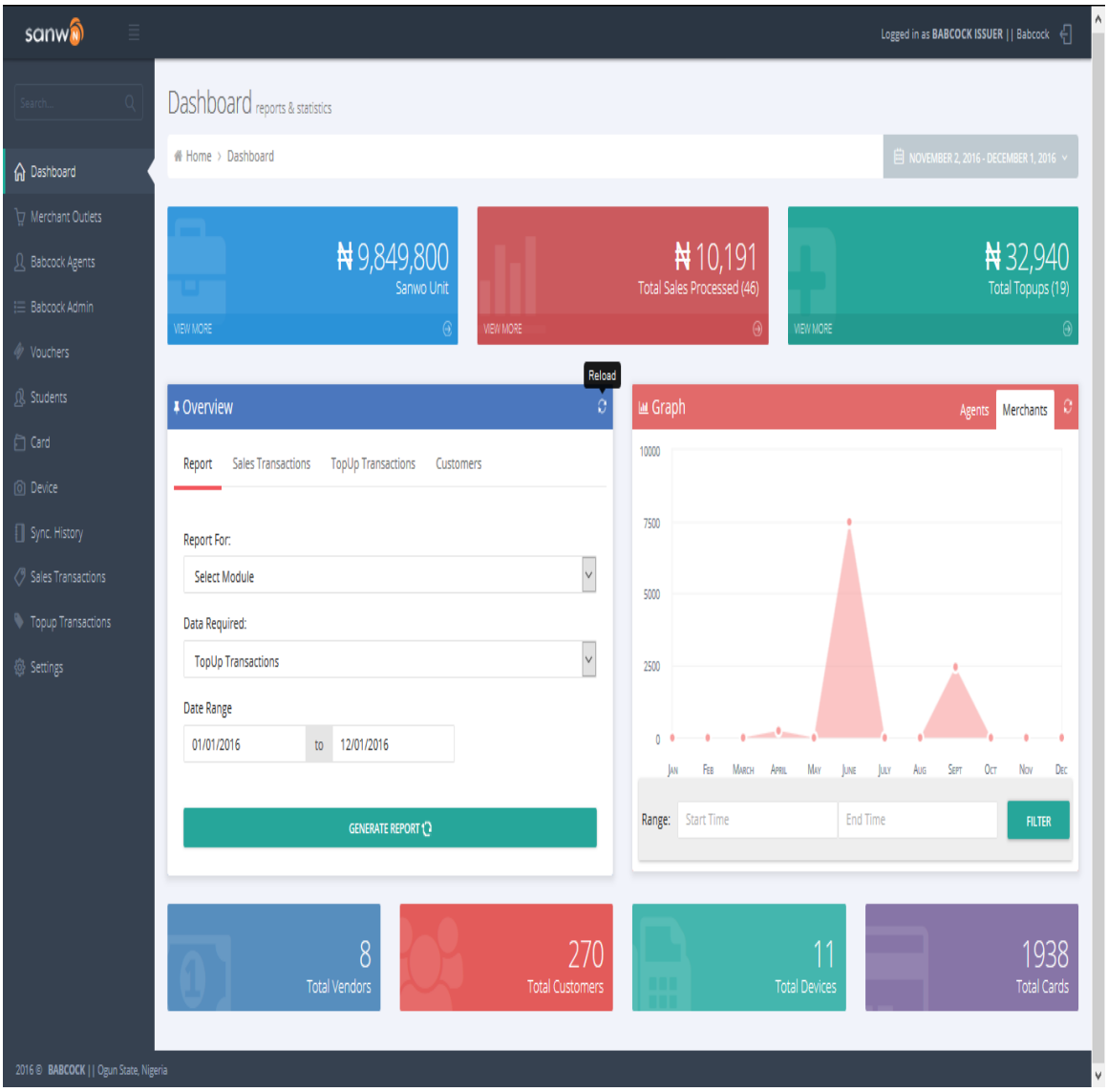

Figure 6: Sanwo Dashboard View for remote monitoring

6. CHALLENGES AND SOLUTIONS DURING SYSTEM INTEGRATION

The current successes recorded by Sanwo RFID solutions were clouded with some challenges during the implementations and deployment of the solutions:

1. Adoption of the new paradigm of solution: It took a while before the solutions were adopted. More often than not, successful and ongoing pilot deployment needed to be in place before the clients becomes comfortable with the use of the solution. People are naturally scared of new ideas and technology they do not understand. We device a model for a free pilot program, usually for one (1) to two (2) weeks, to build their confidence in the system.
2. Awareness and Education of the Merchants and Vendors: Most of the Point of Sale staffs engaged by Merchants were unlearned in this technology, training them to use the technology was a bit difficult. To solve this challenge, eradication of software and hardware complexity by making the solution extremely simple. The user interfaces come in simple calculator design.
3. Familiarity and FAQs: We ensure that the system is fool-proof by creating user's manual for the merchants.
4. Hardware failures: Because NFC devices are not that main stream, we usually have to make spare available in case of hardware failure to swap-out the failed device while the broken device is fixed.

7. CONCLUSION AND RECOMMENDATION

This paper has presented summary of further enhancements of RFID based student attendance management in [1] to five related industrial applications in some selected developing economy in south western part of Nigeria. It is so amazing how technology can solve complex problems in different sectors. A piece of RFID chip transformed with software has helped to provide vehicle park management solution, e-thrift collection, library solution, helps the government increase her revenue, enables seamless payment within the campus environment and provides data capture and generation for system decision support.

With more empowerment of creativity, and innovation, RFID technology with cloud computing can proffer simple and cost effective solutions to automate every day-to-day activity through a simple tap and go experience. RFID and other technologies such as Internet of things, sensor network can be applied to solve some current socio-economic problems such as cattle rustling, national asset monitoring, security surveillance and monitoring of land borders, among others facing developing nations. We are currently expanding the application scope of the RFID systems and experimental evaluation of algorithms and protocols to enhance security and privacy issues inherent in the course of deployments of these RFID applications.

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