UNIVERSITY OF NAIROBI

SCHOOL OF COMPUTING AND INFORMATICS

Parking Management and Mapping system based on WSN in Nairobi

BY

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SUPERVISOR

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A project report submitted in partial fulfillment for the requirements of Master of Science Degree in Distributed Computing Technology

DECLARATION

The project report presented in this report is my original work and has not been presented for any other university award.

Signature ____________________________________ **Date _______________________________**

Patrick Waweru (P53/65372/2013)

This project has been submitted in partial fulfillment of the requirements of the Master of Science Degree in Distributed Computing Technology of the University of Nairobi with my approval as the University supervisor.

Signature ____________________________________ **Date _______________________________**

Prof. W. Okelo-Odongo

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ABSTRACT

Many cities have significant problems when it comes to traffic management. One of those problems is congestion in the streets and the roads leading to the city. This congestion can get so severe as to cause a complete halt in the movement of the vehicles. This problem has a negative effect on economy as many people waste a long time just sitting idle and also negative on the environment due to pollution from the vehicle exhaust gases. One of the causes of this congestion is the difficulty of drivers finding empty parking slots. As drivers look for spaces to park, they slowdown in the narrow streets and some even stop to let other vehicles reverse from their occupied slots. This effect accumulates over time to cause congestion. The prototype developed here provides information about the occupancy of all parking slots and hence assists the city management to evaluate the utilization of available space, assist drivers in quickly finding empty parking slots as well as assist system designers on the best combination of technologies to use.

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WSN – Wireless sensor networks

ED – Zigbee End Device

P2P – Peer to Peer

MTTF - Mean time to failure

MTTR - Mean time to repair

MTBF - Mean time between failures

CBD – Central Business District

GMR Sensor – Giant Magnetoresistive Sensor

CHAPTER 1: INTRODUCTION

1.1 Background

In Nairobi CBD, vehicles are normally parked on the road sides. Parking is offered and managed by the county government on a first come first served bases. Depending on the width of the roadway, vehicles can either angle park or straight park. Motorists cannot book for parking spaces on daily basis unless the parking space is reserved on monthly basis. Some building owners also offer parking facilities to their tenants as well as to outsiders.

The county government charges motorists for parking in the CBD. Motorists have various methods of payment availed to them.

a) Parking Attendants: These are people assigned to collect cash from motorists once they find parking.

b) Mobile Payment: Motorists use mobile payment methods to pay for parking

c) Pre-Payment: Motorists prepay for the parking and are issued with a vehicle sticker to indicate they have paid.

The payment enforcement is done by cramping agents who go around the streets checking whether every parked vehicle has been paid for. Parking payment is normally done on a daily basis but motorist also have an option to pay on monthly, quarterly, semiannually or annually basis. Motorists have to drive around the streets to look for parking space when they get into the city. Once they find an empty parking slot and park their vehicle, the next task is to make sure they have paid before leaving the vehicle. If they have prepaid, then they can leave immediately. If they want to pay on the daily basis, then they can either use Mobile Payment or locate a parking attendant to pay cash.

When it comes to management of the parking areas in the city, the county government gets data only from the payment systems in place. For Pre-Payment and Mobile Payment, the data is immediately available as they use computer systems to relay this information and store it into a central database. However when it comes to parking attendants who collect the parking fees in cash and give out paper parking tickets, the data has to be fed manually into the system later.

Nairobi CBD has many problems when it comes to traffic management. One of those problems is congestion in the streets and the roads leading to the city. This congestion can get so severe as to cause a complete halt in the movement of the vehicles. This problem has a negative effect on economy as many people waste a long time just sitting idle and also negative on the environment due to pollution from the vehicle exhaust gases.

One of the causes of this congestion is the difficulty of drivers finding empty parking slots. As drivers look for spaces to park, they slowdown in the narrow streets and some even stop to let other vehicles reverse from their occupied slots. This effect accumulates over time to cause congestion. The prototype system developed provides information about the occupancy of all parking slots and hence assist the city management to evaluate the utilization of available space and assist drivers in quickly finding empty parking slots.

There are a number of problems observed here. On the part of the county government, they don't have reliable data to manage and monitor the parking slots. Payment information is also a problem since it is only partly available. On the part of motorists, they have problems locating empty parking slots as well as problems in paying for the parking once they park.

Given the above problems, some of the solutions available would be to use a network of sensors to detect vehicle presence on the parking slots. Vehicle detectors provide essential information about parking occupancy and traffic flow. To cover large areas that lack a suitable electrical infrastructure, wired sensor networks are impractical because of their high deployment and maintenance costs. Wireless sensor networks (WSNs) with autonomous sensor nodes can be more economical. (E. Sifuentes, et.al 2011). Mobile payment has already been implemented. The use of wireless vehicle presence detectors was looked at extensively and a prototype system built as proof of concept.

1.2 Statement of the Problem

There are many problems which arise in cities with the continuous increase of vehicles. Lack of efficient parking systems and cause drivers to waste a lot of time looking for empty parking spaces. The monitoring and management of the parking space is also an issue as most county governments do not have reliable real time data about the occupancy of the parking slots. The problem here is to look at how ICT can be used to monitor the parking, assist motorists in locating empty parking slots and provide useful reports for parking management and planning.

1.3 Research Objectives

The main objective of this research project is to investigate ways in which information and communication technology can be used to assist motorists find empty parking slots in a city.

The sub objectives of this study include:

i. Design a network of vehicle presence sensors.

ii. Design a parking management and monitoring system for use in a city.

iii. Develop a prototype.

iv. Evaluate the prototype

1.4 Research Questions

This research project attempts to answer several fundamental questions:

1) How can a wireless sensor network (WSN) used to support the system?
2) How can the wireless sensor network of vehicle presence nodes be modelled?
3) How would the parking slot information be relayed to the drivers?
4) What is the effect on factors like speed in finding empty parking slots, efficiency in parking fee payment, congestion in the streets?

1.5 Justification and Significance of the Study

This research project is significant to Nairobi city administrations in their search for proper technology to use in the management of parking slots. It also helps them anticipate challenges that come with the adoption of such a system and recommendations of measures on how to counter the challenges. Investors in the parking industry will also benefit from the information that provided in this project report. Motorists will benefit from the convenience of the parking slot occupancy information provided allowing them to find parking space as fast as possible. Scholars in the field of wireless sensor networks will also benefit from the information gathered in this project.

1.6 Scope and Limitation of the Study

This project is intended at developing a prototype that will demonstrate the feasibility of using a network of wireless sensors to provide real time information about the vehicle occupancy in parking slots.

i) Use three vehicle presence sensors to demonstrate a WSN.

ii) Use a single server for data storage, mapping and analysis

iii) Use a section of Nairobi CBD covering three streets to evaluate the prototype.

CHAPTER 2: LITERATURE REVIEW

This chapter presents the literature review relating to research done on parking organization and management, the use of the WSNs including the possible network topologies and use of vehicle detection sensors. The application of ICT in parking systems in cities has advanced over the years with the development of automated payment systems and various management systems being used across the world to solve various problems encountered. (Sifuentes, et al 2011) looks at the development of WSN nodes suitable for vehicle presence detection systems. The sensor nodes would need to be small, sturdy, low power, cost-effective and easy to install and maintain. The paper looks at the combination of an optical sensor and a magnetoresistor sensor to provide a low power consumption sensor node. This is important to this research because the system will need to utilize accurate and highly reliable sensors for the monitoring of the parking slots in a city.

One of the issues likely to face this project is the choice of the best vehicle presence sensor to choose from all the available sensors. (KonTayfun, 2009) offers a comparison of the various types of sensors available and will be a good source of information to come up with the appropriate one to use. The various types of sensors include:

1) Video Image Processors
2) Infrared Detectors
3) Ultrasonic detectors
4) Microwave/Millimeter wave radar detectors
5) Passive Acoustic Detector Arrays
6) Piezoelectric detectors
7) Photoelectric detectors
8) Spread-spectrum wideband radar detectors
9) Inductive loop detectors
10) Magnetic Detectors
11) Acceleration detectors

Given the various types of vehicle presence detectors available, the Magnetic sensors occupy the least space and since they don't require any light or sound, they can be completely buried under the road surface. They also consume the least amount of power as compared to the other sensors and hence they look appropriate for a system using batteries.

(Jingcheng, et al. 2010) describes an experiment to measure performance of a remote sensing network installed in a building. Tests were done to measure power consumption as well as network stability. This is important for this project since we have a test technique that has been shown to work before. The system is a wireless solution for monitoring purpose in cultural buildings in order to protect cultural heritage. The concept of this system utilizes ZigBee networks to carry and transmit data collected by sensors and store them into both local and remote databases. Thus, users can monitor the measured data locally or remotely. Especially, the power consumption is optimized to extend the lifetime of the battery-driven devices. Moreover, since the system has a modular architecture, it is easy to add extra services into this system.

A major concern for many wireless sensors is energy efficiency and reliability. In the wireless sensor network under study in this project (Mario, et al. 2011) these two factors will also be very important. A major concern in wireless sensor networks (WSNs) is energy conservation, since battery-powered sensor nodes are expected to operate autonomously for a long time, e.g., for months or even years. Another critical aspect of WSNs is reliability, which is highly application-dependent. In most cases it is possible to trade-off energy consumption and reliability in order to prolong the network lifetime, while satisfying the application requirements. This paper proposes an adaptive and cross-layer framework for reliable and energy-efficient data collection inWSNs based on the IEEE 802.15.4/ZigBee standards. The framework involves an energy-aware adaptation module that captures the application's reliability requirements, and autonomously configures the MAC layer based on the network topology and the traffic conditions in order to minimize the power consumption. Specifically, it proposes a low-complexity distributed algorithm, called ADaptive Access Parameters Tuning (ADAPT), that can effectively meet the application-specific reliability under a wide range of operating conditions, for both single-hop and multi-hop networking scenarios. The solution can be integrated into WSNs based on IEEE 802.15.4/ZigBee without requiring any modification to the standards. Simulation results show that ADAPT is very energy-efficient, with near-optimal performance.

(Hung-Cheng, 2012) research focused on the use of zigbee based electrical meters feeding the data to a central server through a Zigbee/GPRS gateway. The importance of this research to our research is that the network topology of the electrical meters is nearly similar to the parking slot wireless sensor network being proposed. The zigbee network not only has good scalability, but also makes data transmission more reliable. Multiple subnets can be connected at the same time to form a large geographically dispersed network, making cross-zone sensing and control be easily achieved.

Typical zigbee network topologies looks like:

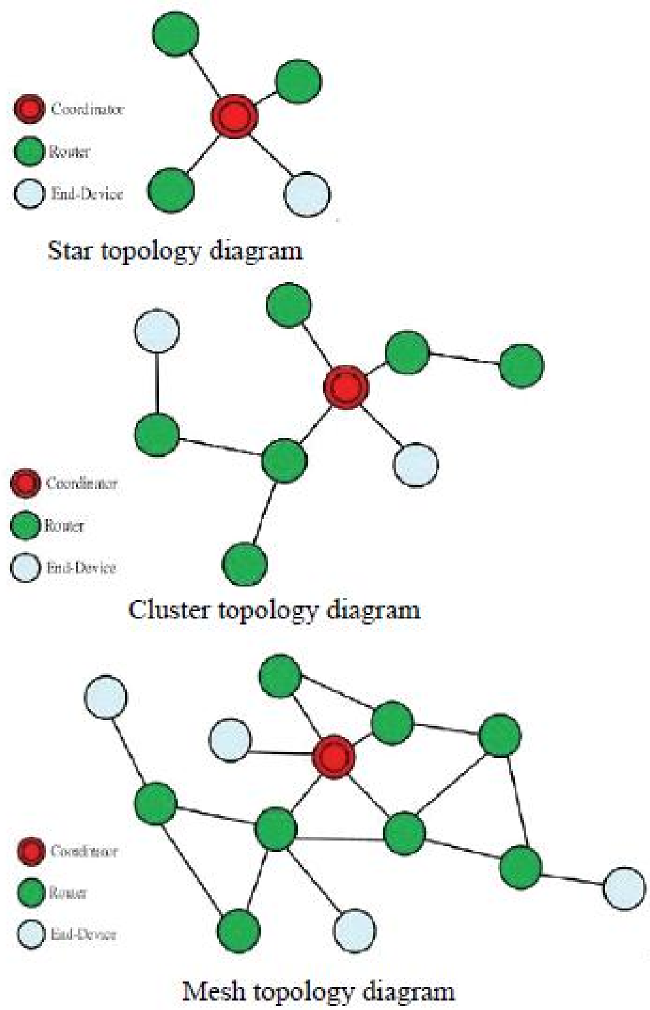


Figure 1: Zigbee Topologies (Hung-Cheng, 2012)

One of the problems encountered immediately after the driver finds an empty parking slot is parking payment. (Jades K.M. et al. 2014) explores the parking problem as a whole before proposing a solution to the payment problem. In the parking industry, savings can be made by providing alternative payment options for customers, such as cashless parking schemes, and providing the parking workforce with more sophisticated equipment. This technological change is expected to contribute to the development of more flexible, convenient and efficient parking services, increases revenue and customer satisfaction. This paper assessed the adoption of mobile parking management information systems in the parking industry in Nairobi County. The research findings indicated that Nairobi county and the parking industry were generally ready to adopt the mobile parking management system whose success is subject to a detailed feasibility study, although as with any technological adoption it is bound to face some barriers which can be overcome. (Karari, et al. 2013) describes a mobile phone based parking system designed to ease the congestion in the streets caused by drivers looking for parking as well as looking for parking attendants to pay for parking spaces. This project is important to our research project since it major objective was to decongest major cities and ease parking. Traffic flow, allocation and availability of parking space within the streets of Nairobi is a major concern to every motorist. The availability of the mobile phone and its increased affordability has led to its adoption as the main gadget and technology for contemporary communication in most developing countries. Furthermore, the convenience it offers to users and its cost effectiveness has made it the technology driver not just in developing world but also in the developed countries. One area where its application has born fruits in some countries is in mobile parking. By use of mobile communication, cities in countries such as Singapore and Germany have experienced increased efficiency in traffic management and parking fees collection. The technology also depends on banking models used in these countries; a fact that makes it necessary for any similar solution been developed elsewhere to consider the local system environment

CHAPTER 3: METHODOLOGY

3.1 Introduction

This project is based on experimental research. A prototype will be designed and developed and afterwards used in analysis of the solution coming up with appropriate conclusions.

3.1.1 System Design

The Service-Oriented Design Methodology for Wireless Sensor Networks (Meshkova, E., et.al, 2008) will be used in the design of the WSN. This design methodology is based on the service-oriented architecture for wireless embedded and sensor networks. The design and implementation cycle includes three stages namely the solution and architecture design, the protocol and application design and finally the implementation. During the design, the abstract definition of user requirements and targeted funtionality and their mapping to the real hardware and software will be considered. Below is an illustration of the methodology:

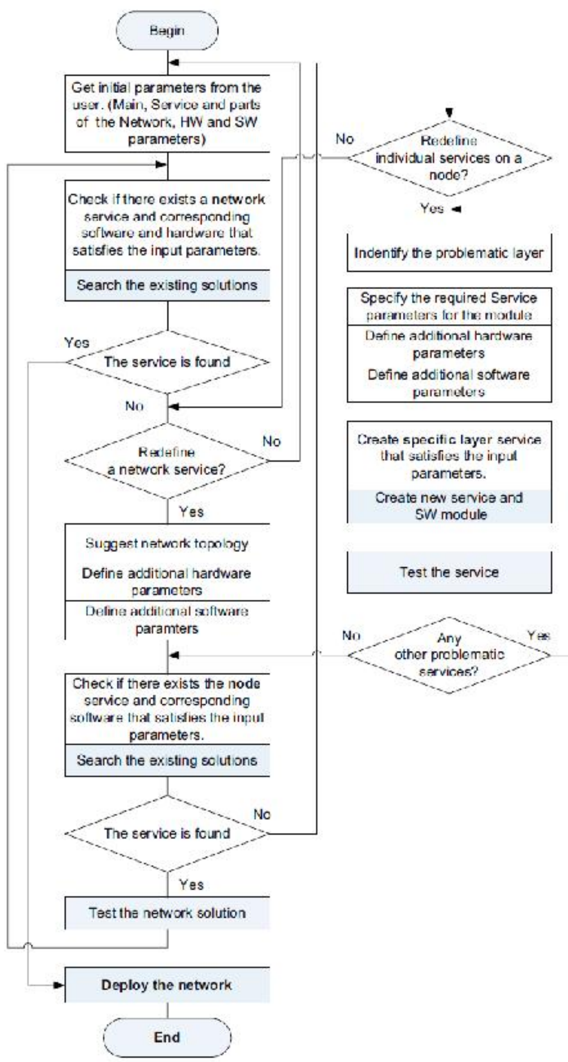


Figure 2: Service-Oriented Design Methodology. Source (Meshkova, E., et.al, 2008)

To design and develop the management module of the parking system prototype, the system development life cycle methodology (Mark McMurtrey, 2013) was used. This involved the following stages:

a) The new system requirements were defined. In particular, the deficiencies in the existing system were addressed with specific proposals for improvement.
b) The proposed system was designed. Plans were laid out concerning the physical construction, hardware, operating systems, programming, communications, and security issues.
c) The new system was developed. The new components and programs were obtained and installed. All aspects of performance were tested. Necessary adjustments were made at this stage.
d) The system was put into use by setting it up in the street with real vehicles.
e) Once the prototype was up and running for a while, it was exhaustively evaluated

CHAPTER 4: SYSTEM ANALYSIS AND DESIGN

4.1 ANALYSIS

4.1.1 FUNCTIONAL REQUIREMENTS

Functional requirements define the functions of a system and its components. These are the functions of the parking management and monitoring system for the Nairobi CBD.

Parking Slots

- Vehicle Detection: The system should be able to tell whether a slot is occupied or not. To consider the slot occupied, a valid vehicle should be parked on the slot and not any other object.
- Unique Slot ID: Every parking slot should be identified by a unique slot ID.
- Data Communications: The data from the parking slots should be communicated in real time using a system that ensures minimum data corruption.
- Database: The slot data should be stored in a central database that ensures data monitoring for guidance and diagnostics.
- Payments: Payment should be possible once a motorist parks on a slot.
- Prototype Coverage Scope: The required area is shown below:

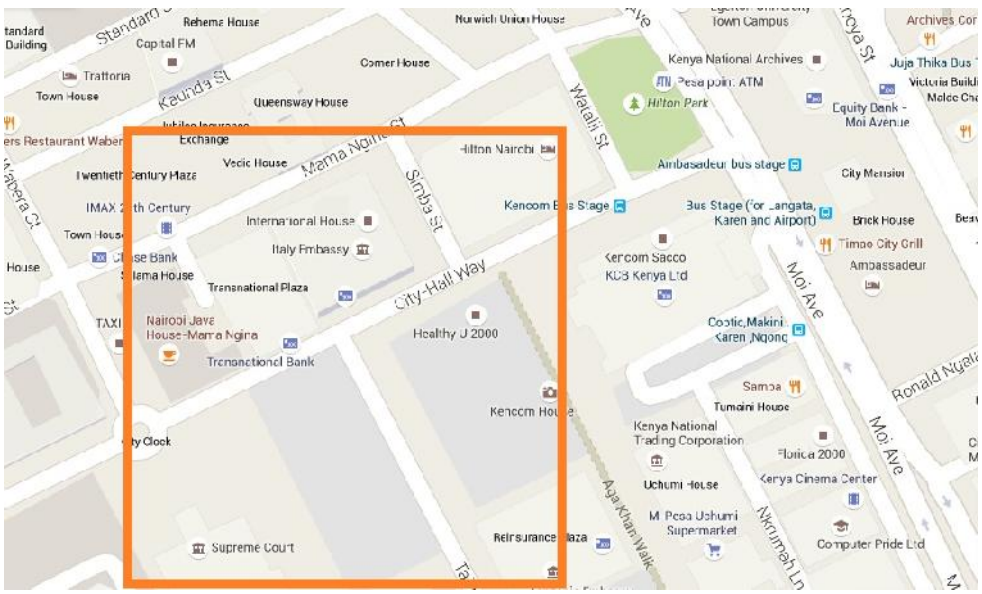


Figure 3: Prototype Street Map

This is an area within the Nairobi CBD that covers 500M of Taifa road upto the junction between taifa road and city hall way. It also covers 500M along city hall way from the junction towards the left.

Mapping

- Slot mapping: The slots should be mapped in the exact way they appear on the ground.

- Real time update of slot status on maps: The slot status should be updated on the maps in real time
- Location search on maps: The maps should be searchable with the user able to search and locate empty slots within a given search area.

Management

- Security Management: The system should include a security module to enable management of various system functions like:
  - User management: add, edit, enable/disable, and assign rights
  - Access control: deny/allow access
- Slot Management: The system should include slot management functionality. This includes, adding, editing, enabling, and disabling slots and streets.
- Map Management: The system should enable adding, removing, enabling, and disabling maps.
- Management Reports: The system should produce management reports on demand and in real time. Such reports include, slot status reports, payment reports, security reports

4.1.2 NON-FUNCTIONAL REQUIREMENTS

- Performance Requirements: The system should operate with minimum supervision upon setup. It should be able to recover automatically or with minimum intervention upon failure of any module.
- Safety Requirements: Sensitive data should be encrypted/hashed before storage
- Software Quality Requirements: The software components should require minimum maintenance.

4.2 DESIGN

4.2.1 Architectural Goals and Constraints

This section describes the software requirements and objectives that have some significant impact on the architecture.

- Technical Platform: The backend application will be deployed on a linux server.
- Security: The system must be secured, so that unauthorized users cannot make changes. The basic security behaviors being:
  - Authentication: Login using at least a user name and a password
  - Authorization: according to their profile, online user must be granted or not allowed to receive some specific services

  For internet access, the following requirements are mandatory
    - Confidentiality: sensitive data must be encrypted if any.
    - Safety: passwords must be hashed before storage
    - Data integrity : Data sent across the network cannot be modified by a tier
    - Auditing: Every sensitive action will be logged
    - Non-repudiation : gives evidence a specific action occurred
- Persistence: Data persistence was addressed using a relational database specificaly MySql.
- Reliability/Availability: High availability is required since there are time and location issues related to the systems availability. The motorists should not be disappointed. The system's high availability will also

ensure motorists satisfaction and loyalty. Targeted availability: 16 hours a day, 7 days a week (Maintenance at night)

- Performance: Search queries should return %90 of the time below 5 sec. Status updates of the slot information was set to be after every 10 seconds. If a node fails to update, it is marked as unknown.

4.2.2 User Interactions with the system

This section provides a functional overview of the system by a use-case diagram.

a) Actors: These are the system users

i) Administrators: These are the people who create, edit and modify system settings.

ii) Managers: These are the people who are interested in observing the information generated by the system to make management decisions.

iii) Technicians: These are the people who maintain the wireless sensor network components and the whole system infrastructure.

iv) Motorists: These are the users interested in finding the available parking slots in the Nairobi CBD.

v) WSN: This is the wireless sensor network. It updates the slot status on the system as well as sending parking fee payment information

b) Use cases

i) Administrators

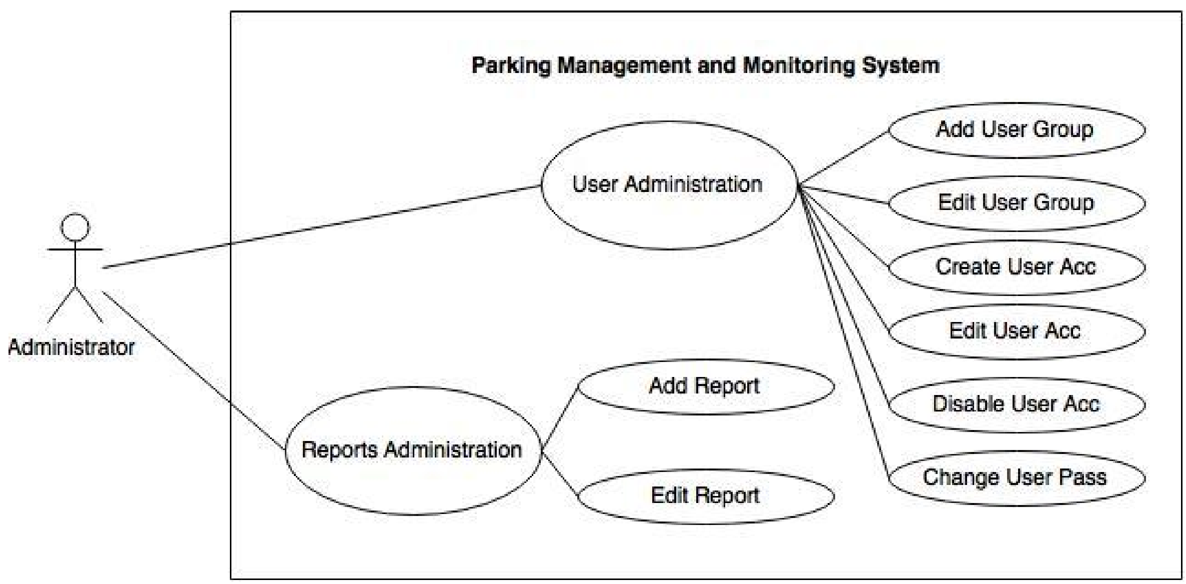


Figure 4: Administrator Use Case

ii) Managers

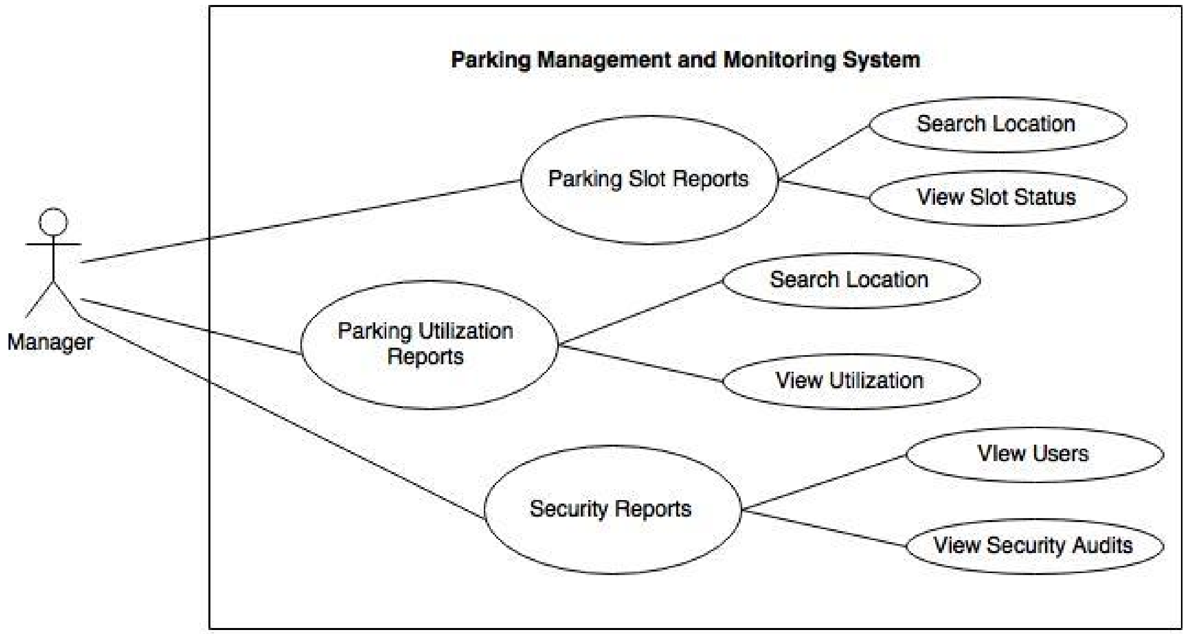


Figure 5: Manager Use Case

iii) Technician

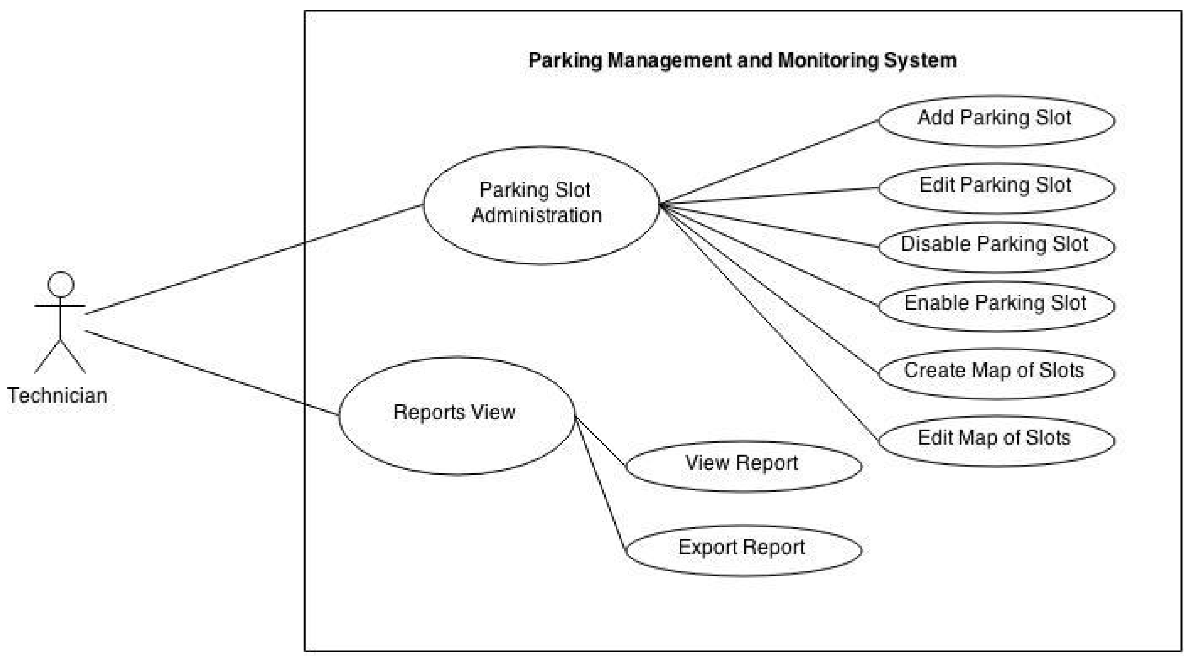


Figure 6: Technician Use Case

iv) Motorists

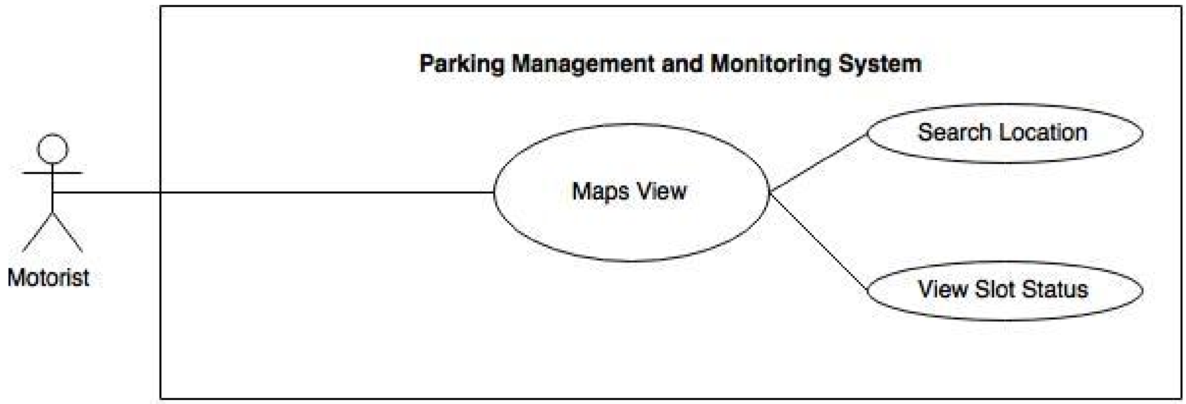


Figure 7: Motorist Use Case

v) WSN

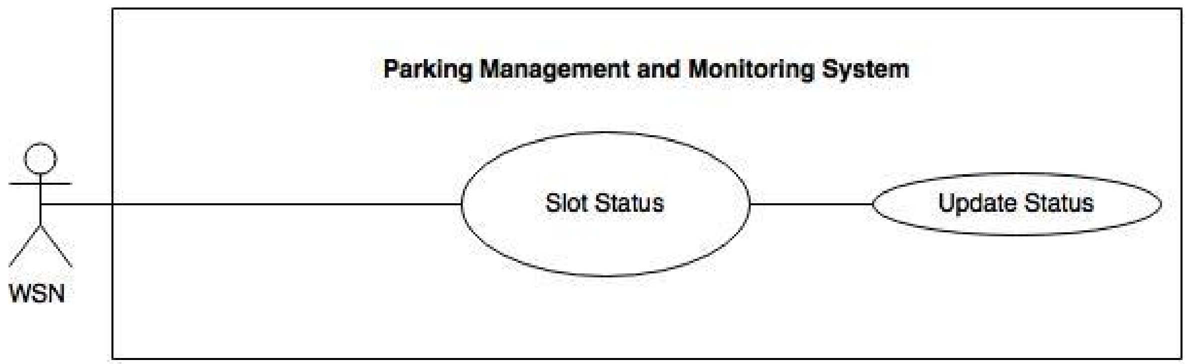


Figure 8: WSN Use Case

4.3 Data Flow Diagram

This is how the data will flow in the system

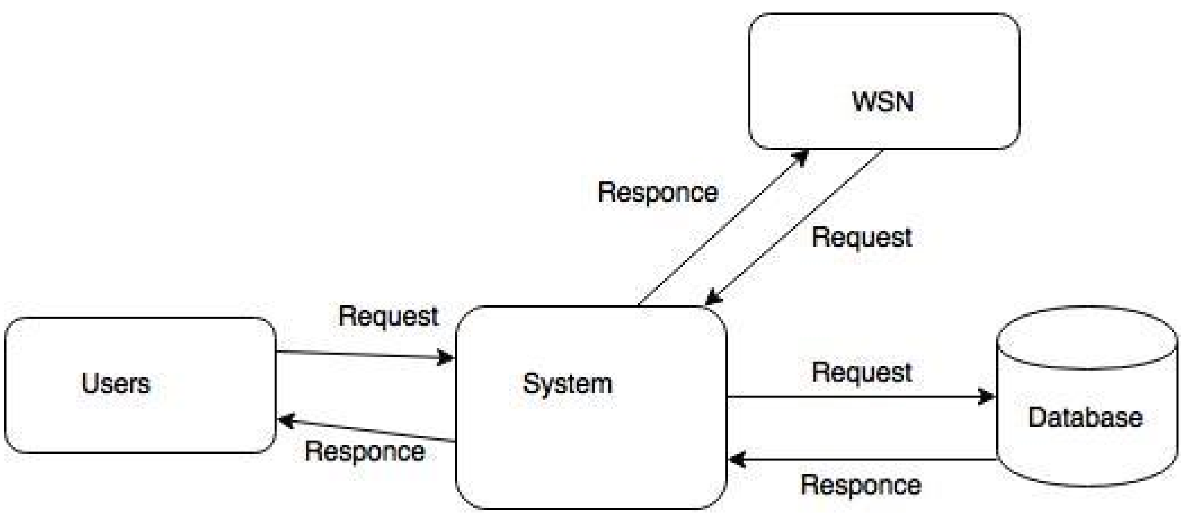


Figure 9: Level 1 DFD

All requests will have to pass through the security module which checks if the user is authorized to access the data. Once the request is authorized, it is passed to the appropriate system process.

Node Update

The sensor nodes send updates to the central server which then updates the database:

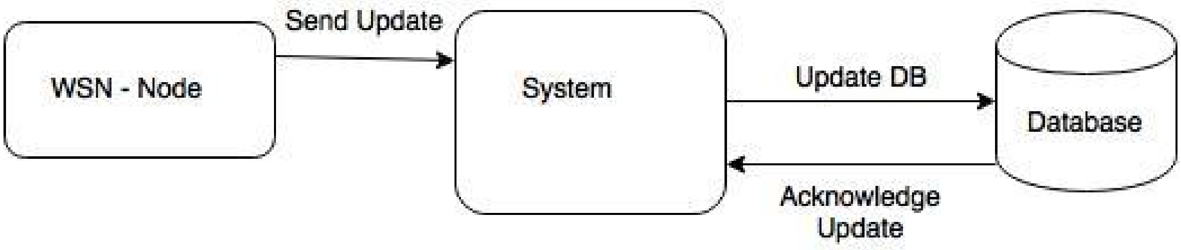


Figure 10: Node Update DFD

Motorist Maps View

A motorist requests a map from the system. The system displays the map with updated parking slot data.

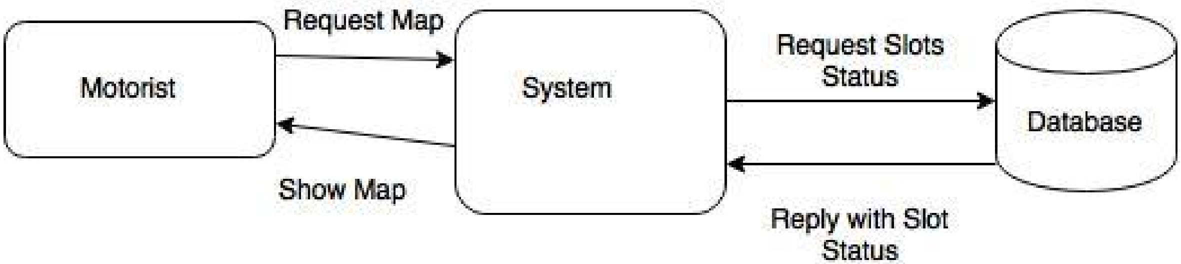


Figure 11: Motorist Maps DFD

4.4 Wireless Sensor Network Overview

This prototype will consist a network of vehicle presence sensors used in parking areas to manage a parking slot management and mapping system. The practical layout of the sensors will be dynamic so the network will be required to self reconfigure on demand and the sensor nodes to be location aware.

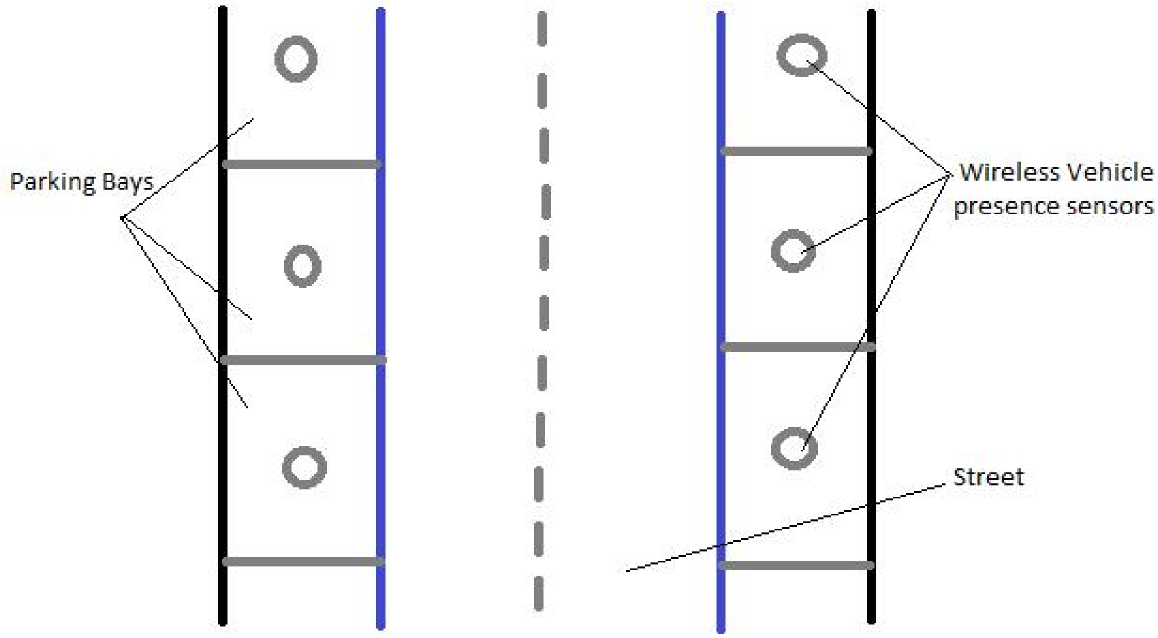


Figure 12: Street Placement of Sensors

The zigbee based sensor network was chosen for this project based on previous research work showing it to be the best as compared to other networks. The table below shows the comparison (Bastin Tony Roy Savarimuthu, et al. 2009)

	ZigBee	Wi-Fi	Bluetooth	Wireless USB	Wibree	Z-Wave	EnOcean
Standard	802.15.4	802.11x	802.15.1	USB	N/A	N/A	N/A
Application Focus	Monitoring & Control	Wireless LAN	Short range cable replacement	USB cable replacement	Low-power Bluetooth (eg. sensors)	Monitoring & Control	Monitoring & Control
Bandwidth	20 – 250 Kbps	54 Mbps	1 Mbps	110 – 480 Mbps	1 Mbps	40 Kbps	120 Kbps
Network Size	65536	32	7	N/A	*	232	*
Transmission Range	10 – 100m	50 – 100m	10m	10m	5 - 10m	30m	300m
Power Consumption	Very low	High	Medium	High	Low	Very Low	Extremely Low
Typical Applications	Home & Building automation, industrial controls, sensors	Wireless LAN connectivity	Wireless connectivity between devices (e.g. laptops & phones)	Computer peripherals	Low power connectivity, e.g. watches, sports sensors, toys	Home automation & sensor networks	Home & Building Automation, Sensors, Medical

Figure 13: Comparison Of Wireless Networks. Source (Bastin Tony Roy Savarimuthu, et al. 2009)

Of particular importance here are four aspects namely the bandwidth required, network size, transmission range and power consumption. The nodes will be required to transmit minimal data about vehicle presence. Payment information and network speed is not important. The network size is considered since there are numerous numbers of parking slots in Nairobi. Each of these slots requires a sensor. Transmission range of 50 to 100 meters is sufficient since most parking slots are at most 4 to 5 meters apart. Power consumption is important because these sensors require to be buried under the surface and hence will need be low maintenance. The batteries need to stay for at least a year.

In the zigbee sensor network, the placement of the coordinator, router and end device nodes will be of particular importance since the network needs to maintain a virtual map. The virtual map will enable the sensors to be location aware.

The payment network will be based on an overlay network on top of the wireless sensor network. This network will be a peer to peer structured network offering a mix of various features such as robust wide-area routing architecture, efficient search of data items,
selection of nearby peers, redundant storage, permanence, hierarchical naming, trust and authentication, anonymity, massive scalability and fault tolerance. Peer-to-peer overlay systems
go beyond services offered by client-server systems by having symmetry in roles where a client may also be a server. It allows access to its resources by other systems and supports resource sharing, which requires fault-tolerance, self-organization and massive scalability properties. (Eng Keong Lua, et.al 2004)

4.5 Wireless Sensor Network

Zigbee Network and System Management Server

The system architecture:

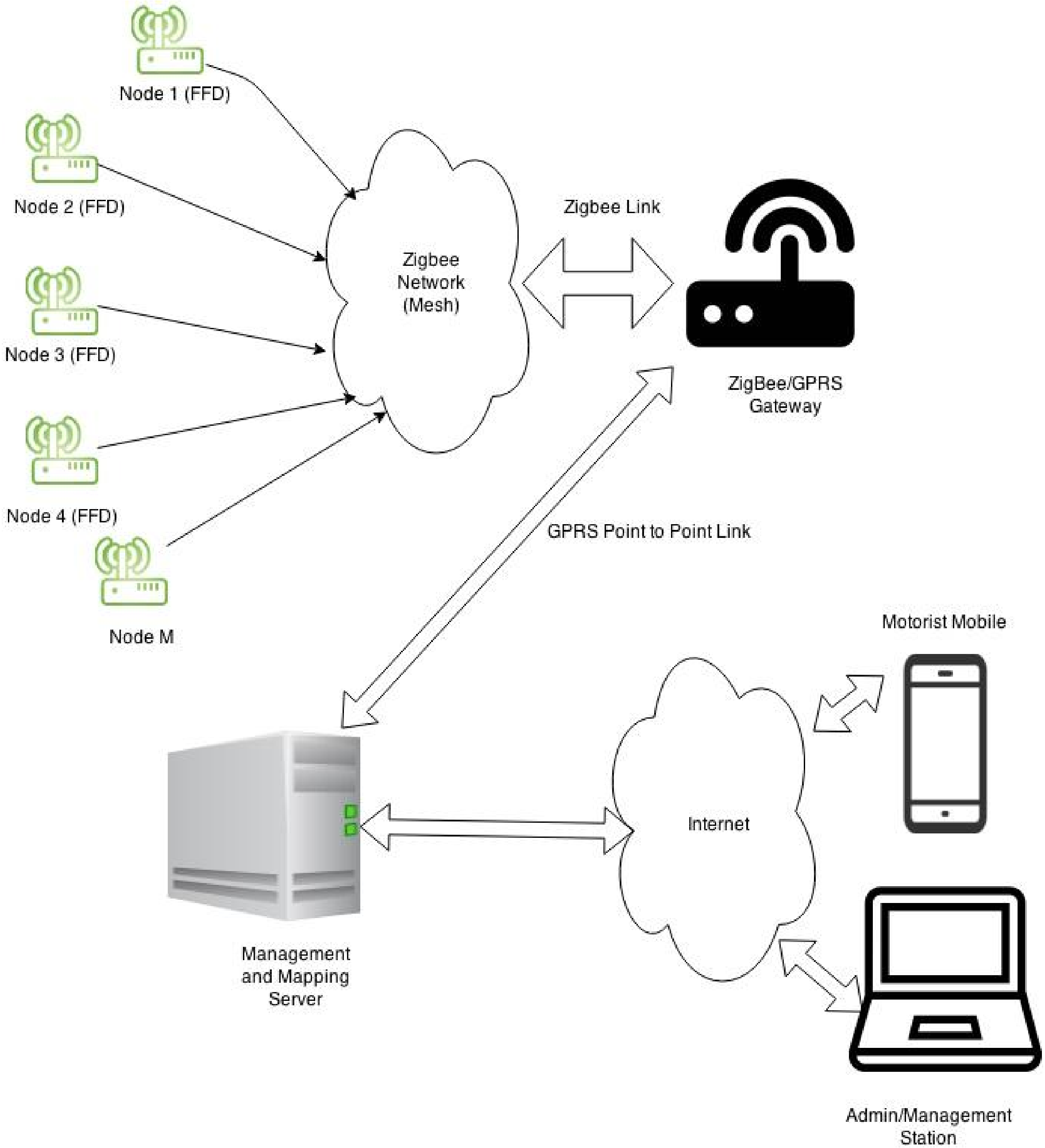


Figure 14: System Architecture

The sensor network layout:

a) Single street overview

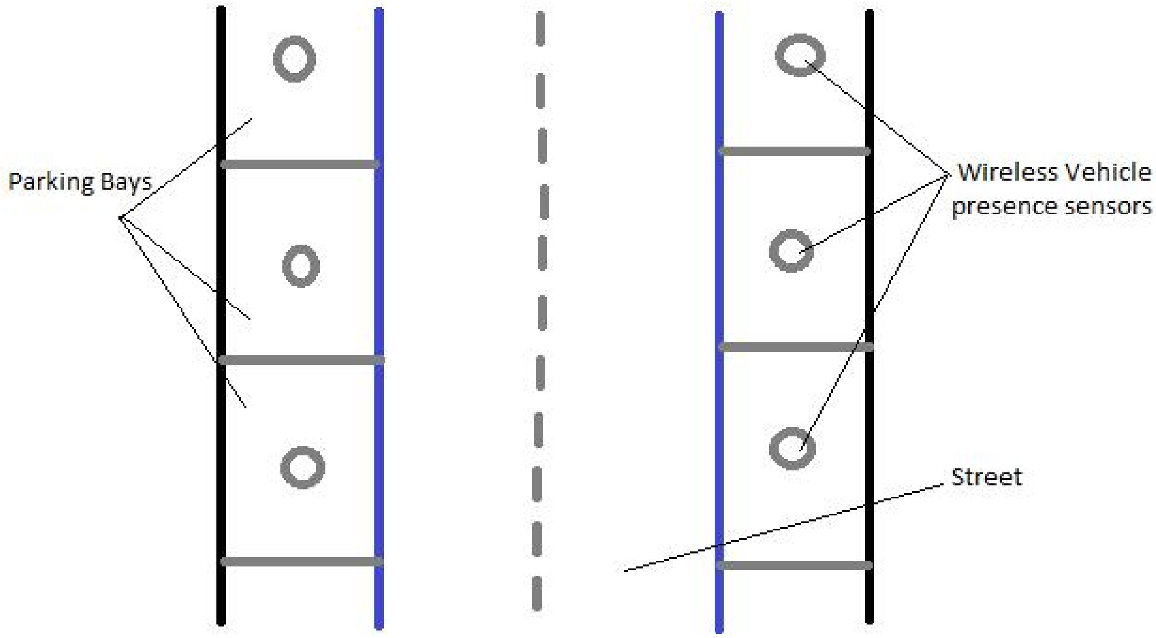


Figure 15: Single Street View

Each parking slot requires its own vehicle presence sensor.

b) Multiple street layout:

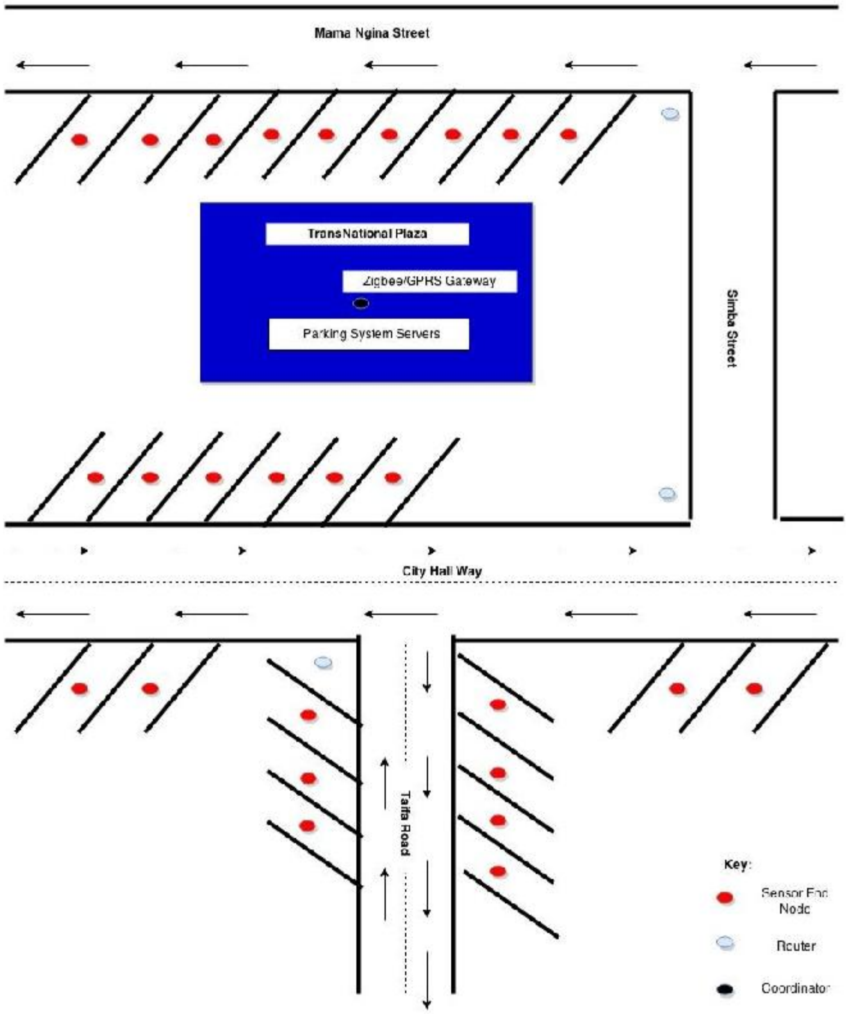


Figure 16: Multiple Street Deployment

4.6 Sensor Node Design

Sensor node architecture

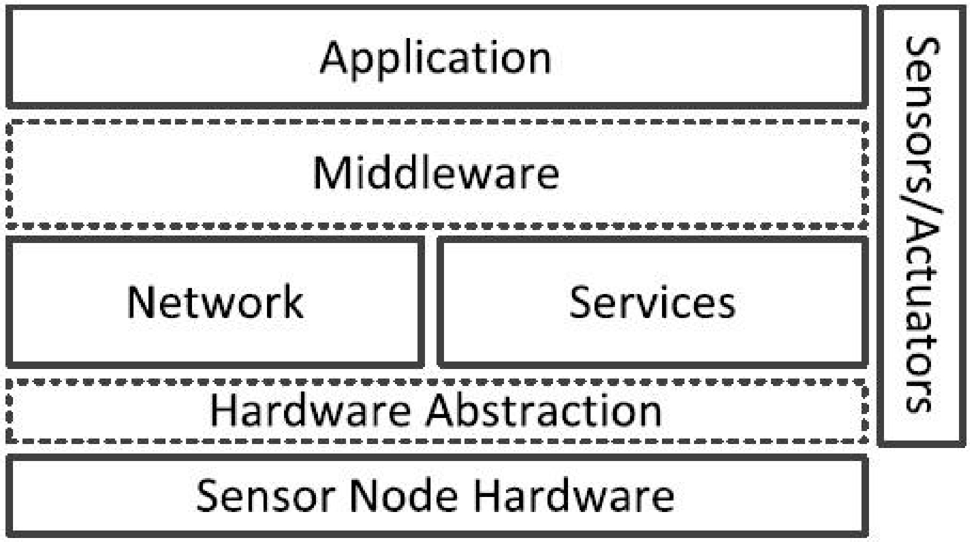


Figure 17: Node Architecture

To design the sensor node, the above architecture will be used.

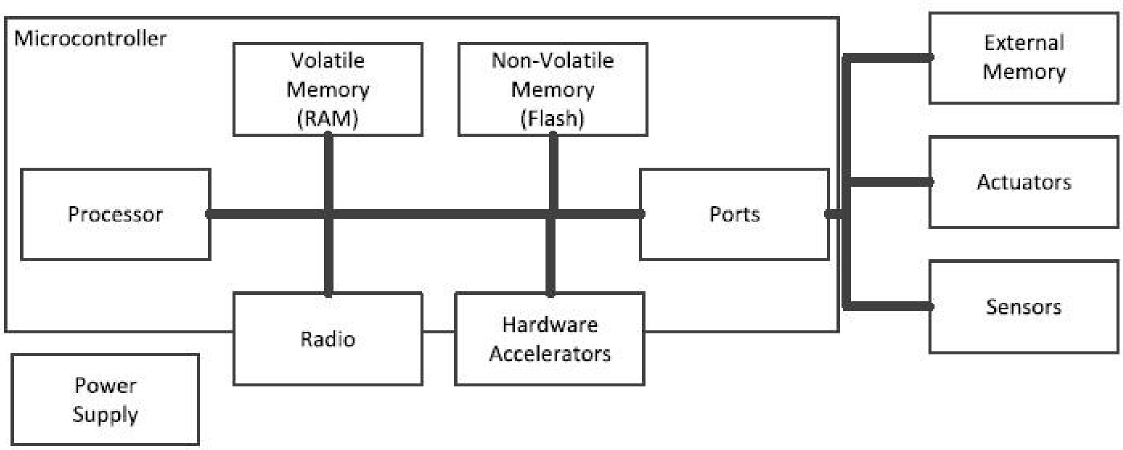


Figure 18: Node components layout

The microcontroller used in the prototype node will be used to process the signal received from the vehicle presence sensor. It will run on a battery. To conserve the battery life, the sensor will go to sleep during those hours it is not required for example at night. The prototyping board used will be the Arduino uno R3.

The sensor is based on a Giant Magneto Resistance (GMR) sensor. The specific model used is AAH002 NVR as described in (E. Sifuentes, et.al 2011). The internal structure of the sensor looks like:

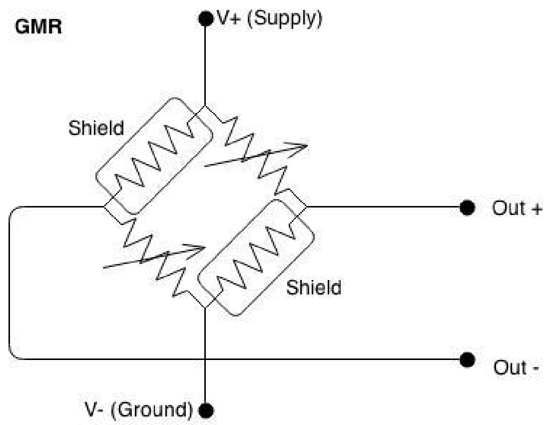


Figure 19: GMR Sensor

The GMR sensor is built as a Wheatstone bridge with two sensing resistors connected to opposing arms. The output of the each sensor is 11mV/V to 18mV/V and the sensor gets saturated by a magnetic field of 6oe.

This means that the signal output of the sensor at maximum field (6oe) is 40mV/V. Since the circuit being built will have a supply voltage of 5V, this means we can expect a maximum signal output of (40mV *5V) 200mV.

The Analogue to Digital converter (ADC) of the AtMega680 chip of the Arduino prototyping board operates at an input voltage of between 0V to 5V. This means we need to amplify the 200mV output of the GMR sensor to 5V max to get the best resolution. This will be done using an operational amplifier.

The output of the sensor will be fed through an op-amp (LMC6484) to boost it before it is fed into the microcontroller (Arduino). The signal amplification circuit looks like:

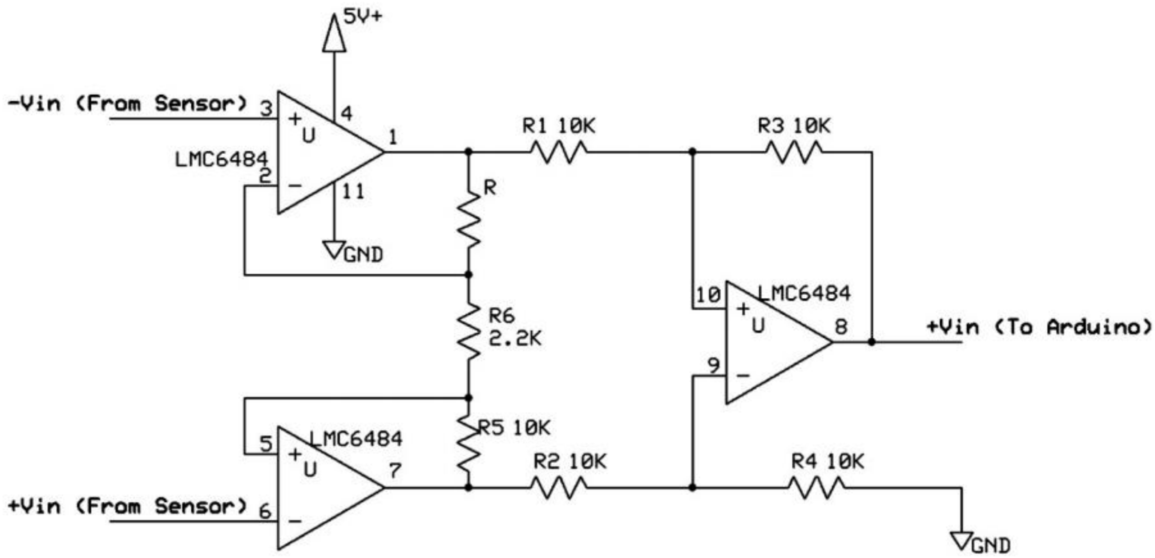


Figure 20: Amplification Stage using an Operational Amplifier

A simulation was done using the ti-tina simulation software from Texas Instruments to make sure the expected behavior will be achieved. Below is the circuit diagram used:

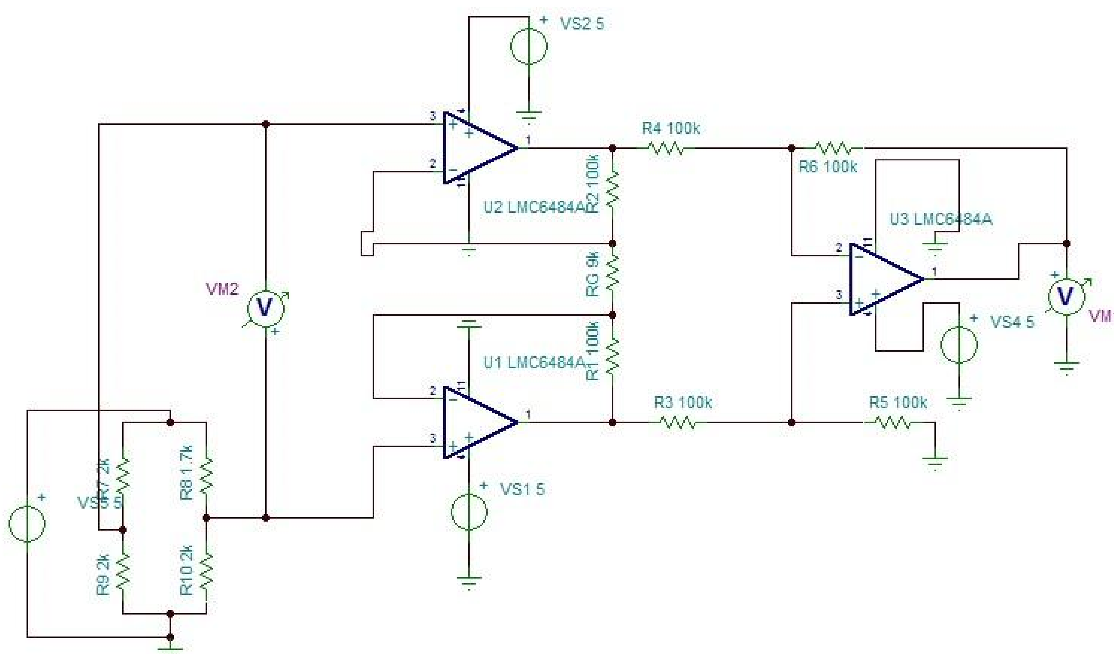


Figure 21: Circuit simulation using Ti-Tina

A fully balanced wheatstone bridge would have all resistors being 2Kohms. To simulate the 200mV expected output of the sensor, the following wheatstone bridge equation was used:

VB= Vin*(Rx/(R3+Rx)- R2/(R1+R2))

Rx = (R2*R3 - R3* (R1+R2)*(-VB/Vin))/ (R1- (R1+R2)*VB/ Vin)

Given that we want a maximum output voltage of 200mV, the resistor Rx is calculated as:

Rx = ((2K * 2K) - 2K*(2K + 2K) *(-0.2/5)) / ((2K – (2K + 2K) *(-0.2/5))

= 1.7Kohms

To simulate, we can look for the output as the resistance of the resistor Rx moves from 1.7Kohms to 2Kohms. This was the output of the simulation.

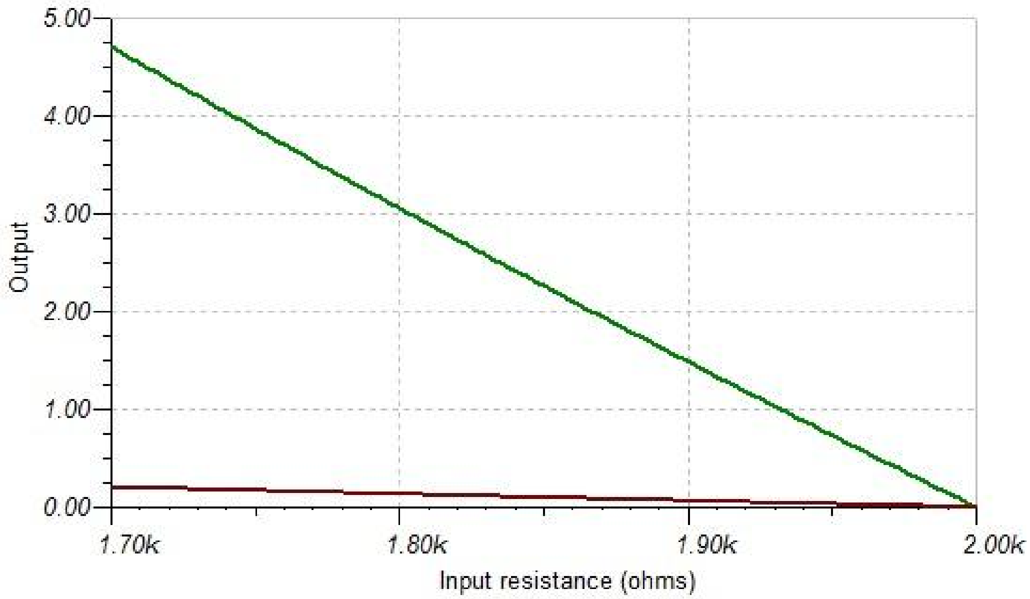


Figure 22: Simulation Results

This shows the voltage amplification by the operational amplifier from the range 0mV – 200mV to the range 0V to 5V.

The Analogue to Digital Converter (ADC) of the AtMega380 microcontroller will then pick this range up and map it to the range 0 to 1023.

This is the state machine for the nodes:

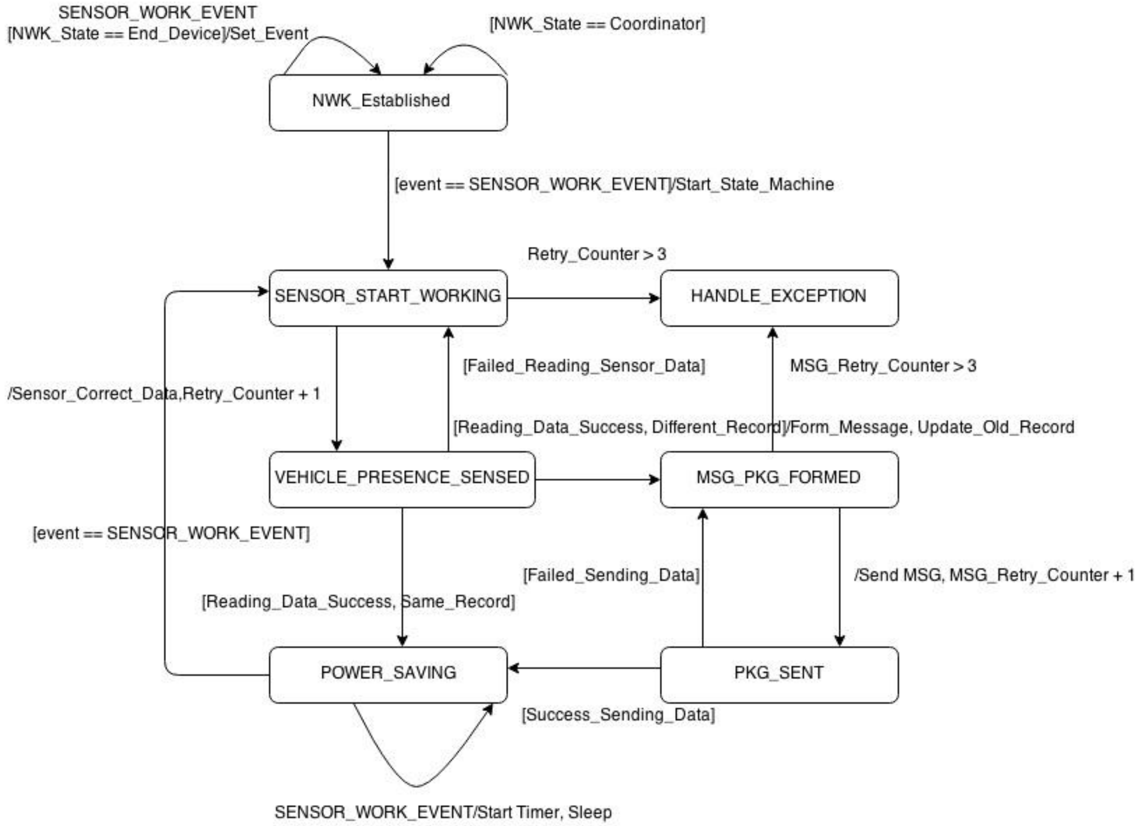


Figure 23: Sensor Node State Machine

The state NWK_ESTABLISHED is triggered by the ZigBee stack when an end device successfully joins the ZigBee network. Meanwhile, the SENSOR_WORK_EVENT is also triggered to start the state machine. After that, the sensor module tries to collect the vehicle presence status from the sensor and go into the VEHICLE_PRESENCE_SENSED state. If the return value of sensor reading is correct, the newly collected value is compared with the "old value" stored from last time. If the "new value" is equal to the "old value" the sensor module will not send out any message and go to the POWER_SAVING state. Otherwise a new message is formed and the state machine goes into the MSG_PKT_FORMED state.

The end device will send the sensor status message to the coordinator of the ZigBee network. If the message sent successfully, the state machine will go into the PKG_SENT state and automatically jump to the POWER_SAVING state. At the POWER_SAVING state, a timer that triggers the SENSOR_START_WORKING event is set and then the end device goes into the sleep mode to save power. When the timer fires, the SENSOR_WORK_EVENT state is triggered, and the state machine will jump to SENSOR_START_WORKING state for the next round sensor module operation. The state machine will go into the HANDLE_EXCEPTION state when the sensor fails to collect the sensor information for three times or the sensor module fails to send out data after retry 3 times at the state SENSOR_START_WORKING and MSG_PKG_FORMED.

4.7 Management and mapping server design

a) System architecture

The purpose of this server is to log sensor data and produce live maps of the situation of parking slots. This information can be picked up by other systems like the payment system to enable efficient and automatic payment by the drivers.

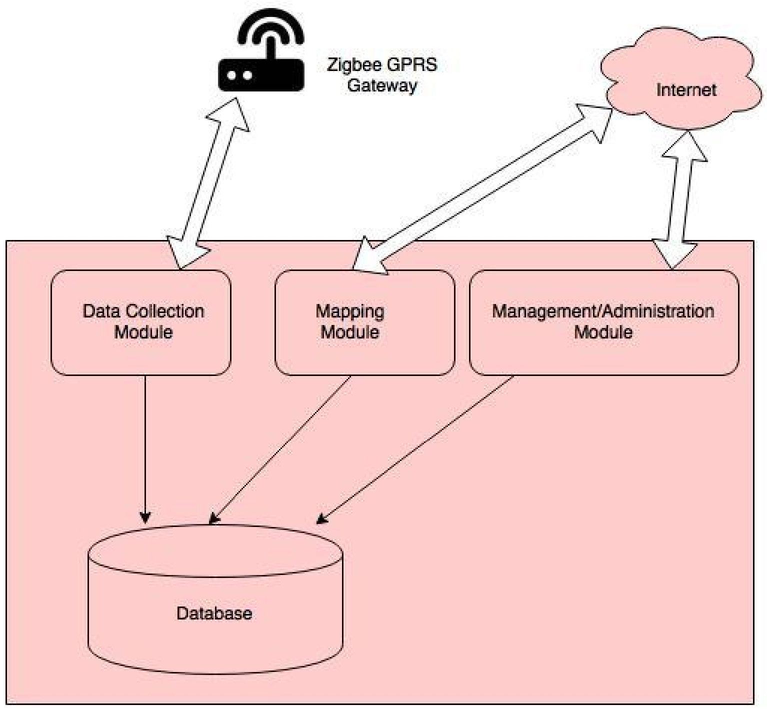


Figure 24: System Modules

a) Data collection module

The data collection module will be responsible for picking the sensor data sent from the Zigbee/GPRS gateway. This data is saved in the database.

b) Mapping module

The mapping module is used to analyze the sensor data into information on a map of the city. These maps can be presented to drivers to guide them find empty parking slots. The maps are also useful to city administration in providing utilization data of the overall available parking area in the city.

c) Payment module

The payment module is used to process payment information in a parking management system.

d) Security module

The security module is used to authorize the various users of the system. It ensures that the users are granted access depending on their set roles.

e) Management/Administration module

This module presents the interface used by parking system managers and administrators to control various functions of the system like parking slot administration, user administration, parking fee administration, business intelligence and map administration.

4.8 Database Design

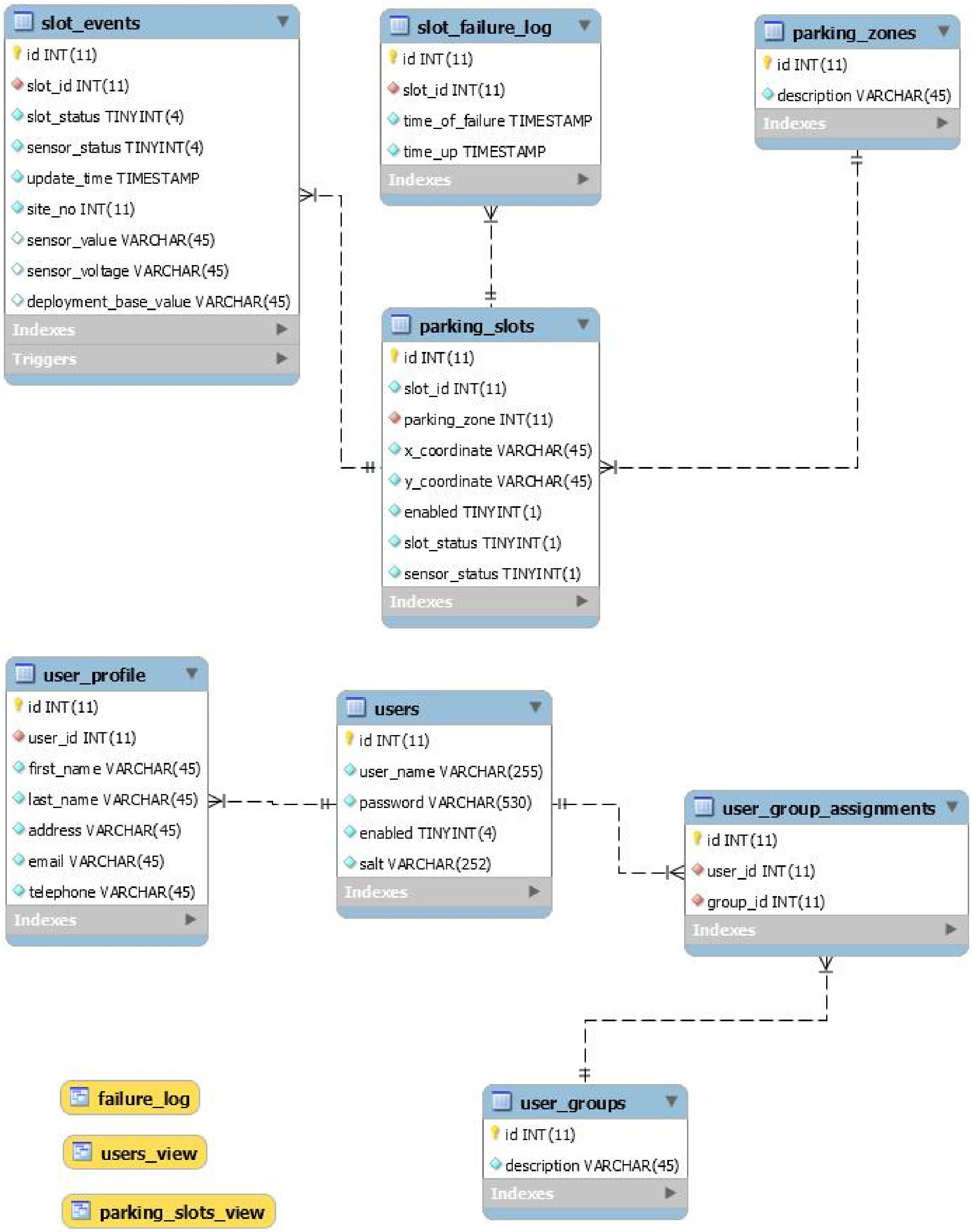


Figure 25: Database Structure

These are the tables and their relationships

No.	Table	Field	Type	Description	Related To

1	parking_slots			**Table to hold data on sensor nodes**	
		id	Integer	Primary Key	
		slot_id	Integer	Unique ID of parking slot	parking_slots.slot_id
		parking_zone	Integer	ID of parking zone where slot is located	parking_zones.id
		x_coordinate	String	X coordinate of node	
		y_coordinate	String	Y coordinate of node	
		enabled	Boolean	node enabled = 1 or disabled = 0	
		slot_status	Boolean	Status of the slot occupied = 1 or empty = 0	
		sensor_status	Boolean	Status of the sensor working = 1 or malfunctioning = 0	
2	parking_zones			**Table to hold data on parking zones**	
		id	Integer	Primary Key	
		Description	String	Description of parking zone	
3	slot_events			**Table to hold data on node updates all updates are logged here**	
		id	Integer	Primary Key	
		slot_id	Integer	Unique ID of parking slot	parking_slots.slot_id
		update_time	DateTime	Time the update occurred	
		sensor_value	Integer	ADC reading on sensor	
		sensor_voltage	String	Voltage reading on sensor	
		deployment_base_value	Integer	ADC base value during deployment	
		slot_status	Boolean	Status of the slot occupied = 1 or empty = 0	
		sensor_status	Boolean	Status of the sensor working = 1 or malfunctioning = 0	
4	slot_failure_log			**Table to hold data on sensor failures**	
		id	Integer	Primary Key	
		slot_id	Integer	Unique ID of parking slot	parking_slots.slot_id
		time_of_failure	DateTime	time when the sensor failed	

		time_up	DateTime	time between failures	
5	user_group_assignments			**Table to hold data on user group assignments**	
		id	Integer	Primary Key	
		user_id	Integer	Unique ID of User	users.id
		group_id	Integer	Group ID in which the user belongs	user_groups.id
6	user_groups			**Table to hold data on user groups**	
		id	Integer	Primary Key - group id	
		description	String	description of group	
7	user_profile			**Table to hold detailed data on users**	
		id	Integer	Primary Key	
		user_id	Integer	Unique ID of user	users.id
		first_name	String	first name of user	
		last_name	String	last name of user	
		address	String	address of user	
		email	String	email of user	
		telephone	String	telephone of user	
7	users			**Table to hold data on users**	
		id	Integer	Primary Key - user ID	
		user_name	String	Unique login username of user	
		password	String	hashed password of user	
		enabled	boolean	whether user is enabled = 1 or not = 0	
		salt	String	String used as salt in hashing the password	

The database will run on MySQL RDBMS.

4.9 System Interfaces

The system consists of various modules. There are also various entities communicating with the system. All these modules and entities need interfaces to facilitate the communication. The diagram below shows the various interfaces required.

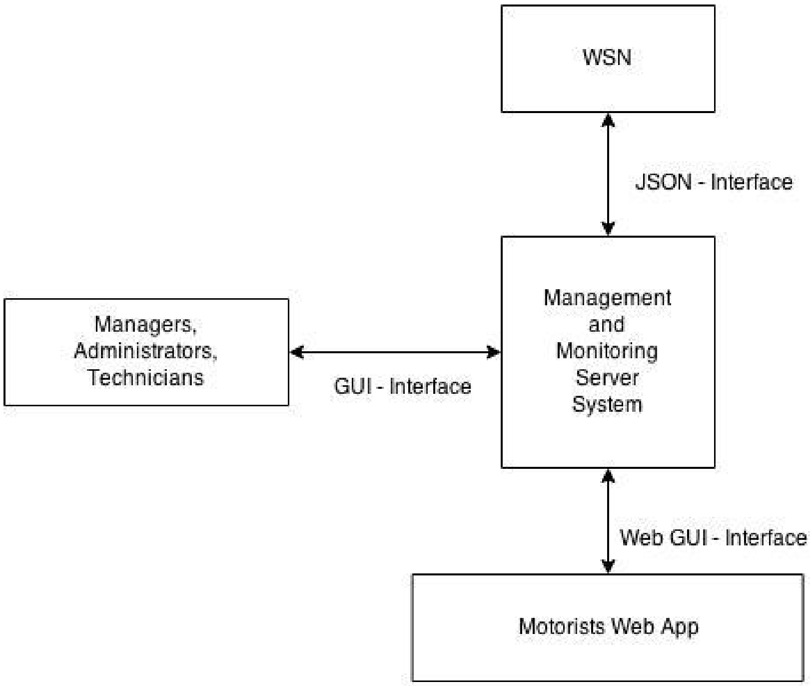


Figure 26: System Interfaces

I) JSON Interface (WSN to System)

The wireless sensor system will communicate with the system using JSON. JSON stands for JavaScript Object Notation and is a standard format used to transmit data in form of attribute –value pairs. It is described in RFC 7159.

A sample message would look like:

Vehicle presence data format:

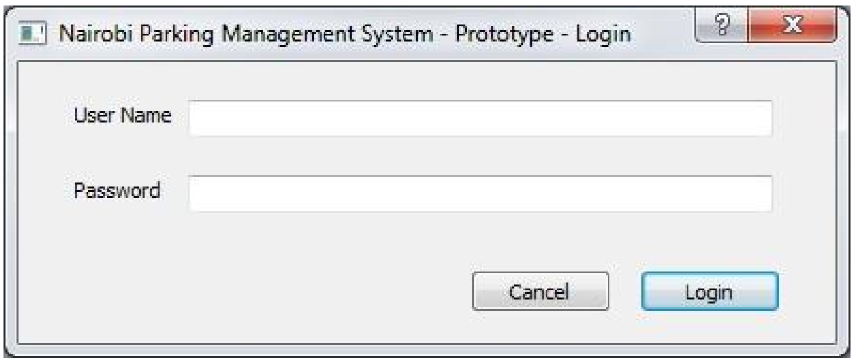
{
“nodeID”:”v0023”,
“sensor_status”:1,
“slot_status”:0,
“sensor_voltage”:”4.69”,
“sensor_value”:”240”,
“deployment_base_value”:”230”,
}

Where nodeID is the unique ID of the sensor node. slot_status 0 means there is no vehicle while slot_status = 1 means a vehicle is parked. sensor_status 0 means there is a problem encountered by the sensor while sensor_status = 1 means the sensor is ok. Time represents the time the measurement was taken. sensor_voltage represents the real voltage output of the sensor. sensor_value represents the ADC reading at the microcontroller. deployment_base_value represents the value of ADC reading during deployment when there is no vehicle parked at the slot. This value is used to check whether a vehicle is parked at the slot by comparing it with the sensor_value reading. The threshold was determined using simulation and found to be 20.

II) GUI Interface (Users to System)

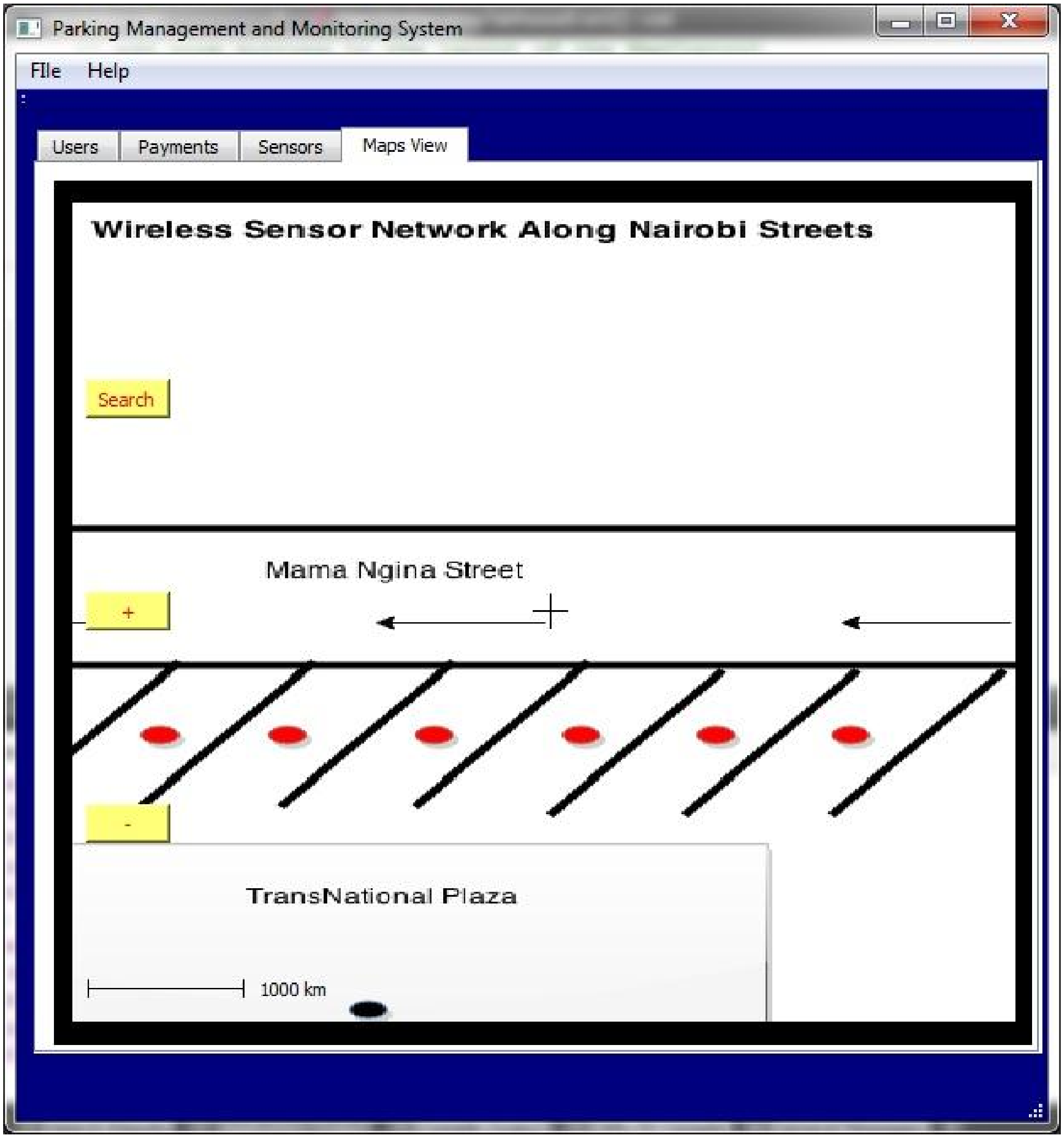
a) Administrator interface

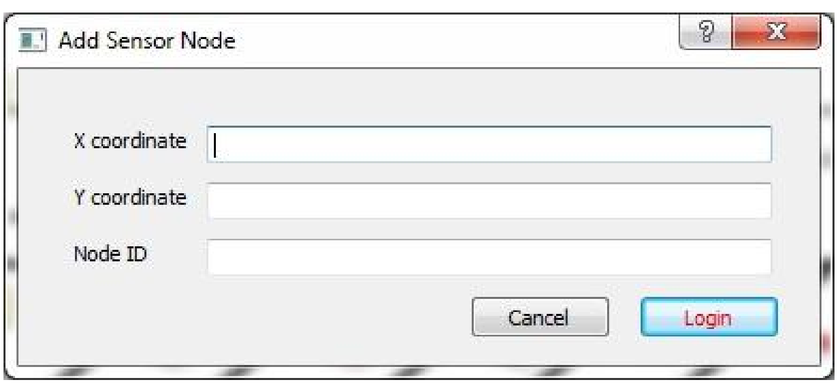
-Login



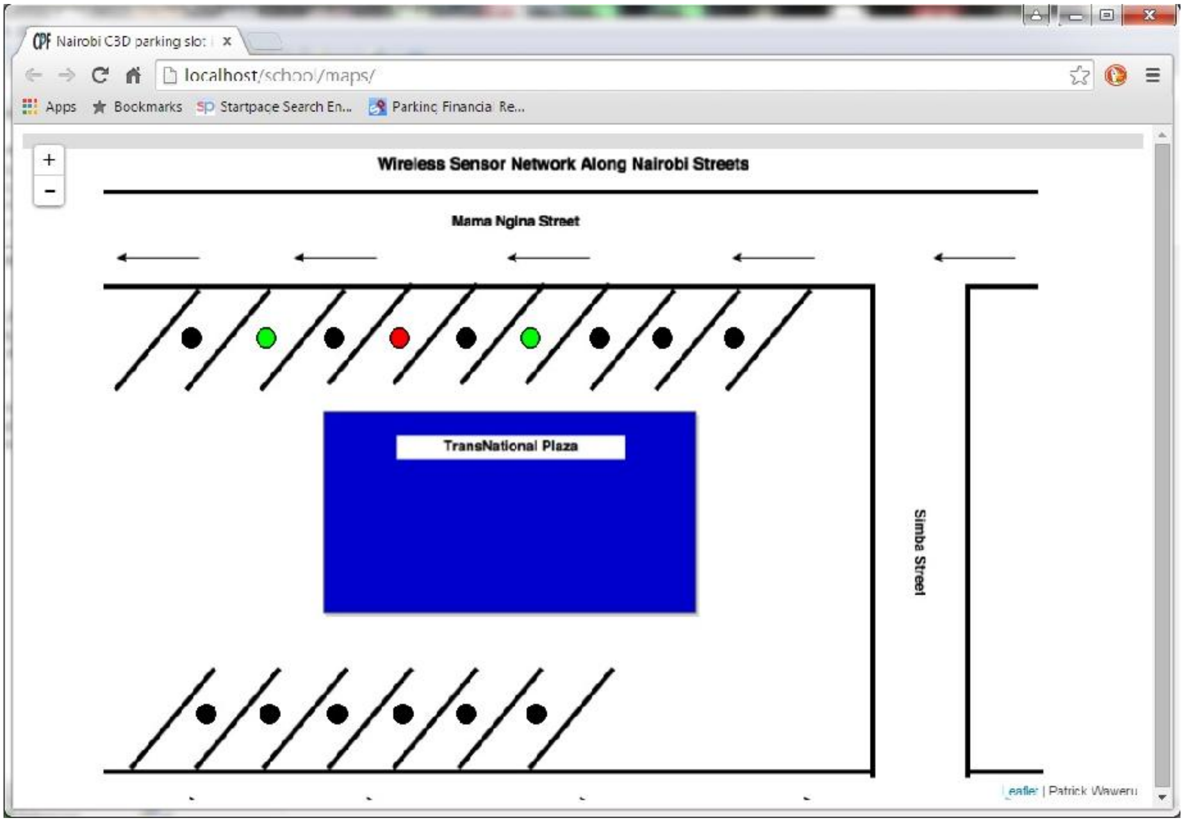
-Administration/Management/Technical

- User Administration





III) Web GUI Interface (Motorists to System)



The motorist can access the maps through the web interface both from the desktop system or mobile device. The mobile access is important since the motorist could be on the move when checking the maps. The web interface is also device independent hence the motorist has a wide choice of devices to use including all modern smart phones.

Reports Design:

a) Parking Slots Report

This shows all the parking slots and their coordinates

Slot ID	Parking_Zone	X_coordinate	y_coordinate

b) Parking Slots Usage Report

Showing each slot and how many vehicles parked per a given duration of time

Slot ID	Parking_Zone	Time_From	Time_To	Usage

c) Users

Show registered system users

User ID	username	First name	Last Name	Address	Email	Telephone	Groups

CHAPTER 5: IMPLEMENTATION

5.1 Sensor Calibration

The purpose of calibrating this GMR sensor is to enable the conversion of voltage output to magnetic field units Tesla. From previous research (Sifuentes, E., et.al 2011), a vehicle produces a deviation of around 5 microTesla.

A prototype circuit was built and calibrated using a commercial magnetometer (I-Prober 520).

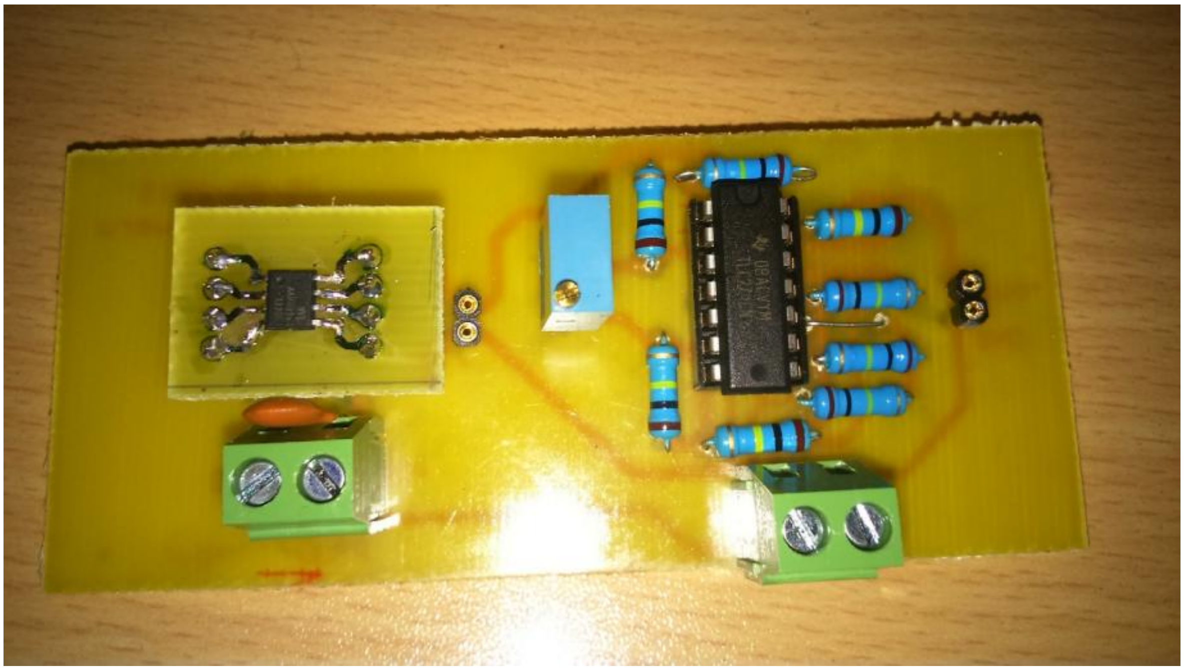


Figure 3A: Prototype calibration circuit

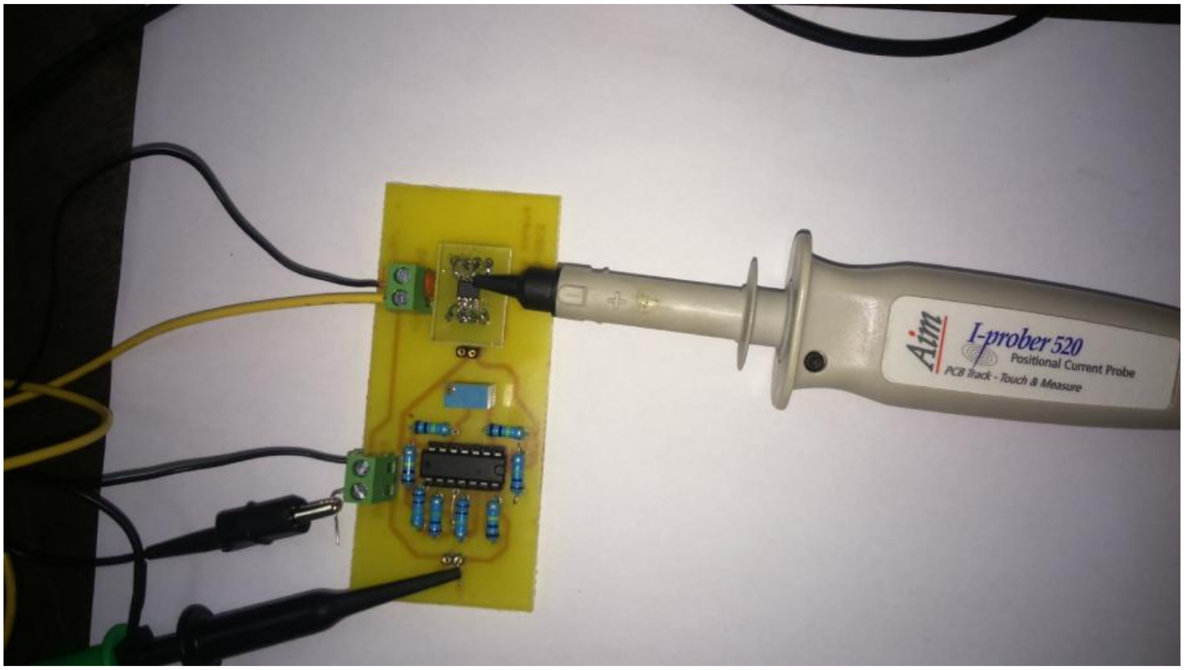


Figure 3B: Placement of the magnetometer on the sensor

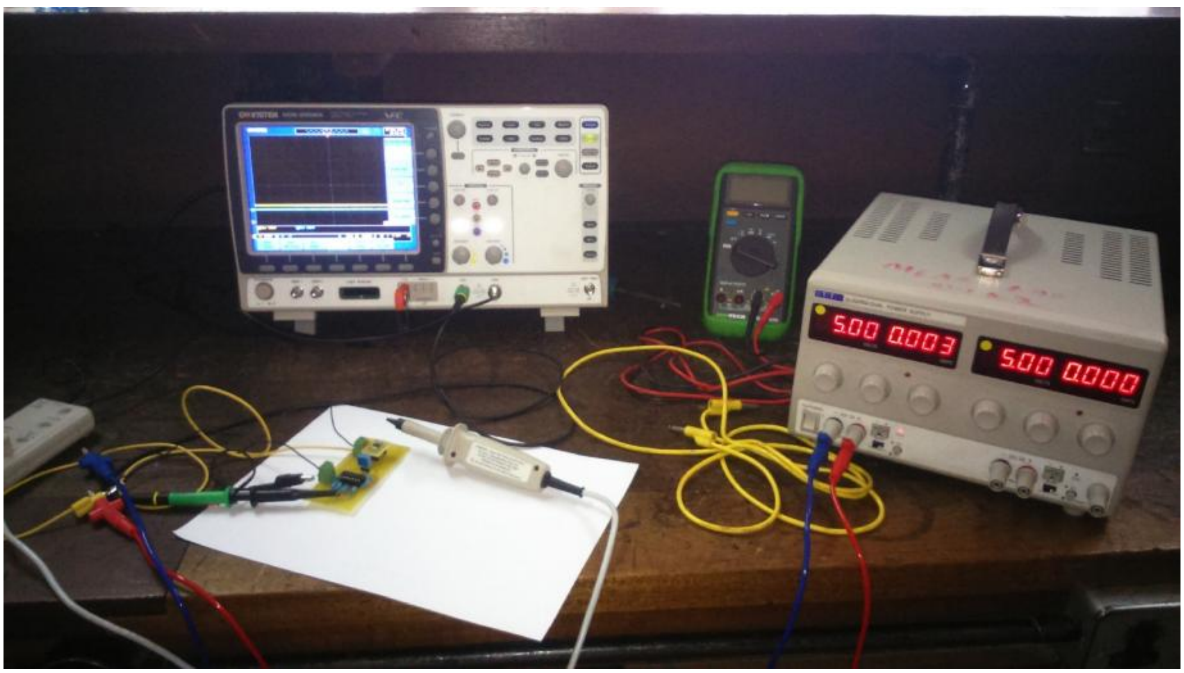


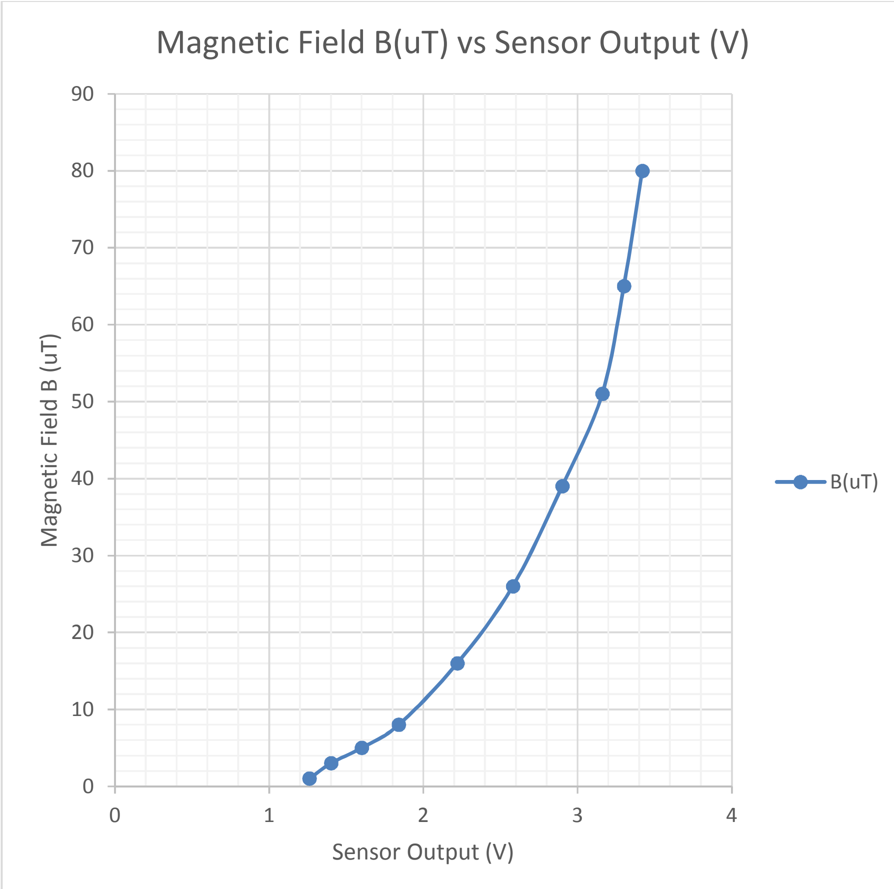
Figure 3C: Circuit supplied with 5V and magnetometer and sensor output observed from the oscilloscope

The magnetometer probe was placed directly on top of the GMR sensor and a permanent magnet brought slowly close to them. The readings obtained are as shown below:

sensor output (V)	probe output (mV)		B(uT)
1.02	0		0
1.52	24		6
2	56		14
2.52	112		28
2.8	144		36
3.08	204		51
3.42	320		80
3.3	260		65
3.16	204		51
2.9	156		39
2.58	104		26
2.22	64		16
1.84	32		8
1.6	20		5
1.4	12		3
1.26	4		1

Table 1: Calibration Data

Ploting this data on a graph:



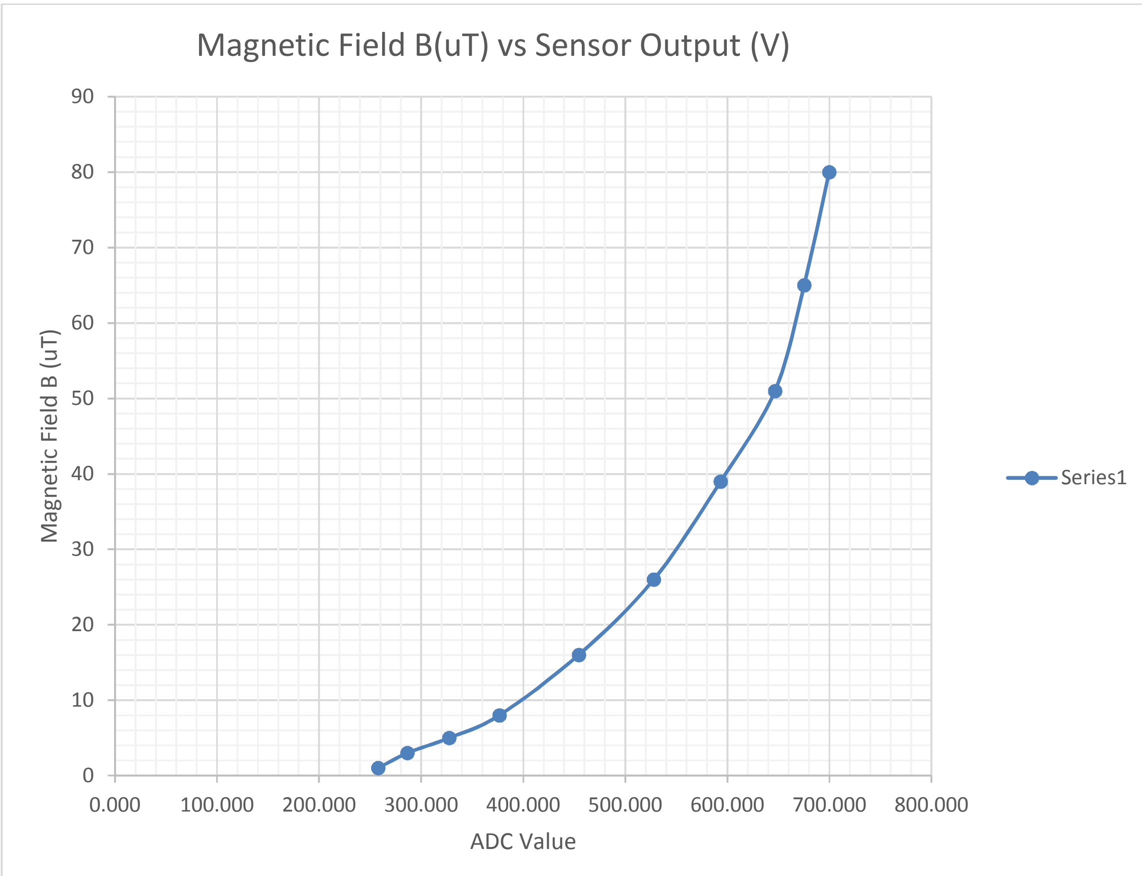
From this graph, it can be seen that the sensor can be used to detect magnetic fields. If the ADC of the AtMega368 microcontroller is introduced in the data, it looks like:

sensor output (V)	**ADC output (0 - 1023)**	**probe output (mV)**		**B(uT)**
1.02	208.692	0		0
1.52	310.992	24		6
2	409.200	56		14
2.52	515.592	112		28
2.8	572.880	144		36
3.08	630.168	204		51
3.42	699.732	320		80
3.3	675.180	260		65
3.16	646.536	204		51
2.9	593.340	156		39
2.58	527.868	104		26

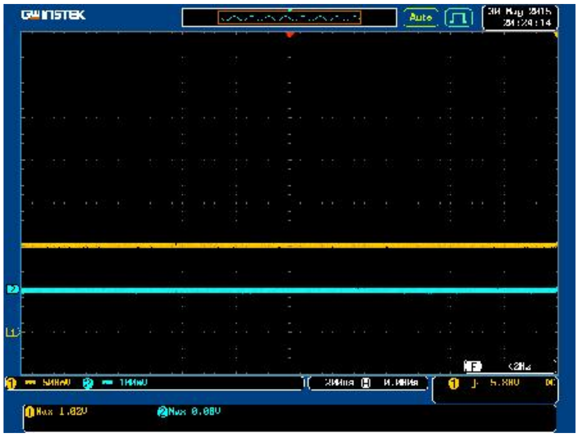
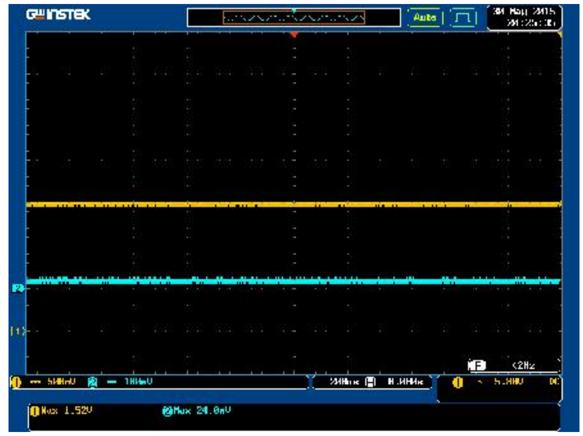
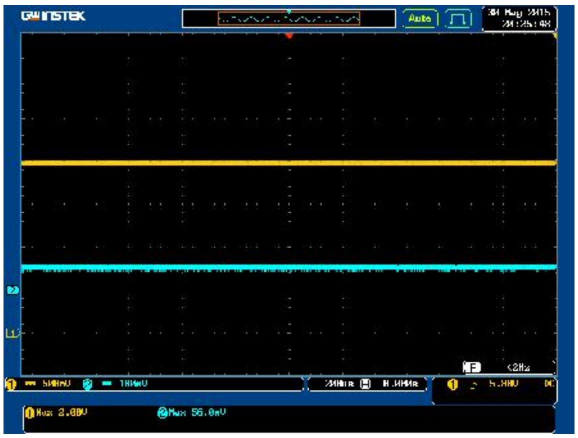
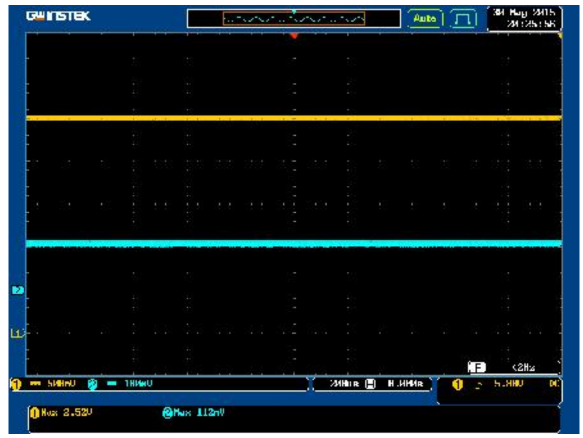
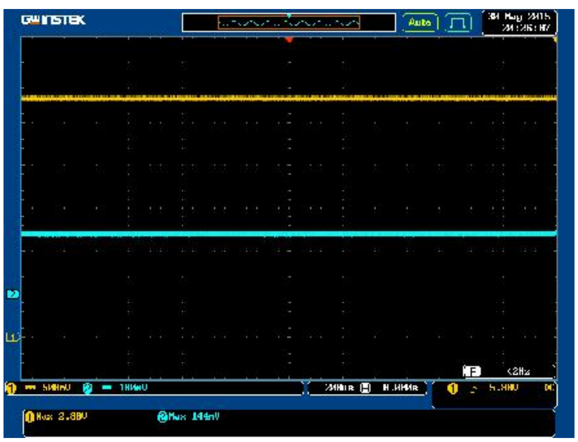
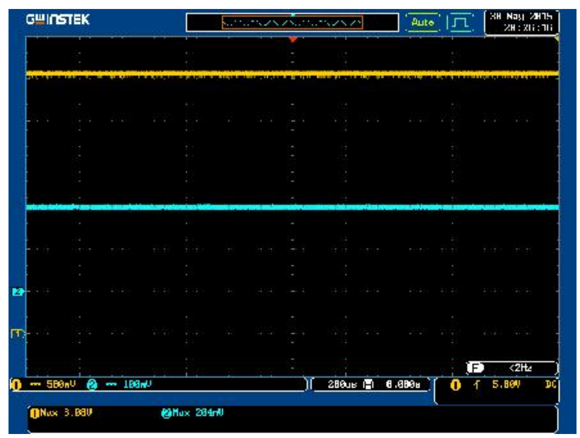
2.22	454.212	64		16
1.84	376.464	32		8
1.6	327.360	20		5
1.4	286.440	12		3
1.26	257.796	4		1

Table 2: Calibration Data

Ploting this on a graph,



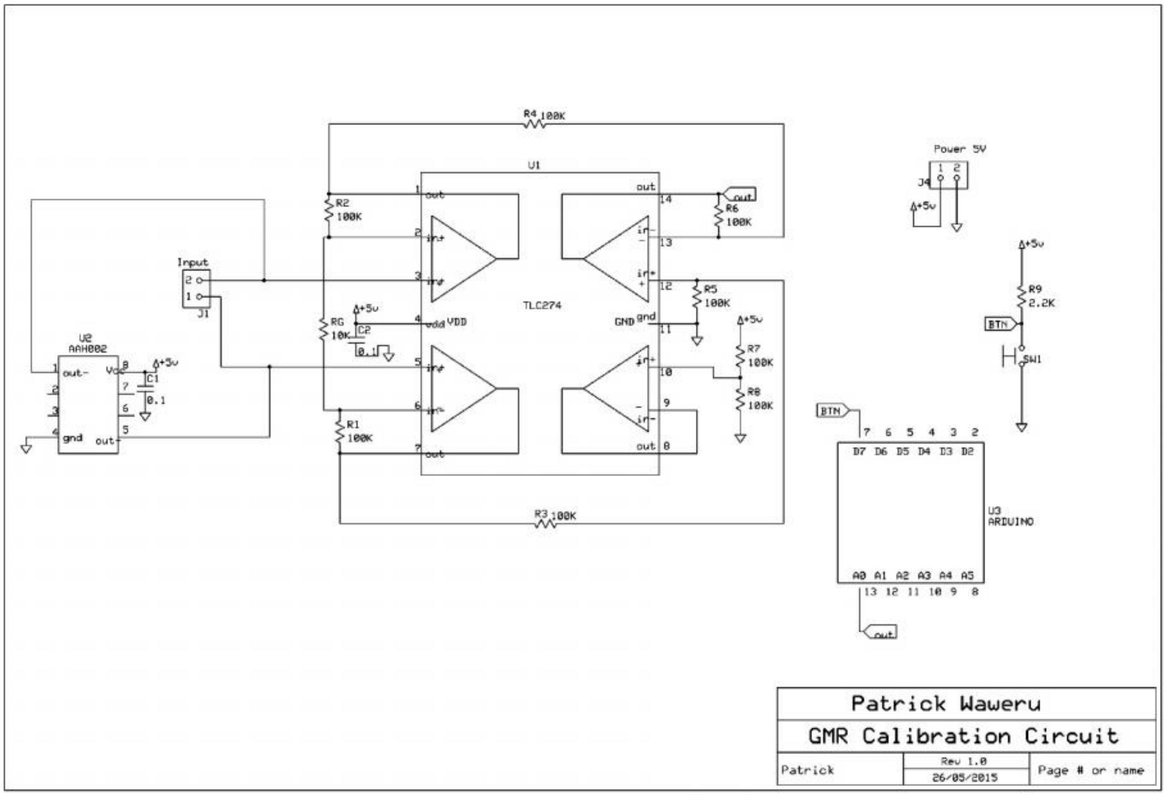
The oscilloscope traces:

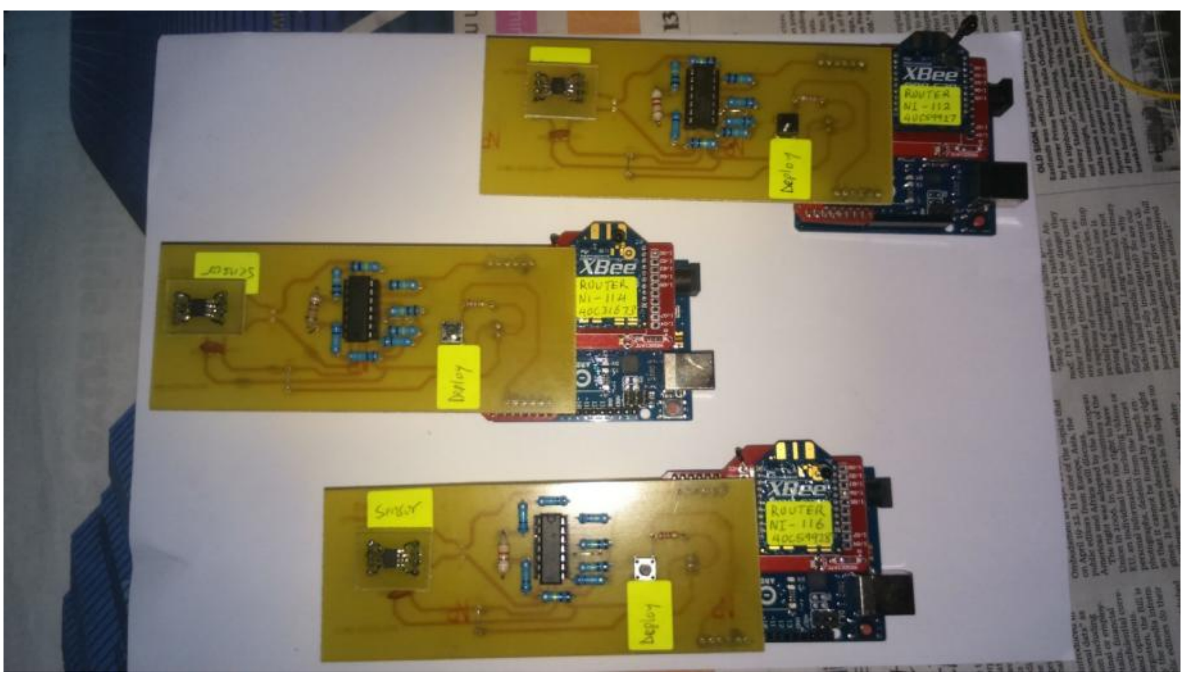







From this information, it can be observed that a change of 5 microTesla will result in a change of approximately 20 in the ADC output of the microcontroller. This was then used to set a treshold upon which we test in the microcontroller program to detect whether a vehicle is present or not.

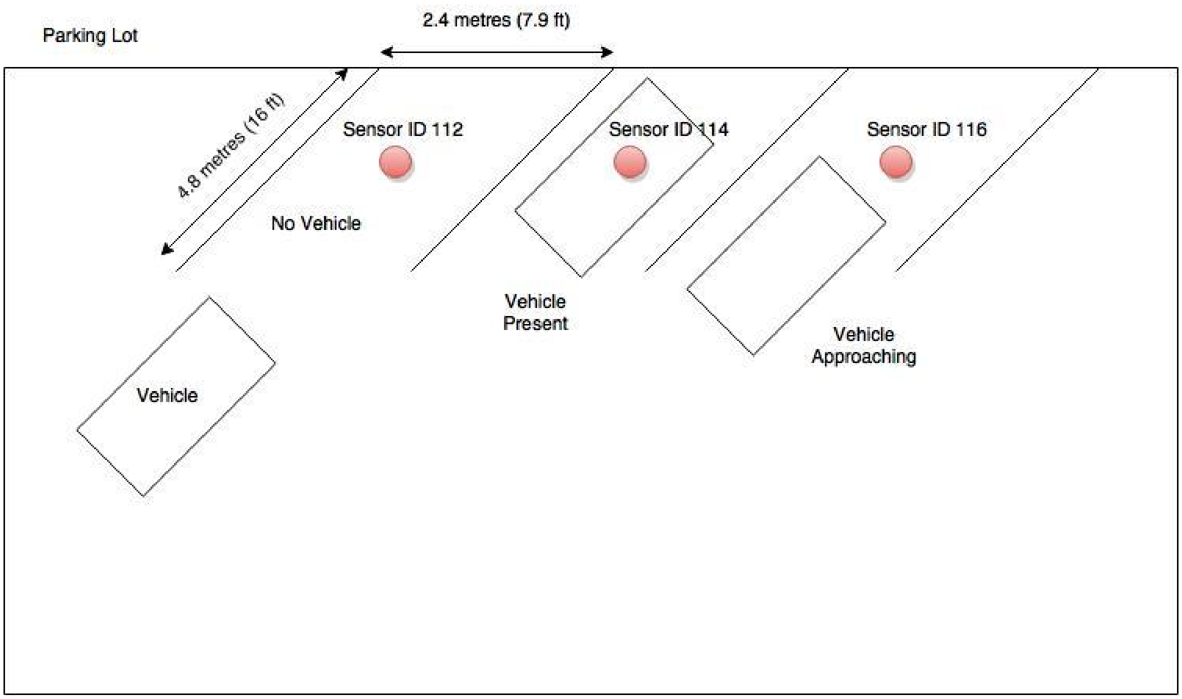
5.2 Prototype Testing

A prototype of the sensor nodes was built and tested on a parking lot.



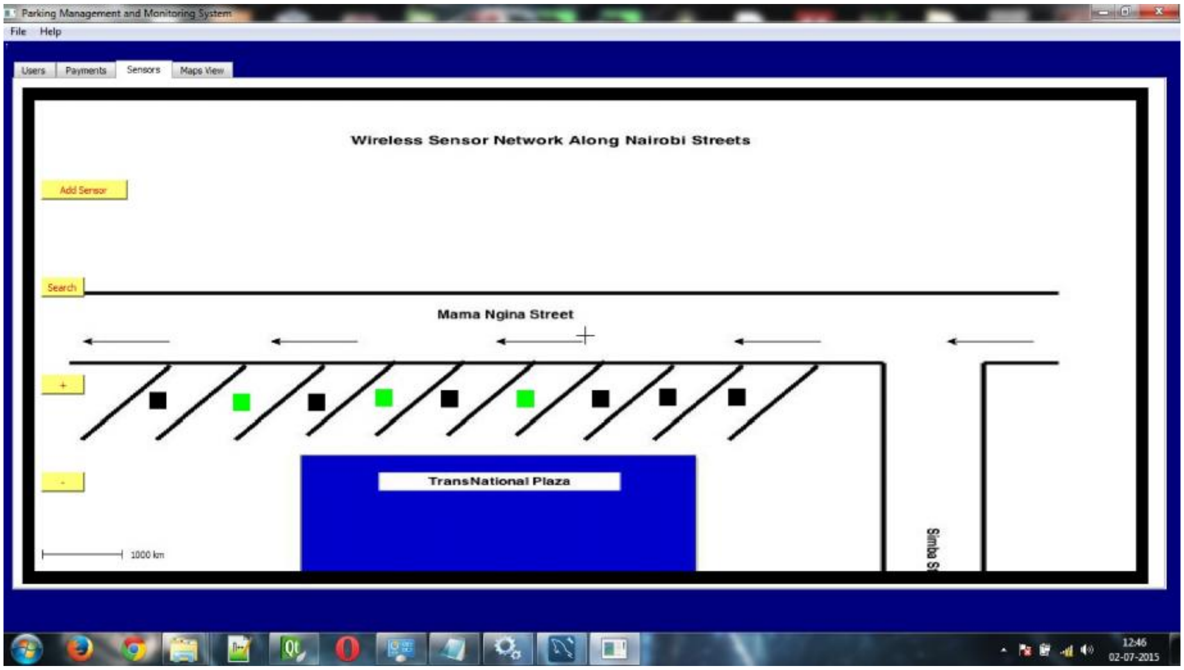


Three nodes were built and powered using rechangeable 9V batteries. To test the nodes, 3 vehicles were used and the readings on the maps observed given the three situations; i) with vehicle on the slot and ii) without a vehicle on the slot. iii) vehicle approaching

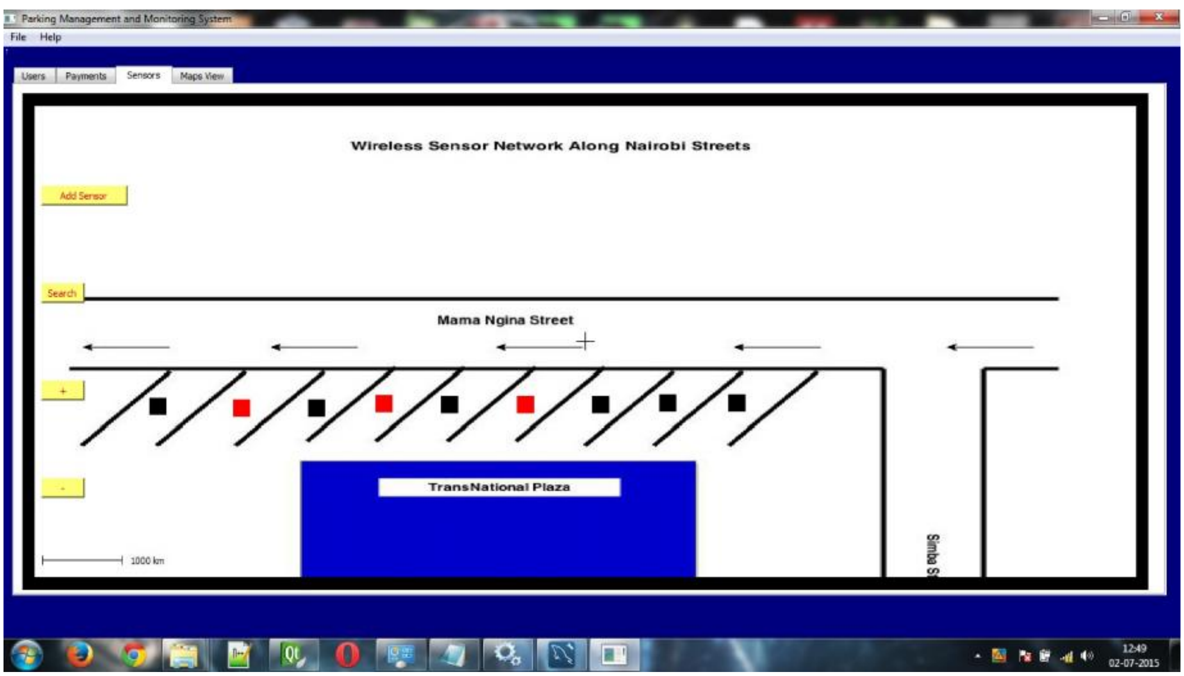


The Results:

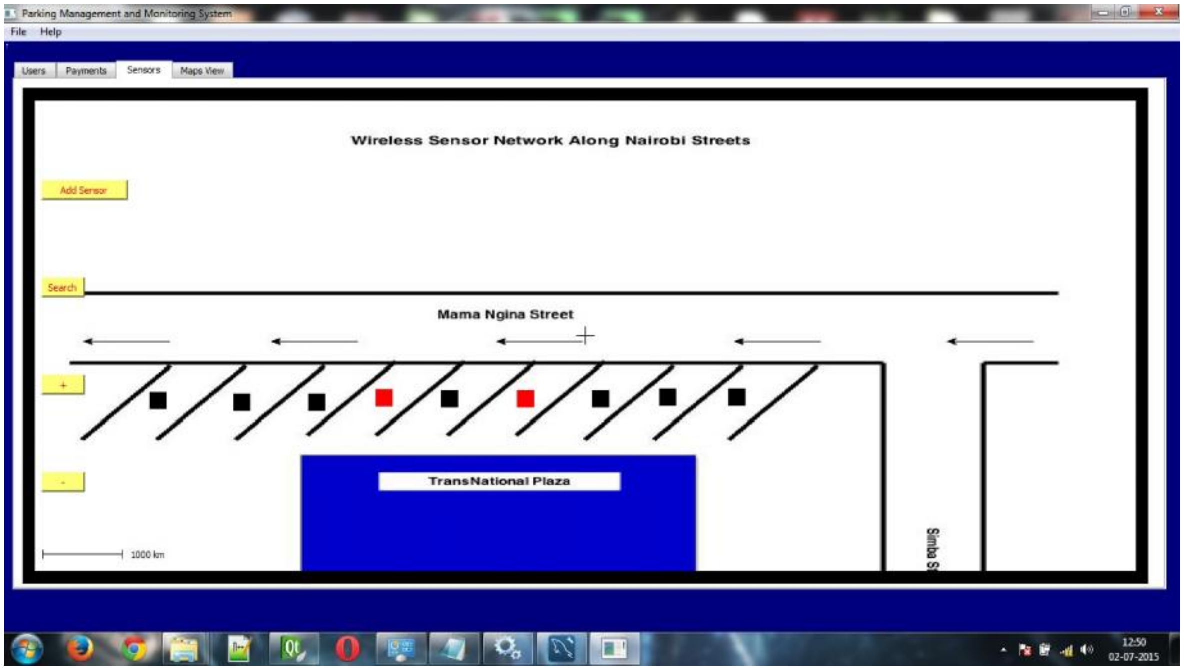
i) Without a vehicle present:



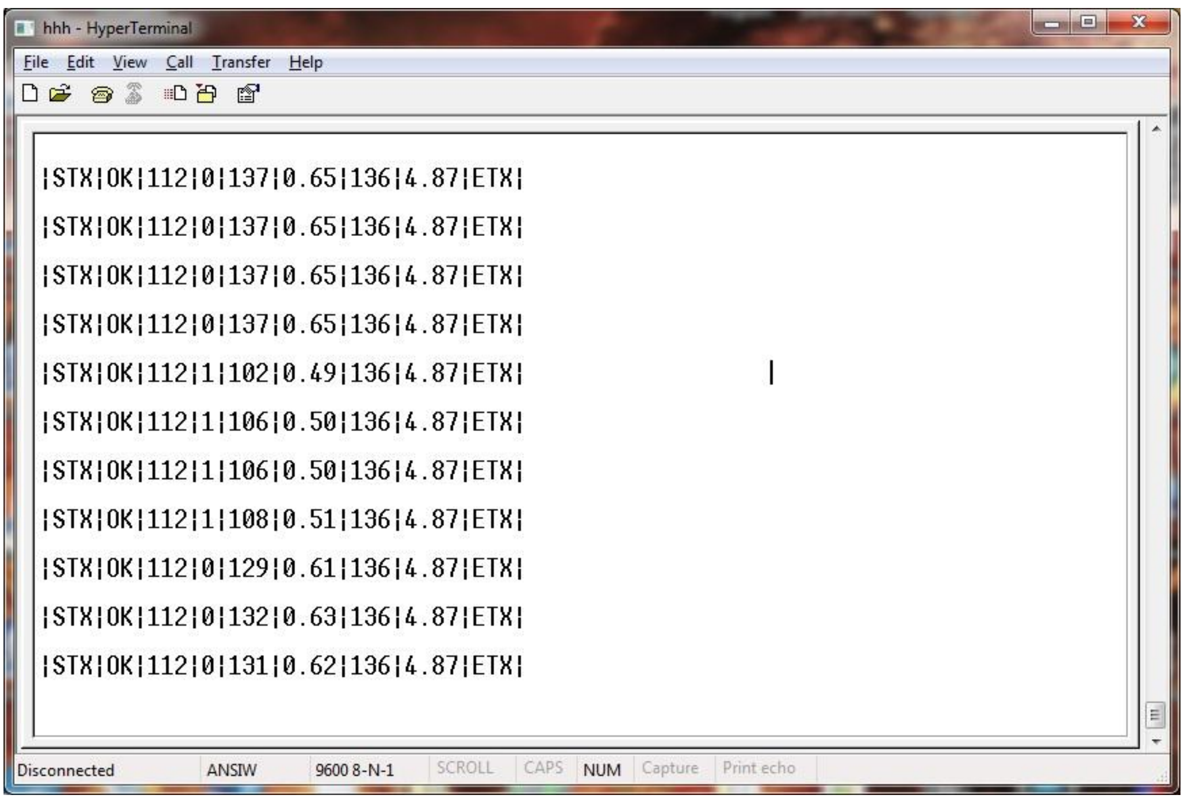
ii) With vehicles:



iii) Node 112 is taken offline:



The raw data obtained from node 112 looks like:



Here we can see the slot status data changing from 0 to 1 indicating a vehicle has been parked and then back to 0 when the vehicle leaves.

The sensors could reliably sense the vehicles and update the server of the event when a vehicle is parked into the parking slot and when the vehicle leaves the parking slot.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

This project proposes a new type of vehicle presence detector using a GMR sensor and addresses its characteristics and performance on the basis of experimental results. Compared to optical, ultrasonic, and inductive loop solutions, the GMR based sensors offer the possibility of very small size installations into and onto roadway structures for reliable function.

This sensor can be used in the city of Nairobi central business district to eliminate problems associated with the search for empty parking slots. The prototype detector has been tested on a local parking area and found to be fully functional and able to fulfil its intended objectives which were; a) Detect a vehicle b) update a central database c)Enable viewing of status on maps. One limitation of this study is that the battery power consumption was not optimized. For a wireless sensor relying on battery power, its power consumption efficiency is very important and should be a priority when designing the final working sensor nodes.

Future research could be focused on making the sensors more compact and improving on their battery consumption to make the batteries last longer and also incorporating a recharging module which collects energy from vibrations in the enviroment. A GPS module could be incorporated into the system so that the coordinates of the parking slots where the sensor nodes are deployed can be sensed automatically and sent to the server. A payment module can also be integrated with the system to enable easy cashless payments by motorists.

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