S	
E1	
E2	
For Office Use Only	

Masters Project Final Report

(MCS)

2019

Project Title	RSSI Based Real-time and Secure Parking Management System
Student Name	W.A.L.T.C. Weliwita
Registration No. & Index No.	2016/MCS/014 | 16440149
Supervisor's Name	Dr. Hiran Ekanayake

For Office Use ONLY

RSSI Based Real-time and Secure Parking Management System

A dissertation submitted for the Degree of Master of Computer Science

W. A. L. T. C. Weliwita
University of Colombo School of Computing
2019

Declaration

The thesis is my original work and has not been submitted previously for a degree at this or any other university/institute.

To the best of my knowledge it does not contain any material published or written by another person, except as acknowledged in the text.

Student Name: W.A.L.T.C. Weliwita

Registration Number: 2016/MCS/014

Index Number: 16440149

____

Signature: Date: 2020-11-09

This is to certify that this thesis is based on the work of Mr./Ms. W.A.L.T.C. Weliwita under my supervision. The thesis has been prepared according to the format stipulated and is of acceptable standard.

Certified by:

Supervisor Name: Dr. Hiran Ekanayake

____

Signature: Date:

Abstract

Vehicle parking has become a great concern that arise vital issues due to rapidly growing number of vehicles in the world. Numerous Wireless Sensor Network based Parking management systems have been introduced to overcome the issues related to vehicle parking. However, the current WSN based parking management systems consists of noticeable drawbacks including lack of scalability, lack of standard security mechanisms and high susceptibility to external interferences. The study adheres to Design Science Research methodology. The current WSN based parking management systems were critically analyzed to identify the defects and propose a solution. The study proposes and develops a novel Received Signal Strength Indicator based approach for detecting unoccupied parking slots in a parking lot. The proposed solution detects occupied parking slots and provide a real-time representation of available slots. It employs a lightweight and scalable communication protocol, that is Message Queuing Telemetry Transport protocol. The RSSI based distance calculation algorithm proposed by Xiuyan Zhu's and non-Linear Least Square method is used to calculate the vehicle positions. The vehicle owners and administrative staff can connect to the Parking Management System via a mobile application to view information on parking slot availability, parking history and unauthorized parking.

The artifacts were developed based on the proposed research design. The artifacts were evaluated based on accuracy, scalability, usability and security criteria. Based on the evaluation results, it was evident that the proposed solution is accurate, highly scalable, secure and user friendly. The proposed solution provides accurate results only on parking lots with flat surfaces. Further studies need to be conducted in order to extend the solution to parking lots with slanted surfaces.

Preface

The author carried out the problem identification and research problem definition. The literature review, research approach and proposed system architecture are entirely authors original work. The RSSI based distance calculation algorithm proposed by Xiuyan Zhu is used in this study. Furthermore, The Apache foundation developed Non-Linear Least Square solver method is used in calculating the vehicle node locations. The implementation of the proposed system, evaluation approach and the simulation tool developed for evaluation are authors own work.

Acknowledgement

I would like to express my deepest gratitude to my supervisor, Dr. Hiran Ekanayake for providing support, guidance, understanding and the encouragement throughout the research study to make it a success.

In addition to that, I would be grateful for the research course coordinators who supported in the submissions as well as provide materials for technical writing to improve the quality of the thesis.

I would like to show my sincere gratitude to my parents and family members who supported me throughout this journey in every possible way.

Finally, my appreciation is also extended to all the people who supported me to fulfil the goals and objectives of the research study.

Table of Content

List of Figures

List of Tables

List of Acronyms

WSN - Wireless Sensor Networks

RFID - Radio Frequency Identification

RSSI - Received Signal Strength Indicator

GPS – Global Positioning System

TLS - Transport Layer Security

API - Application Programming Interface

DoS - Denial of Service

ANPR - Automatic Number Plate Recognition

ToF - Time of Flight

MQTT - Message Queue Telemetry Transport

1 Introduction

1.1 Background to the Research

The rapid growth of the number of vehicles in the world has introduced vital concerns related to vehicle parking. The issues arise with the vehicle parking mainly affect the vehicle owners, passengers, administrative parties of parking lots, security personnel and general population who use the premises [1]. Parking availability is one of the critical issues that vehicle owners face. It takes considerable time and effort to discover an available parking space that fits the vehicle [2]. In some occasions, vehicles must move around the premise to find a parking slot, which can cause unwanted traffic inside the premise as well as cause disturbances to the population who utilize the premise. According to a recent research conducted by INRIX, vehicle owners spend 17 hours on average per year searching for parking space on the streets as well as inside parking lots [3]. Apart from the time taken to search an available parking slot, there are numerous issues related to security and effectiveness of the vehicle parks.

Vehicle owners tend to park in unauthorized places such as roadsides or parking slots that were reserved for other vehicles, due to unavailability of parking slots. This can cause unnecessary on-premise traffic, disturbances for other vehicle owners as well as for the administration of the premise. Considering the above facts, it is crucial to find out if and where the available parking slots are before entering the premises, to avoid latency and unnecessary traffic inside the premise. As security is a major concern for the premises more than ever, it is of great interest for security personnel in the premise to detect unwarranted vehicles entering the premise. The unwarranted vehicles not only become a threat to the people inside the premise, they cause disturbances by occupying parking spaces that were dedicated for authorized vehicles [4]. Moreover, in order to verify that the vehicles are parked in the dedicated parking lot based on the vehicle owners' privileges as well as the vehicle class. As an example, lecturers have dedicated parking slots inside a university premise, and students are not allowed to park in these slots. parking administrative personnel can take immediate decisions that enforces security of the premise if such unauthorized parking of vehicles can be detected real time.

The vehicle parks are designed in a way that different vehicle classes such as cars, motor bicycles, heavy vehicles etc. have dedicated zones/parking slots. It is crucial for parking administrative personnel to determine that the vehicles are parked in their respective zone to utilize the available parking spaces.

As a summary, discovering available parking slots, illegitimate parking of vehicles, parking vehicles outside their respective area based on vehicle class are major issues related to vehicle parking. The above-mentioned parking issues causes latency, unwanted traffic, security violations and disturbances to the people who use the premise.

Various vehicle parking Management Systems implemented with the aim of solving issue of detecting unoccupied parking spaces. Wireless Sensor Network based solution are more popular due to low cost and the high availability of sensor devices. The RFID based systems, pressure sensor-based systems and light/acoustic sensor-based systems are among popular Wireless Sensor Network based solutions. The parking management systems that were analyzed in the literature review contain considerable defects such as accuracy depending on external environment factors, lack of scalability and security.

The Received Signal Strength Indicator (RSSI) is a mechanism that is used to detect distance between objects in a Wireless Sensor Network [5]. Triangulation is a mathematical technique that is used to detect the location of an object based on several known reference points and distances to them. Triangulation is used in Global Positioning System to detect the location of a device using distances to GPS satellites [6]. Triangulation can be used in Indoor Localization to detect an object location inside a building or a small geographical area with a local coordinate system. None of the previous studies had analyzed the applicability of RSSI and trilateration-based techniques to achieve secure and scalable solution to the parking problem.

The study Proposes a novel, Received Signal Strength Indicator (RSSI) based solution combined with triangulation technique to detect available parking slots. Moreover, The Non-Linear Least Square method is employed to calculate the vehicle location with minimum effect from the external interferences. Message Queuing Telemetry Transport (MQTT) protocol and Transport Layer Security (TLS) mechanism are used in order to achieve efficient, scalable and highly secure communication.

1.1.1 Project Objectives

- Detect available parking slots accurately

  Discovering available parking slots is the primary challenge that the vehicle owners face. Proposed solution detects occupied parking slots and provide information about the available parking slots real-time. The vehicle owner can discover the locations of available parking slots even before entering the premise. RSSI and triangulation-based technique is implemented to detect the available parking slots.

- Keep track of the parked location of each vehicle

  Vehicle owners may tend to forget the location where they parked the vehicle if the parking lot is large. The proposed solution keeps track of each vehicle parked and represents the parked parking slots in a map view. The vehicle owners can view the occupied slot of their vehicle and the parking administration/security staff can view every vehicle that entered the parking lot.

- Prevent intruder vehicles accessing the car park

  Security is one of the major concerns for not only the parking lot, but for the whole premises that the car park belongs. In order to detect authorized vehicles, each vehicle node is given a unique identifier and credentials. Vehicle authentication is performed using control nodes deployed in the car park at the entrance gate.

- Detect vehicles parked on unauthorized parking slots

  Parking slots in premises such as universities and Offices have dedicated parking areas for different type of employees as well as based on the type of vehicle. Some drivers may park their vehicle on parking slots that they are not authorized to. The proposed RSSI based parking management system can identify each individual vehicle and where it is parked. Thus, the parking management system filters out all the unauthorized parked vehicles with their information that can be used by the parking administrators.

  The proposed RSSI based parking management system proactively prevent unauthorized parking by showing available parking slots based on the drivers parking privileges as well as vehicle type.

- Provide statistics of the on-premise parking information

  The proposed solution records the parking history of the vehicles that represent the occupied parking slot and the time duration of the occupancy. The recorded data can be utilized to generate valuable information such as average number of vehicles parked on weekdays, average duration of parking for different vehicle classes. The calculated information can be used to make crucial decisions such as redesign the parking areas, extending the parking space, suggest additional security measures for preventing intruder parking.

1.1.2 Scope of the study

This project aims at proposing a Parking Management System that detect available parking slots real-time, identify intruder vehicles entering the car park by validating the vehicles upon entering and detect unauthorized parking of the vehicles.

1. Proposed System's Deployment Scope

The proposed RSSI based Parking Management System can be implemented/deployed in any car park on a premise such as a University, Office or a Hotel. The proposed system consists of four main layers. The layers can be named as edge layer, intermediate layer, data access layer and presentation layer which described in Methodology chapter. For the edge layer to function, the reference nodes that are used for RSSI triangulation needs to be deployed in each parking slot. Furthermore, the vehicles need to equip with the sensor node proposed in Methodology chapter as well as the parking lot information such as each parking slots location coordinated, and dimensions need to be pre-configured in the database.

The aimed users of the proposed solution are vehicle owners, administrators of the vehicle park and security personnel of the premise.

2. Proposed System's Hardware Scope

The available parking slots are detected based on RSSI and triangulation mechanisms. Thus, the main functionality of the system is taken care on the edge layer's Wireless Sensor Network. This project does not implement any hardware devices for the proposed solution as commercially available sensors and intermediate devices are used. The project designs an architecture that utilizes the hardware, representing their interconnections and the physical locations of the reference hardware needed.

3. Proposed System's Network Communication Scope

The network connectivity between the edge sensors, mobile devices and upper layers are based on Open Systems Interconnection (OSI) model. This project does not propose a novel network protocols or end to end (transport layer) connection mechanisms, as existing protocols used for the connections.

1.2 Research problem and Research Question

The previous implemented WSN based vehicle parking Management Systems consist of considerable defects such as accuracy depending on external environment factors, lack of scalability and security raising the need of a highly accurate, scalable and secure solution. RSSI based techniques are popular among indoor localization approaches to identify distances between two objects. None of the previous studies had analyzed the applicability of RSSI and trilateration-based techniques to achieve secure and scalable solution to identify available parking slots. The study Proposes and designs a novel, Received Signal Strength Indicator (RSSI) based solution combined with triangulation technique to detect unoccupied parking spaces. Moreover, the accuracy, scalability, usability and the security of the proposed approach is evaluated and compared with the existing solutions.

None of the previous studies have proposed a RSSI based solution for detecting available parking slots. Thus, the accuracy of the proposed solution is compared with detecting the available parking slots by human eye. Detecting available parking slots with human eye considered to be 100% accurate.

Research Question 1:

"How does proposed novel RSSI based approach impact the accuracy of identifying occupied parking slots?".

Hypothesis:

"When proposed RSSI based approach used, the average accuracy of identifying occupied parking slots remains above 70%".

Null Hypothesis:

"When proposed RSSI based approach used, the average accuracy of identifying occupied parking slots falls below 70%".

The RSSI based approach directly depends on the Wi-Fi signal strength that is received from reference access points. Thus, it is essential to evaluate the impact on the accuracy when the distances between the Wi-Fi nodes increases.

Research Question 2:

“What is the impact on accuracy of the parking slot availability calculation of the proposed approach when the parking lot size increases?”.

Hypothesis:

“When the parking lot size increases by 2.5 times, the accuracy remains above 70% for 100 test iterations”.

“There is no statistically significant accuracy reduction when the parking lot size increases by 2.5 times”.

Null Hypothesis:

“When the parking lot size increases by 2.5 times, the accuracy drops below 70% for 100 test iterations”.

“There is a statistically significant accuracy reduction when the parking lot size increases by 2.5 times”.

The performance of a parking management system is one of the important aspects as the system should provide real-time representation of the parking slot availability even with large number of vehicles in the parking lot.

Research Question 3:

“What is the impact on response time of vehicle location update request when the total number of vehicles in the parking lot increases?”.

Hypothesis:

“There is no statistically significant increase in response time when the total number of vehicles in the parking lot increases”.

Null Hypothesis:

“There is a statistically significant increase in response time when the total number of vehicles in the parking lot increases”.

Security is an essential element in every software/hardware system. As the proposed system is a WSN based system, it is vulnerable to both software and hardware related security threats. Thus, it is crucial that the proposed solution is highly secure to be able to use as a real-world application. Since the proposed system uses low processing power sensors, it is important to know what the impact on the performance is when the security mechanisms are in place.

Research Question 4:

"What is the impact on response time of vehicle location update request when TLS mechanism are in place?".

Hypothesis:

"There is no statistically significant increase in response time when the TLS mechanism are in place".

Null Hypothesis:

"There is a statistically significant increase in response time when the TLS mechanism are in place".

1.3 Justification for the Research

The chapter 1.1 identified that discovering an available parking space is a major problem that vehicle owners face. Among the current studies that aims to solve this problem, the WSN based solutions are more popular due to relatively low cost and wide availability of sensor devices. Due to the major issues that the existing WSN based solutions have, a need for an accurate, scalable and secure solution arises.

Indoor localization is a popular research topic that aims at identifying the location of an object inside a building or a small geographical area that GPS can’t be used [7]. Nonetheless, the current research studies have not analyzed the use of indoor localization technique such as RSSI based triangulation techniques to identify available parking spaces. Thus, there is a research gap to identify the use of RSSI based techniques to calculate the parking space availability. The study aims to fill the identified research gap by proposing a novel RSSI based solution to the identified parking availability problem.

1.4 Methodology

The study follows the Design Science Research approach as the research methodology introduced by Kuechler & Vaishnavi [31]. It is essential to evaluate the practical usage of the proposed solution in real world rather than only proposing a solution. The design science research methodology allows this by suggesting developing artifacts based on the design. The developed artifacts can be evaluated to find out the applicability of the proposed solution to real world. Therefore, the study delivers a product according to Design Science Research approach. Chapter three defines and introduces the research methodology in detail followed by the higher-level architecture of the proposed solution.

1.5 Outline of the Dissertation

The chapter one identifies and defines the research problem that the study aims to solve. The main stakeholders of the problem are identified along with the higher-level requirements of the identified stakeholders.

The chapter two identifies the similar WSN based solutions to the identified problem and critically analyze their design, advantages and flaws. Further, the theories and methods that are used in this study is presented in detail.

The chapter three defines the research methodology the study uses and justifies the selection of the methodology. Furthermore, this chapter describes the higher-level architecture of the proposed solution, the modelling diagrams that are formulated and UI designs.

The chapter four compiles the tools and technologies that used to implement the proposed architecture in chapter three. Moreover, the third-party software tools that were used are described and the deployment details of the proposed solution are presented. Finally, a cost analysis of the proposed solution deployment followed by a cost comparison with industrial systems are presented.

The chapter five describes the evaluation approach and criteria that is used in the study. The tools that are used and the datasets generated in order to carry out the evaluation are described in detail. The evaluation results for each evaluation criteria are presented and compared with similar systems.

The chapter six concludes the research study by providing an overall summary of the literature, design and evaluation of the study. Moreover, the limitations of the research study are identified and the future work that needed are described.

1.6 Delimitations of Scope

The research study analyses and employs RSSI based distance calculation algorithm that only takes 2-dimentional plane into account [8]. This means that the algorithm can only calculate distances accurately, when the objects are at same height. Due to this, the proposed solution limits to parking spaces with flat surface.

1.7 Conclusion

The chapter one laid the foundation to the research study by identifying a real-world problem, the affected stakeholders and critically analyzing the existing solutions and their flaws. Next, the research questions were defined, and hypothesis were formulated. The purpose of the research study was justified and the research methodology that the study uses was briefly described. The outline of the dissertation was briefly described, and the limitations of the study was identified.

2 Literature Review

Various parking management systems are introduced to overcome the issues of vehicle parking stated in the problem section. The related work section focuses on compiling the solutions that were previously introduced and critically analyze their advantages and flaws. The WSN distance measuring techniques were identified and critically analyzed to select the most suitable candidate. Moreover, the lightweight communication protocols and security mechanisms that are suitable for WSN are analyzed with the intention of finding a suitable protocol and security mechanism.

WSN composed with a large number of low-cost sensors that are interconnected wirelessly. The sensor nodes in a wireless sensor network are used for collecting, processing and transmitting information that are used in positioning and surveillance [9]. Due to cost effectiveness and availability, Wireless Sensor Networks based systems are getting more popular.

2.1 Parking availability management systems

2.1.1 Intelligent Car Park Management System

A WSN based car park management system consists of magnetic, acoustic and light sensors is discussed [10]. The system consists of two main components, set of low-cost wireless sensor nodes that are deployed in each parking slot, parking management system that makes decisions based on the information provided by the sensors. The aims of the implemented car park management system were listed as reduce manpower costs, minimize human supervision and operations, provide higher flexibility in operations and provide high accuracy.

The figure 2.1 shows the architecture of the intelligent parking management system. The sensor node collects real-time occupation data and periodically reports back to a gateway using wireless communication. The gateway forwards the collected data to a database server via internet. The management system accesses the database to perform functions such as searching for available parking slots, managing security and generating statistical reports.

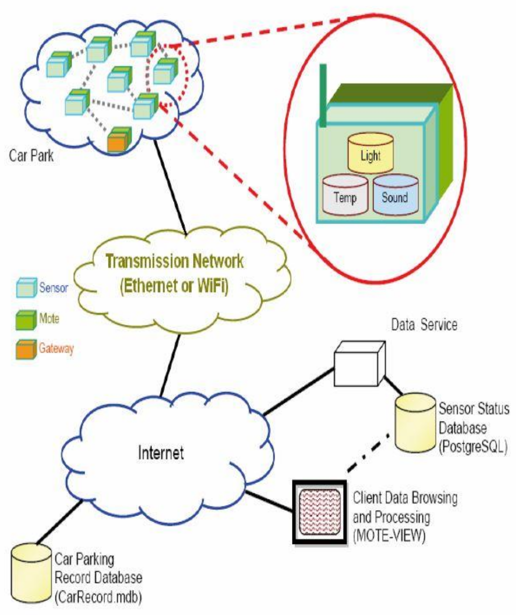


Figure 2.1: Intelligent Parking Management System Architecture [8]

Mainly three hardware components that were used in this system, which are motes, sensor boards and gateways. Motes are battery powered and contains TinyOS as the operating system. Sensor boards are used for data acquisition and directly connected to the motes. The motes are of three types, light sensor, temperature and acoustic sensor motes. Gateway allows sensory data acquisition via RS232 serial interface.

There are few main disadvantages in the analyzed system in [10]. Authentication of the sensor devices are not provided, so the intruders can hack into the sensors and gain unauthorized access. The accuracy of the sensor inputs is highly depending on the ambient condition of the environment such as lighting level and background noise. Furthermore, sensors are deployed in the parking slots and not in the vehicles, due to this, it is not possible individually distinguish the vehicles. So, the system cannot verify that the vehicles are only parked in their respective authorized parking space.

2.1.2 WSN of magnetic sensors for locating parking spaces

A magnetic sensor based WSN designed to locate available parking spaces [11]. The sensors are placed in different positions in the parking lot. The sensor nodes are not placed in each individual parking slot in order to conserve hardware costs. Information from the sensors are combined to determine the number of available locations and vacant parking slots approximately.

The figure 2.2 depicts the implemented magnetic Wireless Sensor Network based system. Two sensor nodes are placed at the entrance and exits of the car park, intermediate sensor nodes are placed in the path, and two or more router nodes placed for data collection. The sensors placed near the entrance and exit count the number of vehicles that enters/ exist the parking lot using magnetic signatures of the vehicles. Intermediate sensors are placed at mid of each lane and at the turning points of the lanes to monitor/estimate the number of vacant parking spots in each lane. Intermediate nodes detect the passing vehicles to determine the occupied and vacant parking slots.

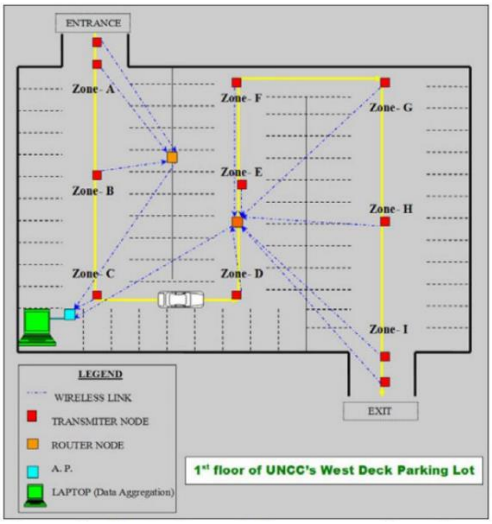


Figure 2.2: Magnetic sensor based WSN model [11]

The main disadvantage of the implemented system is that it only provides approximation of available parking spaces and not an exact number. The magnetic sensors that used in the system is sensitive to environmental issues such as earth’s magnetic fields. Furthermore, magnetic sensors are not intelligent enough to only identify vehicles, in certain situations, system may detect other objects as vehicles. Thus, the measurements can be unreliable at certain conditions [9]. Furthermore, it does not provide authentication for vehicles, due to this, intruder can enter and park.

2.1.3 RFID Based Smart Car Parking System

Infrared transmitters and receivers are used in detecting vacant parking slots in a Radio Frequency Identification (RFID) based smart car parking management system [12]. A visual representation of the current parking slot status is shown to the users with a video display at the entrance of the car park, which shows the vacant parking slots in green and others in red. RFID tag is provided and needs to be placed on the vehicle windshield and this tag contains the user information which obtained from the user registration.

The Infrared sensors in each parking slot is connected to a Raspberry Pi device, that sends the collected data to a database. The video display at the entrance is updated every 5 seconds with the information on the database. When the user enters the vehicle park, the parking management system reads the RFID tag and logs an entry into the database. Upon exit, the database is updated again to indicate that the vehicle left. In addition to the video display, the Raspberry Pi is connected to the google app engine which sends information to mobile app and Twitter. A Twitter bot was implemented to tweet the parking information availability to the users. Figure 2.3 represents the higher-level architecture of the implemented system.

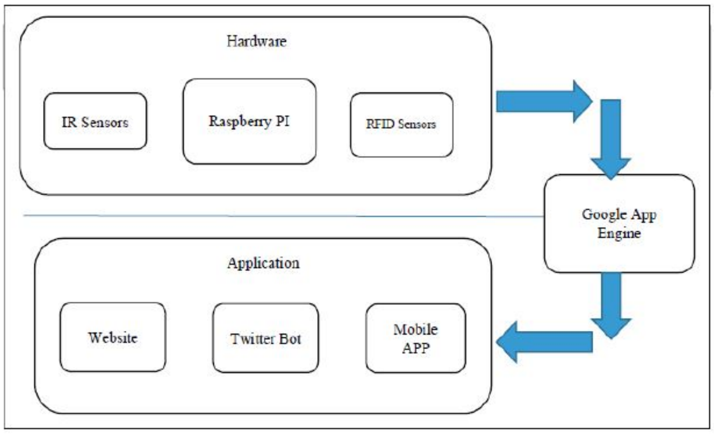


Figure 2.3: Modular architecture of the RFID based smart car parking system [12]

The implemented system contains several disadvantages and issues. The main issue is that the RFID tag in the vehicle contains user’s personal information and payment information which can easily be stolen. Since, the users are not authenticated at the entrance, stolen RFID tags can be used to enter the parking lot which causes a major security issue for the premise and people in the premise. RFID based systems are susceptible to major security attacks such as denial of service attacks [13], node replication and selective forwarding attack and Signal Radio Jamming attack [14].

Considering the above analyzed parking management systems, it can conclude that these systems lack security consideration such as vehicle authentication and features such as authorization based on vehicle class. Furthermore, the accuracy and maximum range of the RFID sensors are depending on the quality of the sensor. A high-quality sensor costs a substantial amount making it costly to deploy in a large parking lot.

2.1.4 Automated Vehicle Parking Management using ANPR

A recent study introduced an automated vehicle parking management system based on Automated Number Plate Recognition [15]. The study argues that the solution was implemented to avoid common problems that the vehicle owners face such as, locate the owner of a vehicle that’s blocking a certain vehicle, finding the responsible person for the damages caused to vehicles, finding vehicles that the owner has forgotten the parked location.

The implemented solution mounts Automatic Number Plate Recognition (ANPR) cameras on the entrance, exit and certain areas inside the parking lot. ANPR is an advanced machine vision technology used to identify vehicles by their number plates without direct human intervention [16]. The parking management system software processes the captured images and a mobile application is implemented for end users to view information. The main advantages of the ANPR Cameras are, ability to view a wider field view of the whole parking lot and suitability in all weather conditions.

The figure 2.4 shows the design of the implemented vehicle parking management system. The information about the vehicles, vehicle owners, parking zones and parking lots are registered in the parking management system. The ANPR cameras are installed on the entrance/exit and inside the parking lot. These cameras capture vehicle license plate numbers when a vehicle enter/exit the car park as well as when parking on a parking slot. The captured license plate numbers are stored in the database. The parking management system stores enter/exit timing information of the vehicles and information about the owner of the vehicle as well as the parking location. The mobile application can be used to find the location where the vehicle was parked and find owner information if any vehicle has blocked the other parked vehicles.

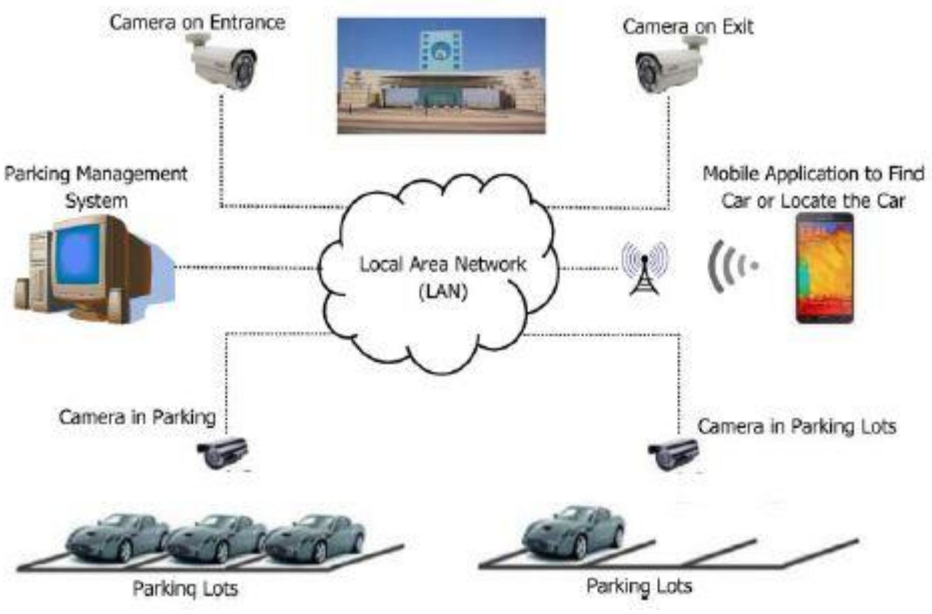


Figure 2.4: Automated Vehicle Parking Management System design [15]

There are some limitations associated with the implemented vehicle parking management system. Due to requiring high performance hardware in order to perform intensive image processing, cost of installation is high. Due to the Number Plate Detection is dependent on ambient lighting, there can be issues when detecting number plated on low light conditions as well as at night. Furthermore, there can be issues with the visibility of the parking lots as some parking lots may not be visible to the cameras. Finally, damaged vehicle identification is not accurate as considers the nearby vehicles that were parked near the damaged vehicle. There can be situations where a vehicle getting damaged by another vehicle which was parked at a distance and while that vehicle entering/exiting parking lot.

2.1.5 Image processing based Intelligent Parking Management System

An intelligent car parking management system based on image sensors was implemented to identify the available parking slots [17]. The implemented system is integrated to an intelligent transport architecture that detect, manage and notify the drives about available parking spaces. The implemented system uses image sensors to capture images of the parking lot. The captured images are sent to a cloud datacenter that performs image processing. The data center is implemented using RESTful web architecture. The drives can use a mobile application that can run on a smartphone or tablet to detect available parking slots.

Each image sensors are connected to a Raspberry Pi model B device that capture an image whenever it detects a motion. Information regarding the parking lot is saved on a SQL database that's hosted on the cloud. Furthermore, a base image that contains all the parking slots is captured and stored for each parking lot. When the vehicles occupy the parking spaces, the motion is detected, an image is captured and sent to the server. The server uses the base image, current image and information about parking slots to calculate the parking slot availability. The OpenCV library was used in developing the image processing algorithm. The calculated availability will be updated in the database and the system draws red rectangles on the occupied slots. The mobile application consists of a grid interface that shows the status of each parking space defined in the system. The study used a scale model of a parking lot with 20 parking spaces to conduct testing. It showed 93% accuracy on the tested scale model.

The parking management system depends on image sensors to capture the parking space availability. Thus, the system accuracy is highly affected by the lighting conditions of the parking lot. Furthermore, it requires a costly infrastructure setup and high bandwidth to send the images to the cloud and process them.

Table 2.1 compares the proposed novel approach with the current WSN based smart parking management systems.

Table 2.1: Comparison between present solutions and Proposed Solution

System	Cost	Security	Timeliness	Accuracy	Detect Individual Vehicles	Detect unauthorized parking	Scalability	Reusability
Magnetic sensor based	Low	No Security (1*)	Real-time	Medium: Depends on magnetic interferences	No	No	Low (2*)	Low (2*)
RFID based	Low	No Security (1*)	Real-time	High	No	No	Low (2*)	Low (2*)
Light sensor, temperature and acoustic based	Medium	No Security (1*)	Real-time	High	No	No	Low (2*)	Low (2*)
ANPR Camera based	High	High	Real-time	Medium: Depends on ambient lighting	Yes	No	Medium (2*)	Medium (2*)
Image Sensor Based	High	Medium	Real-time	Medium: Depends on ambient lighting	Yes	No	Medium (2*)	Medium (2*)
Proposed RSSI based	Low	High: Uses authentication/ TLS Certificates	Real-time	High (3*)	Yes	Yes	High: Does not have a sensor in each parking slot/ Uses MQQT protocol	High: Less hardware and minimum software configuration needed/ easily deployable

Special Notes:

1* - Due to No authentication mechanism provided

2* - Due to Sensors deployed in each parking slot

3* - RSSI location calculations are susceptible to interferences. However, accuracy of parking slot detection increased using Non-linear Least Square method.

2.2 Distance Measuring using WSN based Techniques

Provide parking slot availability data to vehicle owners is the most important function of the proposed system. Thus, a reliable and accurate technique needs to be suggested to find out the locations where the vehicles are parked. Furthermore, based on the parked vehicle location, system should calculate which parking slots are occupied by the vehicles. In this section, the distance measuring techniques are evaluated in order to choose the mostly suited technique.

2.2.1 Comparison between WSN based Distance Measuring Techniques

a. Received Signal Strength Indicator (RSSI)

The Received Signal Strength Indicator is one of the widely used and simple approach for indoor localization that calculate the location of a node based on the signal strength that received [18]. The RSSI can be used primarily to measures the distance between a signal transmitter and a receiver based on the receiver ends signal strength. In order to measure the distance from a received signal, a known reference RSS value is needed. The formula to calculate the RSS is shown below.

$$RSSI = -10n \log10(d) + A$$

In the formula, A is denoted as the RSSI value at a known reference distance from the receiver and n is the path loss component. N-Point Lateration can be used to calculate the location of a node using the calculated RSSI values. In this method, there are N number of nodes with known locations and RSS is calculated for signals received by the each of the nodes at another location unknown node. Based on the RSSI of reference nodes, the distances from each node are calculated and based on the distances, the location of the unknown node is calculated. The trilateration is the most widely used N-Point Lateration technique that uses three nodes with known location. Cost effectiveness and simplicity of the algorithm are the main advantages of using RSS based approach over other localization approaches [19]. Furthermore, RSSI technique does not require additional hardware as the RSS can be detected by using already available Wi-Fi sensor, and not having a significant impact on the local power consumption [20]. The figure 2.5 shows the RSSI based location calculation.

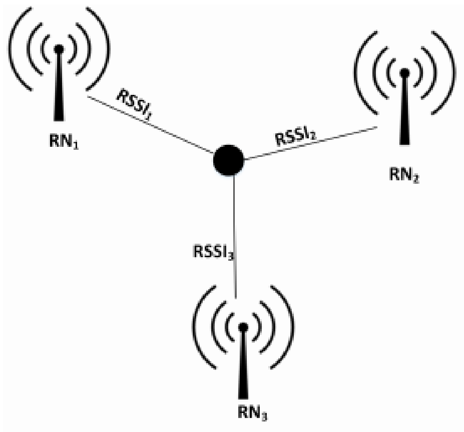


Figure 2.5: RSSI based location calculation [21]

b. Time of Flight (ToF)

Signal propagation time is used to calculate the distance between the transmitter and the receiver [21]. As the signals are propagated with the speed of light, multiplying the signal propagation time with the speed of light, the distance between nodes can be calculated. Similar to calculating the unknown nodes location in RSSI approach, ToF approach uses three reference nodes to calculate the location using distances calculated.

The bandwidth of the signal is the key factor that affects the accuracy of the calculation. When the bandwidth is higher, the accuracy of the distance estimate is higher. However, when a direct line of sight is not available between transmitter and the receiver, the ToF approach has higher error rates [21]. The ToF approach requires synchronization of clocks between the transmitter and the receiver. Due to this, the timestamps need to be transmitted with the signals.

c. Angle of Arrival

The Angle of Arrival approach uses a set of antennas at receiver's side in order to measure the angle of the signal which received by the receiver node [19]. The time difference of the signal receiving at each antenna is used to calculate the arrival angle. This technique provides accurate results when the distance between the transmitter and the receiver is small. When the distance is larger, it needs complex hardware and antenna calibration in order to provide a higher accuracy. Furthermore, the accuracy of the calculation can deteriorate due to distortion and multipath propagation of the signals.

According to the table 2.2, the RSSI does not depend on antenna angles or bandwidth. Furthermore, antenna calibration or clock synchronization is not needed as in Time of Flight and Angle of Arrival methods. Based on the analysis and comparison of available distance measuring techniques, RSSI is the most suitable technique for calculating the location of parked vehicles.

Table 2.2: Comparison between different distance calculation techniques

Technique	**depends on angle of the antenna**	**Direct line of sight needed between nodes**	**Depends on network bandwidth**	**Antenna calibration needed**	**Clock synchronization needed**	**Depends on electro - magnetic interference**
RSSI	No	No	No	No	No	Yes
Time of Flight	No	Yes	Yes	No	Yes	No
Angle of Arrival	Yes	Yes	Yes	Yes	No	Yes

2.2.2 Increasing RSSI Distance Calculation and Trilateration Accuracy

2.2.2.1 Increasing the accuracy of the distance calculation between WSN nodes

RSSI is affected by two main groups of factors that causes errors in localization measurements and reduce the accuracy. There two groups can be named as device errors and environmental errors. Device errors are caused by calibration errors. Device errors can be avoided by using a battery power supply that provides nearly constant power to the device. The environmental errors are caused due to electromagnetic interferences from other nodes that provide radio frequency waves, shadowing effect, and multipath propagation [23].

RSSI value is inversely proportional to the squared distance between the transmitter and the receiver. The above-mentioned factors can cause the relationship between the distance and transmitted power to be different than expected.

The distance measuring calculation formula introduced as,

$$RSSI = -10n \log10(d) + A$$

In the formula, the path loss component denoted as "n". The path loss component is a coefficient that depends on the environmental conditions. The path loss coefficient can vary between 1.6 to 6 depending on the environmental factors such as electromagnetic interreferences and temperature.

The path loss coefficient is a constant in the original distance measuring formula. However, the accuracy of the distance calculation can be increased by recomputing the path loss coefficient according to the changing environmental conditions [23].

$$N = RSSI + A / -(10 \log (10) d)$$

In order to recompute the path loss coefficient, a reference anchor node needs to be introduced. As the distance to the reference anchor node from the base node is already known and both of the nodes are static, the path loss coefficient can be calculated between the reference and base node. The above equation can be used to calculate the path loss coefficient and the calculated coefficient can be used to calculate the distances to the unknown node using the original formula.

Figure 2.6 shows the design of the WSN nodes for calculation the distance of a moving node using 3 anchor nodes and a reference anchor node. The moving node periodically transmits signals continuously and the anchor nodes that are located at four corners calculate the signal strength (RSSI) transmitted by the moving node. Each anchor node transmits the calculated signal strengths to the base node. The base anchor node calculates the location of the moving node using the signal strength information transmitted from anchor nodes. The trilateration technique is used to calculate the distance of the moving node using the RSSI received from three anchor nodes.

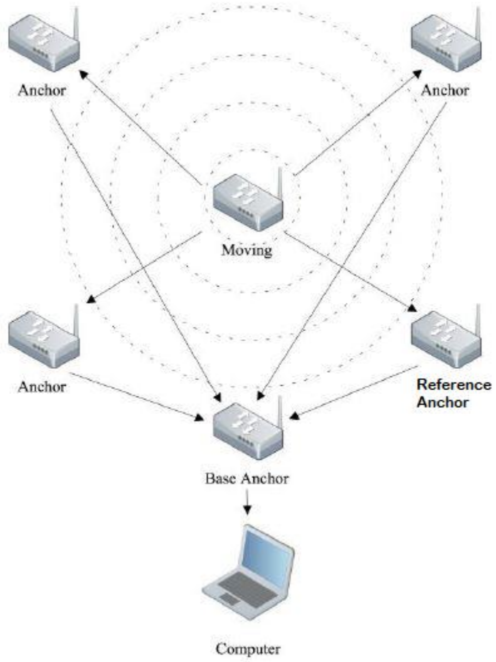


Figure 2.6: Design of the nodes for dynamic path loss coefficient calculation [23]

The path loss coefficient is calculated by the base anchor using the distance between the reference anchor node and the base node. Since the fixed distance between the base station and the reference node is already known, the RSSI from the reference node can be used to produce path loss coefficient at the base node. Thus, the fourth anchor node is used as a distance reference and the base node dynamically calculates the path loss coefficient and use it for calculating distance to the moving node. As the path loss coefficient value is calculated dynamically, the accuracy of the distance calculation at the base node is not affected by environmental changes.

The reference anchor node-based model was compared with the three-node traditional localization model using simulations.

Figure 2.7 shows that the three node and reference anchor node models are compared in three scenarios. Each table show the average, maximum, minimum and standard deviation values calculated for between the moving node location and the calculated location of the node from three node and reference anchor models. The top left table shows the results when the real coordinates of the moving node is (50,50), the top right table shows when the moving node is at (75, 50) and bottom table shows when the moving node is at (28, 37). The reference anchor model shows the closest average result in all the three scenarios.

(50;50)	3 anchor		Reference anchor	
	x	y	x	y
Mean	49.240	52.878	50.589	50.619
Maximum	62.572	60.936	60.289	60.106
Minimum	38.097	45.359	40.347	40.251
Standard Dev.	6.1650	3.362	4.905	4.5923

(75;50)	3 anchor		Reference anchor	
	x	y	x	y
Mean	82.510	54.105	75.765	50.624
Maximum	97.675	63.725	85.964	63.694
Minimum	69.729	44.505	64.390	35.498
Standard Dev.	6.803	4.298	5.4186	6.109

(28;37)	3 anchor		Reference anchor	
	x	y	x	y
Mean	21.517	33.800	28.073	37.261
Maximum	32.240	47.457	35.852	42.079
Minimum	10.128	18.346	16.510	28.925
Standard Dev.	5.726	7.035	4.276	3.263

Figure 2.7: Simulation results between three node and reference anchor node models [23]

The results showed that the reference anchor-based model produces superior results than traditional three node model.

2.2.2.2 Increasing the accuracy of the trilateration location calculation

The trilateration technique uses three or more distances from known set of reference nodes to an unknown node in order to calculate the location of the unknown node.

The location of the unknown node is calculated by taking the distances between the know reference as radiuses and forming circles for each distance value. The overlap point of the circles is calculated, and this will be the location of the unknown node.

The formula in figure 2.8 assumes the distances between the known reference nodes and unknown node form circles that perfectly overlap in a particular location. However, in real situations, the distances calculated by receiving RSSI values often don’t form a perfect overlap. The figure 2.9 shows a perfect overlap in the left side and imperfect overlap in the right side. If the overlap is imperfect, the above formula cannot be solved. Thus, it needs a method to calculate an approximation of the overlapping location in order to calculate the unknown node’s location.

$$r_1^2 = x^2 + y^2 + z^2$$
$$r_2^2 = (x - U)^2 + y^2 + z^2$$
$$r_3^2 = (x - V_x)^2 + (y - V_y)^2 + z^2$$

Thus, letting $V^2 = V_x^2 + V_y^2$, the coordinates of **P** are:

$$x = \frac{r_1^2 - r_2^2 + U^2}{2U}$$
$$y = \frac{r_1^2 - r_3^2 + V^2 - 2V_x x}{2V_y}$$
$$z = \pm\sqrt{r_1^2 - x^2 - y^2}$$

Figure 2.8: Trilateration location calculation formula [24]

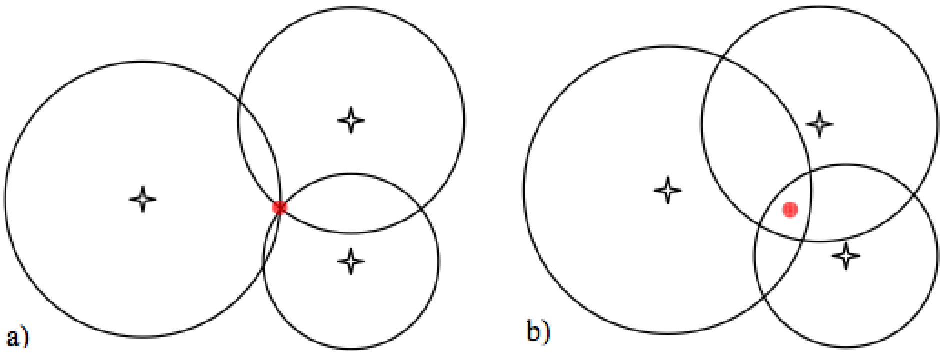


Figure 2.9: Perfect overlap vs real life overlap between circles drawn by distances [25]

The Non-Linear Least Square method is used to fit a set of *m* observations with a model that is non-linear in *n* unknown parameters that is a form of nonlinear regression [25]. This model iteratively approximates the observations to fit the expected curve.

The figure 2.10 shows how Non-Linear Least Square method solves non-linear regressions. The red dots show the approximated values to fit the actual curve show in blue color. The Non-Linear Least Square method iteratively calculates the square difference between the approximated values and the real curve minimizing the total difference.

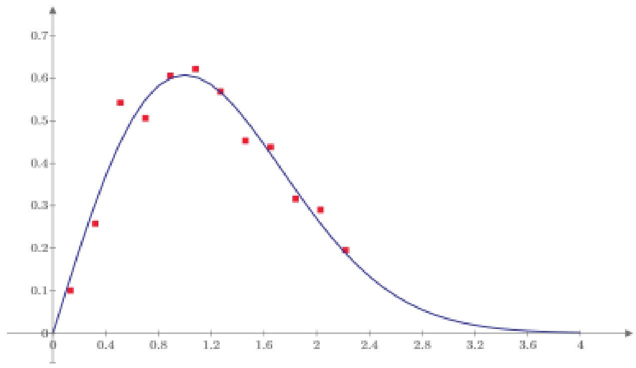


Figure 2.10: Non-Linear Least Square method approximation [25]

2.3 Wireless Sensor Network Scalability

Scalability is one of the leading considerations when designing a Wireless Sensor Network. It is more important in the current study due to two main factors, the timeliness and accuracy requirement and the low processing power and battery power of the edge layer sensor nodes. The proposed parking management system must provide timely and accurate representation of the parking lot, even when the total vehicles in the parking increases. Furthermore, the processor and battery usage should not increase dramatically with the increase of total number of vehicles in the parking lot. In this chapter, a lightweight communication protocol is analyzed based on its scalability, secureness and reliability.

Message Queue Telemetry Transport (MQTT) protocol is a lightweight publish/subscribe network protocol that can be used to transport messages between devices. MQTT protocol runs on top of TCP/IP protocol and designed to be used in networks with limited bandwidth and limited processing power of the devices [24]. Figure 2.11 represents the architecture of the MQTT protocol. MQTT protocol has two main entity types, a message broker and clients. MQTT message broker acts as a server that receives, processes and re-route messages from the clients. MQTT client is a device that connects to a MQQT broker over a network and sends/ receives messages from other clients. The MQTT broker can be deployed on-premise device or in the cloud. The message broker needs to configure message queues named 'Topic' to re-reroute messages to subscribed clients. The clients who wants to receive messages to a specific topic, need to subscribe to that topic. The client who sends out messages to a specific topic is called a publisher and clients who listens to the messages are called subscribers. MQQT supports architecture that multiple publishers can publish different topics to a single subscriber and single subscriber can subscribe to multiple topics. MQTT client only communicates with the broker and has no knowledge of the locations and number of other clients.

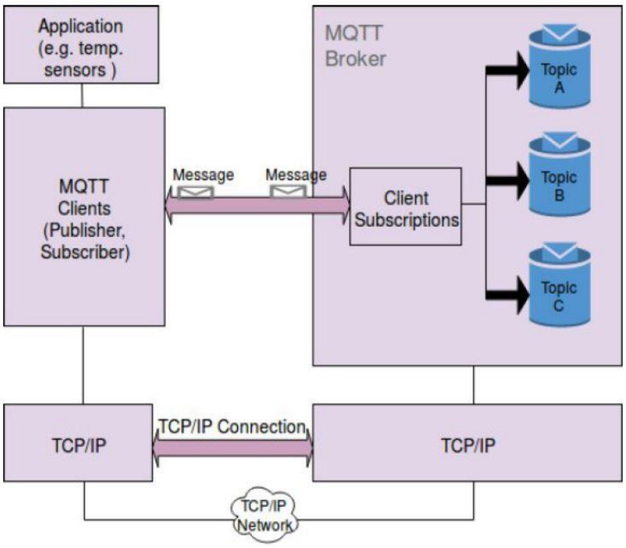


Figure 2.11: MQTT Architecture [27]

There can be multiple brokers configured to one client, in case of primary broker failed to respond, it automatically hands over to backup broker. Furthermore, load sharing can also be configured between backup brokers [26]. MQTT supports TLS encryption to make the connection secure by configuring TLS authentication and certificates [29].

Advantages of using MQTT protocol for a WSN can be listed as below.

1. Supports WSN with low processing and battery powered devices
2. Can work over a low bandwidth network connection
3. High scalability
4. Supports TLS security mechanisms
5. Supports redundancy

2.4 Wireless Sensor Network Security

Security is one of the essential requirements in any Wireless Sensor Network in order to protect the network and its data from intruders. This project addresses the security requirements of the premise such as identifying unauthorized parking of the vehicles in restricted areas. In order to cater for on premise security requirements, each node in the WSN needs to be uniquely identified. Furthermore, the communication between the edge nodes and the control node needs to be secure from intruder inceptions.

According to a recent study [30], confidentiality and integrity are the two major security concerns for transmitting credible information. Most of the security mechanisms that exist to mitigate the security vulnerabilities suffer from computational overhead, communication delay, and complexity in communication, storage requirements and battery life. Thus, it is beneficial to analyze security mechanism that are power and processor efficient.

Digital certificate certifies the identity of the certificate holder using a secure digital key scheme. Digital certificate is issued by a certification authority who is an internationally recognized business entity. Digital certificate is used to digitally sign the information that a node sends, so that the middle parties cannot read or alter the information. The digital certificate can be used to identify the sender that sent data is legitimate as well as the sent data is unaltered, fulfilling both authentication and integrity requirements of a communication. The encryption is usually handled by encryption mechanisms such as Diffie-Hellman or RSA and the trust between nodes are created by Public Key Certificates.

Transport Layer Security (TLS) is a cryptographic protocol that is designed for provide secure communication over a computer network [31]. It encrypts the data traffic between sender and receiver and using digital certificates that creates trust between nodes.

The devices which has low storage/memory use can use public key fingerprints. Public key fingerprint is generated by encoding the digital certificate public key into hexadecimal representation which can be used to identify a longer public key [32]. The WSN with low storage and memory can use fingerprints to create trust between the client node and the service provider server. SHA-1 or MD5 algorithms can be used along with Base64 or Base32 encoding to generate a 64bit or 32bit fingerprint for a digital certificate public key.

The MQTT protocol allows use TLS in order to design secure message queues using digital certificates. The MQTT broker creates a secure key store and generate TLS certificate. The generated certificate needs to be distributed to the clients that access the message broker via a secure channel. For lightweight sensor nodes, a certificate fingerprint can be configured in order to communicate with the message broker. The TLS security mechanism provides two-way trust between the client nodes and the message broker.

3. Research Methodology and Design

3.1 Research Methodology

The study follows the Design Science Research approach as the research methodology. Design Science Research is a mixed method research approach where both quantitative and qualitative methods are used.

According to Kuechler & Vaishnavi [33], "Design Science Research involves creation of new knowledge through design of novel or innovative artifacts and analysis the use and performance of such artifacts along with the reflection and abstraction to improve and understand the behavior of aspects of information Systems."

The effort of design science research aimed towards producing an artifact as a solution to a social or business technology problem. It is difficult to measure in advance the applicability of the proposed method, unless there is designed artifact based on the proposed solution. Thus, Design Science research with its inherent characteristic of producing such artifacts to problems at hand, delivers results with high-perceived value [34].

Evaluating the compatibility of the proposed solution in real world is an essential aspect rather than only proposing a solution. The design science research methodology facilitates the evaluation by suggesting developing artifacts based on the design. The developed artifacts can be evaluated to infer the applicability of the proposed solution to real world. Therefore, the study follows the Design Science Research approach and delivers artifacts based on the proposed design.

According to Figure 3.1, the first step of Design Science research methodology is the awareness of the problem. The awareness gained from knowledge of the problem by studying the relevant domain and literature. The second phase is where a solution is proposed based on the problem awareness. This includes tentatively designing a solution that provide solution to the problem and evaluate its applicability.

In the development phase, the tentative design is further developed and evaluated. Evaluation of the developed artifact follows up next. In the evaluation step, both qualitative and quantitative deviations from the expected results are gathered and evaluated. The results are fed back again to the suggestion stage. Based on the feedback, the design can be changed, the changes can be re-developed and re-evaluated.

Finally, in the conclusion stage, the effort ends when the artifact is judged good enough and the new knowledge learnt are reported and areas that need further research are identified.

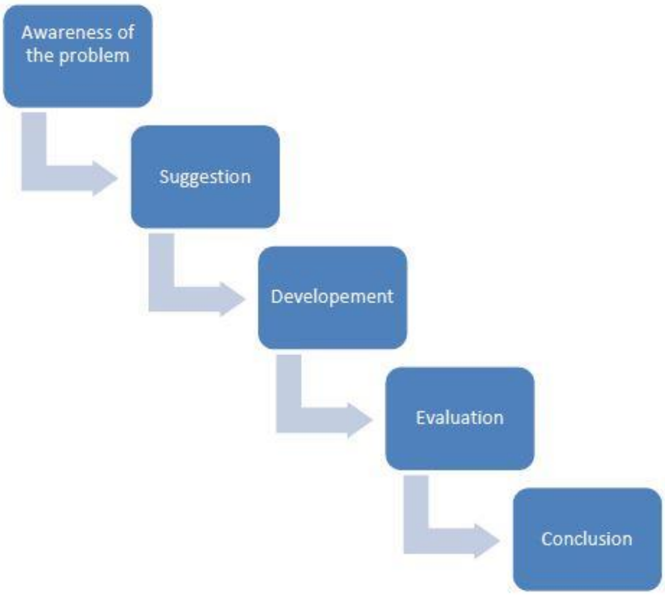


Figure 3.1: Steps of Design Science research methodology [33]

3.1.1 Research Process

Figure 3.2 represents the research process and the following chapter describes each steps.

Phase 1: General Problem Awareness

The initial step of this research starts with problem awareness followed by a brief background study to get an initial understanding about the scope, research goals, and objectives. The awareness of the problem and its background became known by reading research papers in similar domains and through the media.

Phase 2: Literature Review

Literature review is the next stage to identify different types of solutions implemented in the relevant context to address similar research problem. The practicability and feasibility of those solutions were identified, and each solution was compared along with their advantages and disadvantages. Moreover, during this stage, the trilateration algorithms and how to improve the accuracy of the trilateration calculation were analyzed. Furthermore, the security consideration in the Wireless and Sensor Network context were given attention and methods to improve security of the proposed system were analyzed.

Phase 3: System Design

The design phase started with designing the system architecture and depicts different components contained and how they communicate with each other. Next, the business entities were identified, and the use cases were designed. Furthermore, the UML class diagrams, and sequence diagrams were designed to represent the flow of activities and how the user interact with the proposed system. Finally, User Interfaces were designed for the mobile application based on the user experience requirement and design considerations.

Phase 4: System Implementation

In the system implementation phase, the proposed system is implemented based on the outcomes of the literature review and design phase.

According to the system architecture, the hardware and intermediate layer of the system contains embedded devices and they form a wireless sensor network. NodeMCUs are used as end nodes to be deployed in the edge layer and Raspberry Pi is used as the control node in the intermediate layer. The edge layer NodeMCU devices are programmed using Arduino IDE and C++ language, where the intermediate devices (Raspberry Pi) is programmed using Eclipse IDE and Python language.

The database that is used in the proposed system is MongoDB and it is designed and deployed in a remote database server.

A mobile application is developed as the frontend to the target users in order to perform functions such as searching for available parking spaces, manage user owned vehicles and user profile as well as viewing unauthorized parked vehicles.

Phase 5: Evaluation

Under the evaluation phase, the usability of the mobile application evaluated based on a questionnaire given to the target audience. The evaluation conducted on the available functionalities of the mobile application, user friendliness and comparison with similar systems. Responses regarding the usability of the application gathered using a likert scale questionnaire. An open-ended question was used as the final question of this questionnaire to get opinions and further improvements necessary from the viewpoint of the vehicle owner. Therefore, this phase also contributed to the study by generating both quantitative and qualitative data.

The next part of the evaluation phase consisted of evaluating the accuracy and scalability of the proposed solution. In this regard, the proposed system was deployed in a real environment and the functionality such as finding an available parking slot was tested.

In the final step, vulnerability assessment conducted on the proposed system in order to evaluate security considerations that were identified in the literature survey.

Phase 6: Conclusion

Under the conclusion phase, firstly, the research question hypotheses are concluded based on the results of the evaluation. Furthermore, the uniqueness of the proposed solution and main research contributions from the study is presented. Next, future work identified and defined to suggest other researchers about available knowledge gaps.

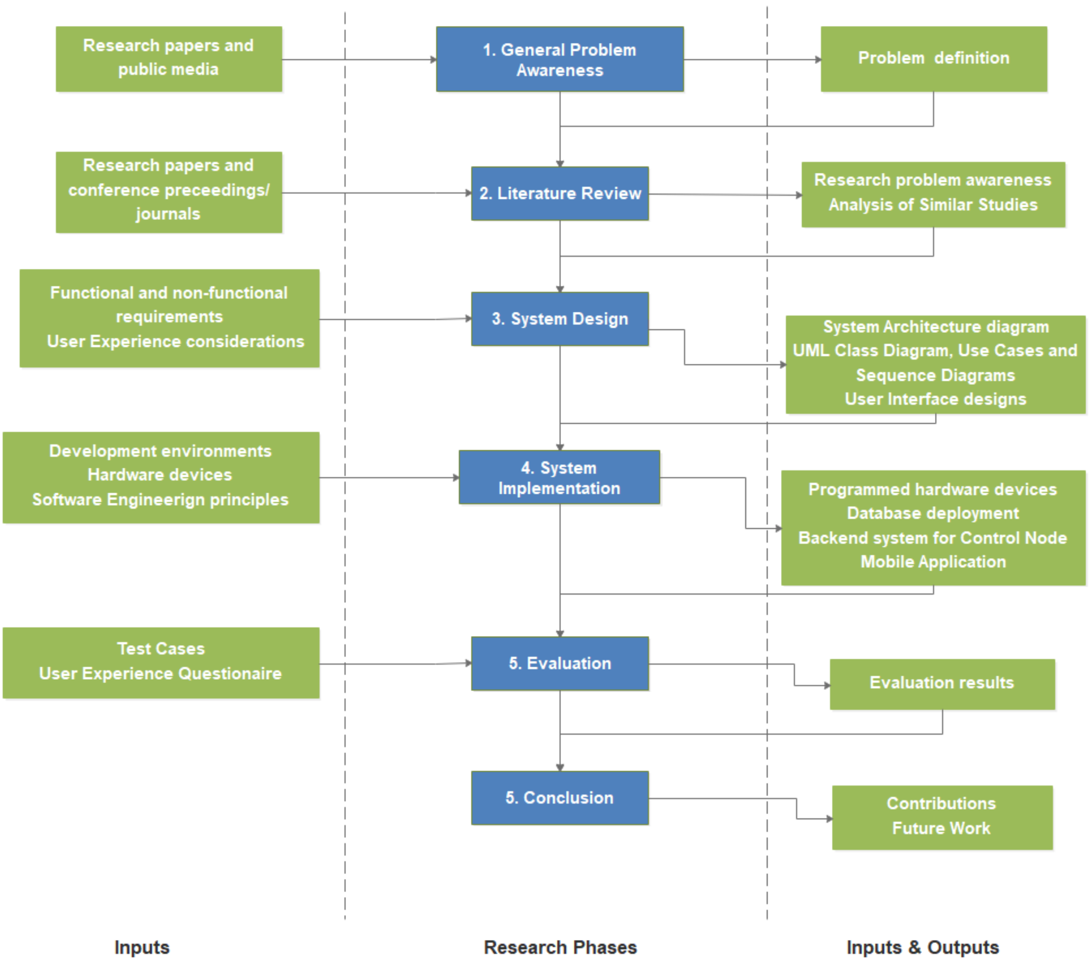


Figure 3.2: Research Process

3.2 System Design

3.2.1 System Architecture

Vehicles are equipped with a sensor device that forms a Wireless Sensor Network of vehicle nodes. Each sensor node in the vehicle contain authentication information to distinguish the vehicle and contain information about the vehicle including owner information, vehicle type and dimensions that aids finding an available parking spot. Each vehicle's position can be calculated using Received Signal Strength (RSS) from the sensors in combination with tri-lateration technique. Based on the calculated positions of the vehicles, the occupied parking slots can be determined. Based on the unoccupied parking slots and information about the vehicle such as vehicle dimensions, available parking slots for the given vehicle is calculated.

Upon entering the premise, the authentication details that are on the sensor is verified. The authentication process aims at identifying intrudes/ unauthorized parties from using the vehicle park. A centralized node handles authentication and managing the network of vehicular sensors.

A mobile application is developed to view parking information. Vehicle owners can view vacant parking spaces through the mobile application. The security personnel can view unauthorized vehicles parked and administrative parties can get to know the vehicles that are parked in unauthorized parking slots.

Database stores the parking information related to occupied parking slots, details of the vehicles that occupies the slot. The mobile device connects to the database to retrieve parking information.

Figure 3.3 describes the high-level architecture of the proposed system. There are four main layers as depicted in the figure. The Edge Layer which contains the sensor devices deployed in vehicles and parking lot and Intermediate Layer contains one or more control nodes. The Data Access Layer contains the data base and finally, Application Layer consists of a mobile application.

The edge layer consists of a WSN of NodeMCU sensor devices that are deployed inside the vehicles and placed on the parking lot. NodeMCU is a low cost, open source IoT platform which uses ESP8266 microchip as the System on Chip (SoC) [35]. The main reasons to select Node MCU is, its ability to support TCP/IP network stack including Wi-Fi networks, cost effectiveness and ability to use Arduino IDE for programming [36].

The Intermediate Layer consist of one or more controller nodes that manages the ad-hoc network of the edge layer devices. RaspberryPi device is used as control nodes as it is cost effective device that has a higher processing capability and efficient power consumption. The edge NodeMCU devices are connected to the intermediate layer via MQTT message queues. The edge NodeMCU devices connects to a preconfigured MQTT message broker using a TLS certificate fingerprint and subscribes to a secure message queue which is dedicated to vehicle nodes. The Control Nodes connects to the message broker using a secure TLS connection and subscribes to a message queue which it receives authentication requests and vehicle update requests. The edge layer NodeMCU devices and intermediate layer Control Nodes communicates with each other by using the above-mentioned message queues. Multiple control nodes in the intermediate layer supports scalability, fault tolerance and load balancing.

The proposed system is designed in a way that edge layer vehicle nodes send location update requests to the control nodes in a round robin fashion. One control node act as a primary control node and handles the vehicle node authentication. Each control node has a unique sequence number pre-configured and the number of control nodes in the parking lot is communicated to each vehicle node when the vehicle node first authenticates. The vehicle nodes then send the location update requests with a sequence number. The control nodes verify the received message’s sequence number and only processes the message if its own sequence number.

The primary control node performs the authentication of the edge devices in the network and keeps track of the sensor positions based on the transferred data. The control device calculates the parking slot occupancy to identify available parking slots and update the database with parking information. The database is accessed through the server computer at Data Access Layer.

The Data Access Layer contains the database server that contains user authentication data, registered vehicle data, current occupancy of each parking slot in the parking lots and past data about the vehicle occupancy.

Finally, the Application layer consist of a mobile application which the users can gain parking information. The mobile application provides the details via accessing the database that updated by the control device. The main users of the system are vehicle owners, car park administrators and security staff. The vehicle owners can use the system to view available parking slots and view current location of the parked vehicle. The parking administrators and security staff can view information regarding the parked vehicles, manage parking slots, and identify vehicles parked on unauthorized slots.

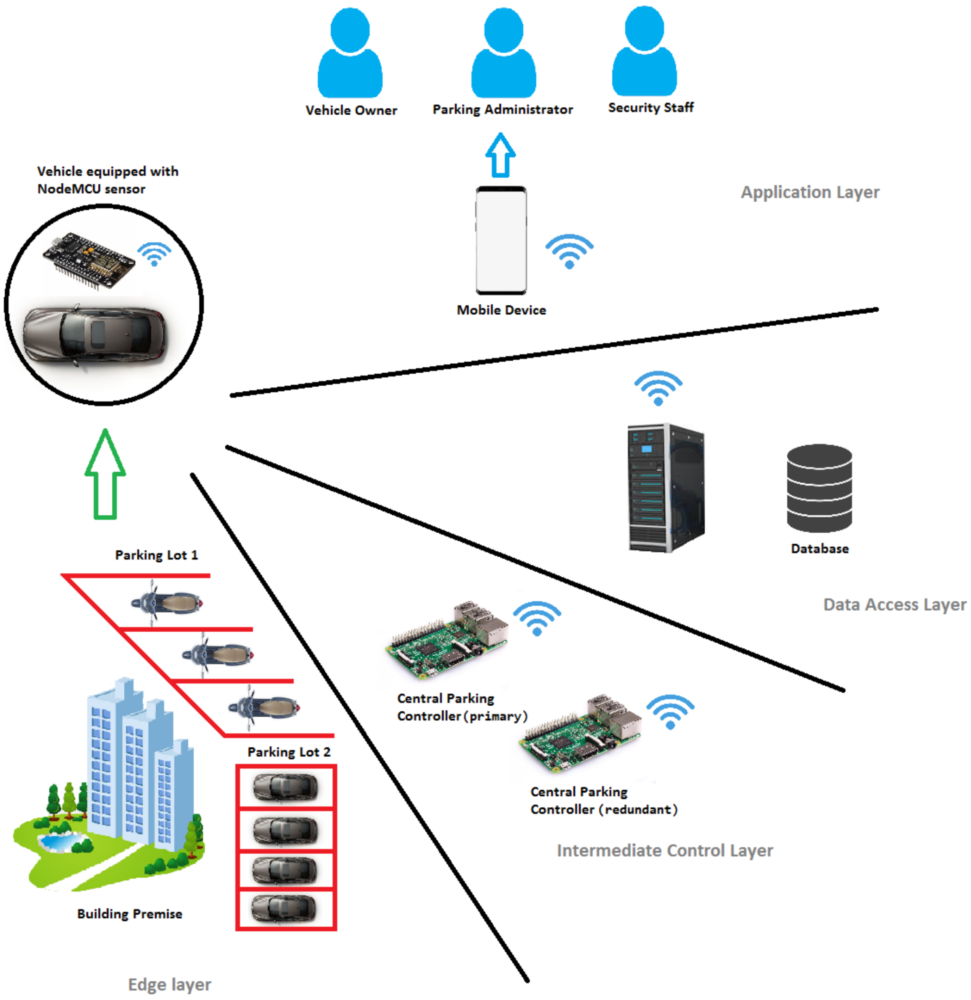


Figure 3.3: Higher level architecture of the proposed system

Figure 3.4 shows the sensor setup for calculating parking slot availability using RSSI trilateration method. The parking lot contains four reference access points deployed in fixed known locations. The vehicle nodes calculate RSSI values from these reference access points.

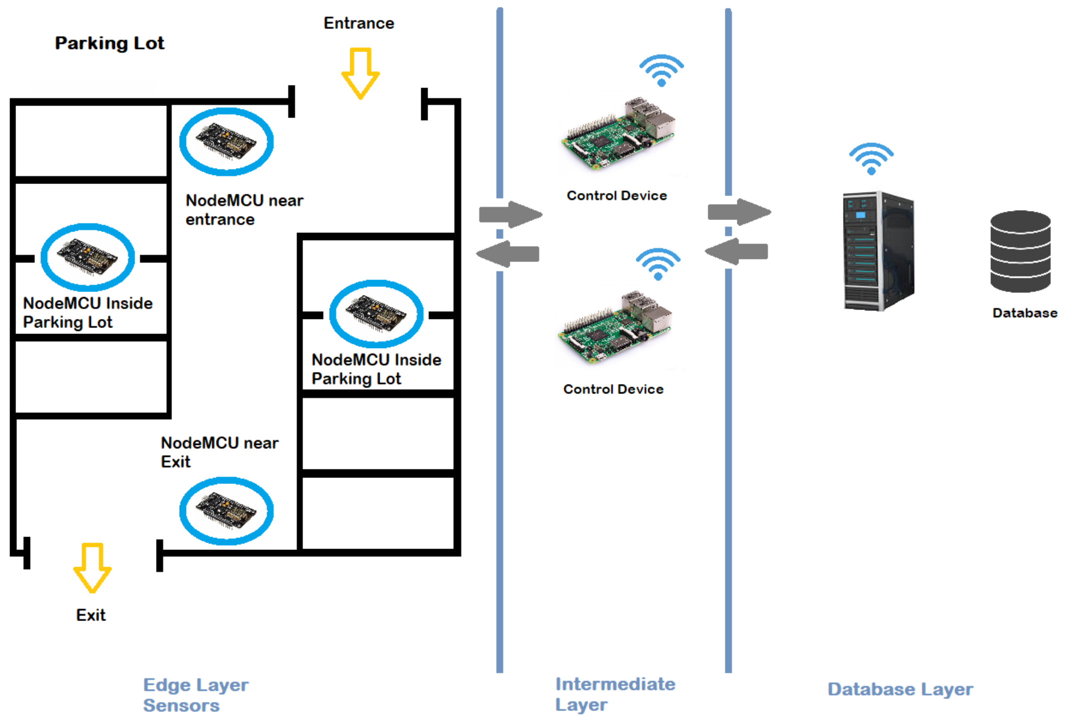


Figure 3.4: Sensors setup to calculate distance to vehicle using RSSI

Figure 3.5 represents the architectural components of the proposed system. The Edge layer devices contain RSSI receiver function that detects the received Wi-Fi signal strength of the reference nodes. The MQTT client function connects to the MQTT broker with the Vehicle Node's credentials and the digital certificate hash.

The intermediate layer contains the MQTT broker component that runs as a separate program. The controller node's main program connects to the MQTT queues using MQTT client component. The MQTT client receives the authentication and location update messages sent by vehicle nodes. It passes the received requests to the Location Calculator component which calculates the distances to each reference node based on the received RSSI values. Next, the Location Calculator component passes the calculated distances to the Trilateration Engine. The Trilateration Engine runs as an individual program that employs Non-Linear Least Square solver to calculate the vehicle location. The calculated location is passed back to the Location Calculator. The location Calculator passes the calculated vehicle location to Parking Occupancy Handler component. It calculates the occupied parking slot of the vehicle. The result is updated to the database using a Database Adapter class.

The Application layer consists of a mobile application. The vehicle owners and administrative and security staff can view the parking slot availability using a list view as well as a map view.

The vehicles and users that are registered in the system can be viewed as list views. The Application layer connects to the database using a Database Adapter class. Whenever a user opens a list/map view, the respective Controller class generates the database query and pass it to the Database Adapter. The Database Adapter executes the query on the remote database server. The received results are passed back to the Controller. The Controller creates/updates the results to the respective Model object. Finally, the view is populated with the received data.

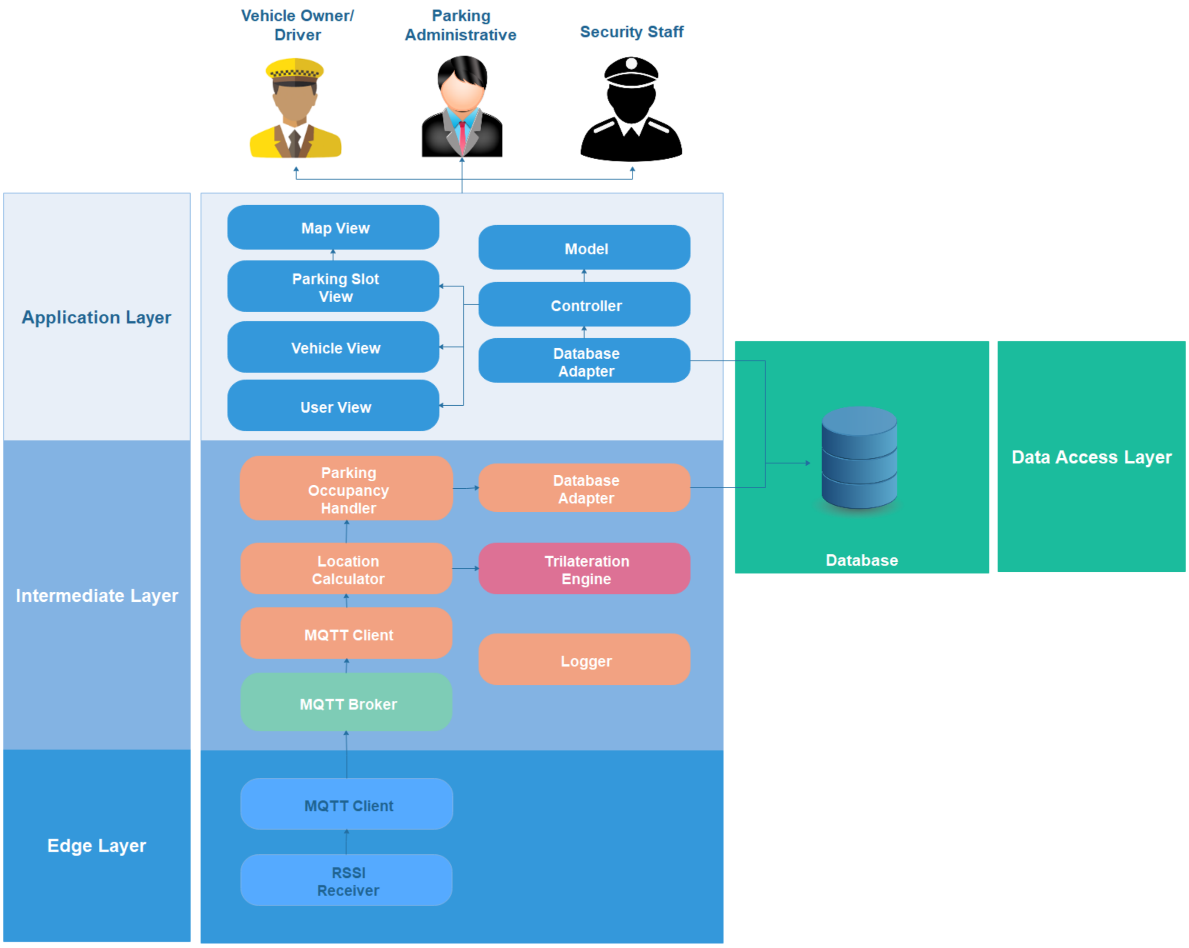


Figure 3.5: Architectural components of the proposed system

3.2.2 Process of parking and calculating parking slot availability

Figure 3.6 shows the parking slot availability calculation process steps. When a vehicle first arrives at the parking lot entrance, the sensor node connects to the parking lot's Wi-Fi network. The vehicle connects with the controller node using a secure TLS certificate fingerprint. The vehicle then sends authentication request to the parking lot's primary control node. The authentication request contains the vehicle node's id and the username passwords of the vehicle owner. The request is sent via a secure network to a message queue using MQTT protocol. The vehicle node subscribes to MQQT broker queue that is dedicated to the vehicle nodes. The control nodes are already subscribed to the message queues where the authentication and location update requests are sent.

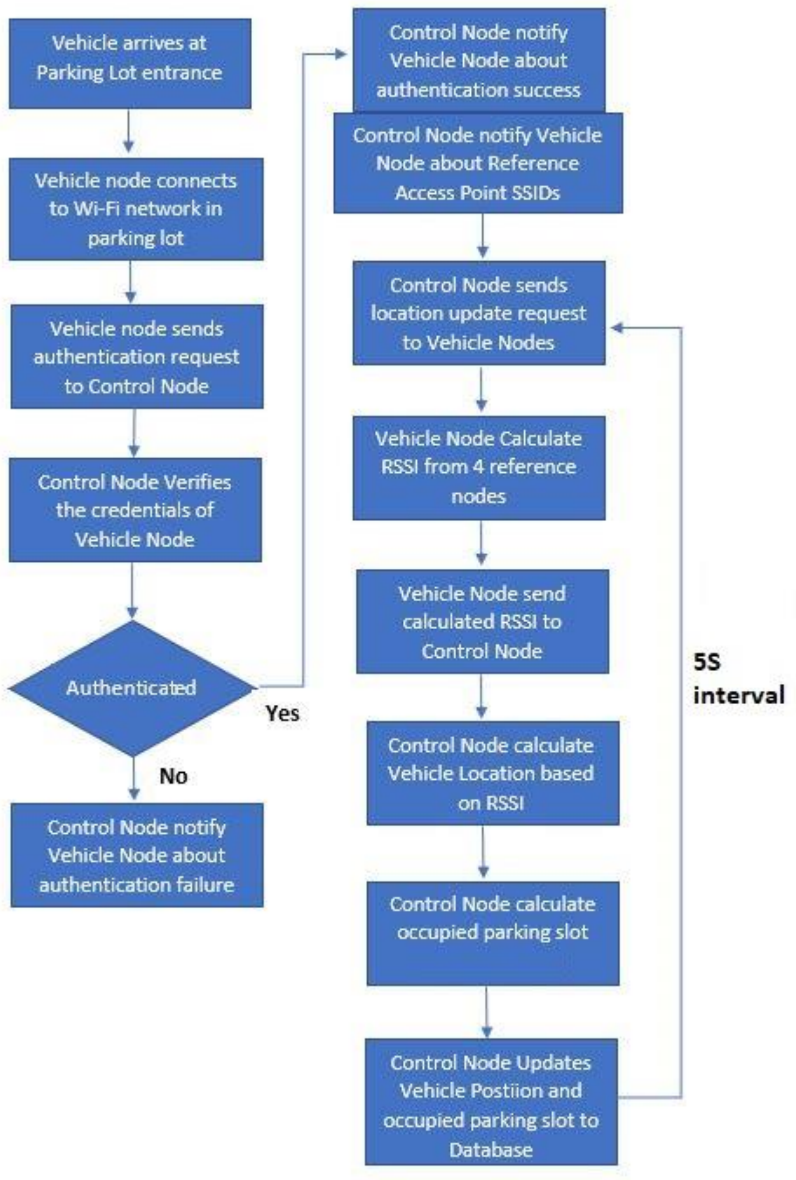


Figure 3.6: Parking slot availability calculation process

The primary control node receives the vehicle node's authentication request and it is processed. The control node checks the database and verify the request if it's received from a valid vehicle node. If it is a valid request and the credentials are correct, then the control node sends notification message regarding the successful authentication. Then the primary control node sends list of reference access points and their SSIDs to the authenticated vehicle node. The vehicle node receives the message and processes the request and gain a list of reference access points in the parking lot.

The primary control node periodically sends location update request to the vehicle message queue. All the vehicle nodes subscribed to the message broker receives this message. Each vehicle node upon receiving the location update request, gains RSSI values from four reference access points and creates a location update message. The location update message sent to the location update queue with the control node sequence number. The control nodes listen to the message and process them if its dedicated to it.

The vehicle location is calculated based on the received RSSI values in two steps. The distances to each reference node are calculated by Xiuyan Zhu's RSSI based distance calculation algorithm [8]. The location of the vehicle is calculated using Non-linear Least Square Solver algorithm developed by Apache foundation [37]. The calculated distances on step one is fed into the Non-linear Least Square Solver algorithm to calculate the vehicle location.

The database contains a parking lot map with the location and orientation of each parking slot. The control node connects to database and retrieves the parking lot map. Based on the calculated vehicle location and the parking lot map, the control node identifies the parking slot that the vehicle occupies. The calculated vehicle location and the occupied parking slot is updated to the database.

The vehicle owners and parking administration can use the mobile application to view the occupied and available parking slots as the mobile application connects to the database that is being updated by the controller nodes real time.

Handling unauthorized vehicles and bogus vehicle sensor nodes

The vehicles with a valid sensor node are given access to the parking lot at the entrance. If the vehicle does not contain a sensor, then it will not be given permission to enter the parking lot.

The vehicle nodes can only communicate with the Control nodes using a secure MQTT message queue. Each vehicle node is preconfigured with an TLS certificate fingerprint. Only the vehicle nodes with valid TLS certificate fingerprint is allowed to connect to the MQTT message broker. In that way, a bogus sensor who pretends to be a vehicle node can't connect to the WSN.

On the other hand, vehicle nodes have a valid TLS fingerprint of the MQTT broker. Thus, even if a bogus device pretends to be a message broker, vehicle nodes can identify the correct message broker using the certificate fingerprint.

3.2.4 Benefits of the proposed system

1. Avoid latency in parking

By allowing the vehicle owner to find an available parking space real-time, the unnecessary waiting time and driving around the premises is avoided.

2. Enforce the security inside the premise

By providing data on the vehicles that are parked, security personnel can enforce the on-premise security.

3. Utilize the available parking spaces

By detecting the unauthorized parking outside the respective zone, parking administrative personnel can utilize the available parking slots.

4. Provide statistics for long term decision making

The proposed solution collects data regarding the duration of parking, vehicle class and other important data regarding the parking. These data can be used to calculate important statistics to make future decisions regarding the vehicle park.

5. Cost efficiency of the proposed system

The proposed Parking Management System uses low cost sensor equipment, and it does not need sensor devices for each parking slot. This makes the proposed system cost effective as well as less hardware complexity.

6. Reusability of the edge sensor devices

The main hardware in the proposed system is installed in the vehicle itself, so the sensor can be used in different premises/ car parks (if intermediate control devices and servers exist). Unlike the parking management systems that were analyzed in literature survey, if the premise extends its parking space to different geographical locations, the existing edge layer does not need additional hardware.

3.3 System Modelling

The system design chapter include the UML designs of the proposed Parking Management System.

3.3.1 Classes, Attributes and Operations

The main classes of the proposed system are identified along with the attributes and the dedicated operations of the respective class. Following chapter lists down the classes, their operations and attributes.

- User

The user has main attributes username, password, firstName, lastName and userGroup. The main user groups are “Admin”, “Academic Staff”, “Non-Academic Staff”, “Student” and “Guest”. The user groups other than “Admin” belongs to main category “Vehicle Owner”. The validateUser() and editUser() are the main operations involves the User class.

- VehicleInfo

This class represents the information of the vehicles such as vehicleId, vehicleClass, Model, Color, dimensions of the vehicle. The main vehicle classes are “Light Vehicle”, “Dual Purpose”, “Heavy Vehicle”, “Motor bycycle”. The main operations of VehicleInfo class are getAllVehicles(), editVehicle().

- ParkingLot

Parking lot is a block that contains a number of parking slots. lotId, address, floor and dimentions are the main attributes of ParkingLot. The operations include editParkingLot() and getAllParkingLots().

- ParkingSlot

slotId, allowedUserGroup, allowedVehicleClass, occupiedVehicle and dimentions are the main attributes of ParkingLot. The operations include editParkingSlot() and getAllParkingSlots().

- RefNode

Ref nodes are used in the calculation of vehicle position. There can be multiple reference nodes per parking lot. The main attributes of the RefNode include deviceId, password, lotId and active flag.

After identifying the classes, attributes, operations and the relationship among them, a class diagram modelled based on the information. Figure 3.7 depicts the class diagram of the proposed system.

Figure 3.7: Class Diagram

3.3.2 Use Cases

The main users of the proposed system include Vehicle Owner, Administrator and Security personnel. Every user must login to the system in order to perform actions. The access privileges to certain functionality is based on the type of the user.

- Vehicle Owner

The vehicle owner can login to the system and once logged in, the home screen appears. Vehicle owner can select “Available Parking Slots”, this opens “Parking Slots” screen and list down the parking slots that are available to park.

The vehicle owner can select “My Vehicles” from the home screen and it opens “Vehicles” screen and loads all the vehicles that belongs to the logged in user.

Vehicle owner can click on “Vehicle Location History” on home screen and it displays the “Vehicle Location History” screen and list history of the vehicle parking’s of the logged in user. The location history can be filtered by vehicle ID.

Vehicle Owner can click on “My Profile” and it loads the “Profile” screen. The Profile screen contains the information about the current logged in user. User can then edit certain user details.

- Administrator

The Administrator can login to the system and once logged in, the home screen appears. Administrator can select “Parking Slots”, this opens “Parking Slots” screen and list down all the parking slots. Administrator can filter parking slots by slot id and add/edit parking slots.

The Administrator can select “Registered Vehicles” from the home screen and it opens “Vehicles” screen and loads all the vehicles in the system. Administrator can filter vehicles by vehicle id and add/edit vehicles.

Administrator can click on “Vehicle Location History” on home screen and it displays the “Vehicle Location History” screen and list history of the vehicle parking’s of the parking lot.

Administrator can click on “Users” and it loads the “Users” screen. The Users screen contains the information about the users of the system. Administrator can filter users by username and edit certain user details.

Administrator can click on “Unauthorized Parked Vehicles” and it loads the “Unauthorized Parked Vehicles” screen. This lists down all the vehicles that are parked in an unauthorized parking slot. Administrator can filter unauthorize parked vehicles by vehicle id.

- Security Personnel

Security Personnel can login to the system and once logged in, the home screen appears. Security personnel can select “Parking Slots”, this opens “Parking Slots” screen and list down all the parking slots. The Security personnel can filter parking slots by slot id and add/edit parking slots.

Security Personnel can select “Registered Vehicles” from the home screen and it opens “Vehicles” screen and loads all the vehicles in the system. Administrator can filter vehicles by vehicle id.

Security Personnel can click on “Vehicle Location History” on home screen and it displays the “Vehicle Location History” screen and list history of the vehicle parking’s of the parking lot.

Security Personnel can click on “Users” and it loads the “Users” screen. The Users screen contains the information about the users of the system. Security Personnel can filter users by username.

Security Personnel can click on “Unauthorized Parked Vehicles” and it loads the “Unauthorized Parked Vehicles” screen. This lists down all the vehicles that are parked in an unauthorized parking slot. Security Personnel can filter unauthorize parked vehicles by vehicle id.

Use case diagram modelled based on the identified users and their use cases. The figure 3.8 shows the use case diagram of the proposed system.

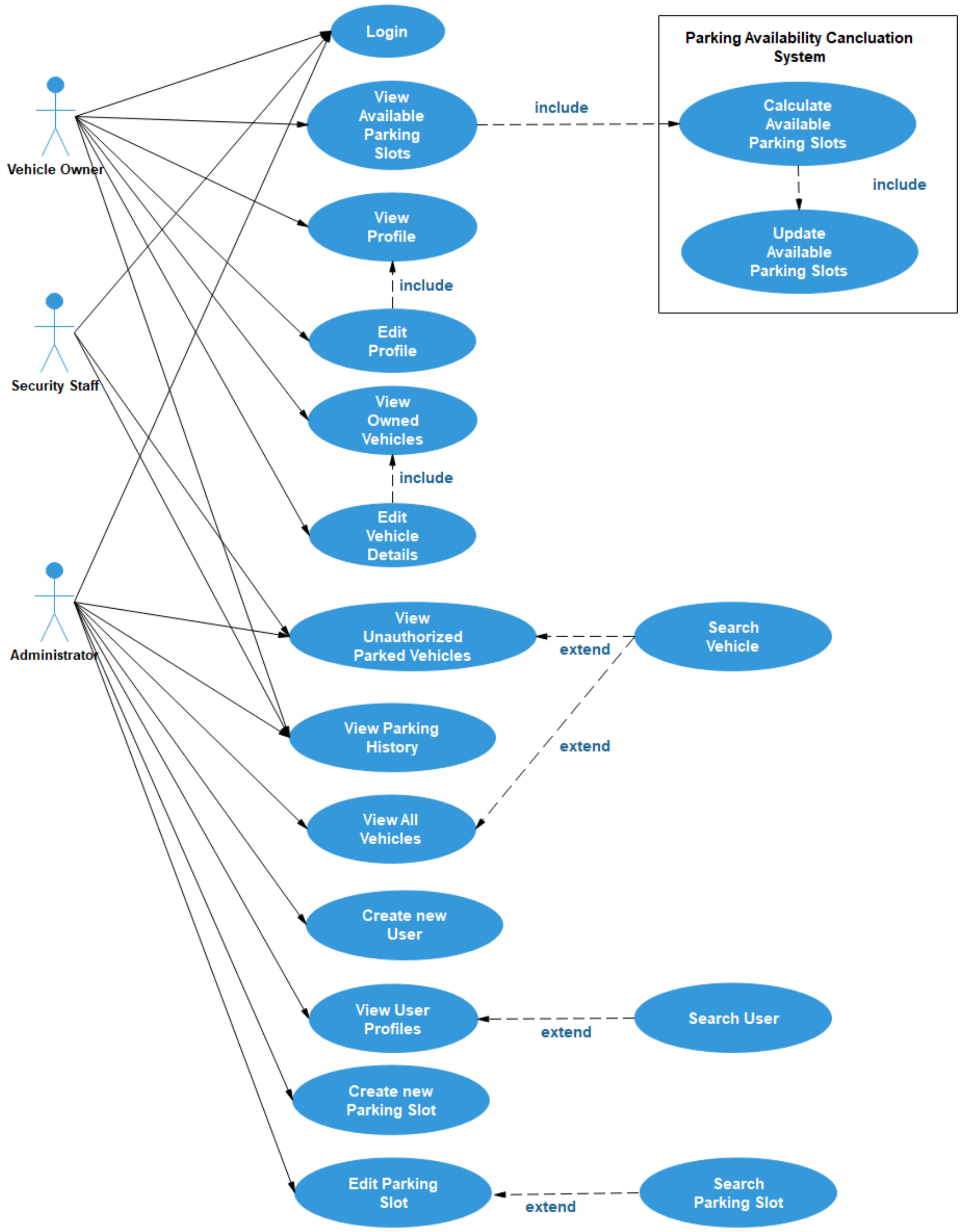


Figure 3.8: Use Case Diagram

4. Implementation

4.1 Tools and Technologies Used

The proposed system contains following main architecture components.

1. Wireless Sensor Network of Edge Layer NodeMCUs and Intermediate Layer control nodes.
2. MongoDB database in the Data Access Layer
3. Mobile Application in the Application Layer

4.1.1 Edge and Intermediate Layer

The backend system contains wireless sensor network of NodeMCU sensors attached to the vehicles, reference access points and the control nodes deployed on the parking lot. The edge layer NodeMCU devices were programmed using Arduino IDE version 1.8.9. The C++ programming language was used to implement the program that is running on NodeMCU. The vehicle nodes were programmed to communicate with JSON message format using MQTT protocol. The intermediate layer devices were programmed using Eclipse IDE. Python programming language was used to program the Control Nodes. The Python MQTT library was used to implement the server running on the control nodes.

The distances between the vehicle node and each reference node are calculated by Xiuyan Zhu's RSSI based distance calculation algorithm [8]. The Non-Linear Least Square solver method was used to calculate the vehicle location based on the previously calculated distances to the reference nodes. The algorithm that was developed by Apache foundation was used in this study [37]. The trilateration location calculation module was developed on Eclipse IDE using Java programming language with Apache commons library version 3.3.4. The Java program that calculates the vehicle location was linked to control node’s main program using Pi4J library.

HiveMQ is used as the MQTT message broker that is deployed on the primary control node. HiveMQ is an open source message broker that enable transfer data in efficient, fast and reliable manner. It supports heterogeneity by allowing connect any device in a reliable and secure manner via the IoT standard protocol MQTT.

4.2.2 MongoDB Database

The database that is used in the proposed system is MongoDB version 4.2.0. The database was deployed in the remote MongoDB cloud (Atlas Cloud) in order to make it more secure. The MongoDB Compass Community tool was used to access the remote database for administrative purpose.

4.3.3 Mobile Application

Mobile application that is developed for the target users is an Android Mobile application. The development of the mobile application was carried out by Android Studio version 3.5.3 Integrated Development Environment. The application was compiled with Application Programming Interface (API) 28: Android 9 (Pie). The minimum android version the application is supposed to work with is API 26: Android 8.0 (Oreo).

MongoDB Snitch library was used to connect to remote MongoDB database in order to retrieve data to the mobile application. The minimum API level that the MondoDB library supports it API 26. Thus, Minimum SDK required could not be lower than API version 11.

For application testing purposes, Android Virtual Device emulator was used. Android Virtual Device is a fast and efficient android emulator using the x86 architecture virtualization. This emulator was integrated to the Android Studio IDE.

4.2 Functionalities Offered by The Proposed Solution

The main functionalities offered to the user by the proposed system can be categorized into three sections based on the main user types.

1. Vehicle Owner
   a. List available parking slots in the parking lot
   b. Managing owned vehicles
   c. Managing user profiles

2. Administrator
   a. List available parking slots in the parking lot
   b. Detect unauthorized vehicle parking
   c. Managing parking slots
   d. List vehicles in the parking lot
   e. Managing vehicles
   f. List user profiles
   g. Managing user profiles

3. Security Personnel
   a. List available parking spaces in the parking slot
   b. Detect unauthorized vehicle parking
   c. List vehicles in the parking lot
   d. List user profile

a. List available parking spaces in the parking slot

The main functionality of the parking management system is detecting occupied parking slots and allow target users to list available parking slots in a parking lot.

When the user logs into the system, the "Available Parking Slots" button in the home screen navigates the user to the parking slots view. In this view, the available parking slots in the lot displayed with a green circle. The unavailable parking slots are displayed with a red circle and the yellow circle depict the parking slots that user is not authorized. The user can scroll down to view all the parking slots. The administrator can add new parking slots and edit existing slots by navigating to the add/edit parking slots view. Figure 4.1 shows Screens related to managing parking slots.

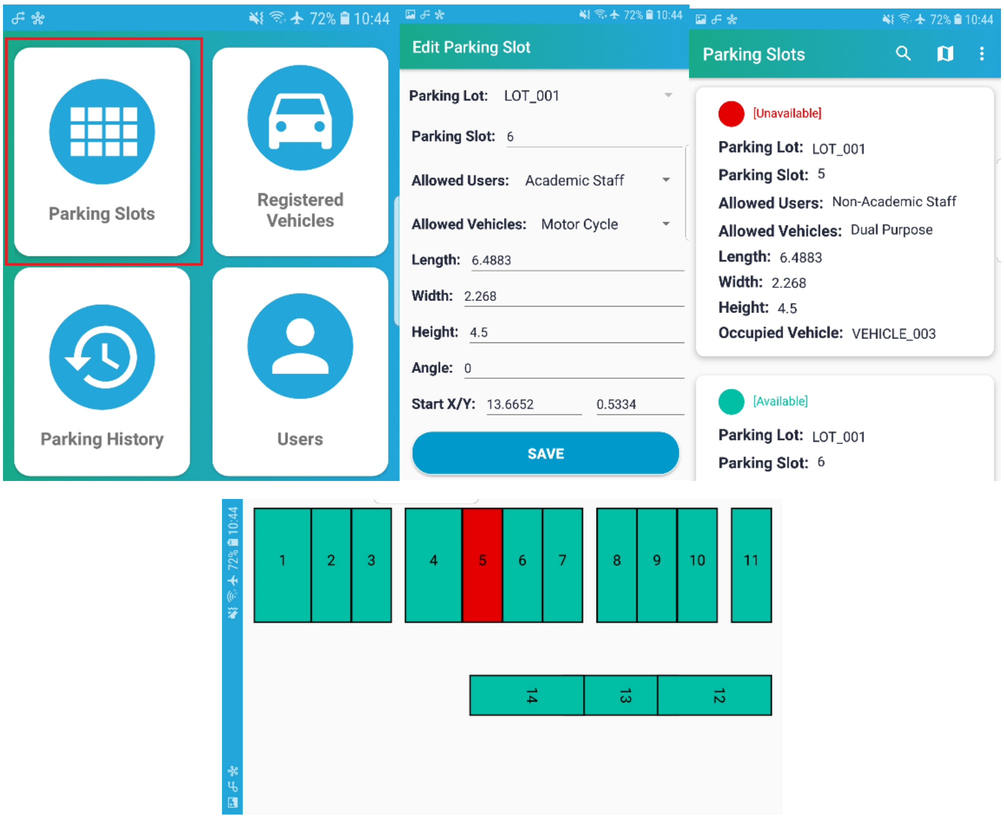


Figure 4.1: Screens related to managing parking slots

b. Detect unauthorized vehicle parking

The administrators and security personnel can view the vehicles that are parked in parking slots that they are not authorized. When the administrator/ security personnel logs into the system, the “unauthorized parking” button in the home screen navigate the user to the Unauthorized parking view. The unauthorized parking view list all the parking slots that parked by an unauthorized vehicle. The details such as parking slot id, vehicle id, owner name, owner’s email address and telephone are displayed. Figure 4.4 shows Screens related to listing unauthorized parking.

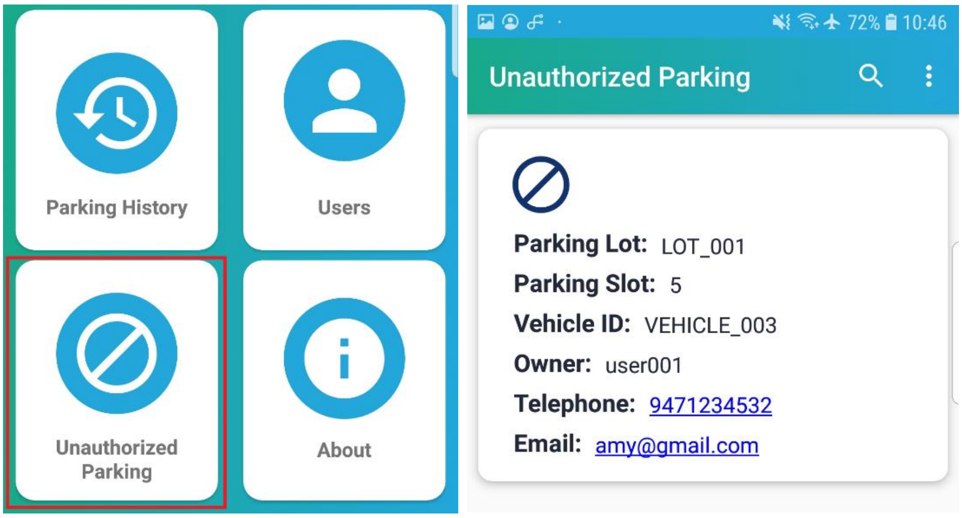


Figure 4.2: Screens related to listing unauthorized parking

c. Managing vehicles

The user can list their own vehicles where the administrator and security personnel can view all the vehicles in the parking lot.

When the administrator/security personnel logs into the system, the “Registered Vehicles” button in the home screen navigates the user to the vehicle list view. When the vehicle owners log into the system, “My Vehicles” button in the home screen navigates the user to the vehicle list view that only shows user owned vehicles. The vehicle view shows details such as model, make, color, vehicle class and vehicle dimensions. Administrator can add or edit new vehicles using the add/edit vehicles view. Figure 4.4 shows Screens related to managing vehicles.

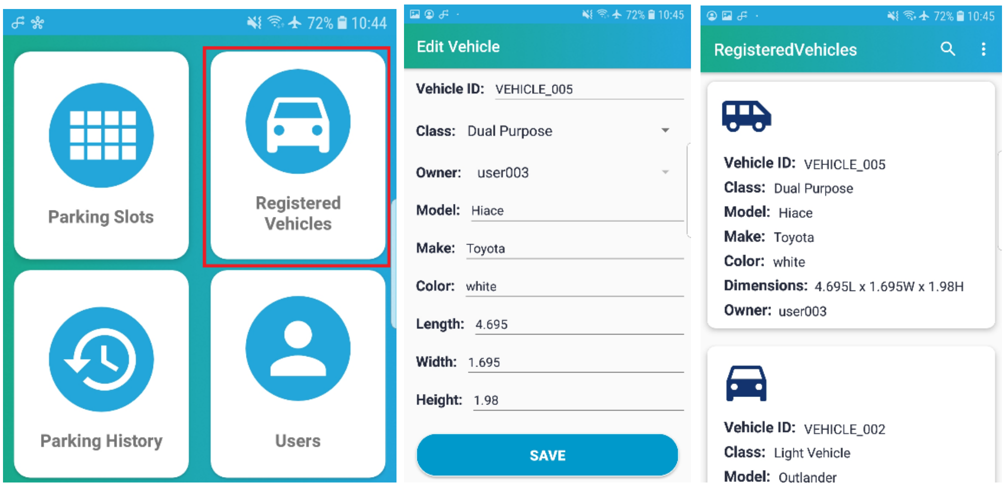


Figure 4.3: Screens related to managing vehicles

d. Managing user profile

The user can list their own profile where the administrator and security personnel can view all the users that are registered.

When the administrator/security personnel logs into the system, the button named "Users" in the home screen it navigates to the Users view. When the vehicle owners log into the system, "My Profile" button in the home screen navigates the user to the User Profile. The Users view shows details such as username, first name, last name, user group, email and telephone. Administrator can add new users or edit existing users using the add/edit user view. Figure 4.4 shows Screens related to managing users.

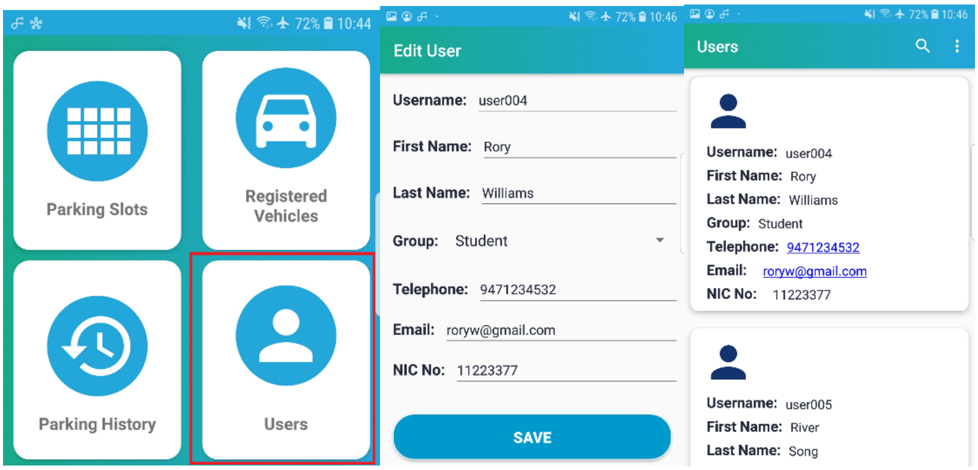


Figure 4.4: Screens related to managing users

4.3 Translations and localization

The implemented mobile application is localized to Sinhalese and Tamil locales. The field labels, error messages and text inputs are translated to the user device's language at runtime. Figure 4.5 shows the translations of the mobile application.

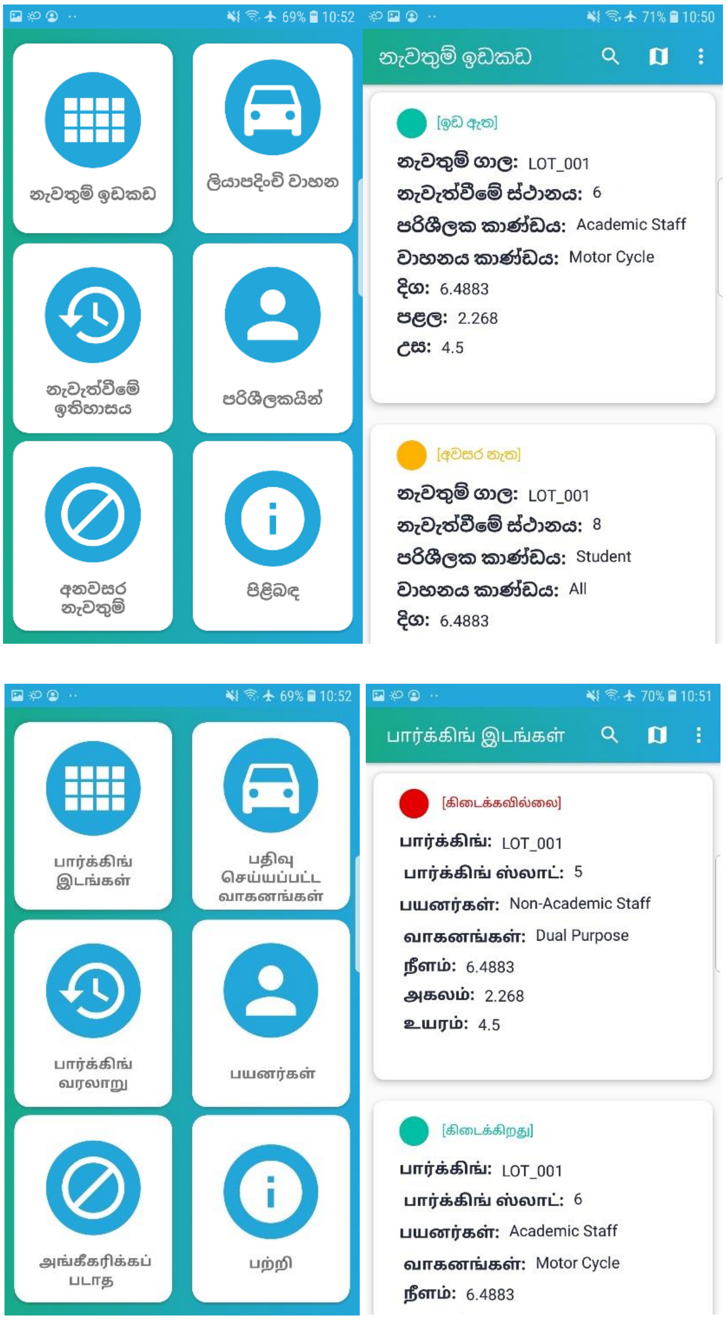


Figure 4.5: Translations of the mobile application

4.4 Deployment of the implemented system

4.3.1 Edge Layer

The Edge Layer contains the vehicle nodes and reference access points. The reference access points are deployed in the parking lot and their location needs to be recorded in the database in the relative parking lot coordinates. The vehicle nodes need to be installed in every vehicle that utilize the parking lot. NodeMCU ESP8266-12F devices are used as vehicle nodes and reference access points. Lithium battery shields are used as the power supply for edge layer nodes. The lithium battery shield contains two 18650 lithium ion batteries that provide 15600mAh with 5V output. Figure 4.6 shows the edge layer nodes and vehicle node deployment.

Figure 4.6: Edge layer nodes and vehicle node deployment

4.3.1 Intermediate Layer

The intermediate layer contains one or more control node devices. The control node device utilized is a Raspberry Pi 3B device. The control nodes should have a stationary power supply as it consumes more power in processing the edge layer requests. The table 4.1 shows the edge and intermediate layer devices that is used and their technical specification details.

Table 4.1: Edge and intermediate layer nodes technical specifications [38] [39]

	Edge Layer		Intermediate Layer
Device	Node MCU	Lithium battery shield	Raspberry Pi
Model	ESP8266-12F	V8	3B
Processor	80 MHz	N/A	1.2GHz
Flash memory	4Mb	N/A	16Mb/8Gb SD card
Voltage	3.3V	3-5V	5V
Wi-Fi Protocols	802.11b/g/n	N/A	802.11n
Wi-Fi Range	90m	N/A	100m

4.3.1 Data Access Layer

The data access layer contains the database that is used by the control nodes and the mobile application. The database is a lightweight MongoDB version 4.2.0 database that is deployed in the MongoDB Atlas Cloud. The Atlas cloud is a database as a service for applications that typically requires performance, high availability, security, and disaster recovery [40]. The free plan allows 100 operations per second with 512mb storage space. The Application layer devices connect to the MongoDB using MongoDB Snitch which provides extra layer security to the database.

4.3.1 Application Layer

The application layer consists of a mobile application that is targeted for Android devices. The minimum requirement is Android Operating System 8 (Oreo). The developed application can simply be deployed by signed APK file that is gnateater after implementation.

4.5 Cost analysis of the proposed system

Analyzing the cost of the proposed system is crucial in order to convey its practical use in real world.

Table 4.2 represents the unit cost of each sensor devices/accessories that are used in the proposed system. The unit costs were calculated on 2020-05-10. The cost of the development tools, Operating Systems and other technologies are effectively zero as all the tools and technologies used are free and open source.

Table 4.2: Unit cost of devices and accessories [38] [39]

Layer	**Device**	**Model**	**Cost (USD)**
Edge Layer	Node MCU	ESP8266-12F	2.19
	Lithium battery shield	V8	3.30
	Lithium Ion Battery	18650 cells	0.80
	USB Cable (0.5m)	N/A	0.90
Intermediate Layer	Raspberry Pi	3B	37.88
	SD Card (16Gb)	Kingston	3.28
	Power Adapter	N/A	1.39

The cost analysis is performed for a parking lot with average of 40 parking slots. The table 4.3 depicts the number of needed units from each device/accessory and the total cost for a parking lot.

Referring the table 4.3, it can be identified that the proposed system costs approximately 14,166.00 LKR per parking lot and 1,340.00. LKR per vehicle. The deployment in a parking lot needs only 4 reference access points and a controller node to support up to 44 vehicles. Thus, the cost per parking lot does not depend on the number of parking slots. The NodeMCU device deployed on vehicle can be reused among every parking lot that the proposed system has deployed. Due to the, scalability and reusability, the cost increase of the proposed system with the parking lot size is lower than the current suggested systems.

Table 4.3: Cost Analysis of the proposed system

Device	**Unit cost (USD)**	**Required qty**	**Cost (USD)**
Per Parking Lot			
Node MCU	2.19	4	8.76
Lithium battery shield	3.30	4	13.20
Lithium Ion Battery	0.80	8	6.40
USB Cable (0.5m)	0.90	5	4.50
Raspberry Pi	37.88	1	37.88
SD Card (16Gb)	3.28	1	3.28
Power Adapter	1.39	1	1.39
Total Cost			**75.95**
Per Vehicle			
Node MCU	2.19	1	2.19
Lithium battery shield	3.30	1	3.30
Lithium Ion Battery	0.80	1	0.80
USB Cable (0.5m)	0.90	1	0.90
Total Cost			**7.19**

Several commercial parking management systems were identified, and their costs were compared with the proposed solution. The cost of the identified systems is calculated for 40 parking slots.

Parkalot is a Mobile Application based parking reservation system that allows detecting available parking spaces. The application subscription for a parking space with 40 slots cost 99 USD per month [43]. The Thinkpark parking guidance system is an ultrasonic sensor-based parking management system that deploys ultrasonic sensor in each parking slot. It costs 120 USD to deploy the parking management system in a parking lot with 40 parking slots [44]. Lora Smart Wireless Parking Lot Sensor System is a magnetic sensor-based parking management system. The parking management system costs 200USD to deploy the sensors in a parking lot with 40 parking slots [45]. A low-range CCTV camera costs approximately 70USD making the ANPR based solution that’s stated in literature review chapter cost approximately 210USD as it requires 3 cameras [46]. When comparing the proposed solution to the current WSN based systems, it is evident that the proposed solution dramatically lowers to total cost per parking lot.

Table 4.4: Cost comparison of proposed system with commercial solutions

Parking management System	**Cost per 40 slots**
Parkalot	99USD/month
Thinkpark Ultrasonic Parking guidance	120USD
Lora	200USD
ANPR based solution	210USD
Proposed Solution	75.95USD

5 Results and Evaluation

The proposed Parking Management System is evaluated based on accuracy, scalability, usability and secureness criteria.

5.1 Accuracy Evaluation

The accuracy of the proposed RSSI based solution was evaluated in this chapter. The most suitable evaluation approach was determined base on accuracy evaluation approaches used in similar research studies. The accuracy evaluation experiments were designed based on the selected evaluation approach and the results were statistically analyzed.

5.1.1 Evaluation Plan

5.1.1.1 Evaluation Approach

The RSSI based technique is designed and implemented in order to calculate the available parking slots as described in chapter 3 and 4. Trilateration based calculation is used in order to measure the vehicles' current positions based on received RSSI values. The vehicle positions are then mapped to the respective parking slot they occupy and decide parking slot availability based on that. The distances measured from RSSI technique is not 100% accurate due to the environmental factors. The absolute location of each vehicle in the parking lot is not necessary in this study, since the algorithm that the parking management system employ needs only an approximate vehicle location. The approximate vehicle location is mapped to the respective parking slot based on the predefined coordinates of the parking slot. However, the system must provide accurate information on parking slot occupancy/ availability since the main requirement of the users are to find out a vacant parking slot.

In order to decide an accuracy evaluation approach, current WSN based studies and their evaluation mechanisms were analyzed. The smart parking management system analyzed in [47] had deployed magnetic sensor nodes on every parking slot in a selected real parking lot. The parking management system introduced in [17] used a scale model containing 20 parking slots to evaluate the accuracy. Both mentioned systems had measured the accuracy of the system based on the percentage of correct calculations. The proposed system employed a similar method in evaluating the accuracy of the system.

The accuracy of the proposed system is measured by the ratio between the total number of occupied parking slot calculations and number of correct calculations. Three tests are planned to evaluate the accuracy, evaluate the impact on accuracy when the parking lot size increases and the impact on accuracy when external interreferences exist.

Several test scenarios performed for each of the tests mentioned. In each scenario, a target vehicle is selected, and it is parked on a specific parking slot. vehicle is physically moved from one parking slot to another for each scenario. The actual parked slot (absolute occupancy) of the target vehicle is measured by human eyes. In each scenario, 100 test iterations conducted with 5 second interval, in each, the vehicle position is calculated based on the received RSSI values and identify the occupied parking slot based on the trilateration calculation. The calculated parking slot and the absolute parking slot data is used to generate statistics and reflect on the accuracy of the proposed system. Accuracy calculated by the formula stated in Tools and Techniques chapter.

The accuracy evaluations are performed by deploying the proposed system on two different real-world parking lots.

1. Accuracy Evaluation

The Accuracy evaluation was performed in a real parking lot located at Access Tower II, Union Place. The parking lot and slot dimensions are as follows.

Parking Lot: 30.69m (width) * 13.89m (length) * 4.5m (height)

Parking Slot:

Type 1: 3.2286m (width) * 6.4883m (length) * 4.5m (height)

Type 2: 2.268m (width) * 6.4883m (length) * 4.5m (height)

There are parking slots with two different dimensions as stated above. Figure 5.1 shows the model diagram of the proposed system deployment for accuracy evaluation. The parking lot contains 14 parking slots with different sizes and orientations. There are four reference nodes deployed within the parking lot to aid the vehicle location calculation. Four testing scenarios are planned with two different vehicles. The target vehicles are equipped with NodeMCU sensor configured as a vehicle node.

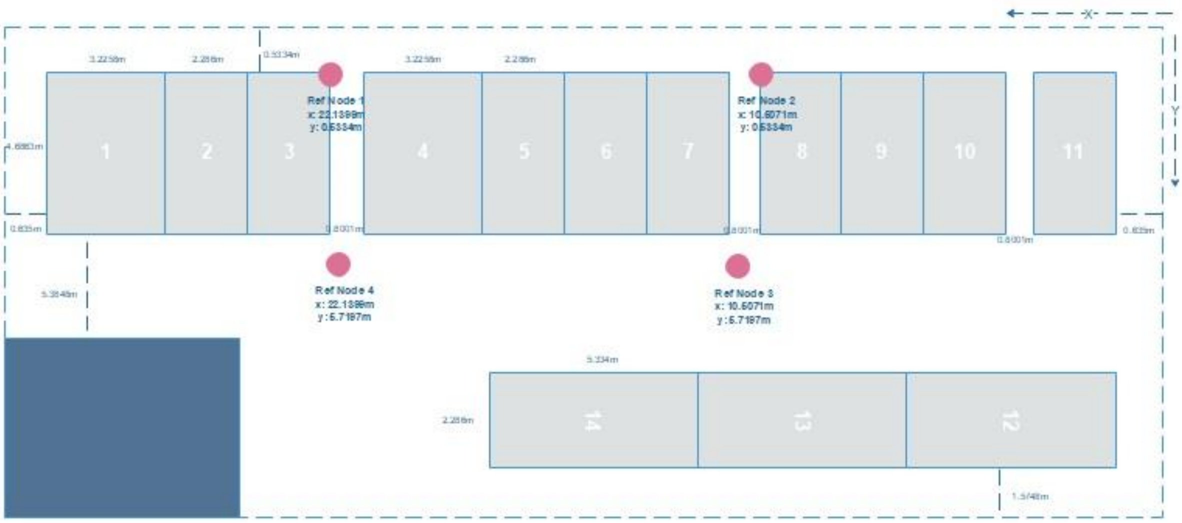


Figure 5.1: System deployment diagram of the selected parking lot in test 1

The table 5.1 and 5.2 show the details of the configuration of the vehicles and parking lots used.

Table 5.1: Vehicle configuration details for test 1

Vehicle	Vehicle ID	Vehicle Class
Vehicle 1	VEHICLE_003	Light Vehicle
Vehicle 2	VEHICLE_010	Motorcycle

Table 5.2: Parking Slot configuration for test 1

Slot	User Group	Vehicle Class
Slot 4	Academic Staff	Light Vehicle
Slot 5	Academic Staff	Dual Purpose
Slot 6	Academic Staff	Light Vehicle
Slot 7	Academic Staff	Light Vehicle

Scenario 1:

Vehicle 1 parked on parking slot 4 and parking slot calculation was performed for 100 test iterations and the calculated parking slot was recorded.

Scenario 2:

Vehicle 1 parked on parking slot 5 and parking slot calculation was performed for 100 test iterations and the calculated parking slot was recorded.

Scenario 3:

Vehicle 2 parked on parking slot 6 and parking slot calculation was performed for 100 test iterations and the calculated parking slot was recorded.

Scenario 4:

Vehicle 2 parked on parking slot 7 and parking slot calculation was performed for 100 test iterations and the calculated parking slot was recorded.

Figure 5.2 shows the real-world vehicle setup for test 1.

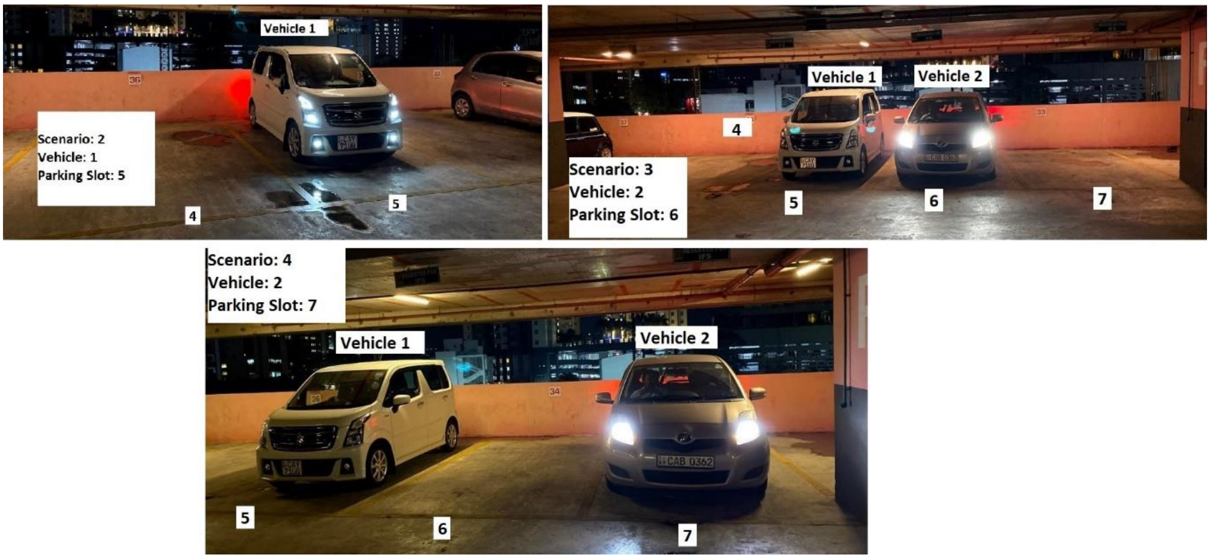


Figure 5.2: Real world vehicle setup for test scenarios in test 1

2. Evaluation of impact on accuracy when parking lot size increases

The impact on accuracy when the parking lot size increases was performed by comparing the accuracy of the calculation for two parking lots with different lot size. A second parking lot was selected that is in Orion City. The parking lot and slot dimensions are as follows. Figure 5.3 shows the model diagram of the proposed system deployment for evaluation of test 2.

Parking Lot: 14.008m (width) * 11.8244m (length) * 4.5m (height)

Parking Slot: 2.268m (width) * 6.4883m (length) * 4.5m (height)

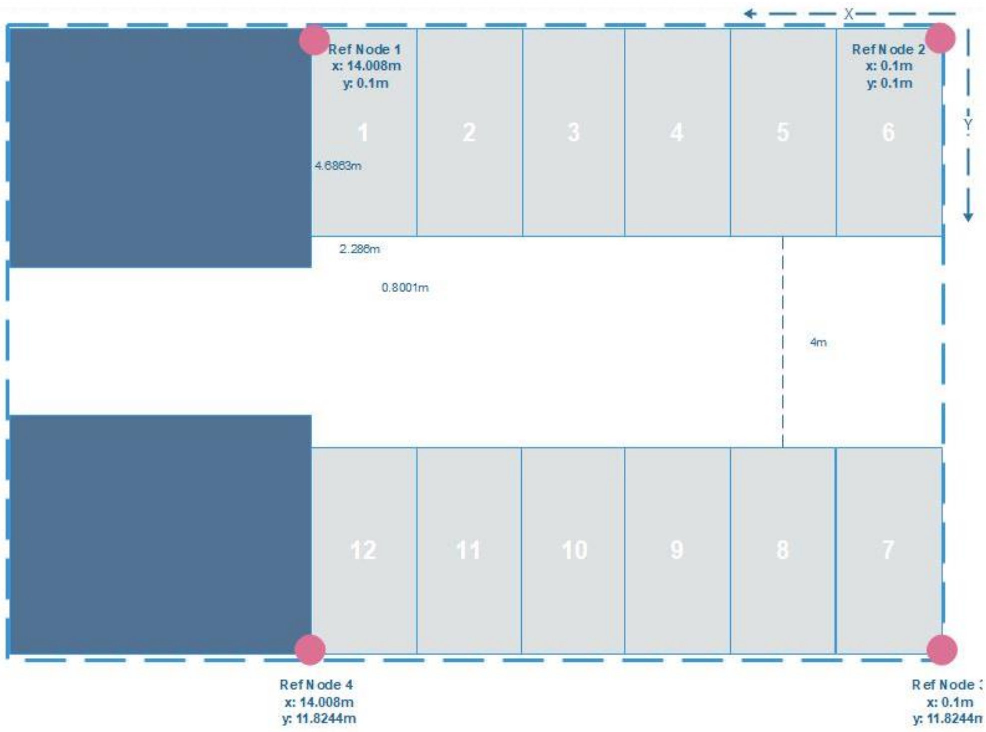


Figure 5.3: System deployment diagram of the selected parking lot in test 2

The table 5.3 and 5.4 show the details of the configuration of the vehicles and parking lots used.

Table 5.3: Vehicle configuration details for test 2

Vehicle	**Vehicle ID**	**Vehicle Class**
Vehicle 1	VEHICLE_003	Light Vehicle
Vehicle 2	VEHICLE_010	Motorcycle

Table 5.4: Parking Slot configuration for test 2

Slot	**User Group**	**Vehicle Class**
Slot 3	Academic Staff	Light Vehicle
Slot 6	Academic Staff	Dual Purpose
Slot 9	Student	Motorcycle
Slot 10	All	Heavy Vehicle

Scenario 1:

Vehicle 1 parked on parking slot 3 and parking slot calculation was performed for 100 test iterations and the calculated parking slot was recorded.

Scenario 2:

Vehicle 1 parked on parking slot 6 and parking slot calculation was performed for 100 test iterations and the calculated parking slot was recorded.

Scenario 3:

Vehicle 2 parked on parking slot 9 and parking slot calculation was performed for 100 test iterations and the calculated parking slot was recorded.

Scenario 4:

Vehicle 2 parked on parking slot 10 and parking slot calculation was performed for 100 test iterations and the calculated parking slot was recorded.

Average accuracy for four scenarios on test 1 and test 2 is separately calculated. The average accuracy values are compared with the parking lot size and reference node placement of each parking lot.

3. Evaluation of impact on accuracy when external interferences exist on the parking lot

The deployment setup for the evaluation of impact on accuracy when external interferences exist is identical to test setup 1 except for the deployed interfering devices. There are two Wi-Fi access points deployed on random locations in the parking lot surrounding the vehicles. The deployed access points interfere with the Wi-Fi communication between the reference access points and the vehicle nodes. Figure 5.4 shows the model diagram of the proposed system deployment for evaluation the accuracy when interferences exist.

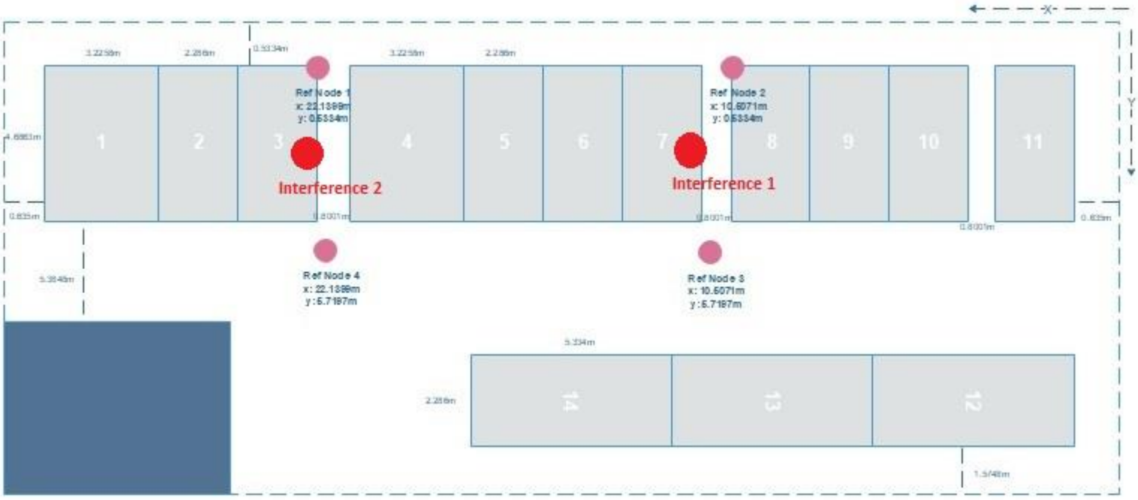


Figure 5.4: System deployment diagram of the selected parking lot in test 3

Vehicle 1 and parking slot 4 was used in two test scenarios.

Scenario 1:

The interfering devices not present in the parking lot. The vehicle 1 parked on parking slot 4. Parking slot calculation was performed for 100 test iterations and the calculated parking slot was recorded. Accuracy calculated by the formula stated in Tools and Techniques chapter.

Scenario 2:

The interfering devices present in the parking lot. The vehicle 1 parked on parking slot 4. Parking slot calculation was performed for 100 test iterations and the calculated parking slot was recorded. Accuracy calculated by the formula stated in Tools and Techniques chapter.

5.1.1.2 Tools and Techniques

The accuracy of the system on providing parking slot availability is measured based on the percentage of correct calculations. The percentage of correct calculations is measured by ratio between total number of calculations versus number of correct calculations. A miscalculation can be identified as the system incorrectly identifies the vehicle’s occupied slot. formula to calculate the accuracy is shown below and it shows the accuracy as a percentage value.

Accuracy = (total parking slot availability calculations – number of miscalculations) * 100 %

/ total parking slot availability calculations

Microsoft Excel is used for generating graphs from the obtained data. The obtained actual parking slot and calculated parking slot data is fed into excel sheet and bar chart is generated for each scenario.

5.1.1.3 Data sets

The dataset for evaluating the accuracy was generated by deploying the proposed system in a real-world parking lot and conducting three tests that described in 5.1.1.1 chapter.

5.1.2 Evaluation Results and Discussion

Three tests were performed to evaluate the accuracy, evaluate the impact on accuracy when the parking lot size increases and the impact on accuracy when external interreferences exist.

5.1.2.1 Accuracy evaluation

Figure 5.5 show the bar chart generated between the successful calculations' vs incorrect calculations for four scenarios tested. Each scenario contains 100 test iterations. The success rates of the parking slot occupancy calculation ranges from 78%-83%. The average success rate for all the scenarios tested were 79.5%.

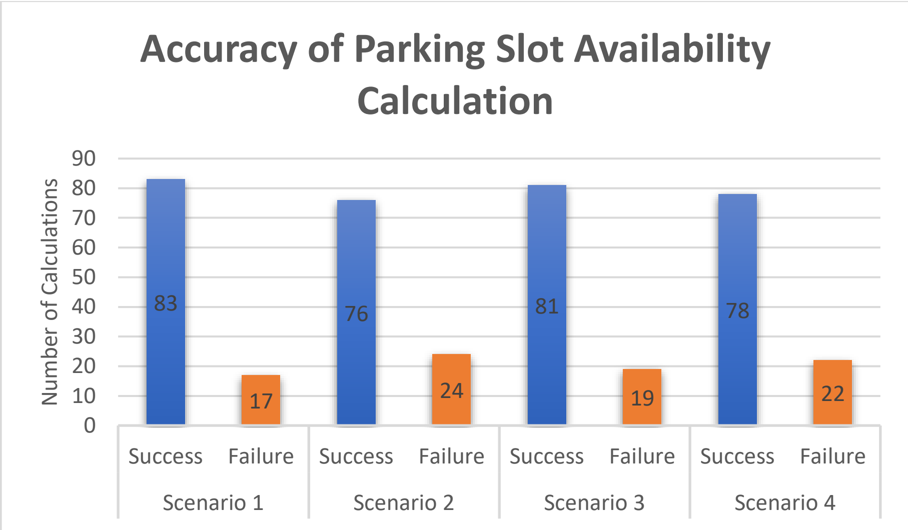


Figure 5.5: Calculated vehicle slot versus the actual parked slot for test 1

5.1.2.2 Evaluation of impact on accuracy when parking lot size increases

Figure 5.6 show the bar chart generated between the successful calculations' vs incorrect calculations for four scenarios tested on test 2. The success rates of the parking slot occupancy calculation ranges from 71%-77%. The average success rate for all the scenarios tested were 73.75%.

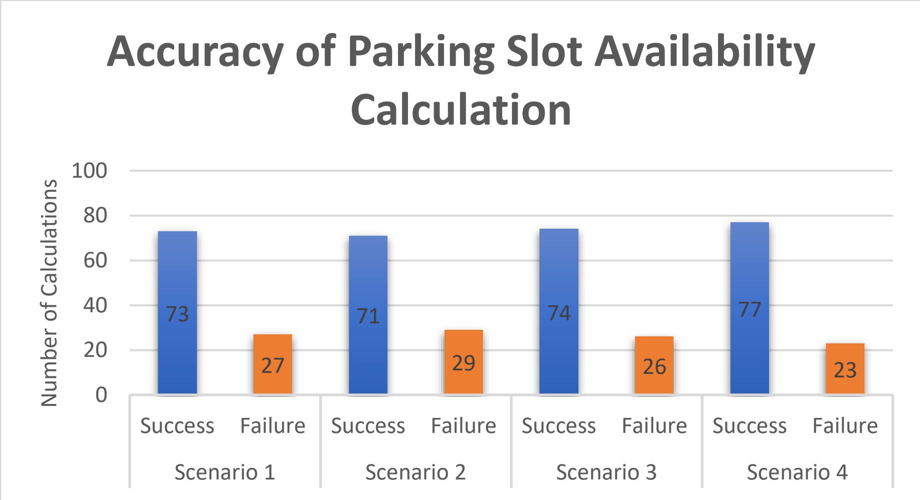


Figure 5.6: Calculated vehicle slot versus the actual parked slot for test 2

The results show that when the distance between the reference access nodes increases by 2 ½ times, the average accuracy of the parking occupancy calculation drops by 6%.

5.1.2.3 Evaluation of impact on accuracy when external interferences exist on the parking lot

Figure 5.7 show the bar chart generated between the successful calculations' vs incorrect calculations for two scenarios tested on test 3. The success rates of the parking slot occupancy calculation when there are no external interferences is 82% whereas 74% success rate shown when there are external interferences.

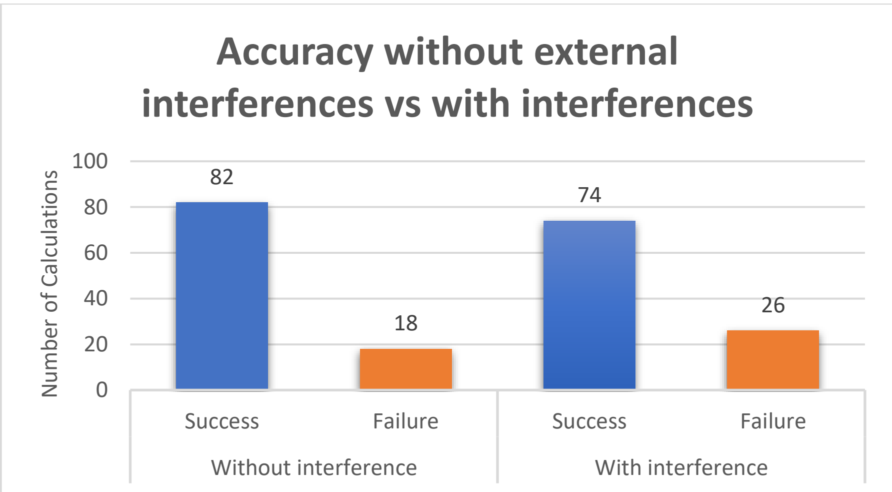


Figure 5.7: Calculated vehicle slot versus the actual parked slot for test 3

The current solution that deploys sensors in each parking slot shows nearly 100% accuracy when external interferences are not present. The presence of electromagnetic interferences rapidly drops the accuracy of the RFID and magnetic sensors. The image sensor-based solution that was analyzed showed 93% accuracy testing with a scaled model. However, the image sensors do not provide accurate results in low lighting conditions.

The proposed solution shows slightly low accuracy compared to above stated WSN based solutions analyzed in the literature review. However, the proposed solution shows stable results in presence of external interferences. Furthermore, the accuracy only dropped by 5.75% when the parking lot size increased by 2.5 times, making the proposed solution most scalable. The current analyzed systems do not work well when the parking lot size is larger as the image sensors and RFID sensors meteorite its quality in long distances.

5.2 Scalability Evaluation

Scalability is one of the important aspects of a WSN as the response time is crucial for the parking slot availability calculation. Thus, it is beneficial to analyze how the proposed parking management system would behave when the number of vehicles in the parking lot increases.

5.2.1 Evaluation Plan

5.2.1.1 Evaluation Approach

A simulation program is developed to mimic the behaviors of vehicle nodes in order to analyze the behaviors of the proposed system under different number of total vehicles.

A magnetic sensor based smart parking management system analyzed in [48] that measures the performance of the system based on response time. Similarly, the proposed system measures the scalability in terms of response time. The response time is calculated for a location update request from a specific vehicle node when the proposed system is under different loads. Scatter graphs are generated between the response time and total number of vehicles in order to depict the fluctuation of the response time when the total number of vehicles increases.

In order to measure the impact on response time when TLS security mechanisms are in place, a separate test designed. The response times from the test is compared with the response times that received when TLS security mechanics are not used. The results are used to evaluate how the TLS affects the WSNs scalability.

5.2.1.2 Tools and Techniques

Scalability of the proposed parking management system is evaluated based on response time for a location update request with increasing number of total vehicles in the parking lot. There are several inconveniences that arise when attempting to use many real vehicles for evaluating scalability.

In order to identify a suitable approach, existing studies and their evaluation approaches were critically analyzed. The WSN based parking management systems in [49] [50] developed simulation models to evaluate the system performance. The trilateration algorithm proposed in [51] employed simulation-based method to evaluate the accuracy of the algorithm. Thus, simulation is the most suited approach for scalability evaluation to mitigate practical inconveniences that arise. A simulation program is built to send location update requests to the controller node. Python programming language is used in building the simulation program with aid of Eclipse IDE.

The program simulates number of vehicle nodes starting with one vehicle and incrementing the vehicle count by one in each cycle. There are 10 iterations in each testing cycle. A target vehicle is selected, and this vehicle sent a location update request to the control node every 5 second interval. The response time for a location update request is measured. A scatter graph is generated between the response time and total number of vehicles in the parking lot. The response times are statistically analyzed to reflect on the scalability of the proposed system.

Two scenarios are tested.

1. How the response time increase/decrease with the total number of vehicles in the parking lot

There were several testing cycles for scenario 1, in each cycle, there is a constant number of total vehicles in the parking lot. The target vehicle sends out location request every 5 second interval and in each testing cycle target vehicle sends 10 requests. Response time is measured for each request and the response time is calculated. In each testing cycle, total number of vehicles in the parking lot is incremented in by one.

2. How the response changes with the total number of vehicles in the parking lot when TLS is used

In scenario 2, the WSN use TLS, and each simulated vehicle and target node communicate with the controller node using secure MQTT connection.

There are several testing cycles for scenario 1, in each cycle, there is a constant number of total vehicles in the parking lot. The target vehicle sends out location request every 5 second interval and in each testing cycle target vehicle sends 10 requests. Response time is measured for each request and the response time is calculated. In each testing cycle, total number of vehicles in the parking lot is incremented by one.

Scatter graphs are generated between the response time and total number of vehicles for the two scenarios. T-test is conducted to conclude whether there is a statistical difference in response time when TLS is used vs it is not used. Microsoft Excel is used for generating scatter graphs and conducting t-tests on the obtained data.

5.2.1.3 Data sets

The dataset for evaluating the scalability is generated by conducting simulations. Two separate simulations conducted. One with TLS on and one without TLS mechanisms. In each scenario, total number of vehicles and the corresponding response time is measured and saved as a .csv comma separated file. The file is imported to Microsoft Excel and statistical calculations are performed.

5.2.2 Evaluation Results and Discussion

Scalability of the proposed system is measured in terms of variation in average response time with the increase of total number of vehicles in the parking lot. Two main scenarios are evaluated, one scenario with TLS in the WSN communication layer and second scenario without TLS. Simulation technique that is described in the chapter 5.2.1 is used to evaluate the scalability.

5.2.2.1 Average Response Time and Total Number of Vehicles without TLS

Figure 5.8 show the scatter graph generated between the average response time and the total number of vehicles in the parking lot, when communication layer does not use TLS. The graph shows a flat line for average response time and the total number of vehicles until the total number of vehicles in the parking lot reaches 44 vehicles. After total number of vehicles reaches above 44, the average response time grows exponentially.

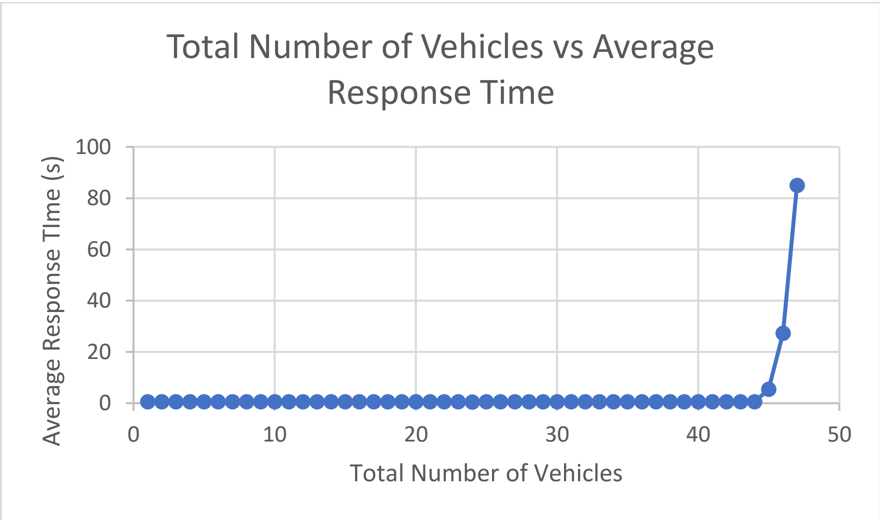


Figure 5.8: Average Response time vs total number of vehicles (without TLS)

5.2.2.3 Comparison between Average Response times with and without TLS

Figure 5.9 show the scatter graph generated between the average response time and the total number of vehicles in the parking lot, when TLS is used and not used. The blue color trendline shows the average response time variation when TLS is used and the orange color trendline shows the average response time variation when TLS is not used. When TLS is used, after total number of vehicles reaches above 35, the average response time grows exponentially.

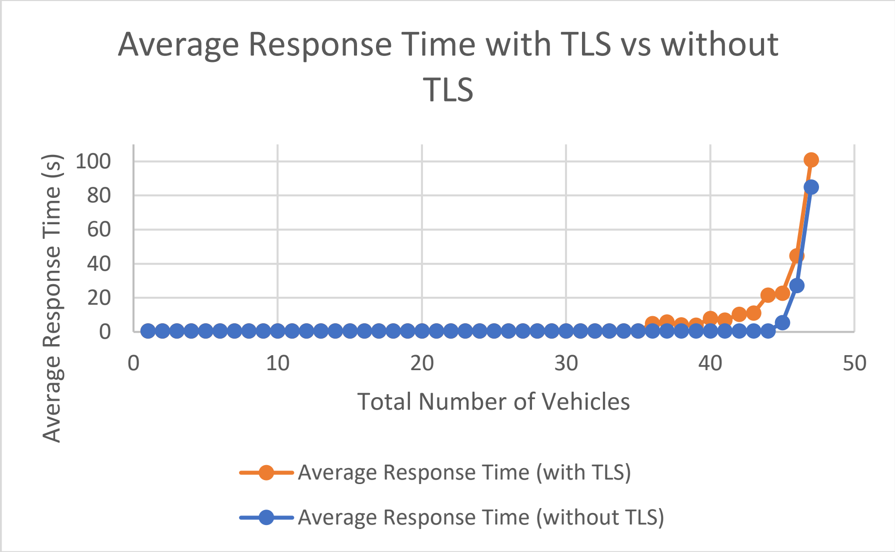


Figure 5.9: Average response comparison with and without TLS

T-test and Person Correlation is used to find out whether there is a significant difference between the average response time of TLS and no TLS scenarios. The person Correlation shows 0.9572, which concludes that there is a strong correlation between the two data sets. The calculated t-statistics value is 1.2901 and the t-critical one tail value is 2.0128. Since the t-statistics value is smaller than the t-critical one tail value, it can be concluded that there is no statistically significant difference in average response times when TLS used versus TLS is not used.

The statistical results suggest that there is no significant performance degrading in terms of average response time when TLS mechanisms are used.

5.3 Usability Evaluation

The proposed parking management should be user friendly and designed according to match the user expectations. According to chapter 3, the Application Layer contains a mobile application that can be used to interact with the parking management system. Thus, the User Experience of the mobile application need to be evaluated thoroughly.

5.3.1 Evaluation Plan

5.3.1.1 Evaluation Approach

System demonstration and hands on experience session followed by a Questionnaire would be most appropriate approach to evaluate User Experience of a software system [52]. The implemented Mobile Application was demonstrated to a target group and allow them to receive hands on experience with the application. After the demonstration session, a questionnaire was provided to each user in the target group. The suggested approach allows gaining feedback from the users who has a hands-on experience with the Mobile Application.

5.3.1.2 Tools and Techniques

The approach that is used to evaluate user experience is a questionnaire preceded by a system demonstration. A questionnaire was provided to each user that completes hands on experience with the mobile application. The questionnaire contains Likert scale questions and open-ended questions. The Likert scale questions are used to gain quantitative data and open-ended questions are used to gain qualitative data regarding the User Experience of the mobile application [53]. The questionnaire was published as a Google questionnaire and sent to a set of target audience in different ages. A prototype of a mobile application was provided along with a demonstration video. The participants were asked to watch the demonstration video and use the provided mobile application to gain hands on experience.

5.3.1.3 Data sets

The dataset for User Experience Evaluation was gained from the questionnaire that was provided to selected target groups. Both Qualitative and quantitative data was obtained from the questionnaire.

Microsoft Excel was used to record the responses and arrange data in bar charts in order to statistically analyze the questionnaire outcome.

5.3.2 Evaluation Results and Discussion

Evaluation of the proposed system was conducted with three target groups of 30 vehicle owners. A system demonstration was conducted as the first step and the target group was asked to use the system and gain hands on experience. A questionnaire provided to each target group member to gain feedback on the system after the system use. The questionnaire provided to the target group is presented in Appendix A.

Demographic information of the target group is provided in table 5.5**.**

Table 5.5: Demographic information of the target group

Criteria	**Age range**	**No of Participants**	**Percentage**
Age Variety	18-29	18	60%
	30-39	8	26.66%
	40-49	1	3.33%
	50-59	3	10%
	Profession	**No of Participants**	**Percentage**
Profession Variety	Student	6	20%
	Education	1	3.33%
	Engineering/Computing	15	50%
	Transport	1	3.33%
	Other	7	23.33%
	Education	**No of Participants**	**Percentage**
Education Variety	High School	6	15%
	Bachelor's Degree	18	60%
	Postgraduate Degree	6	15%

Likert scale and open-ended questions were provided in the questionnaire. The questionnaire consists of four main categories that are, User Interface, Functionality, Similar Systems and Final Feedback. Latter chapter compiled evaluation results of the respective category.

5.3.2.1 User Interfaces Evaluation

Questions focused on the User Interface evaluation contested of five Likert scale questions. The questions focused on getting user opinion on font and button sizes, text label meaningfulness and comfortless of the color scheme used in the proposed system. Figure 5.10 compile the results in a line chart.

28 out of 30 participants commented that the button sizes are appropriate, and 27 participants agreed that the font sizes are appropriate. 26 participants agreed that the labels that are provided meaningful. 27 participants thought that the color scheme provided in the proposed system is comfortable to their eyes.

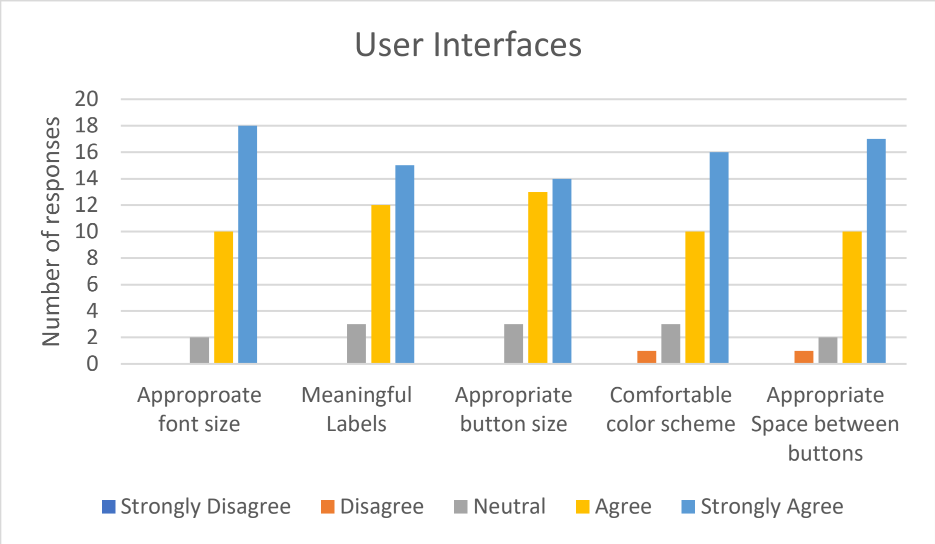


Figure 5.10: Results of the User Interface feedback

5.3.2.2 Functionality Evaluation

Five Likert scale questions consisted in evaluating the feedback on the proposed system's functionality. The category consisted of questions related to receiving user opinion on easiness and quickness to find an available parking lot, correctness of the available parking slots shown by the system, easiness to list available vehicles, easiness to edit the user profile. Figure 5.11 depicts a line chart, compiling the results.

21 out of 30 participants agreed that it is easy to find an available parking slot and 25 participants thought that the proposed system is quickly shows the available slots. 24 participants agreed that the available parking slots shown in the system is correct. 26 participants agreed that editing user profile details is easy.

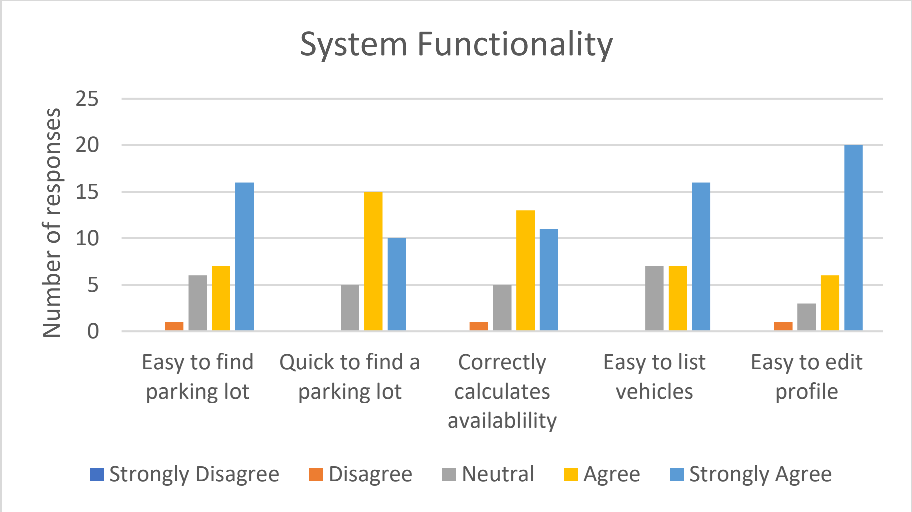


Figure 5.11: Results of the feedback on proposed system's functionality

5.3.2.3 Opinion on Similar systems

Two Likert scale questions and one open ended question were provided to gain opinion on the comparison with the similar systems target group have used. Figure 5.12 represents the feedback of the similar systems.

Only 5 participants had used a parking management system before. 4 participants out of 5 agreed that the proposed system is easier to use than the similar systems they have previously used. All the participants consented that the proposed system is relatively faster than the other similar systems used.

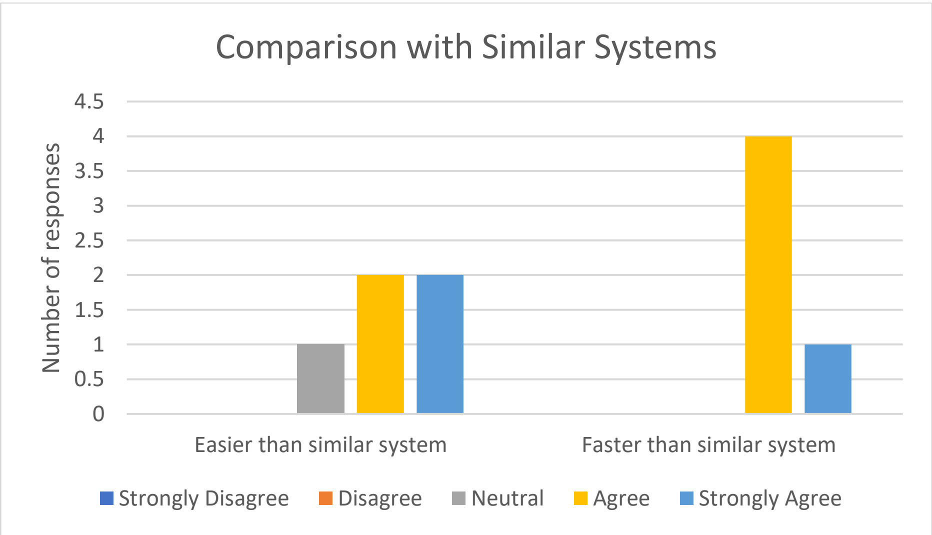


Figure 5.12: Results of the comparison with similar systems

5.3.2.4 Final Feedback

The final feedback section contained questions gaining user opinion on their willingness to use the proposed system and their overall impression. Figure 5.13 depicts the line chart containing the final feedbacks.

27 out of 30 participants stated that they are willing to use the proposed system to find an available parking space. 25 participants expressed that they are willing to recommend the proposed system their friends and family.

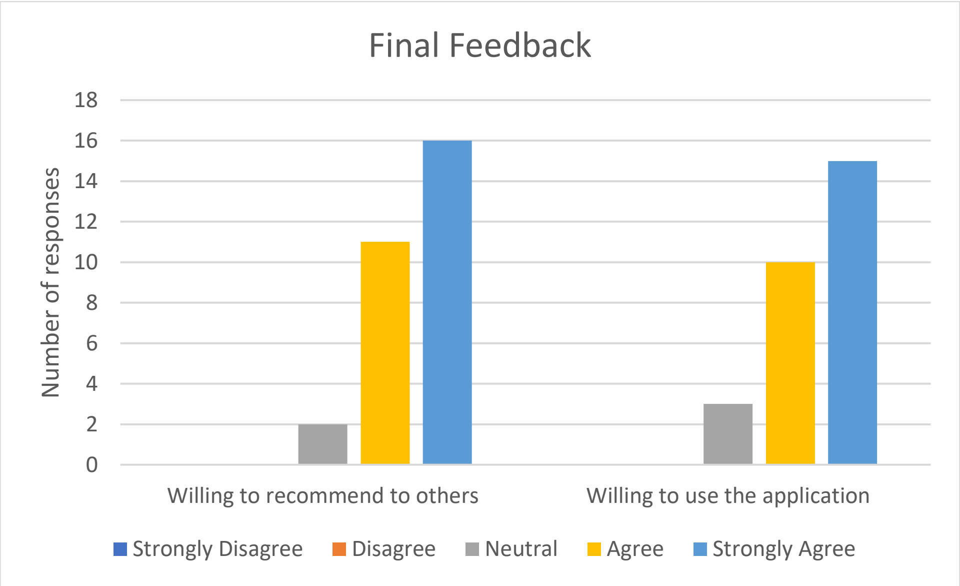


Figure 5.13: Results of the final user feedback

The results of the open-ended questions can be categorized into 2 categories. Overall feedback and suggestions to improve the usability. Following lists few of the feedback gained from the participants. "N" indicates the frequency of particular response.

1. Overall Feedback

"It's a good app to help quickly identify available parking slots and the history of where the vehicle was parked could come in handy in case of damage done to the vehicle" (N=1)

"An app that is easy to use and is very useful especially in a parking lot which consists of several floors. This app saves a lot of time. Especially in a hospital setting." (N=1)

"User friendly and it's able to find an appropriate parking slot quickly" (N=11)

"Spending time and fuel consumption could be reduced through the application" (N=1)

2. Suggestions to Improve the Usability

"It's better when it's necessary if can make the phone call/email by clicking the relevant phone number of already parked user" (N=2)

"I think it will be easy, if this app has an option to give the user notification automatically about free parking slots of his current location, using google current location" (N=1)

"I would like to suggest few things, 1. Add legend or meaningful value to red color, green color and yellow bulbs. 2. Add screen navigation clearly on top of the screen to see where I am" (N=1)

"May be using GPS navigation and google maps to navigate to parking lots would improve UX" (N=1)

The responses to open ended questions were analyzed and found out that 11 participants stated that the proposed mobile application is user friendly. 4 participants commented that the mobile application can be used easily to find an available parking slot.

Several participants suggested to use legends or meaningful texts to display for the colors that were used to indicate parking slot availability. One participant suggested that it is better to enable functionality to make a phone call/ email to the users who parked slots. The feedback to improve the usability was taken into consideration and the mobile application was revised based on some mentioned feedback.

5.3.2 Evaluating the Mobile Application

The application testing is essential to ensure that the proposed system meets the user requirements. Grey Box testing approach was used to test the functionalities offered by the proposed system. Grey Box testing is a technique to test the application with limited knowledge of the internal working of an application and has the knowledge of fundamental aspects of the system [54]. The grey box testing approach is selected because testing focus on both internal structure from a software developers' perspective as well as the functionality of the system from an end users' perspective. The test cases for the testing is developed based on the architecture diagrams and UML diagrams that were created on the design phase as well as the functional requirements identified from the literature review. Test cases were developed to aim at evaluating the usability and the accuracy of the proposed system. Test cases used in the testing process listed in the Appendix C.

5.4 Security Evaluation of WSN

Security is one of the main concerns in the proposed system as the system contains hardware that is deployed in a physical location that communicates with each other over a network and set of software components installed on the devices that conduct the functions of the system. Malicious entity can easily tamper the hardware since the it is physically available in the parking lot. Furthermore, fabricated sensor devices can be deployed in the parking lot as well as inside vehicles. The software components communicate over the available Wi-Fi network that arise security vulnerabilities.

5.4.1 Security Evaluation Plan

5.4.1.1 Evaluation Approach

The design and implementation of the proposed solution have addressed the mentioned security concerns by employing various security mechanisms described in chapter 3. In order to evaluate the suitability and effectiveness of the employed security mechanisms, conducting a vulnerability scan is the most appropriate approach [55].

5.4.1.2 Tools and Techniques

In order to evaluate the secureness of the proposed system, security rating model introduced in [55] is used. The security rating model evaluate the IoT based systems by calculating security factor/ rating of the system. There are three categories of criteria which are critical criteria, important criteria and valuable criteria. Each of these categories contains questions that can be answered with yes/no. Each question has an associated weight and based on the answer, a sum of weighted scores calculated from each category. The table 5.6 shows the points given for each correct answer in three categories.

Table 5.6: Security evaluation criteria and points

Criteria	Points
Critical Criteria	5
Important Criteria	2
Valuable Criteria	1

The final score is calculated by using below formula.

Score = Round (Sum of Weighted Answers / 58.0 X 10)

The final weighted sum score reflects the overall security rating of the IoT based system. A highly secure system scores between 8-10 and a secure system scores between 5-7 whereas an insecure system score between 0-4.

5.4.1.3 Data sets

Dataset for the security evaluation would be the implemented parking management system itself and system architecture design and UML modelling documentation as well as the tools and techniques used in system implementation.

5.4.2 Evaluation Results and Discussion

Appendix D represents the security evaluation results including the answers for each question and the associated score for the answer. The total score received for the security evaluation of the proposed system is 42. The final average score is calculated as below.

Score = (42 / 58.0 X 10) = 7.25

The final score falls within 5 - 8 range. Thus, the proposed parking management system can be concluded as a secure system.

6. Conclusions

6.1 Conclusion about the Research Questions

Four main research questions are formulated based on the defined research problem in introduction chapter. Evaluation approach developed based on the identified research problems and the results were evaluated in evaluation chapter.

1. “How does proposed novel RSSI based approach impact the accuracy of identifying occupied parking slots?”

The proposed solution was deployed in a real-world parking lot and 4 test scenarios conducted to calculate the accuracy. The results showed that the proposed approach is 79.5% accurate compared to detecting the available parking slots by the human eye. Based on the evaluation results, the formulated hypothesis “When proposed RSSI based approach used, the average accuracy of identifying occupied parking slots remains above 70%” can be accepted.

2. “What is the impact on accuracy of the parking slot availability calculation of the proposed approach when the parking lot size increases?”

The proposed solution was deployed in another parking lot that is 2.5 time larger than the parking lot in previous test. The results showed that the proposed approach is 73.75% accurate, indicating a 5.75% drop in accuracy when parking lot size increases by 2.5 times. Based on the evaluation results, the formulated hypothesis “When the parking lot size increases by 2.5 times, the accuracy remains above 70% for 100 test iterations” can be accepted.

3. “What is the impact on response time of vehicle location update request when the total number of vehicles in the parking lot increases?”

The performance of the proposed solution was evaluated in terms of response time. A simulation program was developed by the author to simulate the total number of vehicles in a parking lot. The results showed that the proposed solution is stable until the total number of vehicles reach 44. The response time does not have a significant increase until the total vehicles reaches 44. Based on the evaluation results, the formulated hypothesis “There is no statistically significant increase in response time when the total number of vehicles in the parking lot increases” can be accepted.

4. “What is the impact on response time of vehicle location update request when TLS mechanism are in place?”

The simulation program developed before, was used in evaluating the impact of transport layer security mechanisms on the proposed solution. The results showed that the response time does not have a significant increase until total number of vehicles reaches 35 and then it grows exponentially. Based on the evaluation results, the formulated hypothesis “There is no statistically significant increase in response time when the TLS mechanism are in place” can be accepted.

6.2 Summary of the Research Problem

The main research problem the study addresses is, lack of previous studies regarding the applicability of RSSI and trilateration-based techniques to calculate parking slot occupancy. Several research questions were formulated based on the research problem. The study has analyzed the applicability of the RSSI based techniques and algorithms and proposed a novel RSSI based approach in calculating parking slot occupancy. Artifacts were implemented based on the developed system architecture and evaluated based on the developed evaluation approach. The evaluation approach was developed based on the research questions that were formulated. The evaluation results were compared with the similar WSN based systems and the proposed solution showed considerably low cost, high scalability and security.

6.3 Limitations

The research study analyses and employs RSSI based distance calculation algorithm that only takes 2-dimentional plane into account [8]. Thus, the proposed approach that calculates the occupied parking slots does not provide accurate results for parking lots with slant surface. This limitation needs to be addressed in order to generalize the proposed solution.

The proposed approach maps the parking slot for the calculated vehicle location coordinates if the vehicle is inside the parking slot bounds. The accuracy of the proposed solution can be increased by conducting further research on proposing a new method for mapping parking slots.

6.4 Implications for Further Research

The occupied parking slot of a vehicle is currently calculated by mapping the parking slot for the calculated vehicle location coordinates. In order to increase the accuracy of the proposed solution, further analysis must be conducted to identify applicability of fuzzy logic-based algorithm.

The proposed solution displays the available parking slots in a map view of the parking lot. It will be beneficial to the vehicle owners if the functionality extended to guide the vehicle to the nearest available parking slot. Further studies need to be conducted to analyze and select suitable shortest path calculation algorithm to design and implement parking slot guidance functionality.

The proposed approach is only applicable for flat parking lots. Further research needs to be conducted to extend the approach for parking lots with slant surfaces.

6.5 Uniqueness and Research Contributions

6.5.1 Uniqueness of The Study

RSSI based approach was proposed for the first time in the WSN transportation research domain. Based on the evaluation results, it is evident that the proposed solution is cost effective, scalable, secure and easy to deploy compared to the current solutions.

The proposed solution uses, a light weight, low power and scalable MQTT communication protocol. MQTT like lightweight protocol is used for the first time in a WSN based parking management system. Therefore, the proposed system consumes less bandwidth and low power as well as highly scalable.

TLS mechanisms used for authentication and data encryption in the communication layer. The TLS security techniques were implemented on top of MQQT communication protocol. The MQTT and TLS combination makes the proposed system unique as there is no other current system uses such lightweight communication protocol with security layer on top. The testing and validation show that employing TLS mechanisms does not have statistically significant impact on performance.

6.5.2 Contributions from The Study

The study proposed and developed a novel approach for calculating parking slot availability based on RSSI and triangulation-based techniques and non-linear optimization. The proposed approach can be considered as the main outcome of this research study. Several artifacts were developed based on the proposed approach that are listed below.

- Android Mobile Application
- Control Node program
- Vehicle Node Program

The artifacts were tested based on accuracy, scalability, usability and security criteria. The proposed system was thoroughly tested using several different testing and validation mechanisms. The system was tested for accuracy by deploying it in two real world parking lots. The scalability was tested by using a simulation and usability was evaluated by conducting a survey based on a questionnaire. A vulnerability scan was conducted based on a security template in order to evaluate the proposed system's secureness. The data collected and the evaluation results can be used in future research studies conducted in similar area.

The thesis that compiled the literature on similar researches, model of the proposed system and test results can be considered one of the main contributions. The thesis can be referred by researchers who conduct studies in similar domain.

6.5.3 Publications

Author have submitted extended abstract research paper for 20th International Conference on Advances in ICT for Emerging Regions. The research paper introduces the novel RSSI based approach to the research community including a brief description of the research methodology and the architectural design of the proposed solution. The paper is currently being reviewed for approval. It will provide insight on the novel approach to the researchers in similar domain and potential further research for future research studies.

6.6 Conclusion

Vehicle parking has become a great concern due to rapidly growing number of vehicles in the world. The issues arise with the vehicle parking mainly affect the vehicle owners, passengers, administrative parties of parking spaces, security personnel and general population who use the premises. Various WSN based vehicle parking Management Systems have been proposed with the aim of discovering unoccupied parking spaces. These systems have employed various types of sensors such as Infrared (IR), magnetic, light sensors and cameras deployed on the parking lot. However, the current parking management systems consist of noticeable drawbacks including lack of scalability, lack of standard security mechanisms and high susceptibility to external interferences.

The study proposes a novel RSSI based parking management system for identifying available parking slots in a parking lot. The proposed solution calculates the occupied parking slots and provide a real-time representation of parking slot availability. It is highly scalable and secure since it employs lightweight MQTT communication protocol and TLS security mechanisms. The system can be implemented and deployed with low cost sensor devices. It does not need to deploy sensors in each parking lot making it scalable and cost effective.

During the evaluation phase, the proposed solution was evaluated based on accuracy, scalability, usability and security criteria. The results showed that the solution is 79.5% accurate compared to identifying vacant parking slots by human eye. It shows 73.75% accuracy when the parking lot size increased by 2.5 times. Compared to the current WSN based parking management systems, the proposed system shows stable accuracy when the parking lot sizes increases and in presence of external interferences. The system does not degrade its performance when the TLS mechanisms are employed, and the system is stable until the total number of vehicles in the parking lot reaches 44. Furthermore, the usability evaluation results show that more than 80% of the participants, agreed that the proposed system is usable in terms of button, text sizes, color schemes and the mobile application functionality. The proposed system scored 7.25 marks on security evaluation conducted which can be considered a secure system.

The accuracy of the proposed solution can be increased with further research regarding fuzzy logic-based parking slot mapping for a calculated vehicle location. The algorithm that is used in parking slot availability calculation needs to be extended for parking lots with variable heights to provide accurate results for parking lots with slant surfaces.

The main advantages of the proposed system include, ability to discover available parking spaces remotely using the developed mobile application and saving a significant amount of time and money. Moreover, the it retained stable accuracy with increasing parking lot size and in presence of external interferences. It is highly scalable and secure compared to the current WSN based parking management systems. Finally, the proposed RSSI based parking management system exhibits a great promise as a real-time, cost effective, highly scalable and secure solution.

References

[1] C. Wenzhi and L. Bai, "A smart roadside parking navigation system based on sensor networks for ITS", IET International Conference on Wireless Mobile and Multimedia Networks Proceedings (ICWMMN 2006), 2006. Available: 10.1049/cp:20061316 [Accessed 7 July 2019].

[2] V. Daur, P. Bhandari, L. Jain and N. Nagendran, "Smart Car Parking System", International Journal of Advanced Research in Computer Science and Software Engineering, vol. 6, no. 5, pp. 225-227, 2019. [Accessed 7 July 2019].

[3] INRIX, "Searching for Parking Costs Americans $73 Billion a Year", 2017.

[4] P. Tzouras and C. Lázaro, "Illegal parking in urban streets: connection with the geometric characteristics and its mitigation through traffic calming measures", in 5th Panhellenic Conference of Planning and Regional Development, Volos, 2018.

[5] M. Sauter, From GSM to LTE: An Introduction to Mobile Networks and Mobile Broadband. Wiley, 2011, p. 160.

[6] R. Heale and D. Forbes, "Understanding triangulation in research", BMJ Journals, 2019. [Online]. Available: https://ebn.bmj.com/content/16/4/98. [Accessed: 12- Apr- 2020].

[7] M. Md Din, N. Jamil, J. Maniam and M. Mohamed, "Review of indoor localization techniques", *International Journal of Engineering & Technology*, vol. 7, no. 214, p. 201, 2018. Available: 10.14419/ijet.v7i2.14.12980 [Accessed 16 May 2020].

[8] X. Zhu and Y. Feng, "RSSI-based Algorithm for Indoor Localization", *Communications and Network*, vol. 05, no. 02, pp. 37-42, 2013. Available: 10.4236/cn.2013.52b007 [Accessed 16 May 2020].

[9] M. Faheem, S. Mahmud, G. Khan, M. Rahman and H. Zafar, "A Survey of Intelligent Car Parking System", Journal of Applied Research and Technology, vol. 11, no. 5, pp. 714-726, 2013. Available: 10.1016/s1665-6423(13)71580-3 [Accessed 7 July 2019].

[10] V. Tang, Y. Zheng and J. Cao, "An Intelligent Car Park Management System based on Wireless Sensor Networks", 2006 First International Symposium on Pervasive Computing and Applications, 2006. Available: 10.1109/spca.2006.297498 [Accessed 7 July 2019].

[11] V. Boda, A. Nasipuri and I. Howitt, "Design considerations for a wireless sensor network for locating parking spaces", Proceedings 2007 IEEE SoutheastCon, 2007. Available: 10.1109/secon.2007.342990 [Accessed 7 July 2019].

[12] G. Anusooya, J. Christy Jackson, K. Sathyarajasekaran and K. Kanan, "RFID based smart car parking system", International Journal of Applied Engineering Research, vol. 12, no. 17, 2019. [Accessed 8 July 2019].

[13] A. Wood, J. A. Stankovic, "Denial of Service in Sensor Networks," IEEE Computer, 3 (10):54-62, October 2002.

[14] A.D. Wood, J.A. Stankovic, and S.H. Son. Jam: a jammed-area mapping service for sensor networks. Real-Time Systems Symposium, 2003. RTSS 2003. 24th IEEE, pages 286297, 3-5 Dec. 2003.

[15] M. Aalsalem, W. Khan and K. Dhabbah, "An automated vehicle parking monitoring and management system using ANPR cameras", 2015 17th International Conference on Advanced Communication Technology (ICACT), 2015. Available: 10.1109/icact.2015.7224887 [Accessed 26 October 2019].

[16] D. Bhardwaj and S. Mahajan, "Review Paper on Automated Number Plate Recognition Techniques", Review Paper on Automated Number Plate Recognition Techniques, vol. 4, no. 5, pp. 319-324, 2015.

[17] M. Castro, M. Teixeira, L. Nakamura and R. Meneguette, "A Prototype of a Car Parking Management Service based on Wireless Sensor Networks for ITS", International Robotics & Automation Journal, vol. 2, no. 3, 2017. Available: 10.15406/iratj.2017.02.00021 [Accessed 2 May 2020].

[18] F. Zafari, A. Gkelias and K. Leung, "A Survey of Indoor Localization Systems and Technologies", IEEE Communications Surveys & Tutorials, pp. 1-1, 2019. Available: 10.1109/comst.2019.2911558 [Accessed 8 August 2019].

[19] Z. Yang, Z. Zhou and Y. Liu, "From RSSI to CSI", 2019.

[20] C. Wang, L. Xiao, "Locating Sensors in Concave Areas", IEEE INFOCOM 2006, 25th IEEE Int. Conf. on Computer Communications, 2006, pp. 1-12

[21] W. Dargie and C. Poellabauer, "Fundamentals of Wireless Sensor Networks", 2010. Available: 10.1002/9780470666388 [Accessed 8 August 2019].

[22] S. Kumar, S. Gil, D. Katabi and D. Rus, "Accurate indoor localization with zero start-up cost", Proceedings of the 20th annual international conference on Mobile computing and networking - MobiCom '14, 2014. Available: 10.1145/2639108.2639142 [Accessed 8 August 2019].

[23] U. Bekcibasi, "Increasing RSSI Localization Accuracy with Distance Reference Anchor in Wireless Sensor Networks", Acta Polytechnica Hungarica, vol. 11, no. 8, pp. 103-120, 2014. [Accessed 2 November 2019].

[24] "True range multilateration", En.wikipedia.org, 2019. [Online]. Available: https://en.wikipedia.org/wiki/True_range_multilateration. [Accessed: 02- Nov- 2019].

[25] N. Gould, T. Rees and J. Scott, A higher order method for solving nonlinear least-squares problems, 1st ed. Didcot: Harwell Oxford, 2017.

[26] "MQTT Version 5.0", Docs.oasis-open.org, 2020. [Online]. Available: https://docs.oasis-open.org/mqtt/mqtt/v5.0/mqtt-v5.0.html. [Accessed: 07- Mar- 2020].

[27] D, Soni, & Makwana, A. “A Survey On MQTT: A Protocol of Internet of Things (IOT)”, 2017.

[28] M. Laska, S. Herle, R. Klamma and J. Blankenbach, "A Scalable Architecture for Real-Time Stream Processing of Spatiotemporal IoT Stream Data—Performance Analysis on the Example of Map Matching", ISPRS International Journal of Geo-Information, vol. 7, no. 7, p. 238, 2018. Available: 10.3390/ijgi7070238 [Accessed 7 March 2020].

[29] A. Bashir and A. Hussain Mir, "Securing Communication in MQTT enabled Internet of Things with Lightweight security protocol", EAI Endorsed Transactions on Internet of Things, vol. 3, no. 12, p. 154390, 2018. Available: 10.4108/eai.6-4-2018.154390 [Accessed 7 March 2020].

[30] A. Vardhan, M. Hussain and R. Garimella, "Simple and secure node authentication in wireless sensor networks", 2016 International Conference on Recent Advances and Innovations in Engineering (ICRAIE), 2016. Available: 10.1109/icraie.2016.7939543 [Accessed 2 November 2019].

[31] "Transport Layer Security (TLS)", IEEE.org, 2019. [Online]. Available: https://site.ieee.org/ocs-cssig/?page_id=658. [Accessed: 08- Aug- 2019].

[32] S. Dechand, D. Schurmann and K. Busse, "An Empirical Study of Textual Key-Fingerprint Representations", in 25th USENIX Security Symposium, 2016, pp. 193--208.

[33] V. Vaishnavi and W. Kuechler, "Design science research in information systems", 2004, viewed 3 June 2004, http://www.desrist.org/design-research-in-information-systems

[34] B. Kuechler and V. Vaishnavi, "Promoting relevance in is research: an informing system for design science research", The International Journal of an Emerging Transdiscipline, Vol.14, No.1, Viewed 2 October 2014, www.inform.nu/Articles/Vol14/ISJv14p125-138Kuechler570.pdf

[35] "Overview - NodeMCU Documentation", Nodemcu.readthedocs.io, 2019. [Online]. Available: https://nodemcu.readthedocs.io/en/master/. [Accessed: 07- Jul- 2019].

[36] "ESP8266EX Datasheet", 6th ed. Espressif IOT Team, 2018, p. 1. [Online]. Available: http://espressif.com/sites/default/files/documentation/0a-esp8266ex_datasheet_en.pdf [Accessed: 07- Jul- 2019].

[37] "Apache Commons Math 3.6 API", *Home.apache.org*, 2020. [Online]. Available: http://home.apache.org/~luc/commons-math-3.6-RC2-site/apidocs/index.html?org/apache/commons/math3/fitting/leastsquares/LeastSquaresOptimizer.html. [Accessed: 16- May- 2020].

[38] Raspberry Pi Compute Module 3+, 1st ed. Raspberry Pi (Trading) Ltd, 2019, pp. 6-13.

[39] ESP-12F Datasheet, 1st ed. Shenzhen Ai-Thinker Technology Co, 2018, pp. 4-5.

[40] "MongoDB Atlas Cloud", mongodb.com, 2020. [Online]. Available: https://www.mongodb.com/cloud/atlas. [Accessed: 13- Apr- 2020].

[41 "Raspberry Pi 4", *Raspberrypi.org*, 2020. [Online]. Available: https://www.raspberrypi.org/products/raspberry-pi-4-model-b/. [Accessed: 10- May- 2020].

[42] "Node MCU Development Kit V3 CH340", *aliexpress.com*, 2020. [Online]. Available: https://www.aliexpress.com/item/4000529999380.html?spm=a2g0o.productlist.0.0.7e9d54caf3jbM1&algo_pvid=7e627d7c-ced8-44a6-9c2f-41d531e5cfb8&algo_expid=7e627d7c-ced8-44a6-9c2f-41d531e5cfb8-9&btsid=0ab6fab215891064762428552ed81a&ws_ab_test=searchweb0_0,searchweb201602_,searchweb201603_. [Accessed: 10- May- 2020].

[43] "Parkalot.io 2019 | Workplace Car Park Sharing and Management App", *Parkalot*, 2020. [Online]. Available: https://parkalot.io/. [Accessed: 24- May- 2020].

[44] "Thinkpark Ultrasonic Smart Parking Guidance System", *Alibaba.com*, 2020. [Online]. Available: https://www.alibaba.com/product-detail/Thinkpark-Ultrasonic-Smart-Parking-Guidance-System_60722902962.html?bypass=true&spm=a2700.galleryofferlist.0.0.855f17aahHQSKj&s=p. [Accessed: 24- May- 2020].

[45] "Lora Smart Wireless Parking Lot Sensor System", *Alibaba.com*, 2020. [Online]. Available: https://www.alibaba.com/product-detail/Lora-Smart-Wireless-Parking-Lot-Sensor_60480023750.html?spm=a2700.details.deiletai6.6.1ccb2c52ntEB5H&bypass=true. [Accessed: 24- May- 2020].

[46] "ASVIEWER SONY IMX327 1080P Security Intelligent LPR Camera", *aliexpress.com*, 2020. [Online]. Available: https://www.aliexpress.com/item/32968439489.html?spm=a2g0o.productlist.0.0.15b76842tuKEsm&algo_pvid=d32aa113-ee55-4fb1-95ac-3b71119b45fa&algo_expid=d32aa113-ee55-4fb1-95ac-3b71119b45fa-38&btsid=0ab6d70515903152241391618e37c8&ws_ab_test=searchweb0_0,searchweb201602_,searchweb201603_. [Accessed: 24- May- 2020].

[47] Z. Zhang, X. Li, H. Yuan and F. Yu, "A Street Parking System Using Wireless Sensor Networks", *International Journal of Distributed Sensor Networks*, vol. 9, no. 6, p. 107975, 2013. Available: 10.1155/2013/107975 [Accessed 3 May 2020].

[48] A. Ahmed, M. Olaniy, J. Kolo and S. Oyetoro, "Developing Smart Car Parking System Using Wireless Sensor Networks", in *CoRI*, Ibadan, Nigeria, 2016, pp. 201-206.

[49] Hongwei Wang and Wenbo He, "A Reservation-based Smart Parking System", *2011 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, 2011. Available: 10.1109/infcomw.2011.5928901 [Accessed 3 May 2020].

[50] T. Pham, M. Tsai, D. Nguyen, C. Dow and D. Deng, "A Cloud-Based Smart-Parking System Based on Internet-of-Things Technologies", *IEEE Access*, vol. 3, pp. 1581-1591, 2015. Available: 10.1109/access.2015.2477299 [Accessed 3 May 2020].

[51] A. Abdulqader Hussein, T. Rahman and C. Leow, "Performance Evaluation of Localization Accuracy for a Log-Normal Shadow Fading Wireless Sensor Network under Physical Barrier Attacks", *Sensors*, vol. 15, no. 12, pp. 30545-30570, 2015. Available: 10.3390/s151229817 [Accessed 3 May 2020].

[52] B. Laugwitz, T. Held and M. Schrepp, "Construction and Evaluation of a User Experience Questionnaire", Lecture Notes in Computer Science, pp. 63-76, 2008. Available: 10.1007/978-3-540-89350-9_6 [Accessed 9 February 2020].

[51] M. Ehmer and F. Khan, "A Comparative Study of White Box, Black Box and Grey Box Testing Techniques", International Journal of Advanced Computer Science and Applications, vol. 3, no. 6, 2012. Available: 10.14569/ijacsa.2012.030603 [Accessed 9 February 2020].

[53] S. Bairwa, B. Mewara and J. Gajrani, "Vulnerability Scanners: A Proactive Approach to Assess Web Application Security", International Journal on Computational Science & Applications, vol. 4, no. 1, pp. 113-124, 2014. Available: 10.5121/ijcsa.2014.4111 [Accessed 9 February 2020].

[54] J. Rowley, "Designing and using research questionnaires", Management Research Review, vol. 37, no. 3, pp. 308-330, 2014. Available: 10.1108/mrr-02-2013-0027 [Accessed 9 February 2020].

[55] “A Security Rating Model for the Internet of Things (IoT)", affinity-it-security, 2019. [Online]. Available: https://affinity-it-security.com/security-model-iot-devices/. [Accessed: 21- Jul- 2019].

Appendix A: Questionnaire for User Experience Evaluation

UCSC The questionnaire is prepared to gather data for final year research project of a postgraduate student who follow Master of Computer Science at University of Colombo School of Computing.

The purpose of the questionnaire is to gather feedback about the user experience of the designed Mobile Application that allows vehicle owners to search for available parking spaces on a parking lot.

Personal Information

1. What is your first name?

2. What is your age?

3. Please select the category that best describe your education:
   - ☐ Primary Education
   - ☐ Middle School
   - ☐ High School/ Diploma holder
   - ☐ Bachelor's Degree holder
   - ☐ Postgraduate Degree holder

4. Please select the category that best describe your profession
   - ☐ Student
   - ☐ Education
   - ☐ Engineering/Computing
   - ☐ Transport
   - ☐ Sales & Marketing
   - ☐ Other

User Interfaces

For question 5 - 9 tick the most appropriate answer among Strongly Disagree, Disagree, Neutral, Agree and Strongly Agree.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
5. The font size is appropriate and visible enough					
6. The label texts are meaningful					
7. The button sizes are appropriate for the usage					
8. Color scheme used in the screens is comfortable for the eye					
9. The buttons are separated from each other without overlap					

Functionality

For questions 10 - 14 tick the most appropriate value from 1 - 5 where 1 is the least and 5 is the most.

	1	2	3	4	5
10. How easier to find an available parking slots using the mobile application?					
11. How quick to find an available parking slot using the mobile application?					
12. Does the mobile application always list the available parking slots correctly?					
13. How easier to list the vehicles that are owned by you?					
14. How easier to edit the profile information?					

Similar Systems

15. Have you ever used a software system that allows searching for available parking spaces?

☐ Yes ☐ No

If the answer to question 15 is yes, proceed with question 16. Otherwise skip to question 18.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
16. Compared to the earlier mentioned system the mobile application is easier to use					
17. Compared to the earlier mentioned system the mobile application is faster					

to list available parking slots					

18. Compared to the earlier mentioned system, what are the improvements that can be made for the mobile application?

Final Feedback

For question 15 - 16 tick the most appropriate answer among Strongly Disagree, Disagree, Neutral, Agree and Strongly Agree.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
19. Are you willing to recommend this mobile application to your family, friends or colleges?					
20. Are you willing to use this mobile application in future when you want to find an available parking slot?					

21. What is your overall impression about the usability of the Mobile Application?

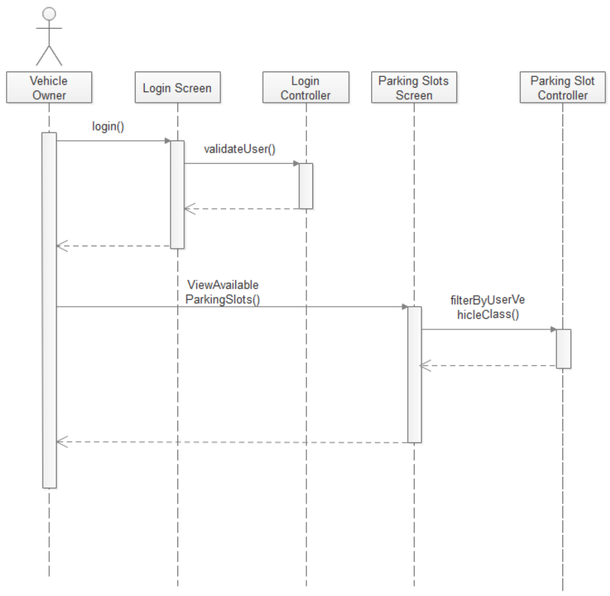
22. Are there any suggestion that you would make in order to improve the user experience of the Mobile Application?

Appendix B: System Design Diagrams

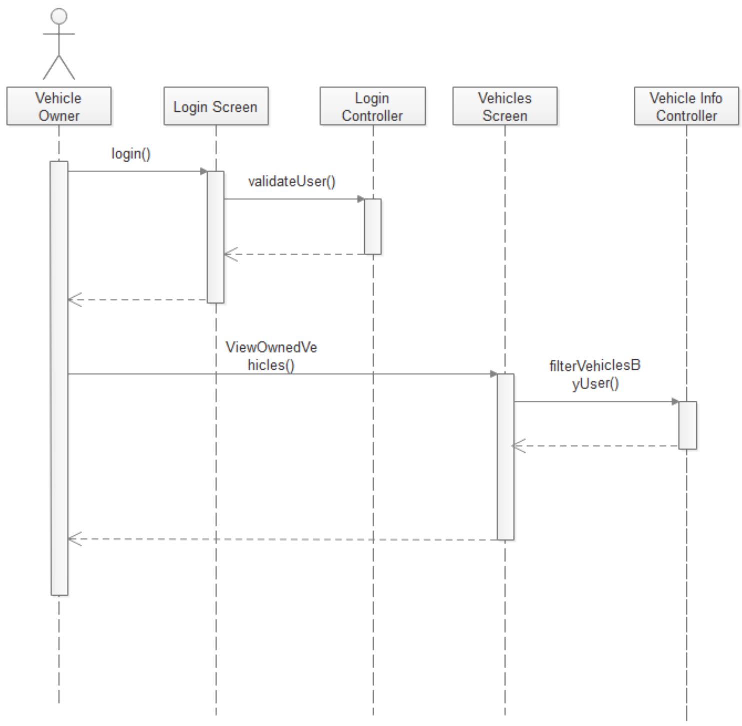
Sequence Diagrams

- Vehicle Owner

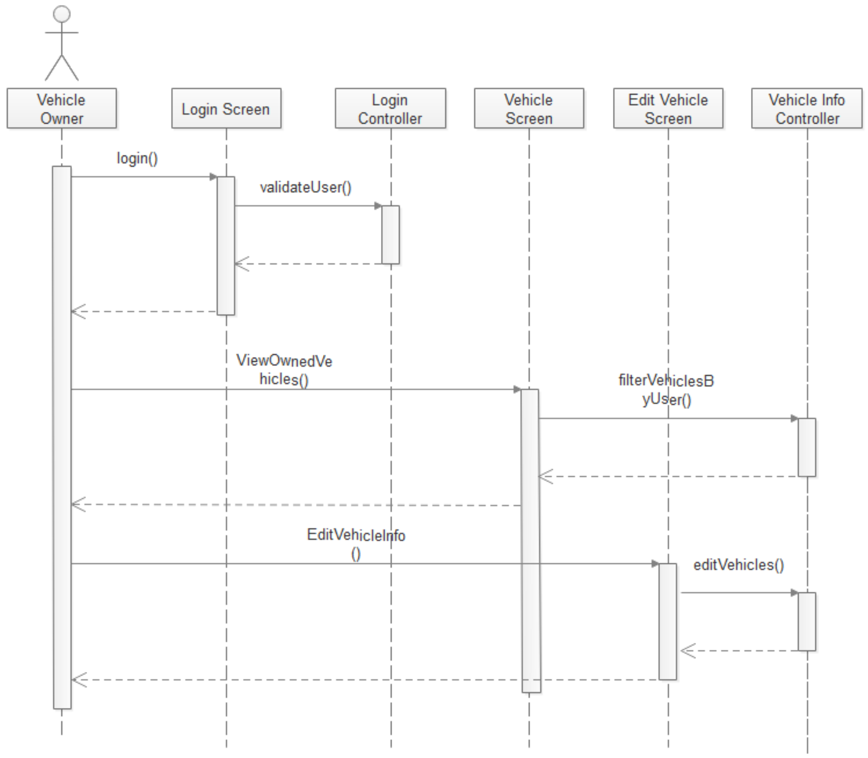
1. View Available Parking Slots



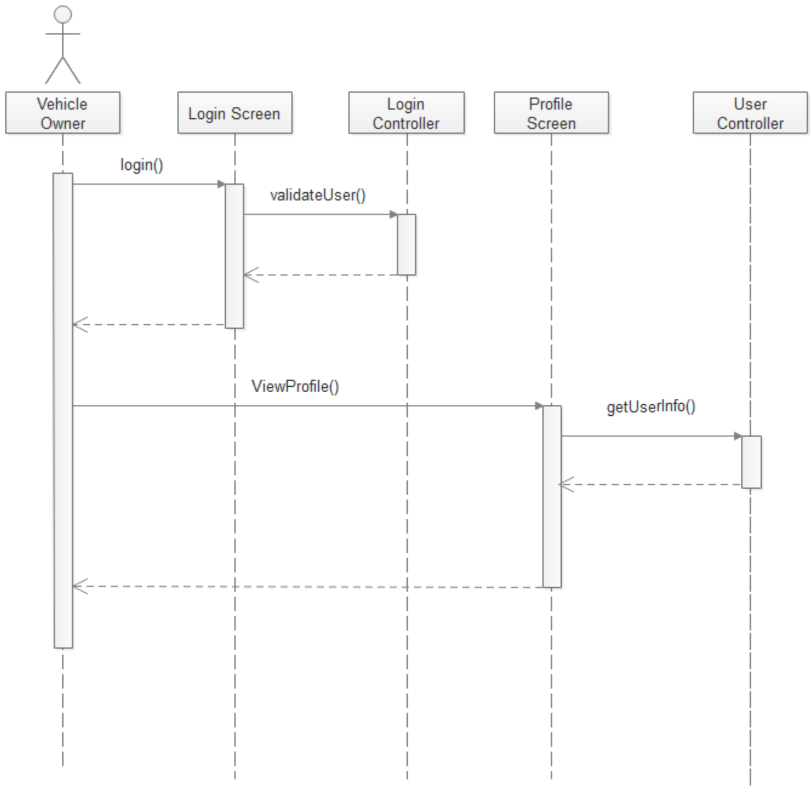
2. View Vehicles



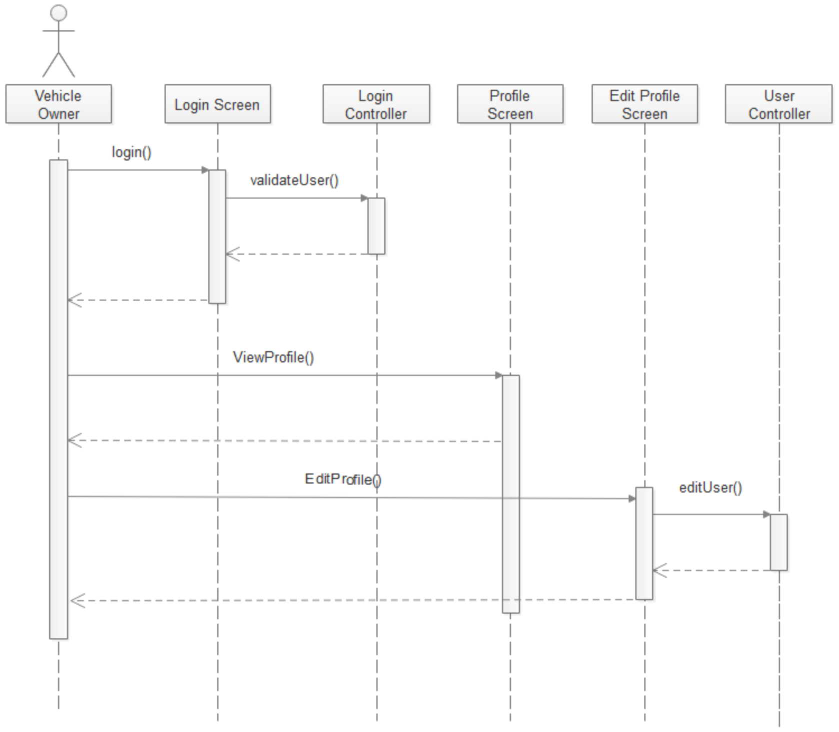
3. Edit Vehicles



4. View Profile

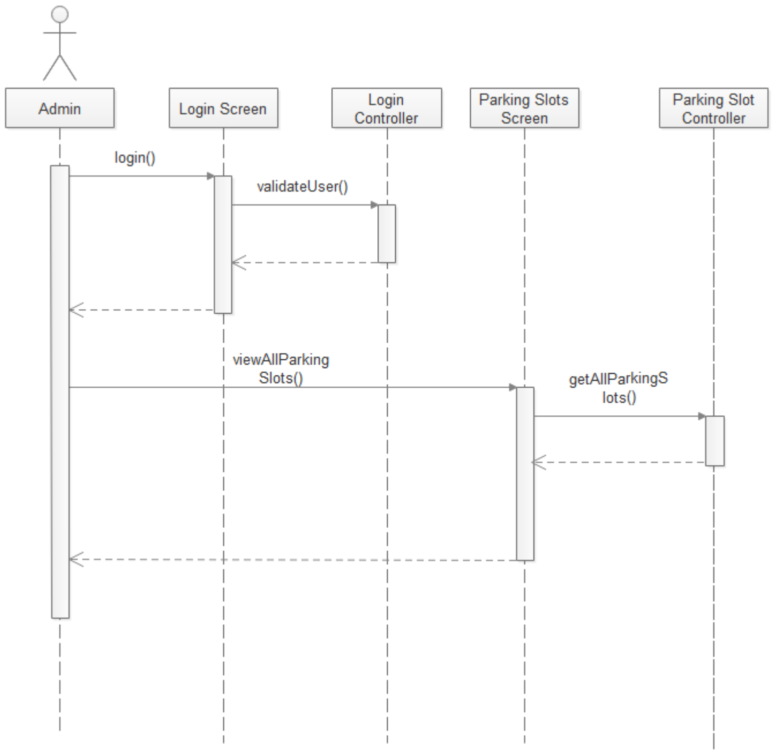


5. Edit Profile

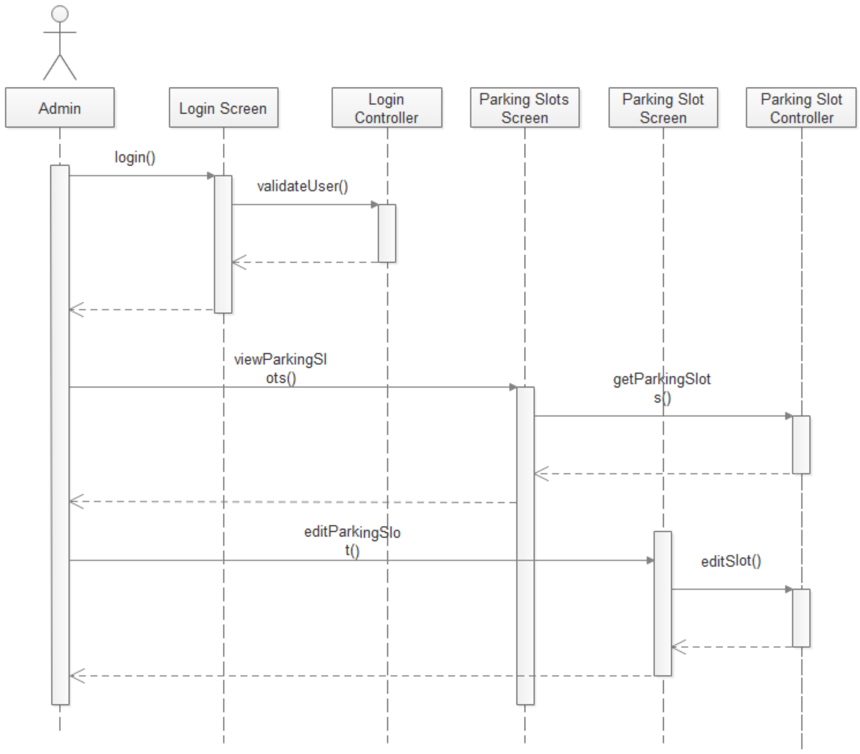


- Administrator

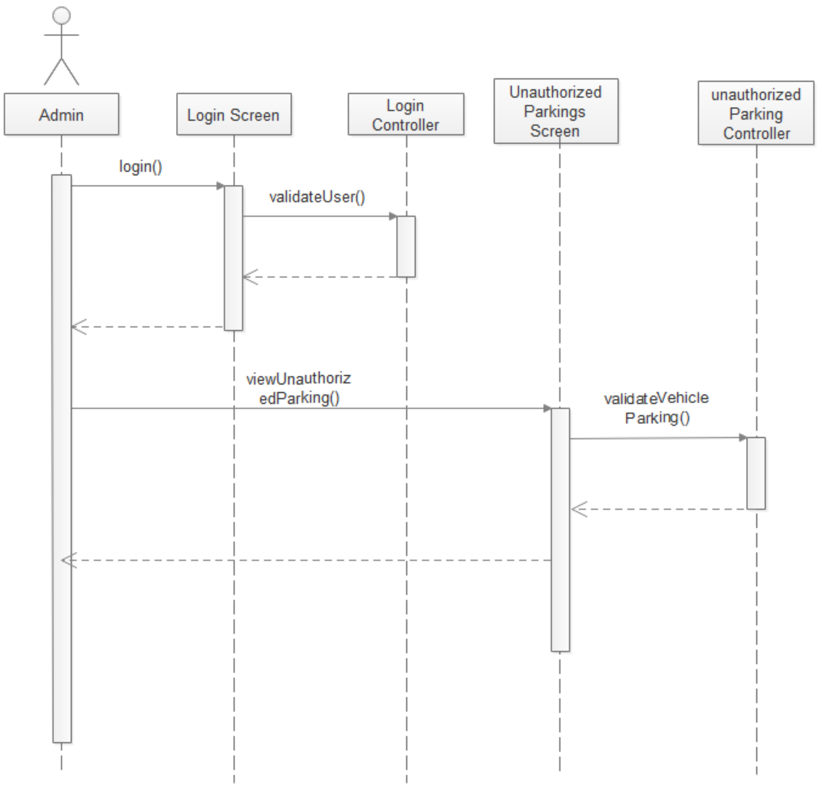
1. View Parking Slot



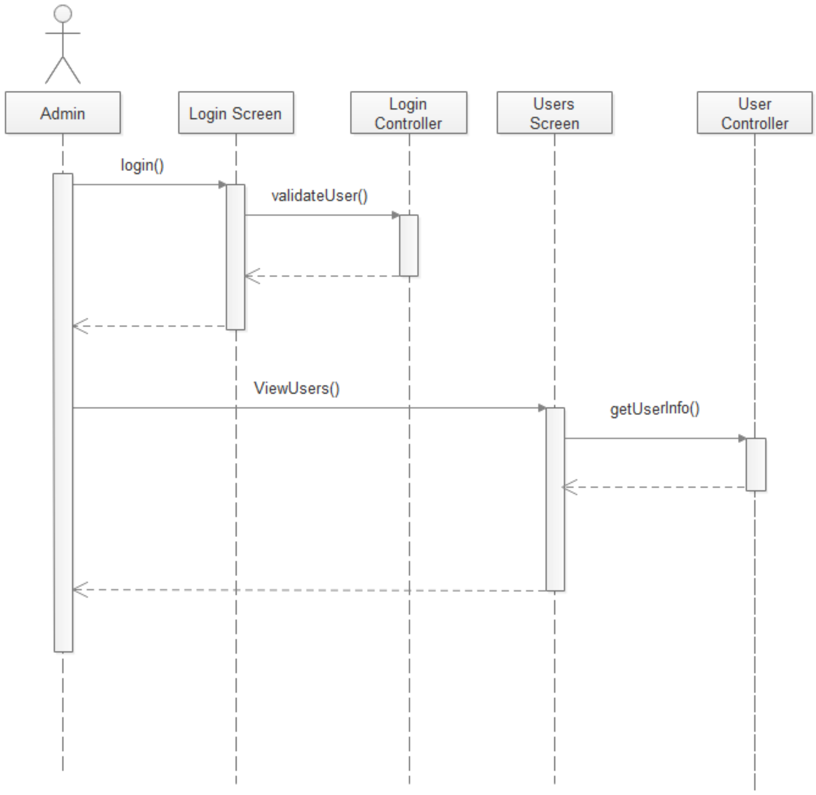
2. Edit Parking Slot



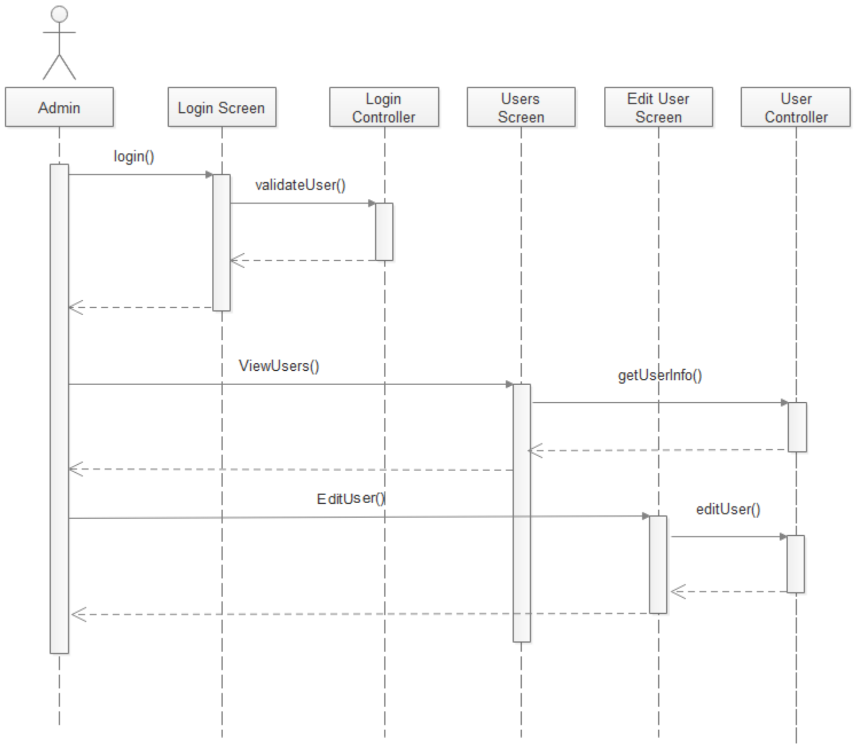
3. View Unauthorized Parking



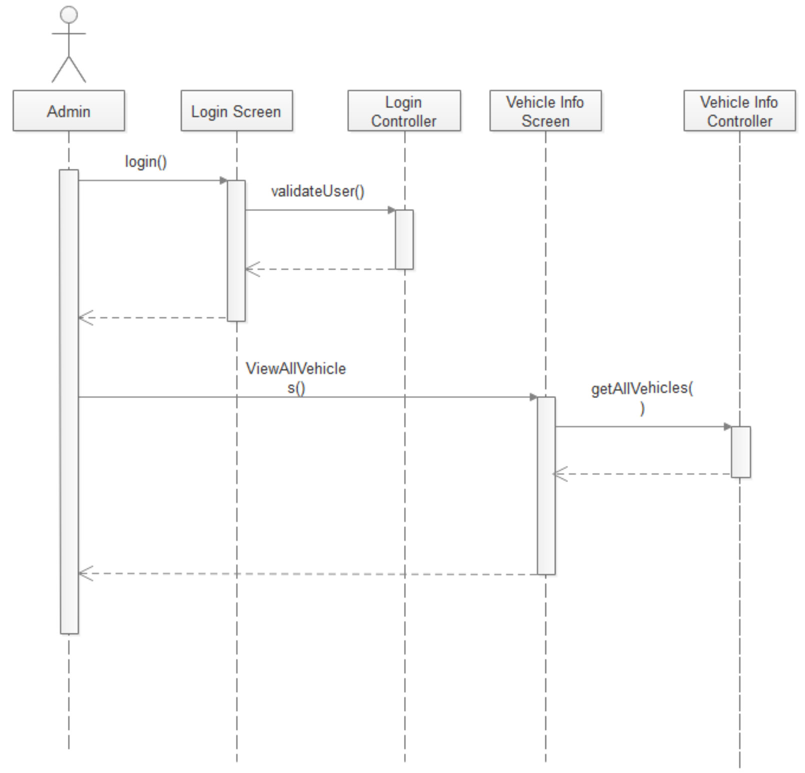
4. View Users



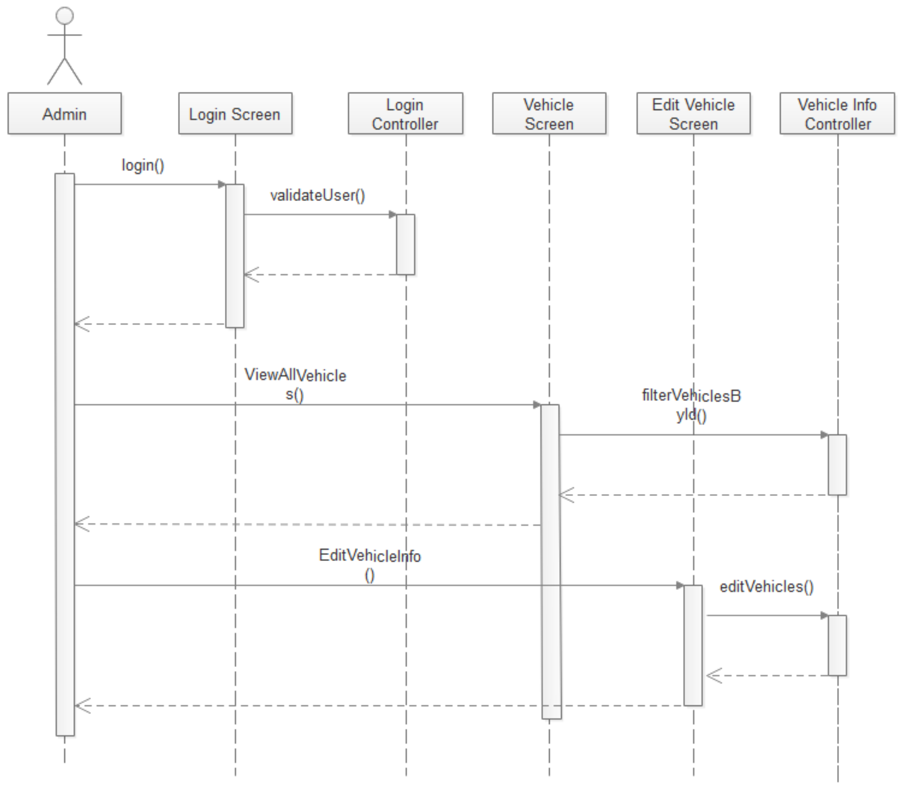
5. Edit Users



6. View Vehicles



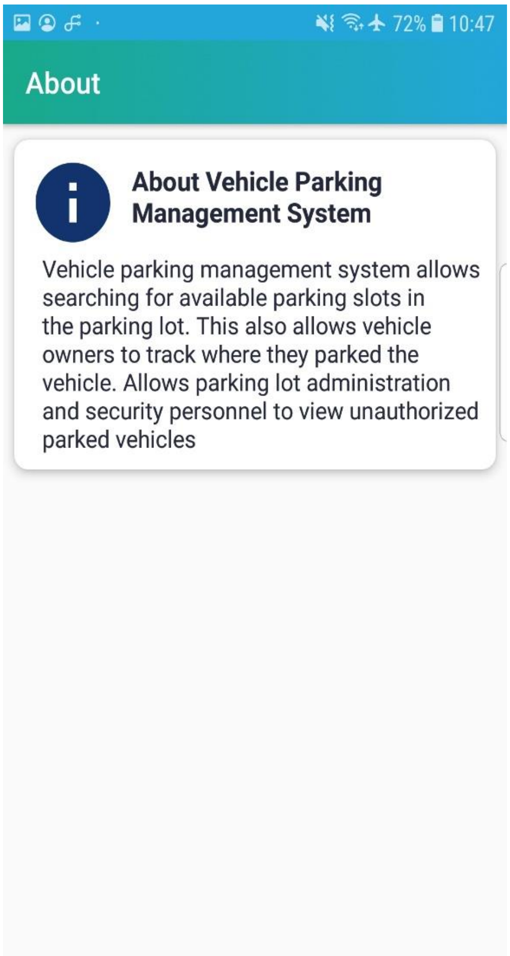
7. Edit Vehicles



User Interface Design

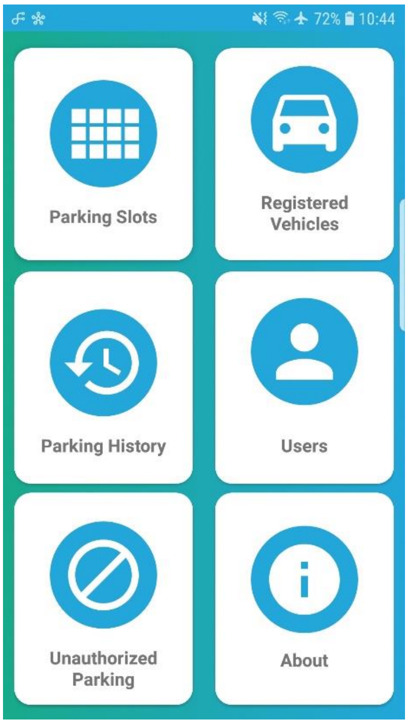
a. Login screen

b. About screen

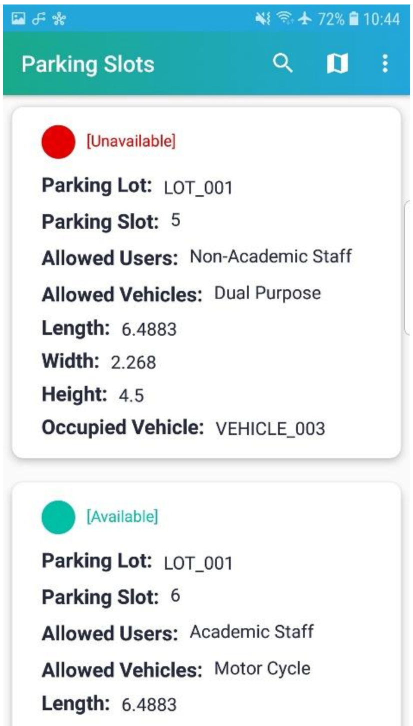


Screens for Admin User

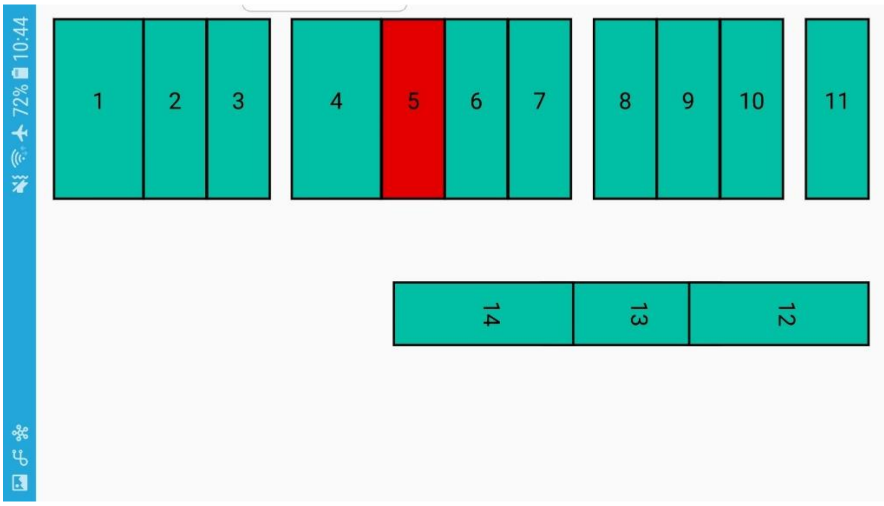
a. Home screen



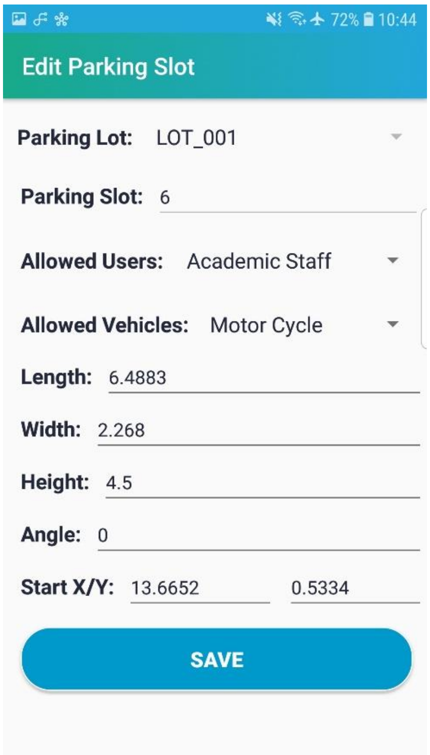
b. Parking Slots screen



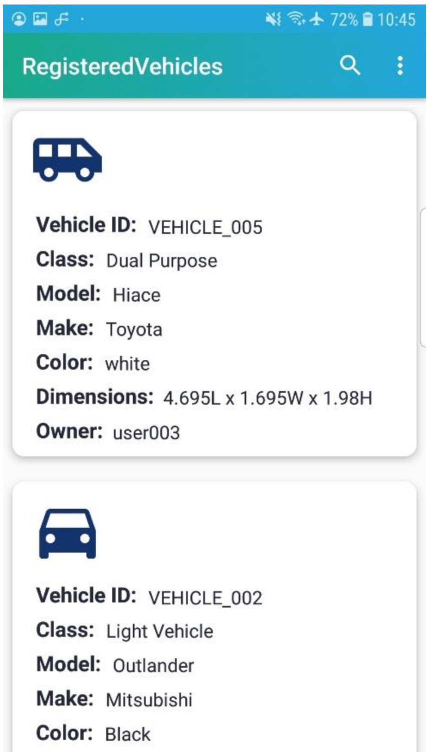
c. Parking Slots Map View



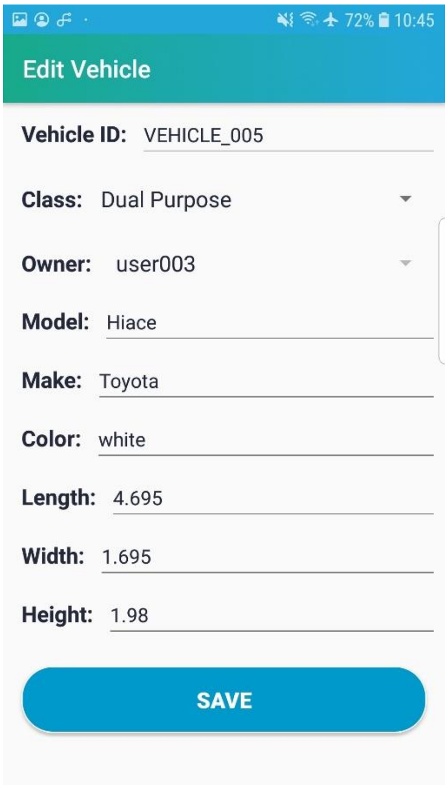
d. Edit Parking Slots screen



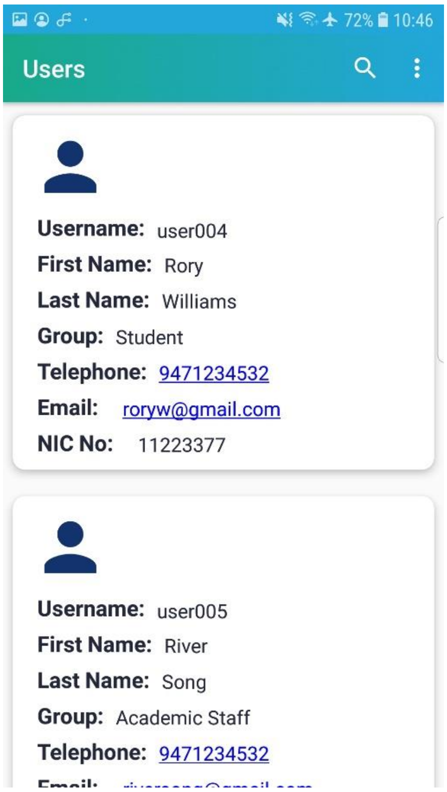
e. Vehicles screen

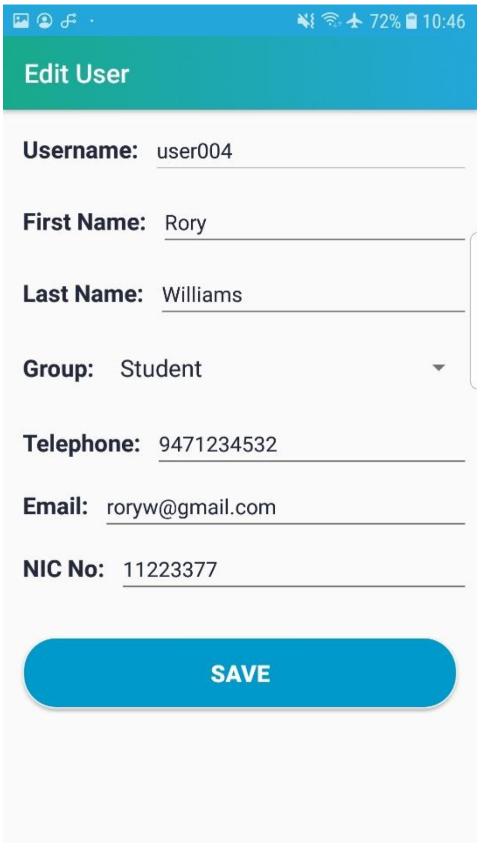
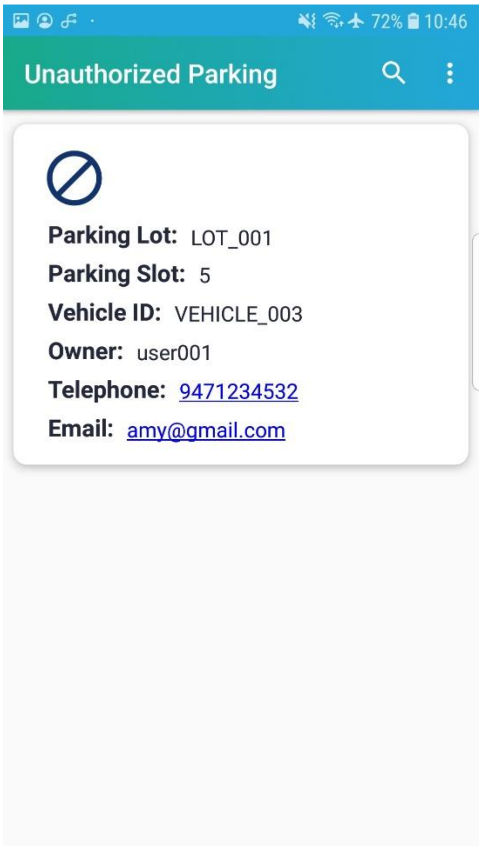


f. Edit Vehicle screen



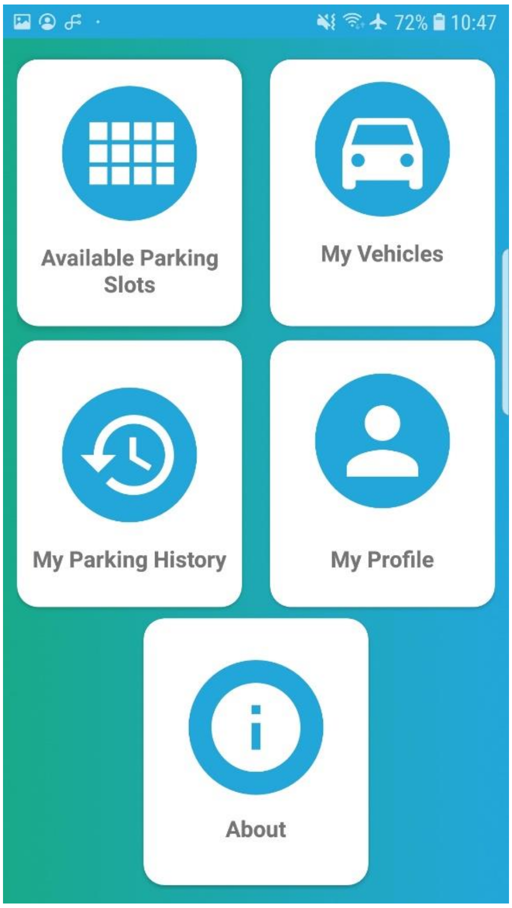
g. Users screen



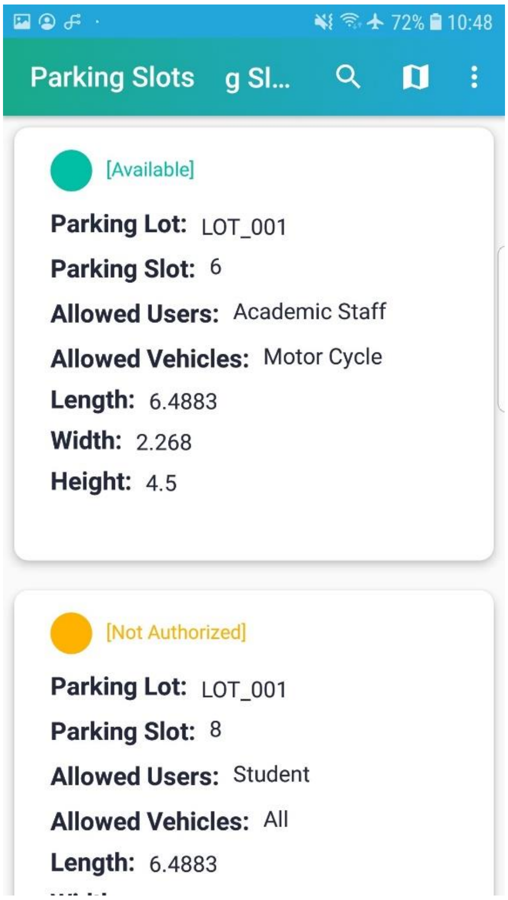
h. Edit users screen	i. Unauthorized Parked Vehicles screen
	

Screens for Vehicle Owner

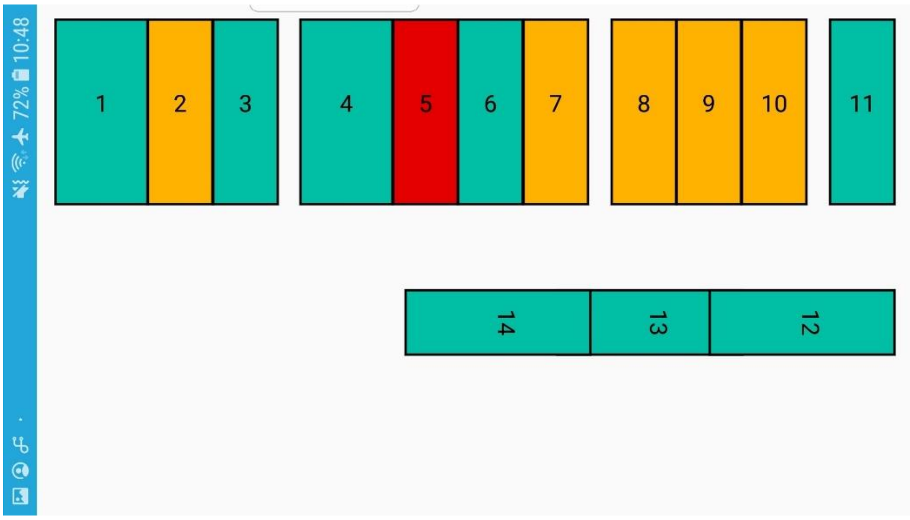
a. Home screen



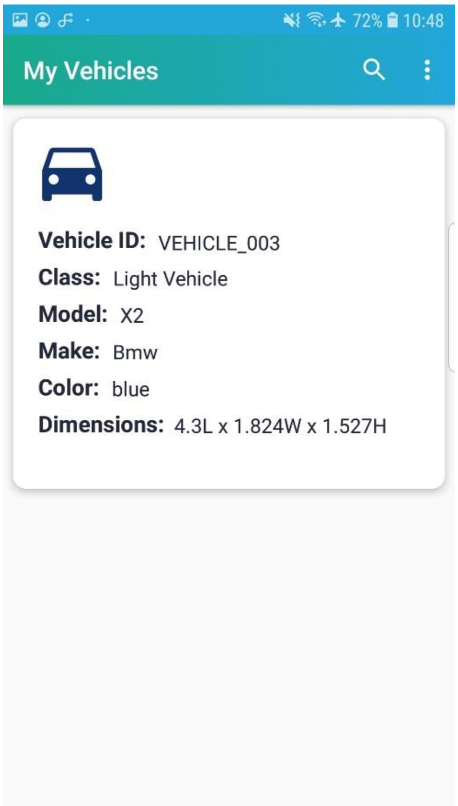
b. Parking Slots screen



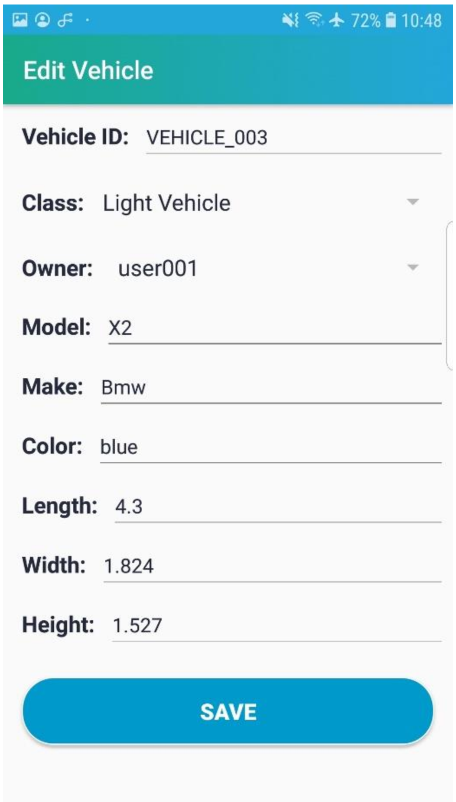
c. Parking Slots Map View



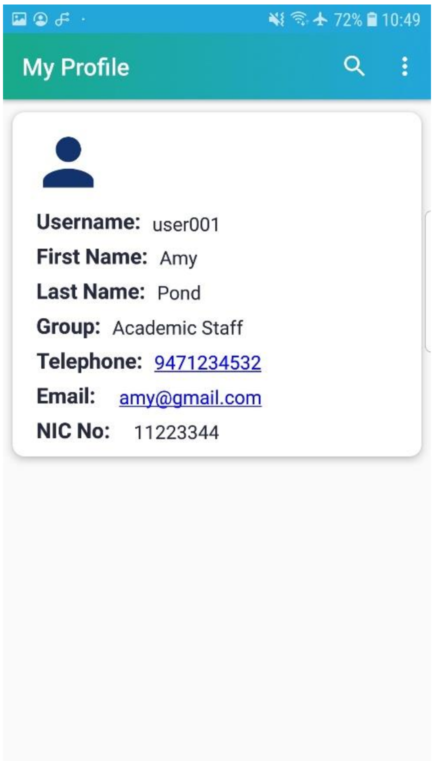
d. Vehicles screen



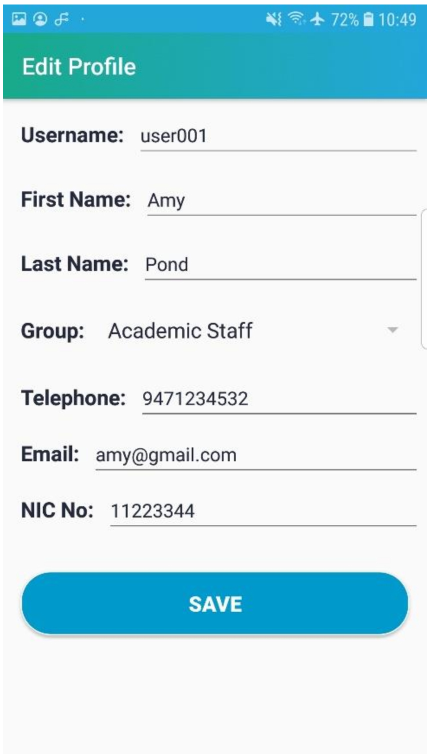
e. Edit Vehicle



f. Profile Screen



g. Edit Profile Screen



Appendix C: Test cases for Android Mobile Application Validation

Login Screen

Test Case	01
Category	UI Test
Prerequisite	N/A
Steps	1. Open the Parking Manager application 2. The login screen will appear
Expected Result	Verify the Username, Password data fields and Login button displays properly in login screen
Actual result	The Username, Password data fields and Login button displays properly in login screen
Status	PASS

Test Case	02
Category	UI Test
Prerequisite	N/A
Steps	1. Open the Parking Manager application 2. The login screen will appear
Expected Result	Verify the Username, Password data fields can be filled, and login button is clickable
Actual result	The Username, Password data fields can be filled, and login button is clickable
Status	PASS

Test Case	03
Category	Functional Test
Prerequisite	N/A
Steps	1. Open the Parking Manager application 2. The login screen will appear 3. Enter an invalid Username, and password with length greater than 6. 4. Press login button
Expected Result	An error message should be raised to the user The user should not be able to login to the parking manager application
Actual result	An error message is raised to the user The user cannot login to the parking manager application
Status	PASS

Test Case	04
Category	Functional Test
Prerequisite	N/A
Steps	1. Open the Parking Manager application 2. The login screen will appear 3. Enter a valid Username, and password with length smaller than 6. Press login button
Expected Result	An error message should be raised to the user The user should not be able to login to the parking manager application

Actual result	An error message is raised to the user The user cannot login to the parking manager application
Status	PASS

Test Case	05
Category	Functional Test
Prerequisite	N/A
Steps	1. Open the Parking Manager application 2. The login screen will appear 3. Enter a valid Username, and invalid password with length greater than 6. 4. Press login button
Expected Result	An error message should be raised to the user The user should not be able to login to the parking manager application
Actual result	An error message is raised to the user The user cannot login to the parking manager application
Status	PASS

Test Case	06
Category	Functional Test
Prerequisite	N/A
Steps	1. Open the Parking Manager application 2. The login screen will appear 3. Enter a valid Username, and valid password. 4. Press login button
Expected Result	User can be able to login to the parking manager application The home screen is visible to the user
Actual result	The user successfully logged in to the parking manager application The home screen is visible to the user
Status	PASS

Home Screen

Test Case	07
Category	UI Test
Prerequisite	06
Steps	
Expected Result	The buttons and layout should be displayed properly in the home screen
Actual result	The buttons and layout are displayed properly in the home screen
Status	PASS

Test Case	08
Category	Functional Test
Prerequisite	06
Steps	1. Click on “Parking Slots” button
Expected Result	The “Parking Slots” screen should be opened The available parking slots should be listed
Actual result	The “Parking Slots” screen opened, and available parking slots listed
Status	PASS

Test Case	09

Category	Functional Test
Prerequisite	06
Steps	1. Click on “Registered Vehicles” button
Expected Result	The “Registered Vehicles” screen should be opened The “Registered Vehicles” should be listed
Actual result	The “Registered Vehicles” screen opened, and vehicles listed
Status	PASS

Test Case	10
Category	Functional Test
Prerequisite	06
Steps	2. Click on “Parking History” button
Expected Result	The “Parking History” screen should be opened The parking history should be listed
Actual result	The “Parking History” screen opened, and parking history listed
Status	PASS

Test Case	11
Category	Functional Test
Prerequisite	06
Steps	3. Click on “Users” button
Expected Result	The “Users” screen should be opened The users should be listed
Actual result	The “Users” screen opened, and users listed
Status	PASS

Test Case	12
Category	Functional Test
Prerequisite	06
Steps	4. Click on “Unauthorized Parking” button
Expected Result	The “Unauthorized Parking” screen should be opened The unauthorized parked vehicles should be listed
Actual result	The “Unauthorized Parking” screen opened, and unauthorized parked vehicles are listed
Status	PASS

Parking Slots

Test Case	13
Category	Functional Test
Prerequisite	08
Steps	1. Click on magnifying glass icon 2. The search bar will appear on top action bar 3. Type a known slot id
Expected Result	The parking slots are filtered and only the slot with the entered slot id should be displayed
Actual result	The parking slot with the entered slot id is displayed
Status	PASS

Test Case	14
Category	Functional Test
Prerequisite	08
Steps	1. Click on an item from parking slot list

	2. The selected item will be highlighted 3. Click on icon with 3 dots 4. Select Edit
Expected Result	The Edit screen for the Parking Slots should be displayed The data from the highlighted item should be populated on the Edit Screen
Actual result	The Edit screen opened, and the highlighted slot's data is populated
Status	PASS

Test Case	15
Category	Functional Test
Prerequisite	14
Steps	1. Edit Length, Width, Height, Allowed Vehicles, Allowed Users fields 2. Click Save button
Expected Result	The changes should be saved to the database
Actual result	The changes are saved to the database
Status	PASS

Test Case	16
Category	Functional Test
Prerequisite	08
Steps	1. Click on icon with 3 dots 2. Select New
Expected Result	The Add new item screen for the Parking Slots should be displayed
Actual result	The Add screen opened
Status	PASS

Test Case	17
Category	Functional Test
Prerequisite	16
Steps	1. Add values for the data fields 2. Click Save
Expected Result	New Parking Slot should be added to the database
Actual result	New Parking Slot is added to the database
Status	PASS

Registered Vehicles

Test Case	18
Category	Functional Test
Prerequisite	08
Steps	4. Click on magnifying glass icon 5. The search bar will appear on top action bar 6. Type a known vehicle id
Expected Result	The vehicle is filtered and only the vehicle with the entered vehicle id should be displayed
Actual result	The vehicle with the entered vehicle id is displayed
Status	PASS

Test Case	19
Category	Functional Test

Prerequisite	08
Steps	5. Click on an item from vehicle list 6. The selected item will be highlighted 7. Click on icon with 3 dots 8. Select Edit
Expected Result	The Edit screen for the Vehicles should be displayed The data from the highlighted item should be populated on the Edit Screen
Actual result	The Edit screen opened, and the highlighted Vehicle's data is populated
Status	PASS

Test Case	20
Category	Functional Test
Prerequisite	19
Steps	3. Edit Length, Width, Height, Class, Owner, Model, Make, Color fields 4. Click Save button
Expected Result	The changes should be saved to the database
Actual result	The changes are saved to the database
Status	PASS

Test Case	21
Category	Functional Test
Prerequisite	08
Steps	3. Click on icon with 3 dots 4. Select New
Expected Result	The Add new item screen for the Vehicles should be displayed
Actual result	The Add screen opened
Status	PASS

Test Case	22
Category	Functional Test
Prerequisite	21
Steps	3. Add values for the data fields 4. Click Save
Expected Result	New Vehicle should be added to the database
Actual result	New Vehicle is added to the database
Status	PASS

Users

Test Case	23
Category	Functional Test
Prerequisite	08
Steps	7. Click on magnifying glass icon 8. The search bar will appear on top action bar 9. Type a known username
Expected Result	The users are filtered and only the user with the entered username should be displayed
Actual result	The user with the entered username is displayed
Status	PASS

Test Case	24

Category	Functional Test
Prerequisite	08
Steps	9. Click on an item from user list 10. The selected item will be highlighted 11. Click on icon with 3 dots 12. Select Edit
Expected Result	The Edit screen for the users should be displayed The data from the highlighted item should be populated on the Edit Screen
Actual result	The Edit screen opened, and the highlighted user’s data is populated
Status	PASS

Test Case	25
Category	Functional Test
Prerequisite	24
Steps	5. Edit First Name, Last Name, Group, Telephone, Email, Nic No fields 6. Click Save button
Expected Result	The changes should be saved to the database
Actual result	The changes are saved to the database
Status	PASS

Test Case	26
Category	Functional Test
Prerequisite	08
Steps	5. Click on icon with 3 dots 6. Select New
Expected Result	The Add new item screen for the users should be displayed
Actual result	The Add screen opened
Status	PASS

Test Case	27
Category	Functional Test
Prerequisite	26
Steps	5. Add values for the data fields 6. Click Save
Expected Result	New user should be added to the database
Actual result	New user is added to the database
Status	PASS

Parking History

Test Case	28
Category	Functional Test
Prerequisite	08
Steps	1. Click on magnifying glass icon 2. The search bar will appear on top action bar 3. Type a known Vehicle ID
Expected Result	The Vehicles are filtered and only the location history with the entered Vehicle should be displayed
Actual result	The Vehicle Location History with the entered Vehicle ID is displayed
Status	PASS

Unauthorized Parking

Test Case	29
Category	Functional Test
Prerequisite	08
Steps	1. Click on magnifying glass icon 2. The search bar will appear on top action bar 3. Type a known Vehicle ID
Expected Result	The Vehicles are filtered and only the unauthorized parking with the entered Vehicle should be displayed
Actual result	The unauthorized parking with the entered Vehicle ID is displayed
Status	PASS

Appendix D: Security evaluation results

Question	Answer	Score
Critical Criteria		
Does the product require a login to access administrative features?	Yes	5
Does the product enforce strong password requirements?	Yes	5
Is it possible to easily update the product software?	No	0
Does the product support automated software updates?	No	0
Does the product validate and reject unacceptable input?	Yes	5
Does the product support secure administrative access?	Yes	5
Does the product fail securely?	Yes	5
Important Criteria		
Does the product feature anti-robot brute-force protection?	No	0
Does the product support multi-factor (i.e. > 1) authentication?	No	0
Does the product allow administrative accounts to be created?	Yes	2
Does the product allow the default administrative accounts to be removed or disabled?	Yes	2
Does the product encrypt the information that it stores?	No	0
Does the product encrypt its communications with other devices?	yes	2
Does the product authenticate other devices and components it interacts with?	Yes	2
Does the product authenticate the update server?	Yes	2
Does the product fully redact its make, model, and software version in non-administrative communications?	Yes	2
Does the product securely log access events?	Yes	2
Valuable Criteria		
Does the product verify downloaded software updates via digital signature?	Yes	1
Does the product feature any Denial of Service (DoS) resistance features?	Yes	1
Does the product resist physical tampering?	Yes	1
Total Score		42