DELHI TECHNOLOGICAL UNIVERSITY

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

Real-Time Smart Garbage Bin Mechanism for Solid Waste Management in Smart Cities Based on IoT

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A dissertation submitted in partial fulfilment of the requirements for the award of the degree of Master of Technology in VLSI Design & Embedded Systems

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CANDIDATE'S DECLARATION

I Ongeri Abuga Dominic roll number 2K19/VLS/24, student of Master of Technology in VLSI design & Embedded system, hereby declare that the project dissertation title 'Real-time smart garbage bin for solid waste management in smart cities using intelligent IoT' which is submitted by me to the Department of Electronics and Communication, Delhi Technological University, Delhi in partial fulfillment for the requirement for the award of the degree of Master of Technology, is original and not copied from any other source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi

Date: 17th June 2021 ONGERI ABUGA DOMINIC

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CERTIFICATE

I hereby certify that the project Dissertation titled 'Real-time smart garbage bin for solid waste management in smart cities using intelligent IoT' which is submitted by Ongeri Abuga Dominic roll number 2K19/VLS/24 Department of Electronics and Communication, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

Unprecedented urbanization and rapid population growth have increased waste generated annually, posing significant challenges to cities globally. The annual World Health Organization reports indicate that we lose many people to preventable diseases because of improper waste disposal and management. The provision of garbage bins is not good enough to manage waste in our smart cities. The major problem is that garbage bins fill up so quickly, and it takes time for municipal workers to notice. This research project focuses on real-time smart garbage bin for solid waste management for smart cities based on IoT (internet of things). Conventional garbage collection and management systems have many shortcomings, such as inaccessibility to actual data required, lack of throughput, and late unloading. The smart garbage bin mechanism proposed accesses real-time information of any garbage bin across the city; this helps resolve the problem of waste overflow from garbage bins. The system ensures that cities are kept clean. Fuzzy logic is applied in the strategic deployment of smart garbage bins across the smart cities. This proposed system will be implemented on Net-logo, which has widely been used in multi-agent modelling environments.

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LIST OF ABBREVIATIONS

EDGE	Enhanced Data rates for GSM Evolution
ETSI	European Telecommunications Standards Institute
FES	Fuzzy Expert System
GCV	Garbage Collecting Vehicle
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
HSCSD	High Speed Circuit Switched Data
IoT	Internet of Things
IP	Internet Protocol
LoRA	Long Range low power wireless communications technology
LPWAN	Low Power Wide Area Network
LTE	Long Term Evolution
NFC	Near Field Communication
RFID	Radio Frequency Identification
SCGCMS	Smart City Garbage Collection Management System
SGB	Smart Garbage Bin
SGBM	Smart Garbage Bin Mechanism
TDMA	Time Division Multiple Access
UMTS	Universal Mobile Telecommunications Service
Wi-Fi	Wireless Fidelity
WLAN	Wide Local Area Network
WSN	Wireless Sensor Network

CHAPTER 1

INTRODUCTION

INTRODUCTION

1.1 Background of the Study

Since the beginning of the new century, there has been significant growth on the internet. This has led to the emergence of new technologies such as the internet of things (IoT). Kevin Ashton first coined the term IoT in the year 1999 when he was working in Procter&Gamble [1]. During this time, Ashton worked in the supply chain optimization department, and he used this terminology to attract some senior people in management to the new emerging technology called radio-frequency identification (RFID). IoT gained popularity in the year 2010, and it was able to reach the broader global market in the year 2014 [2]. IoT is a network of physical devices that are interconnected to one another through the internet. The physical devices include sensors, actuators, and intelligent nodes, passive and active RFID tags that can communicate with one another from any point [2]. IoT is the pillar for future communication systems. The future trends in communication envisage an environment where everything will share information and communicate without any human interference. The physical devices that will be interconnected will be smart objects with the versatile computational capacity that will be used to monitor our physical environment, resulting in the enhancement and creation of smart cities.

Since the emergence of IoT, human beings have incorporated it in various fields such as environmental monitoring, smart farming, smart homes, surveillance, smart cities, smart health, and many other areas [3]. Smart cities are facing many challenges from environmental pollution, insecurity, inadequate housing, and traffic jams [4]. Waste management has been a challenge to city engineers and urban planners for a long time [5]. The significant causes of waste management in the cities are industrialization, increase in household incomes, changing consumer patterns due to changes in taste and preferences, economic growth/development, and the exponential population growth that is caused by rural-urban migration. An increase in the human population results in an increase in waste production, leading to waste management and control. Every household, factory, and industry at least generate some waste daily [6]. The local authorities collect the waste generated and then take it to the dumping sites disposed of or recycled.

Improper disposal of waste can result in health hazards such as outbreaks of cholera and typhoid, which can cause deaths in the cities [7]. In order to keep the environment hygienic, clean, and green proper monitoring of waste and disposal of waste is vital nowadays. Over the last decade, many cities globally are facing significant challenges such as small parking slots for vehicles, overcrowding, waste management, unemployment, housing, traffic jams, and water and sewerage problems [8]. All these challenges affect the livelihood of people living in cities. To overcome and address these challenges faced in urban centers, a new IoT concept has emerged called the smart city. IoT can integrate many services within a city, which has helped improve the living standards of people living in the smart city [9]. In Smart cities based on IoT, physical devices interact over the internet and enable them to provide ease to human beings based on their intelligence. In the subfield of IoT smart homes and smart cities get the highest ranking.

The fast growth in urban population and voluminous generation of waste makes the cities unhygienic and dirty, which poses a health challenge to urban residents [7]. The waste that is generated is divided into solid and wet waste. In this research project, the focus has been in the generation of solid waste. On that account, the research project has focused on a waste management and control mechanism for smart cities called the smart garbage bin mechanism (SGBM); this mechanism will be able to clean and sanitize the environment more intelligently. SGBM is designed and tailored for solid waste management and the applicability of the 3R model of Reduce, Reuse, and Recycle. The waste management and control mechanism is broken down into five steps: a collection of garbage, transportation of garbage, analyzing and processing garbage, recycling garbage, and disposal of garbage. In the SGBM framework garbage bins are placed strategically across all points in the cities with a major concentration in the residential areas. The smart garbage bin mechanism is essentially designed for real-time monitoring of the waste collecting points. The SGBM framework will reduce fuel consumption by the garbage collecting vehicles. It will reduce labor, time, and the cost will be much cheaper than the traditional garbage collection methods. The SGBM has the following modules garbage collecting vehicles, garbage bins, and a centralized database.

According to the World Bank report, globally about 2.03 billion tonnes of solid waste are generated annually. 33% of this waste is not managed safely to cater for the environment this includes nuclear waste and electronic waste [10]. The first world countries generate almost

34% of this annual solid waste. The projection by World Bank is that by the year 2050 the world will be generating between 3-4 billion tonnes of waste annually because of rapid population growth [11].

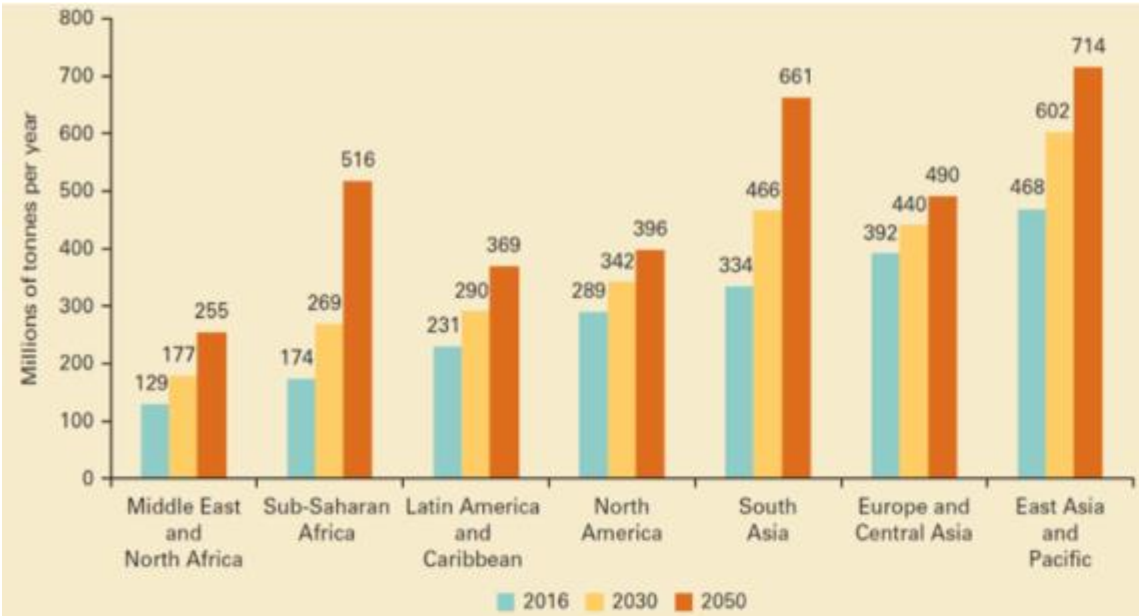


Figure 1. Projected waste generation by region (Millions of tonnes/year).

High income countries have a high wastage collection rate as compared to the low income countries.

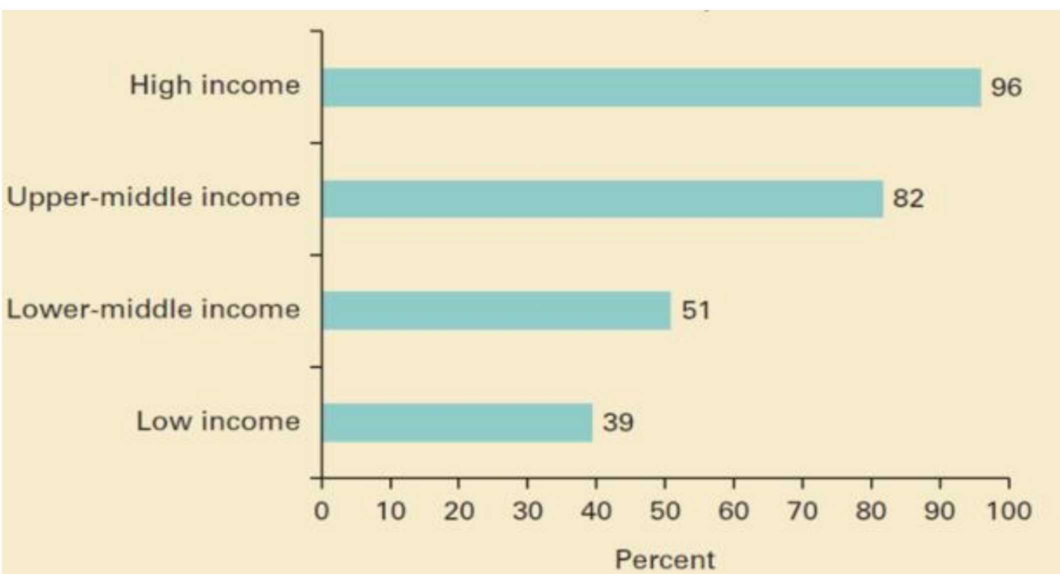


Figure 1.2. Waste collection rates, by income level (in percentage)

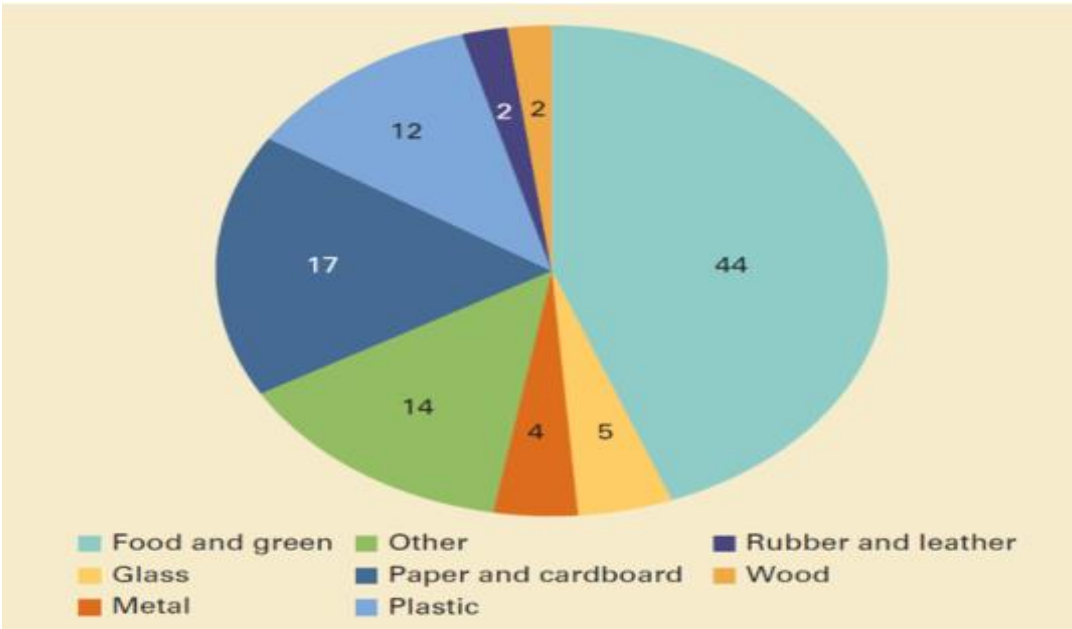


Figure 1.3. Global waste composition (in percentage)

1.2 Problem Statement

Disposal of waste is a challenge to many cities globally due to rapid urbanization. Waste collection and monitoring have emerged as an important field in applying IoT in solving problems that face smart cities. Many existing systems have been designed and developed to tackle this problem. Still, most of these systems are based on municipal authority monitoring of garbage bins that are deployed in various parts within a city or are server-based. The existing systems send garbage collecting vehicles towards the requesting bin upon receiving the request message. One major problem with these existing systems is that they consume a lot of time and energy (fuel) to fulfill a single request. Therefore, a smart garbage bin that incorporates artificial intelligence and the internet of things technology is necessary to collect solid waste from the requesting garbage bins because it consumes less energy and time. The proposed research project is based on edge-nodes that represent garbage bins. When a smart garbage bin reaches a certain threshold level, it sends a request directly to the garbage collecting vehicle instead of forwarding the same request to the municipal authority. The proposed system plays a fundamental role in waste collection and management because it consumes low power because of its novel edge-based mechanism. The system also consumes less time because of fewer iterations from request to request procedures.

1.3 Research Objectives

i. To develop an efficient, effective real-time and IoT based Smart garbage bin for municipalities to help them in solid waste monitoring, management and control.

ii. To improve the environmental and hygiene quality that will lead to reduction in health hazards in smart cities by the timely collection of filled garbage bins.

iii. To enhance less consumption of fuel and reduce man power that translates to less wages in the management of waste in the cities.

iv. To reduce traffic congestion and noise pollution that is caused by the garbage collection vehicles from the municipal

v. To determine the efficiency of fuzzy logic in making decisions for strategic deployment of smart garbage bins.

1.4 Justification of the Research Project

In the past, garbage bins used to be emptied by garbage collectors at specific intervals. Although the method was efficient at that time, the increase in population also translated to more solid waste [12]. With time, this method developed some drawbacks, like some garbage bins filled up faster than others, and it took time for the garbage collectors to be there in time. Another major drawback was that during some special days like festivals, weekends, and public holidays, the bins filled faster compared to other days and required urgent collection.

This research project aims to provide real-time information on the filled smart garbage bins. The project will also use fuzzy logic expert system in the deployment of smart garbage bins strategically across all the locations of the city. The real-time information about the status of the smart garbage bins will help the garbage collecting vehicles to determine the optimal paths to use to reach the filled bins.

1.5 Research Gap

Previously done research projects focused on a waste management and control system controlled by the central authority. The focus will on real-time smart garbage mechanism for solid waste management in smart cities based on IoT. The proposed system aims at dealing with the issue of waste management in a cost effective manner and making cities more clean and habitable

CHAPTER 2

LITERATURE REVIEW

LITERATURE REVIEW

2.1 Introduction

In the past few years, many communication engineering researchers are mainly focusing on Internet of Things based applications. A smart city has been a widely researched area in the recent past. In a nutshell, a smart city is a city where every physical device is interconnected and can communicate over the internet [13]. In a smart city, the assumption is that every physical device is intelligent, with the ability to make decisions based on the environment with any human interference. A smart city provides a clean and hygienic environment to its residents. The city has the following services integrated into one; smart parking systems, intelligent traffic management systems, smart administration, smart health, smart homes, and smart economy [14]. The fundamental principle of a smart city is providing better facilities to its residents and visitors. These facilities assure the citizens of a green and clean environment for all. In this chapter, we will look at the general architecture of IoT systems and then finally look at the existing waste collection mechanisms that have been in existence. In order to make smart cities clean, there should be an efficient solid waste collection mechanism.

2.1.1 IoT Background and Architecture

According to Cisco, "IoT is defined as a network of physical devices/objects that can be accessed through the internet, as defined by technology analysts and visionaries. These objects contain embedded technology to interact with internal states or the external environment. In other words, when the objects can sense and communicate, it changes how and where decisions are made and who makes them. "

IoT is not a new concept in the industry, having been conceptualized by Kevin Ashton in the early 2000's [1-2]. IoT was built on the concept that was a bit simple but very powerful, Ashton envisaged a period where all physical objects/devices used by human beings in daily life could be connected wirelessly and the devices were equipped with specific identifiers. That meant the object had the capacity to communicate with one another and be managed remotely by computers. During this time many impediments had to be resolved which included; the type of wireless communication the physical devices were to be built on, the change in the existing internet infrastructure to allow support of many physical devices ,and the power that was to be used by these devices.

As of today many of the obstacles that existed have been resolved. Wireless radios have reduced in size and cost. The emergence of IPv6 has allowed billions of devices to be assigned with a unique IP address for communication. IoT is used to describe a dynamic system where physical devices have sensors and actuators attached to them, and are connected to the internet wirelessly or by wired internet connections. The sensors and actuators use various types of local area connections i.e. ZigBee, RFID, Bluetooth, NFC, and Wi-Fi. GPRS, GSM, 3G and LTE can also be used to provide wide are connectivity [15].

2.1.2 IoT Applications

CITIZENS	
Healthcare	Triage, patient monitoring, personnel monitoring, disease spread modelling and containment, real-time health status and predictive information to assist practitioners in the field, or policy decisions in pandemic scenarios like Covid19
Emergency services	Remote personnel monitoring (health, location), resource management and distribution, response planning, sensors built into building infrastructure to guide first responders in emergencies or disaster scenarios
Crowd Monitoring	Crowd flow monitoring for emergency management; efficient use of public and retail spaces; workflow in commercial environments
TRANSPORT	
Traffic management	Intelligent transportation through real-time traffic information and path optimization
Infrastructure monitoring	Sensors built into infrastructure to monitor structural fatigue and other maintenance; accident monitoring for incident management and emergency response coordination
SERVICES	
Water	Water quality, leakage, usage, distribution and waste management
Building management	Temperature, humidity control, activity monitoring for energy usage management & Heating Ventilation and air conditioning (HVAC)
Environment	Air pollution, noise monitoring, waterways and industry monitoring

Table 1. IoT Applications

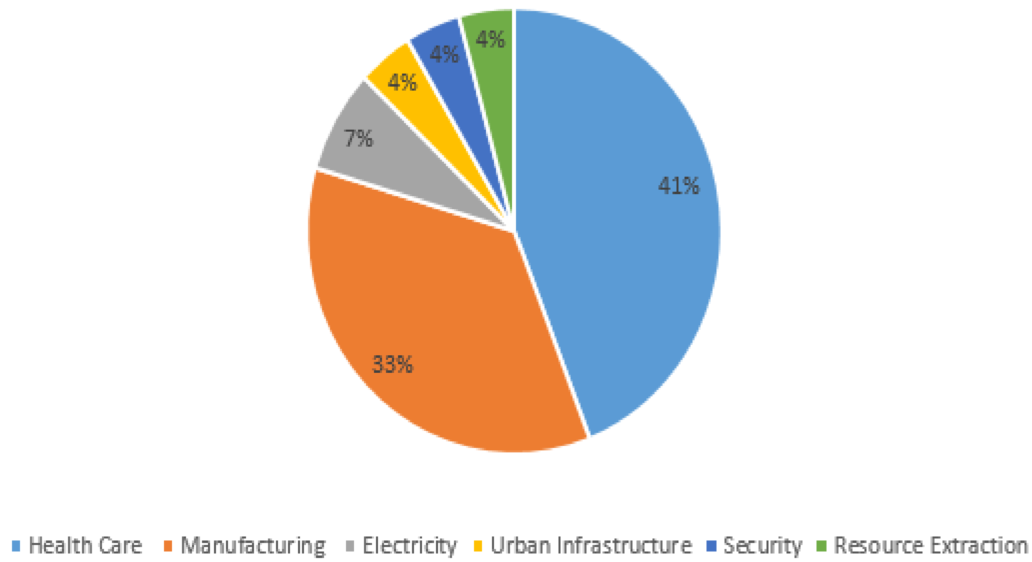


Figure 2.1.Market share projection of IoT applications by the year 2025

Communication is regarded as one of the most critical aspects in the field of IoT. This is mostly enabled by the interconnectivity of various physical devices that can communicate with other physical devices over the internet. Other additional aspects such as data storage, maneuvering, capturing, sensing, and processing is unnecessary unless the physical devices require one of the mentioned properties [16-17]. This notwithstanding, communicating is necessary when classifying a physical device, whether it is an IoT device or not.

2.1.3 IoT Architecture

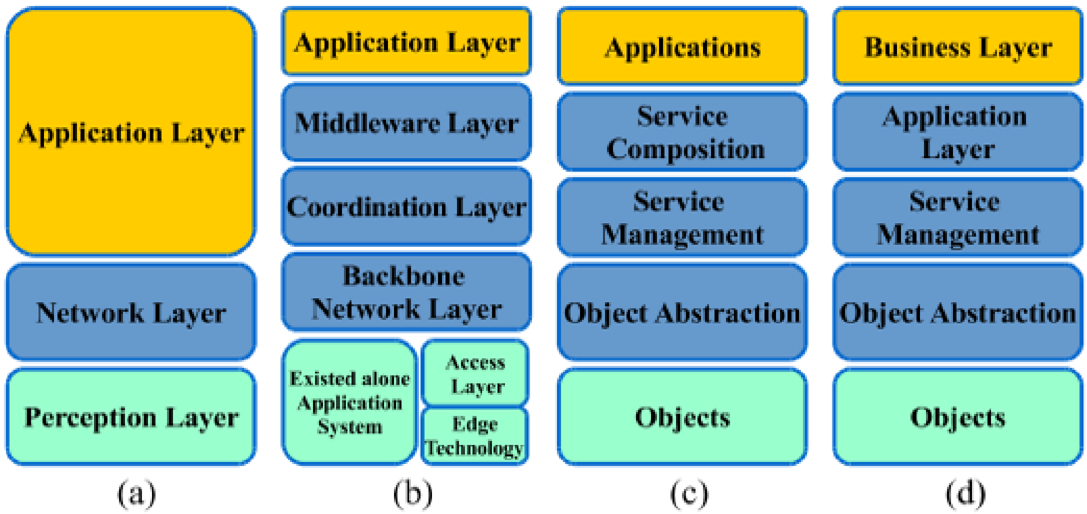


Figure 2.2. IoT Architecture (a) three-layer (b) middle-ware based (c) Service-Oriented Architecture (d) Five layer

I. Objects layer or Perception layer

This layer represents physical sensors in the field of IoT whose role is collecting and processing information. This layer has sensors and actuators. Actuators are used for the translation of electrical signals from IoT system into some physical action. Sensors are devices used for the collection of physical parameters such as acceleration temperature, humidity, weight, vibrations etc. they in turn convert these physical parameters to electrical signals (digital or analog). This layer is also used to configure various heterogeneous object by use of plug and play mechanism that is standardized [18]. Finally, the perception layer digitizes data and transmits the data to the next layer (Object Abstraction Layer) through channels that are highly secured and encrypted. Big data is initialized in this layer.

II. The Object Abstraction Layer

This layer is involved in transferring data produced by the objects in the service management layer through secured channels [18]. Several technologies can be used for data transfer, such as BLE, RFID, GSM, 3G, UMTS, ZigBee, and Infrared. The object abstraction layer also handles data management processes and cloud computing.

III. Service Management Layer or Middleware Layer

This layer does the pairing of service with its request based on the name and address. This layer makes it easier for the IoT programmers to work with heterogeneous objects without considering a specific hardware platform [18]. The service management layer also does data processing, makes critical decisions, and delivers the services over the network wire protocols.

IV. The Application layer

In this layer information is critically analyzed by various softwares in order to provide solutions to key business questions. Presently, we have many IoT applications that vary in functionality and complexity [17-18]. These applications use different operating systems and technology stacks. The examples are

- Analytic solutions that are based on machine learning
- Mobile applications that handle simple interactions
- Control software and physical device monitoring
- Business intelligent services

Numerous applications can be developed on top of IoT platforms. The IoT platforms should offer software development infrastructure that has ready to use instruments for data visualization, data mining and advanced analytics. This layer's significant importance is that it offers high-quality services to satisfy customer needs and preferences. This layer equally covers many vertical markets such as smart homes, smart buildings, smart healthcare, industrial automation, and the transport industry.

V. Business Layer

This layer manages all the IoT services and the system activities. This layer is responsible for the building of flowcharts, business models, and graphs. The business layer is also used to develop, evaluate, monitor, and implement internet of things system related elements. The layer does all this to support decision-making processes that are entirely based on big data analysis [16, 17]. Besides, this layer is responsible for the management and monitoring of the four layers. Equally importantly, this layer analyses each of the four layers with their expected outputs, which helps enhance service delivery and maintain user privacy. It is important to note that the three layer model architecture does not comply with the real IoT environments because the network layer in this model does not have technologies to transfer data on an IoT platform. The three-layer model is designed specifically for certain communication media like WSNs. In the five layer model architecture, the application layer provides an interface where all end-users interact with devices and request data. The model also offers a critical interface for the business layer where reports and high-level analysis is done. The mechanisms of accessing data from the application layer are handled in this layer. This means the fiver layer model is robust for IoT applications because of its complex and computational capacity.

2.2 Integrated technologies and Approaches

2.2.1 Wireless Sensor Network

Wireless sensor network (WSN) can be defined as a network of spatially spread and assigned wireless sensor nodes used for monitoring systems, recording, and monitoring physical environmental conditions [19]. The dedicated sensors are responsible for organizing the collected data and sending it to a central server. The WSNs are always deployed in a large scale and cover a large surface are in an ad-hoc manner. The wireless sensor networks have sensor nodes with embedded onboard processors that monitor a particular area's physical conditions. The sensor nodes then transmit the data to the base station, a central processing unit in a Wireless Sensor Network System. The architecture of a wireless sensor network is composed of four major components [19]:

I. Sensor nodes mainly capture physical environmental variables and then convert them to electrical signals.
II. Radio nodes receive the sensor nodes' data and send it to the Wide Large Area Network (WLAN). The radio nodes consist of a power supply source, transceiver, memory, and a microcontroller.
III. WLAN Access Point receives data that is sent wirelessly by the radio nodes via the internet.
IV. Evaluation software is used for data processing.

2.2.2 ZigBee Technology

ZigBee is an open standard based on IEEE 802.15.4 specification [20]. The technology supports mesh, star, and static network topologies. ZigBee has very low power consumption, it supports over 65,00 nodes, its operating frequency is between 850-930MHz, the operating frequency range is up to 200 Metres, the technology has security of 128-bit Advanced Encryption Standard, its data rates are 250 Kbps, the life span of the battery is more than one year and it has a low latency [21].

2.2.3 Radio Frequency Identification

RFID has been in existence since the beginning of the 21st century and was widely used during World War II [22]. The technology uses radio waves for data transmission and communication between the reader system and object that has an attached or embedded RFID tag.

2.2.4 Global System for Mobile Communication

According to [21], GSM is a standard for cellular digital communications developed by European Telecommunications Standards Institute (ETSI), the standard is used globally. GSM uses a variety of Time Division Multiple Access (TDMA) and it is widely used in these three; TDMA, CDMA and GSM which are the popular technologies in digital wireless telephony. GSM digitizes data and subsequently compress the data before it sends it down on a channel that has two streams of user data, each belonging to its time frequency. GSM operates on the frequency band of 900MHz and 1800MHz. GSM coupled with other technologies have revolutionized wireless mobile telecommunications that is General Packet Radio Service (GPRS), High-Speed Circuit Switched Data (HSCSD) and Enhanced data

GSM Environment (EDGE). To overcome the limits of data service GPRS is introduced because it can operate in packet switching techniques

2.2.5 Geographic Information System

GIS technology helps in the integration of software and hardware, it provides a platform for gathering data, managing the data and analyzing the data. GIS technology also integrates many data types, it allows one to visualize, understand, interpret and question the data in different ways that show patterns, relationships and trends in the form of charts, globes, maps and reports [21]. The GIS technology is also used in location identification.

2.2.6 Other Network Technologies used in IoT

Network	**Connectivity**	**Pros and Cons**	**Application**
Ethernet	Wired, Short-range	✓ High speed ✓ Security • Range limited to wire length • Limited mobility	Stationary IoT: video cameras, game consoles, fixed equipment
Wi-Fi	Wireless, Short-range	✓ High speed ✓ Great compatibility • Limited range • High power consumption	Smart home, devices that can be easily recharged
NFC (Near Field Communication)	Wireless, Ultra-short-range	✓ Reliability ✓ Low power consumption • Limited range • Lack of availability	Payment systems, smart homes
Bluetooth Low Energy	Wireless, short range	✓ High speed ✓ Low power consumption • Limited range • Low bandwidth	Smart home devices, wearables, beacons
LPWAN	Wireless, long-range	✓ Long range ✓ Low power consumption • Low bandwidth • High latency	Smart home, Smart city, Smart agriculture (field monitoring)
ZigBee	Wireless, Short-range	✓ Low power consumption ✓ Scalability • Limited range • Compliance issues	Home automation, health-care and industrial sites
Cellular networks	Wireless, long-range	✓ Nearly global coverage ✓ High speed ✓ Reliability • High cost • High power consumption	Drones sending videos and images

Table 2. Network Technologies used in IoT

2.3 Related Work

2.3.1 Smart Waste Management System

The smart waste management system plays a significant role in reducing garbage and waste in a particular area. Many technologies have initially been developed to help monitor and collect trash. Smart waste management system based on IoT technology is used in managing and collecting waste in a particular area. In this system, all garbage bins are fitted with an embedded device that monitors the level of garbage deposited. The data collected based on the levels of waste in each garbage bin is used to optimize the collecting vans' routes. The architecture of SWMS based on IoT has a master-slave type of configuration for all the garbage bins. The master-slave configuration helps to solve the problem of connectivity in remote areas. The slave garbage bins communicate with the master garbage bins [23]. Every master garbage bin has a microcontroller and three sensors: A level sensor, a load sensor, and a humidity sensor. The humidity sensor will determine whether the waste is dry or wet. Raspberry-pi 3 with an inbuilt Wi-Fi module is the microcontroller used for this system. The information from master garbage bins is continuously streamed to the cloud by use of the Wi-Fi module.

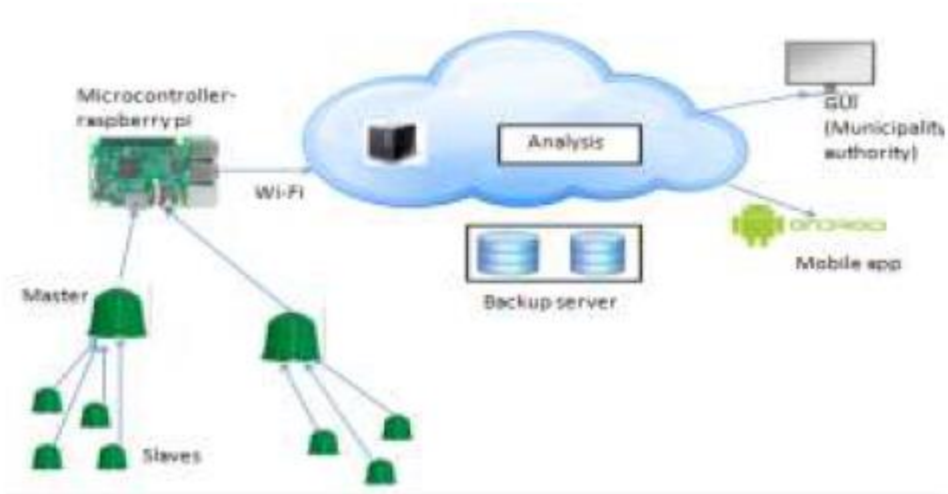


Figure 2.3. Architecture of SWMS

2.3.2 Garbage Monitoring System Using IoT

One of the significant challenges facing developing countries' cities is waste management and control due to rapid population growth [1, 5, and 7]. Waste management and control is important in the development of smart cities. Overflowing waste in garbage bins is a common problem for major cities in developing countries. This problem can result in outbreaks of diseases such as cholera and typhoid, which pose a health hazard to the city's residents. The GMS system based on IoT has been proposed to overcome this crisis in the cities. The system has garbage bins placed strategically across the city. The garbage bins transmit real-time data to the municipal authorities, who are in charge of garbage collection. The block diagram of GMS system based on IoT is shown in the figure below.

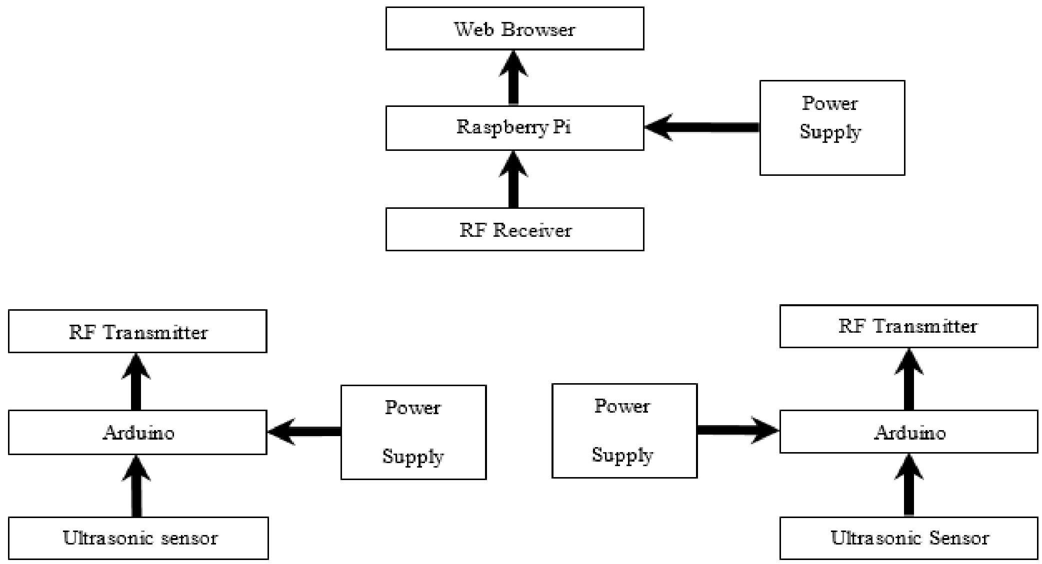


Figure 2.4. Architecture of Garbage Monitoring System using IoT

Every garbage bin has a transmitter installed in it, and the transmitter transmits the collected data from the respective sensors to the receiver end. In the receiver end, a centralized system receives all the data from the garbage bins and process the data according to each garbage bin's levels. The system uses a combination of RF receiver, Raspberry Pi, and the web browser to meet the needs [24]. The GMS has its limits like the other existing systems like, a lack of reliable communication between the different modules.

2.3.3 IoT-Based Smart Waste Management

Waste management is an essential service provided by smart cities through the incorporation of the Internet of Things. Over the years, there has been significant growth in the urban population due to rural-urban migration. The above system provides an enhanced mechanism in waste management and control in cities. The IoT based Smart Waste Management system consists of four modules; smart garbage bins, management centers, waste areas, and the collecting trucks. The enhanced statistical analysis leads to accurate decision making based on the data provided by the modules mentioned [25]. This system can overcome challenges faced such as cleaning costs, optimizing the routes to be used by collecting trucks, and many issues related to waste management and control.

Figure 2.5. The architecture of IoT based Smart Waste management

2.3.4 Smart Waste Management based on K-Query scheduling

Advancement in technology has increased unwanted products and waste from the industries. This system has three modules; Global Positing System Module, Micro-controller module, and the Ultrasonic sensor. These three modules are installed in garbage bins, and the ultrasonic sensor monitors the garbage levels in every container. When the ultrasonic sensor detects levels past a certain threshold, it updates the cloud server's information through Wi-Fi. This information also contains location coordinates as captured by the GPS module. K-Query scheduling plays a significant role in storing the threshold values in an entry table created in the database (MySQL). K-Query is vital because it helps to reduce the number of unknown entries made to the MySQL database [26]. For a relatively shorter path, a code containing the location point and the map is executed only once. This means that it is not essential to execute a code for every event. The system has reduced the labor required in the collection of waste from different locations manually. However, the system faces challenges during power surges and interruptions.

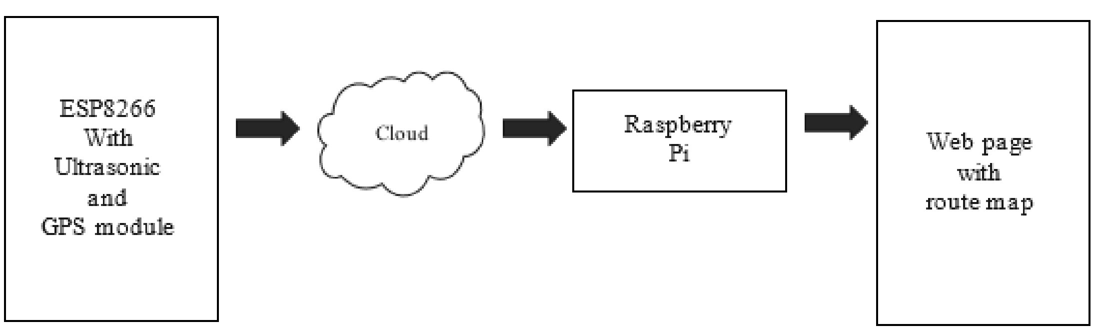


Figure 2.6. The architecture of SWM by K-Query Scheduling

2.3.5 Smart Waste Collection as a Service

The above system is an IoT-based SWC system used to monitor garbage bins in smart cities. Besides, the system is used for the dynamic routing of the waste collectors. The system contains an embedded device used for real-time scheduling and monitoring routes for the garbage trucks [27]. A mobile app has been designed for truck drivers to monitor the incoming data from the garbage bins before transmitting the data to the cloud. In this system, only two garbage bins are deployed in one place, and there is segregation of waste to either dry or wet. The system is effective in decision making because it uses the Google Map API and GPS module to find the optimal route for the garbage bins.

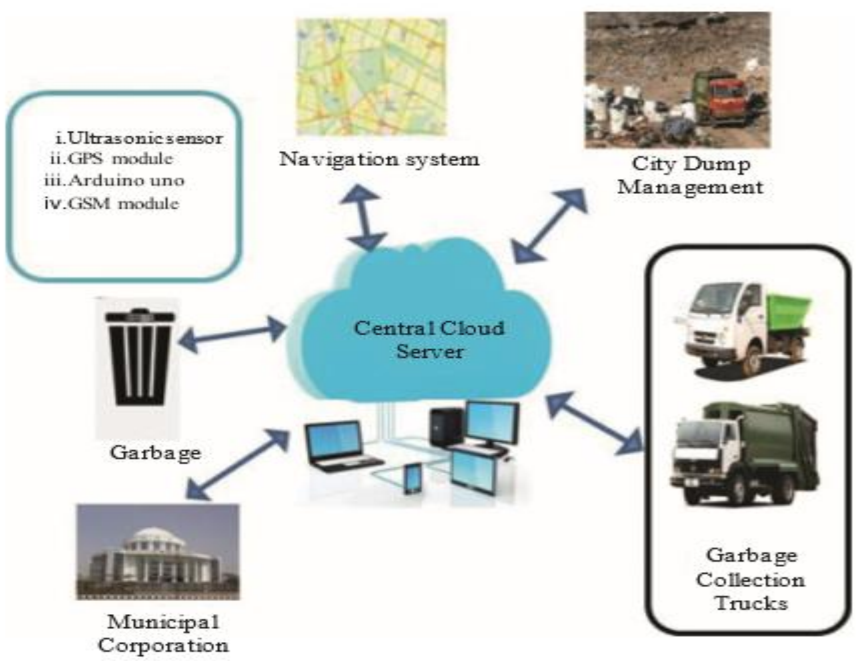


Figure 2.7. The architecture of SWC as a service

2.3.6 Smart City Garbage Collection Management system

This system is essential in the waste collection in smart cities based on IoT technology. The system works in two phases. In the first phase, garbage bins are strategically placed in various locations and then randomly filled. The second phase, the optimized route for collecting the garbage bins, is based on the garbage bin filling ratio. The threshold for each garbage bin is 10 centimeters. In system, genetic algorithms help in the gathering of the waste within a locality. The smart bins in this system are built on a Raspberry pi Uno board, which is interfaced with weight sensors to calculate weight, an ultrasonic sensor for detecting the waste levels, and a GSM modem [28]. The weight sensors are placed at the bottom of the garbage bins, and the ultrasonic sensor is placed on top of the garbage bins to read each bin's level status. The Raspberry is programmed so that when a specific garbage bin is filled up, the other remaining height from the threshold is displayed.

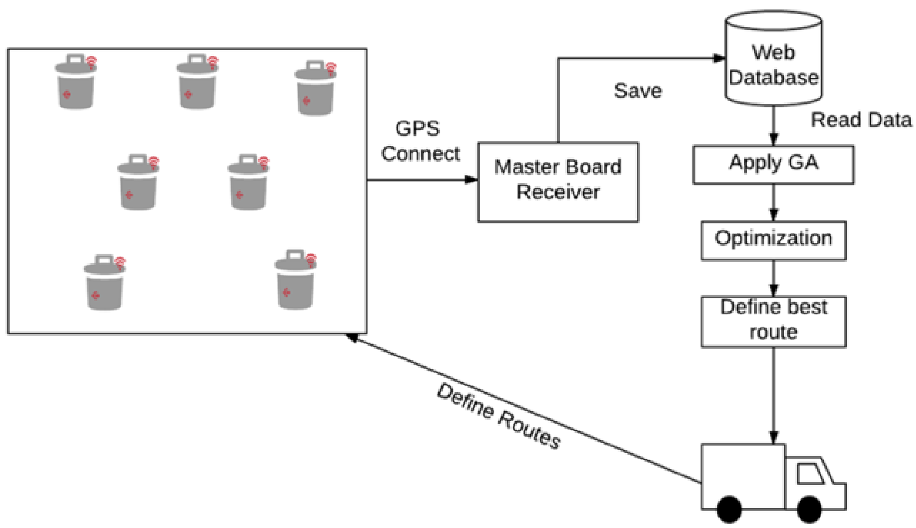


Figure 2.8. The architecture of the SCGCMS system

2.3.7 Machine Learning based Waste Management System

Waste collection, management, and control have been a severe challenge faced by many smart cities globally. In today's world, rapid and advanced growth in the internet of things technology has caused changes in human beings' lifestyle. One of the issues faced by cities in this era is waste management system. The system is designed for a college setup that is based on an IoT environment of Machine Learning. The system uses graph theory and machine learning to optimize waste collection by using the shortest route possible. The graph theory is used to predicting the probability of garbage in the garbage bins. The system is used for real-time monitoring by integrating multichoices: LoRa Spread spectrum technology and ultrasound distance [29]. Two sources supply power to each node, either solar or batteries.

The system proposed here is better than the existing systems in terms of flexibility and optimal route finding.

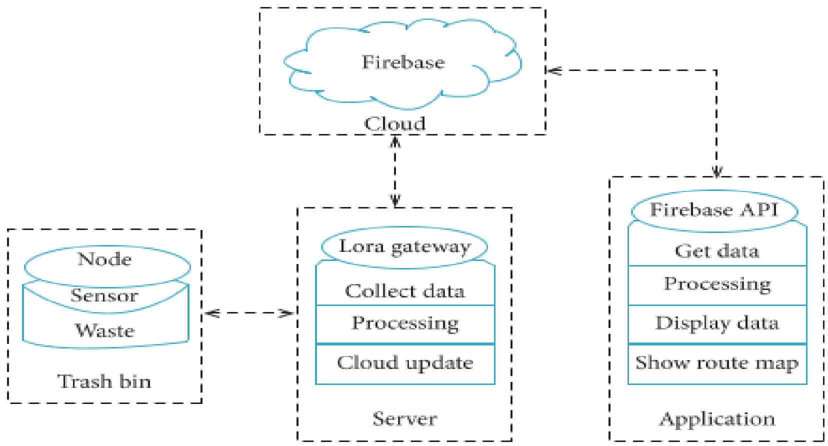


Figure 2.9. An illustration of the overall smart waste collection system

Existing system	Contribution	Limitation
Smart Waste Management System	Path/ route optimization	Sensor failure can result in system failure
Global Monitoring system	Fast transmitting mechanism for waste collection	Lack of reliable communication
IoT based Smart Waste Management	Statistical analysis provision	The four modules can be affected by lazy transportation
Smart Waste Management by K-Query Scheduling	K-Query scheduling used for database management	False monitoring
Smart Waste Collection as a Service	Mobile app for truck drivers	Bandwidth constraints for the cloud can affect the performance of the system
Smart City Garbage Collection Management System	Uses mainly genetic algorithms in waste collection	The complexity of the system results in scalability issues
Machine learning Based Waste Management System	i. Optimal path selection using graph theory and Machine learning. ii. Flexibility	Solar power supply interruption due to weather and battery failure

Table 3. Showing limitations and advantages of the existing systems

CHAPTER 3

METHODOLOGY

METHODOLOGY

3.1 System Design

SGBM has three modules. The SGB, garbage collecting vehicle (GCV) and a centralized database (CDB)

The SGB is an intelligent node, as stated earlier. The SGB is used in the storage of waste from all public and private places within the city. The SGB provides the following critical information to the centralized database that is the smart garbage bin level (SGBL) which are pegged on percentage, the smart garbage bin colour (SGBC) with green colour at = < 50%, yellow colour =<75% and when > 75% it turns to red.

The GCV is deployed to help transport SGB across the smart cities following optimal paths. It is from the database where the GCV receives information about the SGB that have exceeded the threshold of 75%, which means they are ready to be offloaded. After offloading the SGB, then GCV takes them to the dumping site for recycling.

The centralized data-base doubles as the information centre. The following information can be accessed from the CDB. All the details of SGB like levels, colour, weight, and SGB identification.

3.2 Conceptual Design

The conceptual design provides an overview of the proposed system architecture and the general architecture implementation. Figure 3.1 the general architecture reveals the three main actors who are the driver to the GCV, the city resident and the system administrator. The city resident has to buy the SGB from the waste management company contracted by the city municipality and registers it. The company then deploys the SGB to the destination specified. The city resident can also access any information and pay electronically to the waste collection company through the web. The covers of the SGBs are embedded with IC (Integrated Circuit) boards which provide real-time and continuous monitoring of waste levels in the SGB. Together with GSM/GPRS, Arduino Wi-Fi is used as a gateway to transmit solid waste data into CDB. The system administrator manages city resident's registration and updates the payment information, also allocates optimal routes that the drivers of GCV will take.

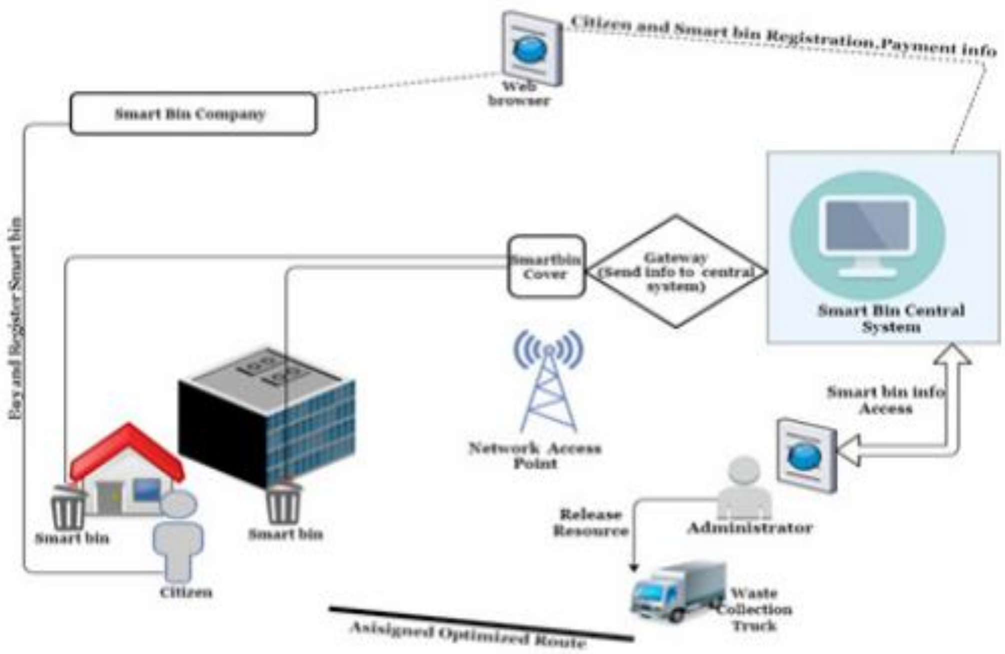


Figure 3.1.The General Architecture of SGBM

Figure 3.2 below shows the system's central architecture, which is made up of a three-tier system lower, middle and upper. In the lower tier, we find sensor nodes such as Arduino Mega 2560 Ultrasonic sensor, Ultrasonic sensors (HC-SR04), and weight sensors (SEN-10245SEN-10245). The gateway is located in the middle tier, and the upper tier contains the CDB, which is allied to optimizing the system. The CDB receives continuous updates from the SGB and stores the solid waste status through different gateways after establishing a stable connection with the server. Data stored is then analyzed, and optimal paths to be used by GCV is established through the linked optimization model. The GUI (graphic user interface) is provided with restrictions to both the city residents and the system administrator based on their respective roles.

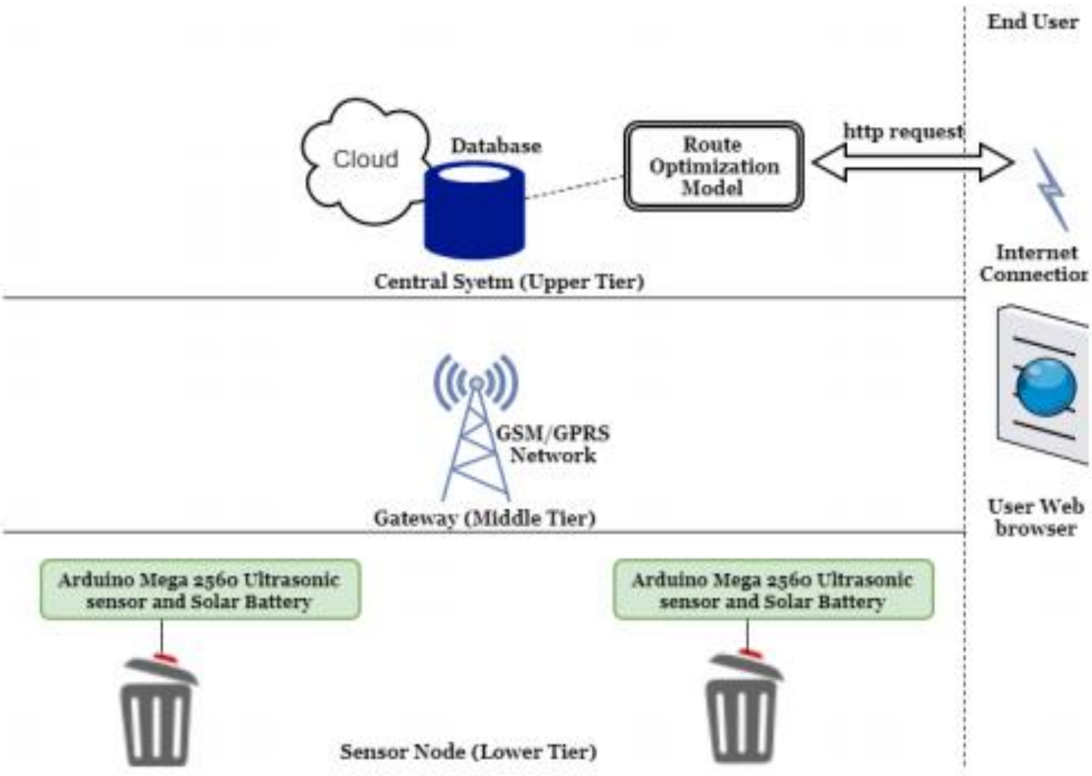
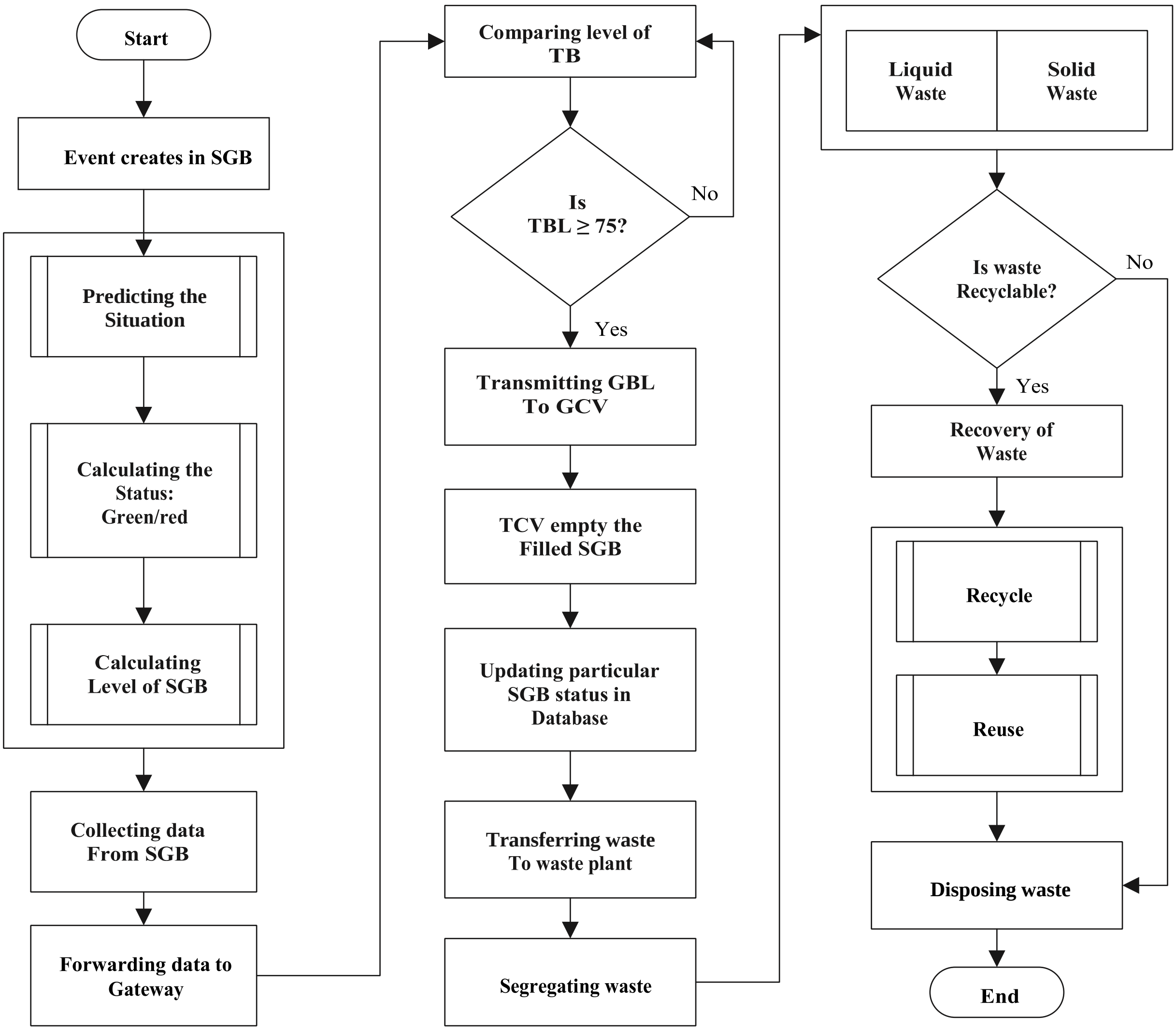
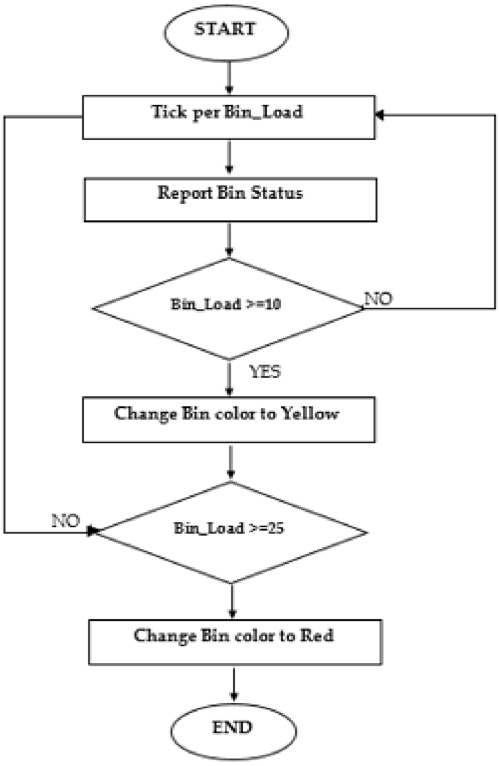


Figure 3.2. Smart garbage bin mechanism and the central system architecture

3.3 Functional flow chart diagram of SGBM



3.4 Decision Logic



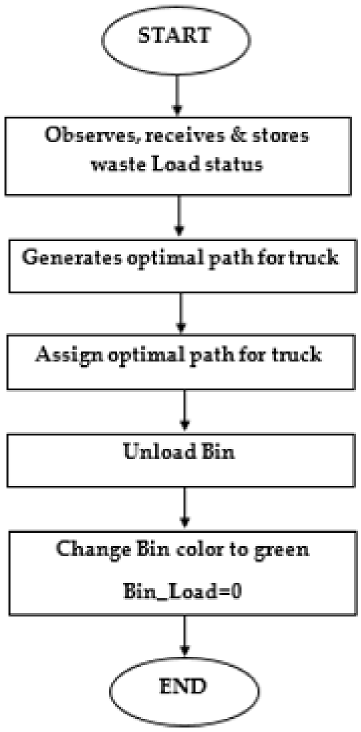


Figure 3.3 Flow chart smart garbage bin decision logic Figure 3.4 Flow chart for waste collection optimization

3.5 Smart Garbage Bin Mechanism using Fuzzy Expert System.

For many years now, Fuzzy logic has played a fundamental role in decision making for real-time world situations. Fuzzy logic was introduced in 1965 by Lofti Zadeh, a mathematician at the University of California [30]. That year, he published his work on Fuzzy sets, which laid a foundation for today's fuzzy logic and fuzzy set theory. Lofti observed that computer logics were not sufficient in manipulating data that had vague and subjective ideas. So he came up with Fuzzy logic that allowed conventional computers to determine the distinct nature of data with shades of grey similar to human reasoning [36]. The fuzzy logic is of significance because it helps in dealing with uncertainties and vagueness in monitoring the physical environment in real-time [30].

3.5.1 The Architecture of Fuzzy Expert System

The fuzzy expert system has three fundamental modules; Fuzzifier, Defuzzifier and Fuzzy Inference Engine/Inference Rules [33]. The Fuzzifier performs Fuzzification, which is converting crisp input/Real variables into linguistic variables. The Defuzzifier performs defuzzification, which reconverts the fuzzy output into crisp value or human-readable form to achieve numerical values [32]. The inference rules apply the appropriate if-then rules, conditional statements used to validate the state of a particular variable [34]. The fuzzy expert system is shown in figure 3.5.

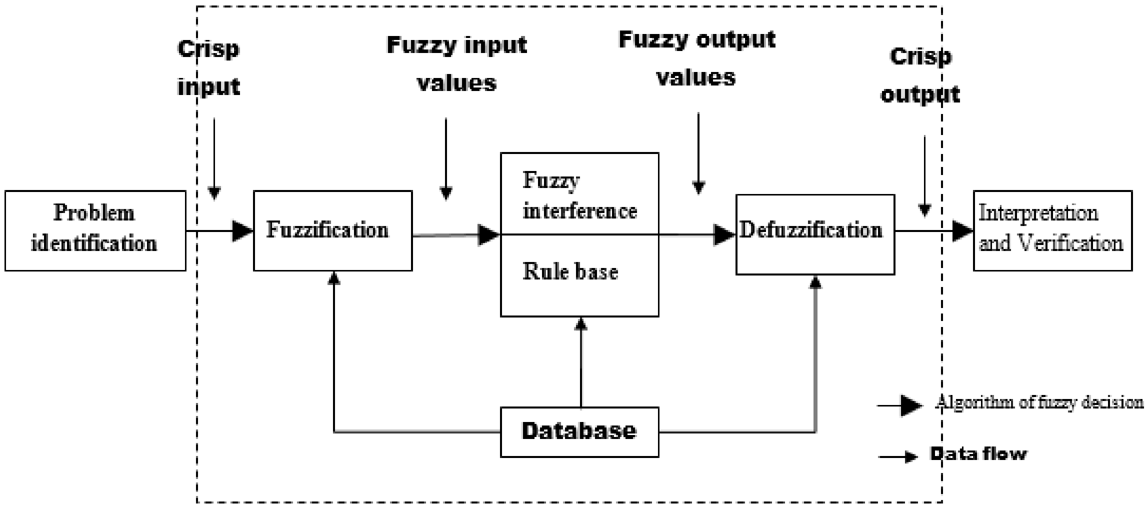


Figure 3.5. Fuzzy Expert System (The dotted Region)

In this research paper, fuzzy logic will be utilized in making decisions that will enable the smart garbage bins to be deployed strategically across the city. Fuzzy logic enhances an efficient way of reading SGB in real-time and monitoring the external environment by using different linguistic variable [30 & 35]. The linguistic variables have various categories and only have three levels of reading.

SGB Level Ratings	**Category**	**SGB Colour Ratings**	**Category**	**SGB Weight Ratings**	**Category**	**SGB Status Ratings**	**Category**
0.1 to 0.5	Low	0 to 0.2	Red	0 to 10	Light	0-33%	Bad
o.5 to 1.0	Medium	0.2 to 0.4	Yellow	10 to 25	Medium	34-66%	Average
1.0 to 1.5	High	0.4 to 1.0	Green	> 25	Heavy	67-100%	Good

Table 4. Showing the corresponding level ratings, colour ratings and status ratings of SGB

Fuzzy Expert System helps make decisions in these scenarios while making an appropriate selection of locations where the SGB will be installed. In this case, only two attributes are used to select suitable places to install garbage bins: distance from the collection points and the level of accessing GCV. Considering these two attributes, the proposed system makes decisive decisions, as illustrated by the table 5 below.

Criteria	Location A	Location B	Location C
The distance from the collection points	Small	Medium	Large
Level of accessing GCV	Medium	Difficult	Large

Table 5. Showing the values of the inputs used for the selection of location for the SGB

The above parameters are essential when selecting the best location to deploy SGB for the city residents. The proposed system is more efficient in providing cleaning services to the metropolitan/municipal authorities and monitoring waste deposited to the SGB in real-time. In the event of decision-making, the fuzzy sets discussed in this chapter are fundamental for the generation of fuzzy rules (such as the if-then rule). The (if then) rules are integrated to produce the required output value [31]. Finally, the (if then) rules are integrated to produce the required output, as illustrated in figure 3.6. From the figure, only two input variables are selected to determine a strategic and suitable place for the deployment of SGB. By applying inference rule, only one output is generated.

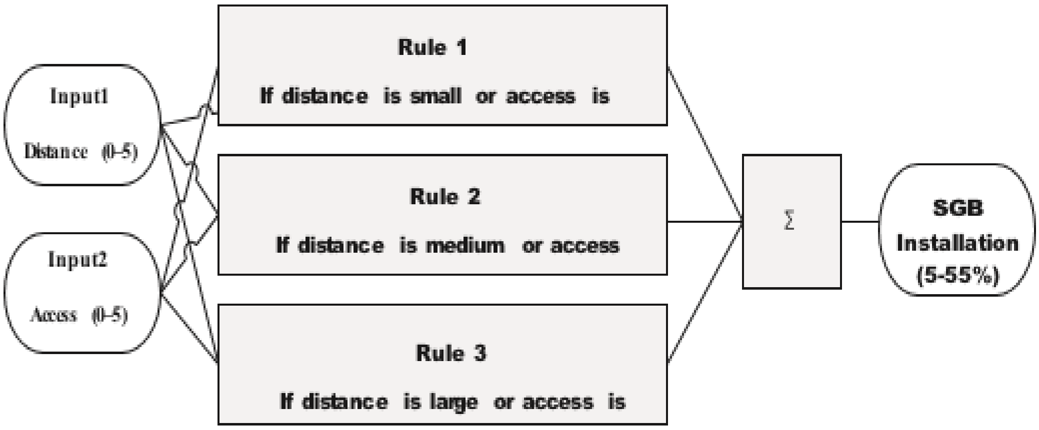


Figure 3.6. The if-then rule that is used for the deployment of SGB

CHAPTER 4

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

4.1 The Simulation Setup

4.1.1 Smart Garbage Bins (Agent Bins)

In this simulation, 25 SGB are distributed randomly across the city using the fuzzy expert System's decision. At the initial stage, the SGB are green since the level of the agent bin[bin_load = 0]. The agent bin levels are increased per tick as soon as the simulation time kicks off [bin_load = bin_load + 1]. When the SGB level [bin_load >= 10], its colour automatically changes to yellow this is considered the first alert. When the SGB level [bin_load >= 25], its colour automatically changes to red. It is assumed the agent bin has reached the threshold and it has achieved the maximum capacity. The levels of the agent bins are continuously reported and are transmitted for analysis. The simulation monitor provides the total number of agent bins that are distributed randomly. Each time the number of full agent bins is reported, the number of the full agent bins should decrease automatically each time a truck is assigned to their path for collection, or else a delay in collation will be observed as shown in figure 4.5

4.1.2 Garbage Collecting Vehicles (Agent trucks)

The agent truck follows an optimal route for waste collection once the following conditions have been fulfilled [bin_load >= 25] and the colour of the agent bin has turned red. The maximum capacity for the agent truck for simulation is [Truck_load >= 100] waste units. Once the collected agent bins have been unloaded, they automatically change the colour to green, and their level becomes zero. Also, when [Truck_load >= 100] has been emptied, the truckload returns to zero.

4.1.3 Agent Citizen

Agent citizen is another agent defined in the model. The movement of citizens across the city portrays the activities undertaken that result in the production of waste. In the simulation system, the citizen is involved in the payment of the cost involved in collecting waste.

4.2 Route Optimization for Waste Collection

Route optimization is a fundamental parameter in waste collection for smart cities because it helps in reduction of operational costs such as fuel consumption costs. In this research project, the concept of route optimization is achieved by the use Dijkstra algorithm of our simulation software (NetLogo). This means for a set of vertices $Q[B, C, D, E \ldots . T]$ as shown in figure 4.1 the Dijkstra algorithm identifies the nodes that have to be visited for garbage collection. The shortest path (Optimized route) is established because the edges link the beginning and the end of the vertices.

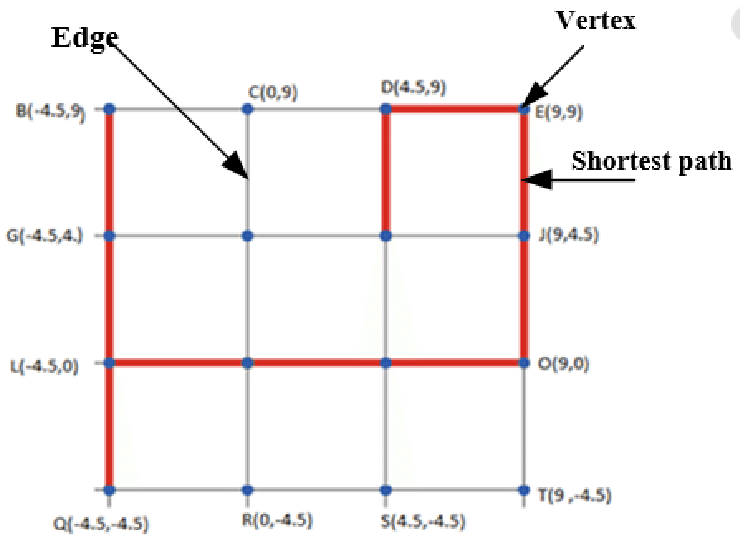


Figure 4.1 Set of edges and vertices connected by Dijkstra algorithm

4.3Discussion

The system was implemented on a NetLogo platform, and this was done by running several simulations at different simulation times. At the initial stage, 25 agent bins were randomly deployed across the city. The initial condition of the agent bin[bin_load = 0]. The NetLogo interface as shown in figure 4.1 shows the number of agent bins distributed across the city, the number of full agent bins, bin parameters, truck parameters, and the cost per waste unit that has to be paid by the citizens.

Figure 4.2. Initial set up before simulation at T_1=0

At simulation T_1 = 0 mins. The Go button icon runs the simulations, and the SGB levels are increased every 1 tick. The agent bins with [bin_load >= 10] has their color turning to yellow, showing that it is almost full. The SGB with [bin_load >= 25] has its color automatically turning to red, which means it is already full.

At simulation T_2 =53 mins .Out of the 25 distributed SGB, 8 SGB were already full SGB are {1,5,6,10,18,19,20,24} as shown in the figure 4.2. It also shows the continuous and periodic recording of waste levels of each agent bin per tick.

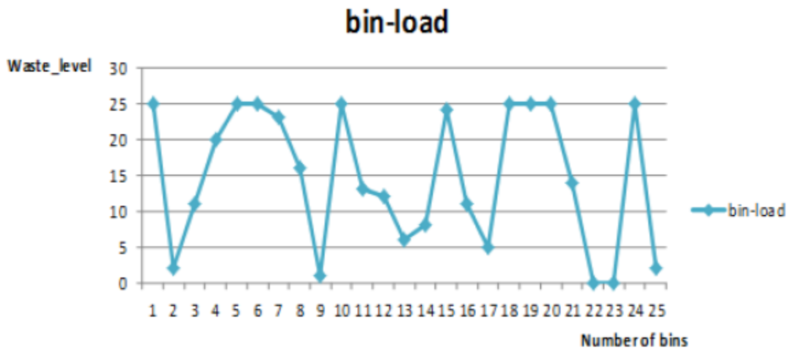


Figure 4.3. Smart Garbage bins showing different levels at T_3

The optimal route for the collection of waste by the agent trucks is as shown in figure 4.3. The figure shows changes in colour for different agent bins according to the amount of garbage in them. The figure also indicates optimal paths used to access agent bins that have exceeded the threshold (agent bins that have turned the colour to red).

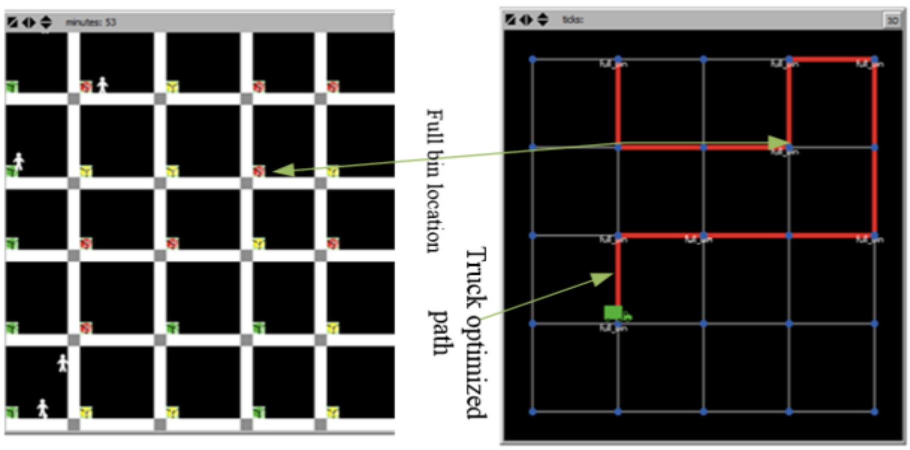


Figure 4.4. Showing colour changes of agent bins and optimal paths used by agent trucks for garbage collection.

At simulation time T_3= 93 mins .The periodic recording of different waste levels for each agent bin per tick is shown in the figure 4.4. The number of uncollected agent bins increased to 12 at T_3.

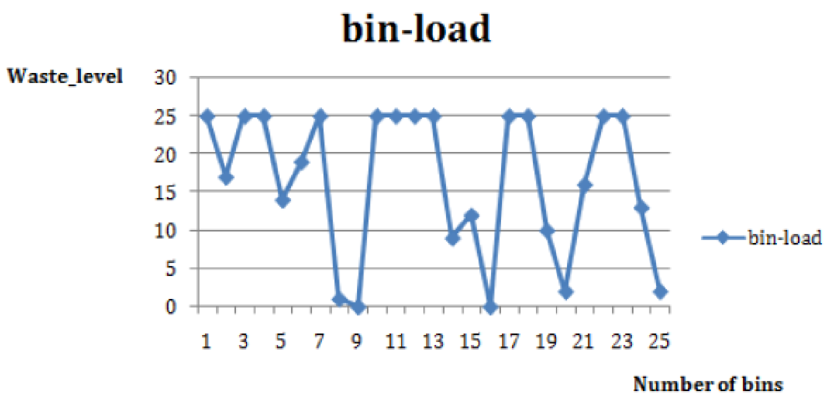


Figure 4.5. Agent bins with different levels of waste at T_3=93 mins

In the simulation time (T_2) 8 agent bins were full, but 4 other agent bins had a delay. Identification of the position of vertices for the different 4 full agent bins that had delays during the collection time of T_2 is shown in figure 4.5below.

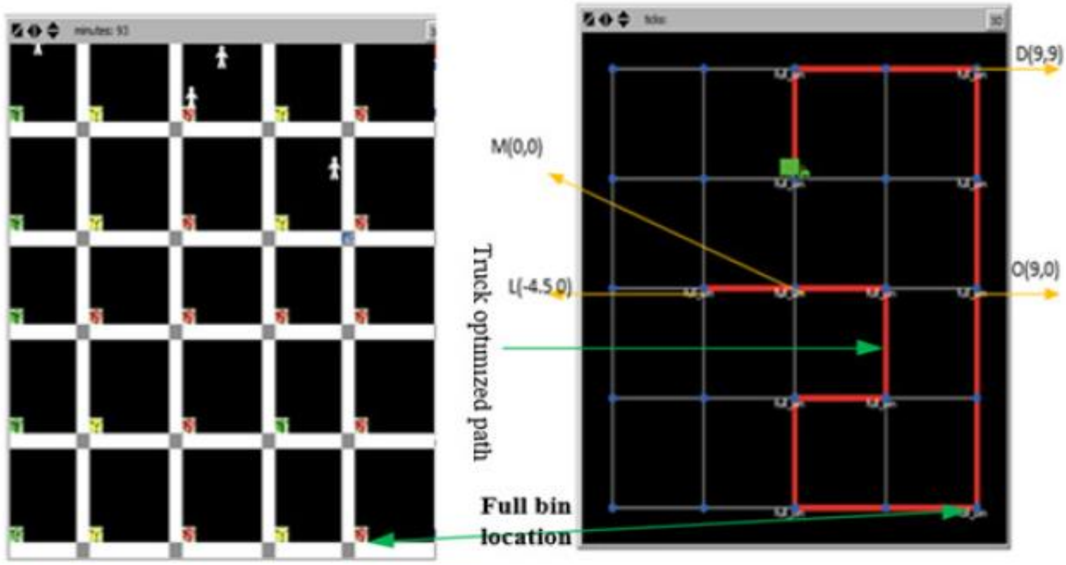


Figure 4.6. Identification of vertices for agent bins that had delay during T_2 and finding their optimal paths

CHAPTER 5

CONCLUSION AND FUTURE WORK

CONCLUSION AND FUTURE WORK

The following are the significant contributions for this research project; the system will reduce wages, save on fuel, and will optimize resources, the system will provide real-time monitoring for smart garbage bins deployed across the city, the system will use fuzzy logic processing in decision making; this will help to establish the exact locations to deploy the garbage bins finally the system is more efficient in providing cleaning services to metropolitan/municipal authorities and monitoring waste deposited to the smart garbage bin in real time.

In this research project, we have presented the real-time smart garbage bin mechanism for solid waste management in smart cities using IoT technology. Existing solid waste collection and management systems have several drawbacks: less accessibility to the actual data, late or delayed unloading of waste from the garbage bins, lack of throughput, and hindrance in embracing new techniques. Therefore, a more pragmatic and advanced approach must be designed and developed to overcome the existing systems' challenges. In general, waste monitoring and collection takes a significant amount of money from the municipal budget. The method proposed in this paper can access real-time data from the smart garbage bins; hence, it can appropriately implement the waste collection procedure. The proposed waste monitoring and collection mechanism is achieved by using both architectural and theoretical models. NetLogo software is used in simulation of the system. The software provides a real-time environment for simulation, and the experimental results show that the system is effective and responsive to the environment. The future work would consider using WSN in the real-time waste collection and management this will also involve integrating the GIS maps into the system for precise location identification of the nodes. Also the future work may consider developing a mathematical model for that will assist in route optimization.

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