Internet of Things-Based Framework for Public Transportation Fleet Management in Non-smart City

Muthoni Masinde[1](✉), Ahmed Shoman[1],
and Mohamed Hassan Mostafa[2]

[1] Unit for Research on Informatics for Droughts in Africa (URIDA),
Central University of Technology, Free State,
Private Bag X20539, Bloemfontein 9300, South Africa
muthonimasinde@gmail.com, admsho@gmail.com
[2] Sustainable, Urban, Roads and Transportation (SURT),
Central University of Technology, Free State,
Private Bag X20539, Bloemfontein 9300, South Africa
mmostafa@cut.ac.za

Abstract. The notable increase in location-based applications especially in smart cities realm is driven by the emergence of miniaturized, cheaper and readily available location-based internet of things' devices. The backbone of the internet of things is a well-orchestrated electronic infrastructure, telecommunication and information technology. Such a backbone is the precursor for the success of internet of things applications that have mushroomed in the public transportation sectors of the developed world. The developing countries such as South Africa have not kept pace with the development of these electronic infrastructures. Implementation of smart city concepts such as intelligent public transportation system in these countries therefore requires novel approaches. As one of the solutions to this, we present an internet of things framework that enables the integration of multiple cost-effective internet of things technologies through which public transport-related information can be obtained in cost-effective and robust ways. The framework was designed and evaluated using a system prototype for the Free State province (South Africa) public transport system case.

Keywords: Intelligent public transport system · Internet of things framework
Free State province · South Africa

1 Introduction

1.1 Background Information

Since the birth of the Internet of Things (IoT) concept at MIT in 1999 [1], tens of other definitions have emerged – mostly depending on the application context. Conceptualization of IoT in terms of the 4As vision (anytime, anyplace, anyone and anything) by ITU in 2005 expanded this definition and closely tied it with ubiquitous computing [2]. In the definition used in the Cluster of European Research projects on the Internet of

R. Zitouni and M. Agueh (Eds.): AFRICATEK 2018, LNICST 260, pp. 3–17, 2019.
https://doi.org/10.1007/978-3-030-05198-3_1

Things (CERP-IoT), the ITU's 4As vision has been extended to 6As by including Any path/network and Any service representing any type of location or network and any available service respectively. The IoT definition in CERP-IoT is adopted in this paper [3]:

> *"a dynamic global network infrastructure with self-capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network"*

The basic concept behind IoT is the interlinking of physical, social and cyber worlds. This has resulted in huge impacts on society and humans as well as social networks. The driver for this impact is the ability of IoT to turn traditional systems into smart systems, for example, smart mobility services that provide citizens with tools to accurately plan their journeys with public transportation [4]. IoT brings tangible benefits, primarily to physical industries such as agriculture, manufacturing, energy, transportation and health care.

Key generic requirements for IoT application include ability to manage heterogeneity, support for dynamism, scalable, support for interoperable communication protocols, cost effective, self-configuration (including self-organization, self-adaptation, self-reaction to events and stimuli, self-discovering of entities and services and self-processing of Big Data), flexibility in dynamic management/reprogramming of devices or group of devices, Quality of Service (QoS), Quality of Experience (QoE), context awareness, intelligent decision making capability and adherence to secure environments [4, 5].

Over the last five years, the number of IoT applications has grown exponentially. Figure 1 below shows the main domain areas under which these applications fall.

Close to half of the application scenarios shown in Fig. 1 below fall under the Smart City domain. The core challenges of this domain are urban sensing and data acquisition, computing with heterogeneous data, and hybrid systems blending the physical and virtual worlds [6]. Of interest to this paper is the transport and mobility aspect of a smart city. Examples of applications in this realm include a system that automatically records public vehicle positioning data [7] and OnRoute – an information services for passengers [8]. Others are cooperative intelligence transport system [9] and internet of vehicles by Kaiwartya et al. [10]. Datta et al. [11] looks at the five challenges around connected vehicles while Rakotonirainy et al. [12] tackle a more complex solution of managing driver's behaviour by incorporating Quantified Self and Artificial Intelligence.

Researchers have proposed various object (the 'things') federation architectures to ensure that the myriad components that are part of the IoT can operate in harmony. Borga [4] presents this in form of three phases: data collection phase, transmission phase and process, management and utilization phase (see Fig. 2 below). Similar architecture for the implementation of low-power applications is presented by Yelmarthi and Khattab [13] while a middleware designed around *inlining* approach is describe in Mhlaba and Masinde [14]. A semantic-based framework that integrates machine learning is found in [15] - here five layers are included: physical entities, abstract entities, data stream, fusion and utility layer.

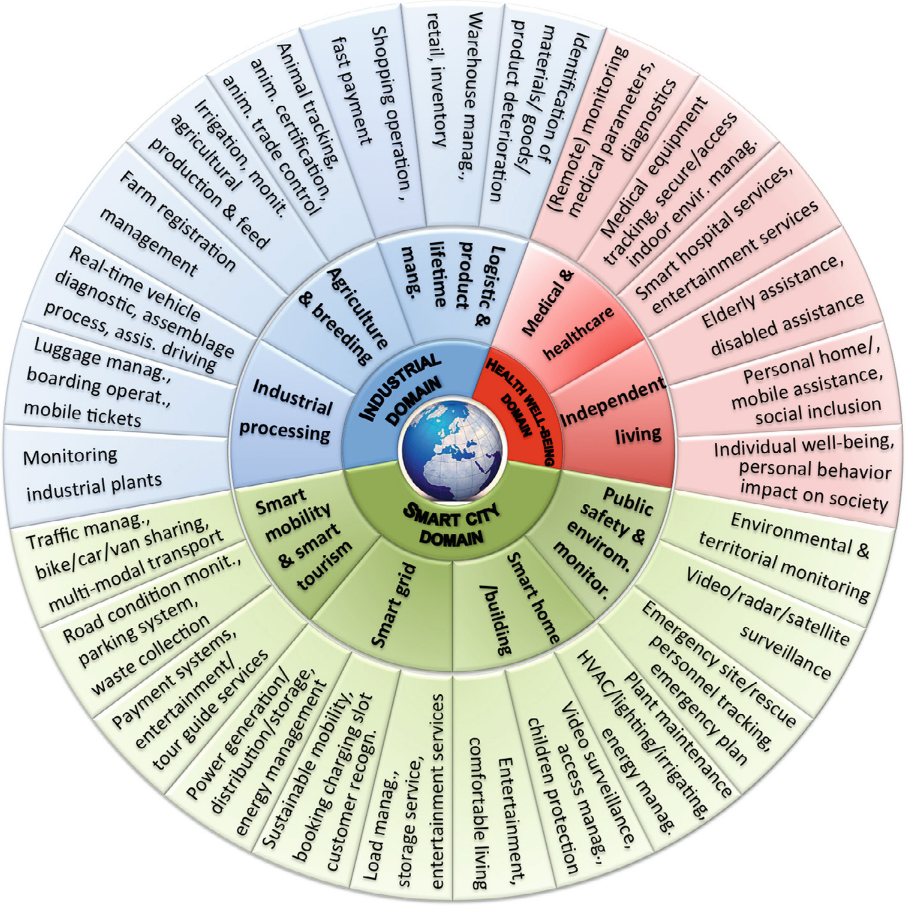


Fig. 1. IoT application domains and related applications [4]

Public transportation is an important area that governments constantly must pay attention to because of the large number of people that depend on it on a daily basis. The South African government established a department of transport to deal with all transport related matters, including the public transportation environment. The Department of Transport, over a period of 10 years has carried out many surveys as part of the initiative to improve the service level of public transportation in South Africa. Some of the results of these surveys indicate that about 19% of the public is willing to make use of public transportation if their service requirements are met [16]. Developments in this field is ongoing in order to improve the service and to meet the requirements of the public [16].

The Internet of Things-technology has already been used to improve the quality of service in the field of public transportation in the country. Cape Town uses the Transport for Cape Town (TCT) application (app) [17] and Johannesburg uses i-Traffic [18]. Uber has also been widely used in the larger South African cities such as

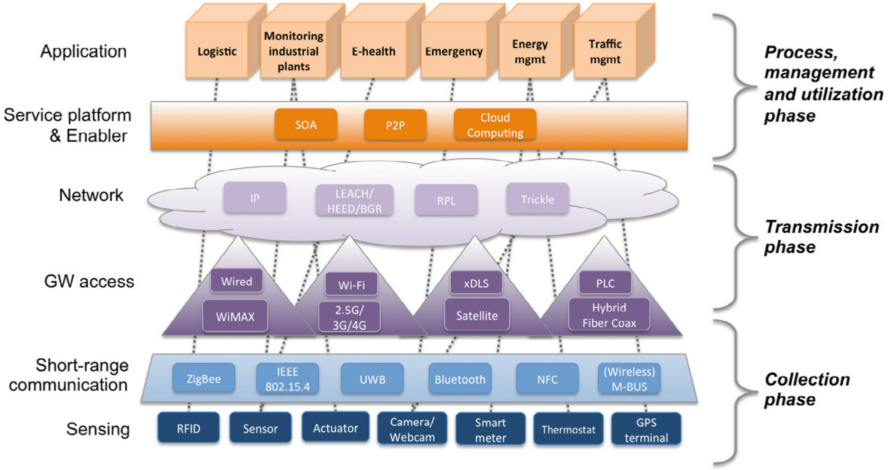


Fig. 2. A non-exhaustive list of technologies and protocols is shown [4]

Johannesburg, Pretoria, Cape Town, Durban, and Port Elizabeth with full support of the ubiquitous concept [19].

Despite great technological strides in the public transportation systems elsewhere in South Africa, none of these have found root in the Free State province. Electronic, communication and ICT infrastructures required in supporting even the basic aspects of smartness are missing. This has partly contributed to the many challenges the provincial government faces in its attempt to offer quality public transportation services [20]. A government survey revealed that many people do not make use of public transportation because of the poor service, the number of safety concerns and unpredictably time schedule of the public transport vehicles [16]. Given the benefits that other cities (in the South Africa and beyond) have reaped from IoT-based public transportation system, it is the thesis of this paper that, tailor-made IoT system is the solution to the problems in the Free State's public transportation system [21].

1.2 Research Objectives

The aim of this research was to develop a framework that would allow the integration of a number of technologies within the Internet of Things (IoT) paradigm in order to provide an efficient and effective way of managing public transportation in a resource-challenged environment such as the Free State province in South Africa. This aim was achieved through two sub-objectives: (1) a detailed investigation of the technological challenges facing the public transportation sector in the province and identification IoT technologies that are applicable to the province's context; and (2) the development of an IoT integration framework, consisting of five IoT components – a system prototype was then developed and used to evaluate the working of this framework.

2 Methodology

2.1 Data Collection Methods

Three data collection methods were employed, namely, observation, interview and questionnaires. In order to experience the challenges faced by the stakeholders of the public transportation sector, the researcher visited a number of the public transport hubs in the city of Bloemfontein (the capital of Free State province). Observation data collection method [22] was then applied and the challenges experienced first-hand recorded. Selected stakeholders of the public transportation sector were interviewed. The findings from these interviews, together with information elicited from literature reviews and the observations, was used to design questionnaires for three categories of the sector's stakeholders. The three questionnaires were targeted to all of the three different participants, namely; passengers who make use of the public transportation, the owners of the public transportation vehicles and the drivers who are employed to drive these vehicles. The order in which these data collection methods were executed is shown in Fig. 3 below.

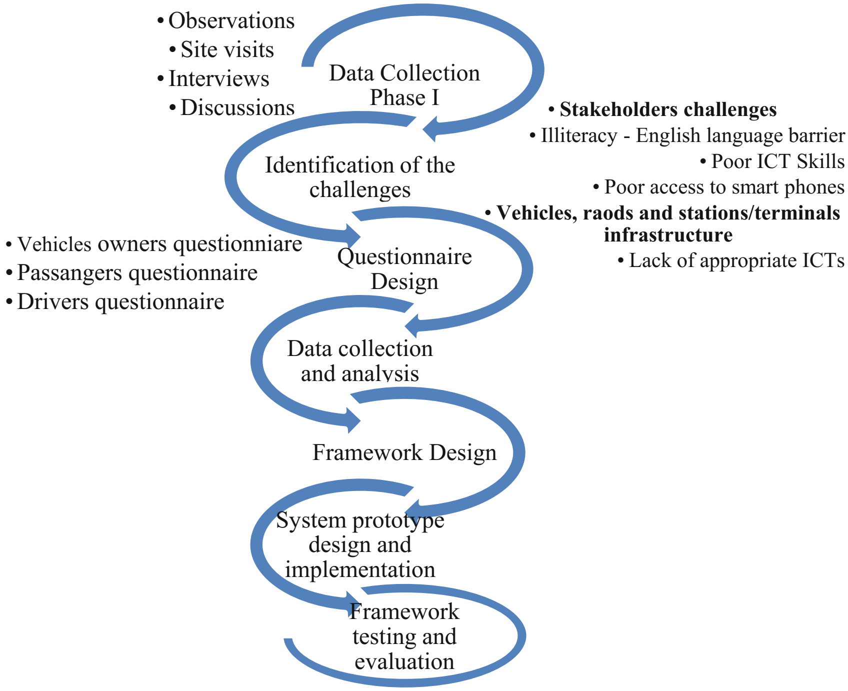


Fig. 3. Research methodology steps

As depicted in the flowchart in Fig. 3, the study was divided into the following five phases: (1) data collection phase 1 (observations and interviews), (2) identification of challenges facing the public transportation sector, (3) design and administration of questionnaires, (4) data analysis and (5) designed, implementation (through prototyping) and evaluation of an IoT integration framework. These phases are discussed in detail below.

2.2 Data Collection Phase 1 - Observation and Interviews

During this phase, the data for the research study was collected by means of observations and interviews. The researcher aimed to gather as much information as possible about the case study of the Free State public transportation management system. This provided the much-needed understanding of the Sector.

Observation
During this phase, the researcher visited the research sites of interest and just observed how the public transportation business was conducted. The sites visited consisted of two public transport terminals in the Free State; Bloemfontein and Thaba Nchu. The researcher also commuted between these two stations by means of public transportation to experience first-hand what the public transportation was all about.

Interviews
The researcher interviewed members of the Public Transportation Committees and took note of their opinions, complaints and suggestions. Some of the public transport vehicles' owners as well as members of some of the organizations were also interviewed in an effort to identify the challenges that they were facing.

2.3 Phase 2 - Identification Challenges

From the interviews and observations in phase 1, the main challenges facing the public transportation sector in Free State were identified. These were divided into two categories: (1) infrastructural limitation in the Free State terminals/stations, and (2) infrastructural needs of the people that make use of the public sector. It also emerged that both of these categories of limitations could be addressed by appropriate employment of Information and Communication Technologies (ICTs), this is especially at the public transportation terminals/stations. It was also discovered that the main key players (passenger, drivers, and owners) had such diverse needs and one-solution-fit-all approach would not work. For instance, the passengers were in need of prior information on vehicles' arrival times and real-time notifications of specific (of interest to them) vehicle arrival. The needs of the passengers differed from one passenger to another– this is due differences in general literacy levels, ICT-literacy, age and gender. As for the drivers, their needs were around ensuring the quality of service to the passengers. Such included prior knowledge of the next stop at which passengers need to disembark. On the other hand, all the vehicle owners needed most was the ability to manage and monitor their vehicles on real-time basis.

2.4 Phase 3 - Questionnaire Administration

In order to gather information on opinions on various stakeholders as well as the of the proposed system, questionnaires designed and administered to passengers, drivers and vehicle owners. All the three questionnaires (for passengers, drivers and vehicle owners) focused on three areas: current infrastructure/ICT/services/management, quality of transportation service, and anticipated/expected improvements in efficiency of the transportation system emanating from the proposed IoT framework. The data collected frm using these questionnaires was analysed and reports compiled in Excel. The results of analysing this data is discussed in Sect. 2.5 below.

2.5 Phase 4 - Data Analysis

Each of the three questionnaires were analysed separately. For demonstration purposes, only data for the passenger questionnaire is presented here.

The participants who completed the passenger questionnaire consisted of 45% males and 55% females. The age of the participants ranged from 18–35 years. The majority of school learners younger than 18 years of age made use of taxis (minibuses) rather than other public transportation vehicles such as buses. The passengers rated the average waiting time for a vehicle as 7 out of 10, where 1 is not having to wait at all, and 10 having to wait for a long time. Approximately 55% of passengers preferred to do shopping while they are waiting at the public transport station, which results in 40% of them indicated that they missed their awaited transport. More than a third of the passengers complained that they never disembarked where they were supposed to as, most of the time, the driver dropped them further down the route. This is due to the method used to notify the driver of a disembarking passenger, which is either by shouting, asking someone to notify the driver, knocking on the window or, in some cases, using a buzz button. However, most of the vehicles were not equipped with buzz buttons, and if they were, the driver is notified too late, not allowing him enough time to prepare to stop the vehicle. The remainder of the passengers, who did not experience these problems, are passengers on long distance routes outside the city, or passengers who drive from one station to another that allows them to avoid stopping between the two main points. The study shows that the majority of the passengers, more than 70%, own smartphones and it is seldom that one finds a passenger without any kind of cell phone.

2.6 Phase 5 - Framework Development

Borrowing from the cross-cutting elements of IoT frameworks presented in [4] and supported by Yelmarthi and Khattab [13] and Mhlaba and Masinde [14], a framework for integrating IoT into the Free State public sector was designed. As discussed in Sect. 3, the framework consists of 5 layers: storage layer, service layer, communication layer, sensor/devices layer and application layer.

2.7 System Prototype Development and Testing

In line with the framework, a system prototype was developed using four IoT ‘things’: Radio Frequency Identifier (RFID), Global Positioning System (GPS), Infra-Red (IR), and Global General Packet Radio Service (GPRS). Mobile phones were incorporated – they played the role of a sensing (camera, motion and GPS sensors) devices, a computing device for the mobile application and finally as input/out device for the resulting system. A mobile application and an integrated web portal were also designed to provide for friendly user input/output interface.

3 IoT Framework for Public Transport System

3.1 Framework Layers

As depicted in Fig. 4, the framework consists of five main layers. The layers interact with each other through the different channels.

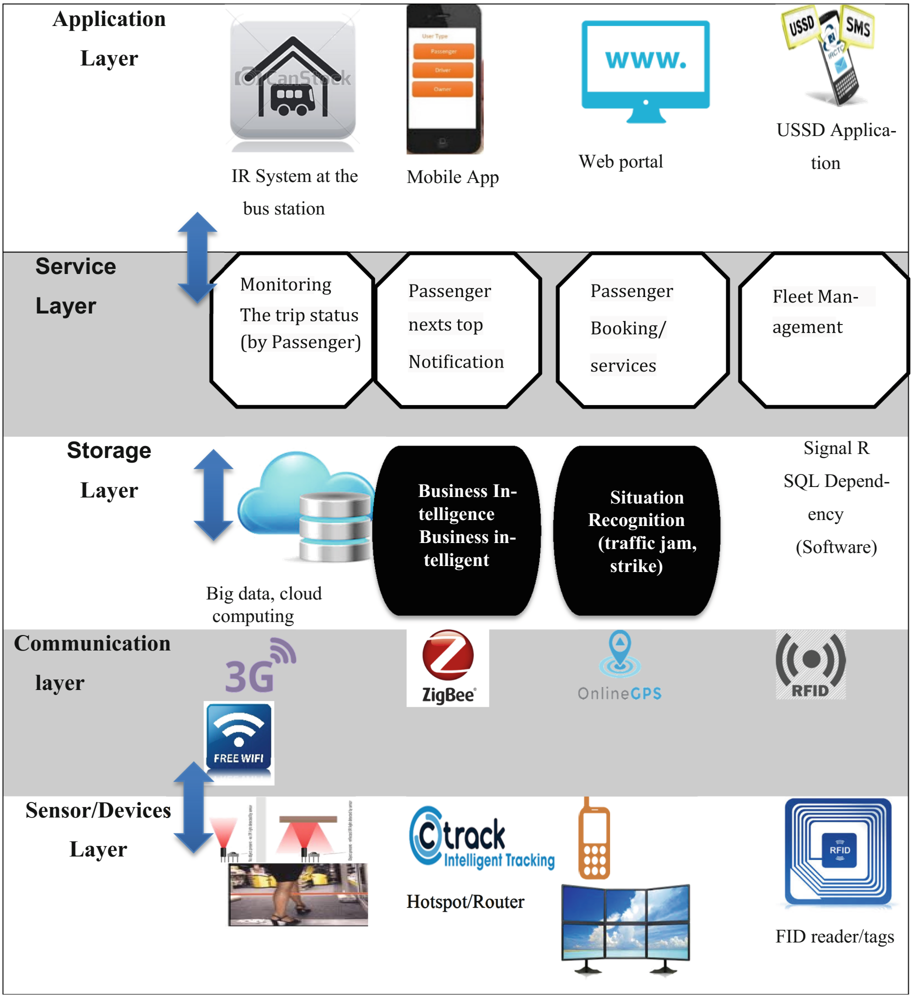


Fig. 4. IoT framework for public transport application

Application Layer

The top layer is the application layer; different user interacts with the system through this layer. In order to achieve this, the layer supports different user interfaces that offer different services to the different users such as monitoring, visualising, analysing, reporting, notifications, guiding, and managing information. It is through this layer that ubiquity (access by anyone, at any time, from anywhere and using any of the supported devices) of the framework is implemented. As currently implemented, the framework is designed to offer an Unstructured Supplementary Service Data (USSD) application for non-smart phones users and an Android mobile phone application for smartphone users. The web portal ensures availability of the system online for all users who have access to the internet.

Device/Sensor Layer

The device layer is where all the IoT devices are located. This layer is responsible for generating data from the sensors and sending it to the server for processing. This layer is currently implemented to support four sensing devices: RFID, GPS, IR and GPRS.

RFID tags are supposed to be attached to each vehicle to identify the vehicle, while the RFID reader is installed at the station/terminal entrance to notify the users of the arrival of vehicles. RFID sensors are linked to a server (Gateway) that transmits its data to the online database.

Each vehicle participating in the system is fitted with a GPS sensor to enable real-time tracking. Together with the GPRS, the GPS transmits the GPS coordinates of the location of the vehicle to the online database.

An IR sensor is used for counting the number of passengers boarding or leaving the vehicle. Each vehicle uses two IR sensors; one of these is located at the gate (the point where the passenger leaves/enters the vehicle) to determine the direction of the passenger. If the outside IR is activated first then the inside IR will indicate that the passenger is getting into the vehicle, conversely, if it is the other way around, it will mean that the passenger is disembarking. The IR sensor is linked to a smart chip that is programmed to count the number of passengers (according to this method), and this information transmit it via GPRS to the online database.

Communication Layer

The next layer is the communication layer, which establishes different types of communication technology (3G, GPS, RFID, Bluetooth, Zigbee and IR-Light Emitting Diode) between the devices, sensors, servers and users. As currently implemented, this layer uses three different types of communication signals. The RFID reader at the gate of the bus station uses a computer that is connected to the internet via Local Area Network (LAN), Wi-Fi or a 3G modem. Both GPS and IR sensors on the vehicles will uses GPRS communication. Users at the station access the station’s Wi-Fi. Users outside the station use the 3G connection on their smartphones, or the general cellular connection for the USSD application in the case of non-smart phones.

Service Layer

The other layer is the service layer; here, several communication services are offered to first layer objects (passengers, owners, drivers, vehicles, stations) [5]. Station administration/vehicle owners are provided with fleet management service, and vehicles are equipped with real-time tracking equipment so that the station can be notified when a vehicle is arriving or leaving. Vehicle owners will be able to receive a real-time location for their vehicles, and keeping records of number of passengers used their vehicle. The passenger can make a booking for the next trip and will be notified of the arrival of the vehicle.

The driver application offers services such as an update on the current number of passengers who have registered for a specific trip and advance notification of the next location where passengers will be disembarking.

Storage Layer
The storage layer is the layer where database engines, such as the Oracle engine or Microsoft SQL, manage and control the database. The database engine is responsible for the following: storing, querying, managing and clouding big data. This layer will be further discussed in the next section. Future extension to the framework will include the ability to support big data, cloud computing, situation recognition and business intelligence (BI) analytics.

3.2 Framework Implementation

The actual implementation of the framework is in form of a working system prototype whose system architecture is presented in Fig. 5 below.

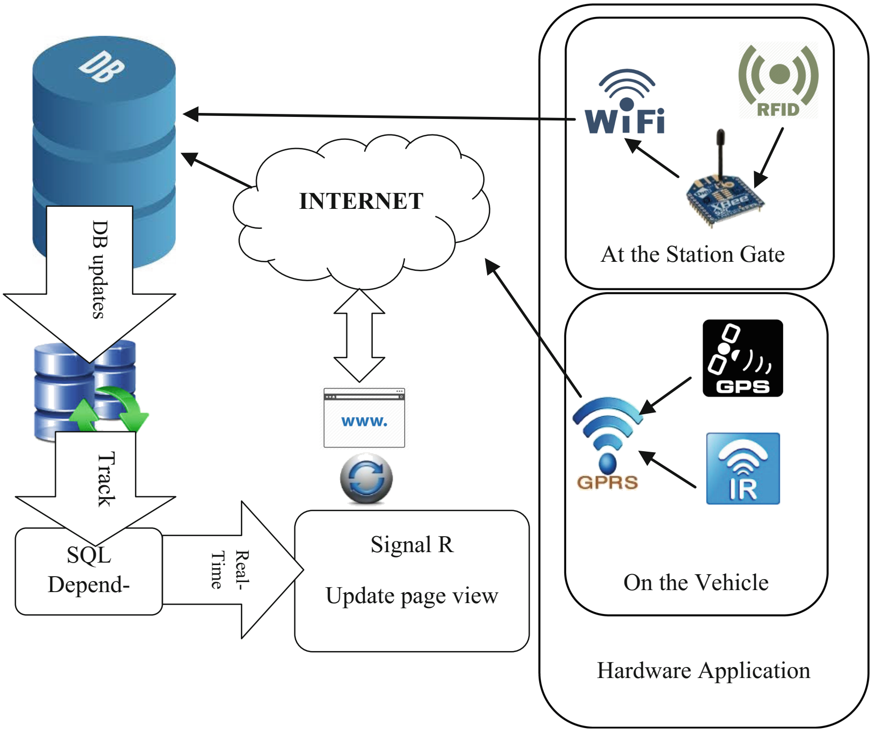


Fig. 5. System prototype architecture

A system prototype was implemented to mimic the working of the framework. Firstly, a GPS sensor was used to determine coordinates of the vehicles' location; these coordinates were published through the internet. Secondly, an RFID sensor was used to identify vehicles that were arriving at and departing from the bus station(s)/terminals. Thirdly, Waspmote sensors[1], that communicate via Zigbee, were used to complement both RFID and GPS sensors. Fourthly, GPRS was used to transmit GPS data to the server. Fifthly, Wi-Fi was used to transmit the received data from Zigbee to the server and used in the station to connect the public monitor and other users. Sixthly, 3G communication was used on a smartphone to register, monitor and manage data by different users. Seventhly, the general cellular signal was used, for non-smartphones, to send the USSD code and to receive SMS for notifications. Finally, the web page was used to register, monitor and manage all the data relating to the entire system. By making use of all of these integrated sub-systems, the successful implementation of the IoT framework was made possible.

3.3 System Prototype Testing

Mobile Application

This application (app) to be viewed. It serves the three main user-types, namely; passengers, vehicle owners and drivers. Although the main page of the app is visible to all users, it distinguishes between the different types of users. After determining the user type, the application page navigates to the next applicable page where the user is able to perform user-specific functions. For instance, a vehicle owner or driver has to complete a login page to navigate to the next page. However, the passenger page will navigate

Fig. 6. Mobile application main page

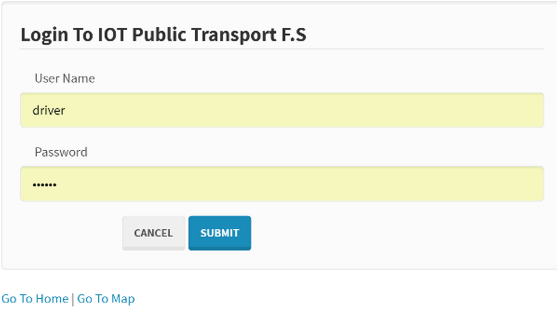
---

[1] http://www.libelium.com/products/waspmote/.

directly to the next passenger page without having to login or sign-up. If the driver/owner is not yet registered, he/she will have to sign up first, and can only be able to use the system once the administrator (admin) user has approved his registration (Fig. 6).

Web Application

Users can browse the web application online from anywhere and using any smart device, e.g. smartphones, tablets, laptops and computers. Module Viewer Controller (MVC) was used in the development of this application; C#.net was the main programming language. It consists of a Login Page visible to all users (passengers, drivers, owners and administrator). The system distinguishes between the different user levels to enable navigation to the relevant page for a specific kind of user. From the login page (Fig. 7).



Login To IOT Public Transport F.S

User Name: driver

Password: ••••••

Fig. 7. We application login page

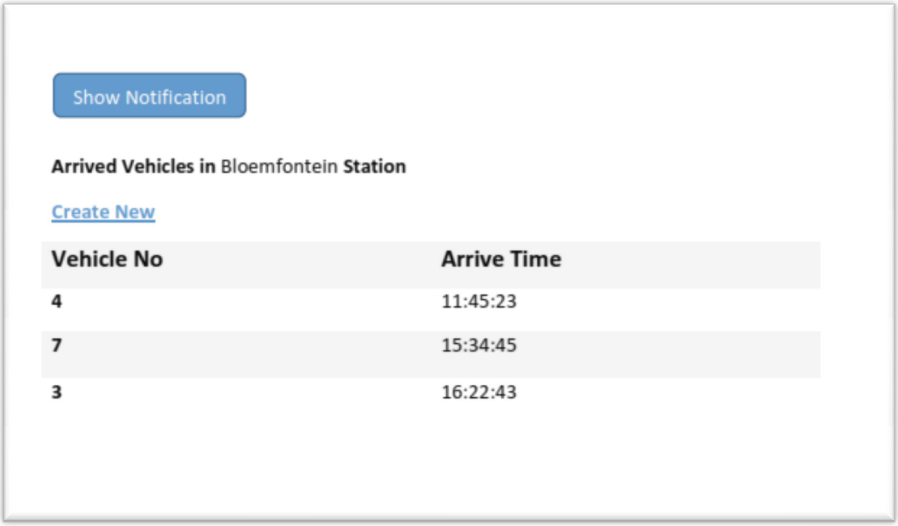
The next page of the web application is the home page that is displayed on one of the public monitors in the station. It lists all vehicles currently at the station and shows the arrival time for each vehicle. It also displays notifications (with a visual pop-up and a sound notification) whenever a vehicle arrives or leaves the station. (see Fig. 8 below)[2]

The other important web page is the administration (admin where admin users will be able to create the credentials for different users. The admin user also registers new vehicles and trips (routes). Further, from this, the admin user assigns every vehicle to all of the drivers, the owner and a route.

On the other hand, the Map Page displays on one of the public monitors at the station real-time tracking for all of the vehicles in transit. Using Signal-R and Database-Dependency with SQL-Dependency, this page offers a real-time update trigger on the database and pages. This acts as an intermediate tool between the GPS tracking sensor on the vehicle and the software application (Fig. 9).

---

[2] https://docs.oracle.com.



Arrived Vehicles in Bloemfontein **Station**

Vehicle No	Arrive Time
4	11:45:23
7	15:34:45
3	16:22:43

Fig. 8. Web application home page

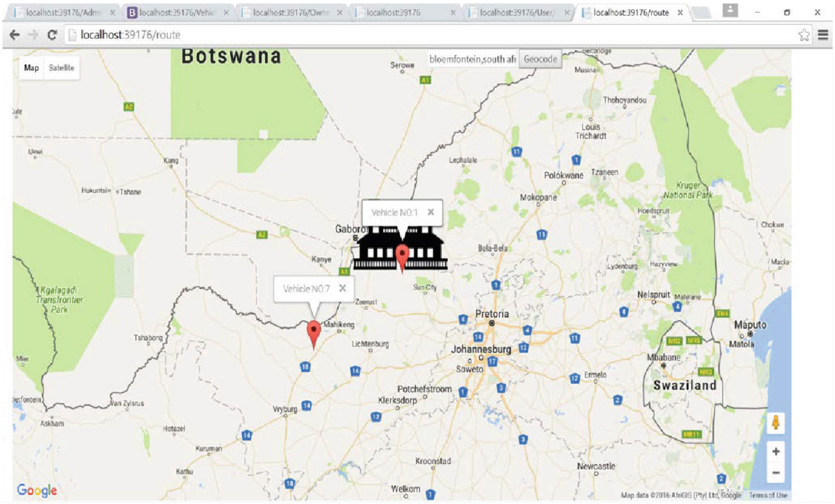


Fig. 9. Web application map page

4 QoS and QoE of the Framework

QoS is measuring the quality level of the offered service. The framework offered some services to achieve this goal like notifying the driver of the next stop, as well as showing the driver, and other notifications can be used like detour, accidents, or congestion, which also available for the passengers to be notified with the delay [23].

QoE was represented by the satisfying level of the participants, and in this study that mainly was the passengers. Dissatisfying of the passenger can be caused by waiting for long time without having a chance to use this time, or waiting for a trip that was cancelled or delayed without their knowledge. The designed framework was designed to avoid such things in order to improve the QOE by using real-time monitoring, and notifying services [24].

5 Discussion and Conclusion

Based on the identified problem, a framework was designed to meet the two objectives that were set out in this research. The framework integrates five IoT devices in a generic fashion such that it is scalable to help using it in any other places. This was made possible by the layered approach that was used; the framework has different layers that serve at different levels (application layer, devices layer, communication layer, service layer, and infrastructure layer). In order to evaluate the framework, a working smart public transport system prototype was implemented and tested using both web applications, and the mobile template which has been discussed previously in a different scenario.

In conclusion, the paper demonstrates the successful achievement overall objective of this research – development of a generic framework that integrates IoT into the public transportation sector of resource-challenged medium size city. Having worked for the Free State, the framework can be adapted and extended to work for city with similar context.

Future work can be made by applying this framework on other public transportation systems such as trains, and by activating USSD application for the non-smart phone users.

Finally, the short comes was encouraging the public transport system to apply the framework by implement those identified sensors to enable the IoT technology which is going to improve the both QoS, and QoE.

References

1. Gama, K., Touseaui, L., Donsez, D.: Combining heterogeneous service technologies for building an internet of things middleware. Comput. Commun. **35**(4), 405–417 (2012)
2. International Telecommunication Union: ITU Internet Report 2005: The Internet of Things. International Telecommunication Union, Geneva (2005)

3. Jain, A.K., Hong, L., Pankanti, S.: Internet of things - strategic research roadmap. Technical report, Cluster of European Research projects on the Internet of Things, September 2009. http://www.internet-of-things-research.eu/pdf/IoT_Cluster_Strategic_Research_Agenda_2011.pdf
4. Borgia, E.: The internet of things vision: key features, applications and open issues. Comput. Commun. **54**, 1–31 (2014)
5. Ray, P.P.: A survey on internet of things architectures. J. King Saud Univ.-Comput. Inf. Sci. **30** (2016)
6. Behrendt, F.: Why cycling matters for smart cities. Internet of bicycles for intelligent transport. J. Transp. Geogr. **56**, 157–164 (2016)
7. Padrón, G., García, C.R., Quesada-Arencibia, A., Alayón, F., Pérez, R.: Using massive vehicle positioning data to improve control and planning of public road transport. Sensors **14** (4), 7342–7358 (2014)
8. García, C.R., Pérez, R., Lorenzo, Á., Quesada-Arencibia, A., Alayón, F., Padrón, G.: Architecture of a framework for providing information services for public transport. Sensors **12**(5), 5290–5309 (2012)
9. Neisse, R., Baldini, G., Steri, G., Mahieu, V.: Informed consent in internet of things: the case study of cooperative intelligent transport systems. In: 2016 23rd International Conference on Telecommunications (ICT), pp. 1–5. IEEE, May 2016
10. Kaiwartya, O., et al.: Internet of vehicles: motivation, layered architecture, network model, challenges, and future aspects. IEEE Access **4**, 5356–5373 (2016)
11. Datta, S.K., Da Costa, R.P.F., Härri, J., Bonnet, C.: Integrating connected vehicles in internet of things ecosystems: challenges and solutions. In: 2016 IEEE 17th International Symposium on A World of Wireless, Mobile and Multimedia Networks (WoWMoM), pp. 1–6. IEEE, June 2016
12. Rakotonirainy, A., Orfila, O., Gruyer, D.: Reducing driver's behavioural uncertainties using an interdisciplinary approach: convergence of quantified self, automated vehicles, internet of things and artificial intelligence. IFAC-PapersOnLine **49**(32), 78–82 (2016)
13. Yelmarthi, K., Abdelgawad, A., Khattab, A.: An architectural framework for low-power IoT applications. In: 2016 28th International Conference on Microelectronics (ICM), pp. 373–376. IEEE, December 2016
14. Mhlaba, A., Masinde, M.: Implementation of middleware for internet of things in asset tracking applications: in-lining approach. In: 2015 IEEE 13th International Conference on Industrial Informatics (INDIN), pp. 460–469. IEEE (2015)
15. Zhang, N., Chen, H., Chen, X., Chen, J.: Semantic framework of internet of things for smart cities: case studies. Sensors **16**(9), 1501 (2016)
16. van Ryneveld, P.: 15 Year Review of Public Transport in South Africa with emphasis on metropolitan areas. Hunter van Ryneveld (Pty) (2008)
17. Berg, R.: Cape Town launches mobile transport app. BDlive, 20 October 2014. https://www.techcentral.co.za/cape-town-launches-transport-app/51895/
18. Sanral: Cameras. Sanral, South Africa (2017)
19. Uber: Uber Cities (2017). https://www.uber.com/en-ZA/cities/. Accessed 29 Nov 2017
20. National Household: Statistics South Africa (2014)
21. Avenri, E.: A cumulative prospect theory approach to passengers behavior modeling: waiting time paradox revisited. Taylor and Francis (2004)
22. Johnson, B., Turner, L.A.: Data collection strategies in mixed methods research. In: Handbook of Mixed Methods in Social and Behavioral Research, pp. 297–319 (2003)
23. Singh, J., Singh, K.: Congestion control in vehicular ad hoc network: a review. In: Lobiyal, D.K., Mansotra, V., Singh, U. (eds.) Next-Generation Networks. AISC, vol. 638, pp. 489–496. Springer, Singapore (2018). https://doi.org/10.1007/978-981-10-6005-2_49
24. Hoßfeld, T., et al.: The memory effect and its implications on web QoE modeling. In: Teletraffic Congress (ITC), 6–9 September 2011, pp. 103–110 (2011)