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A smart city application: A waste collection system with long range wide area network for providing green environment and cost effective and low power consumption solutions

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Abstract

The trend towards cities and urbanisation, which increases the number of people living in urban areas, requires local authorities to provide services and natural resources more efficiently and effectively and develop some strategies for a sustainable environment. The more effective use of resources, growing awareness of sustainable environment, climate confidence and motivation to make cities more livable is a new concept called Smart City. In this study, the proposed system supports the garbage collection of the city government and works with low budget, low energy, and free radio frequencies. The Internet of Things (IoT) sensor node is assembled, and the network is set up based on the long range wide area network protocol to connect it to the sample garbage bin and collect data. Instant data collection by this network is carried out through the IoT and is designed based on the collected data. The goal is to build an ideal system for smart garbage collection in cities and support sustainability in cities by integrating with the city government's information systems. The data received from the sensor nodes and the efficiency of the system were demonstrated for local governments. The main outcome of this research is to develop a practical smart city application with minimal resources and support local governments in their daily work. Moreover, how a low power wide area network communication network with a frequency of 868 MHz works in Istanbul (Turkey) will be investigated further and which alternative to cellular networks is the most suitable for excellent communication in smart cities will be studied.

KEYWORDS

city management, Internet of Things, LoRa, LoRaWan, LPWAN, smart city, smart waste management

1 | INTRODUCTION

The main objective of this study is to investigate the benefits of building an Internet of Things (IoT)-based solid waste collection system. The IoT device will be based on the long range wide area network (LoRaWAN), which offers advantages in many ways. This study will create extensive networks thanks to the LoRaWAN technology, which is not yet used in Turkey. In this study, the problem is studied from different perspectives. These include environmental issues, the sustainability of cities, and the heavy dependence on fossil fuels for energy consumption in Turkey (Table 4).

Before going into the details of the study, the problems are classified into the area in which the study could be useful. For this purpose, attention has been focussed mainly on the growth rate of the population living in urban areas. The rapid population growth requires the use of IoT to meet the needs of the population. On the other hand, in the case of Turkey, its dependence on fossil fuels, which are currently preferred in the disposal of vehicles, as a country and its economic consequences are examined. Third, in support of the objective of the study, the increase of emission repairs over the years and its negative impact on the environment are mentioned. At this point, it is mentioned that the emissions can be reduced by using the IoT. Some of the issues such as effective management of natural resources, reducing environmental problems, supporting sustainable cities, cheaper solutions to urban problems and reducing energy dependency serve as a source of motivation. Looking at the details of routine garbage collection, it is clear that there is a fixed collection route and time. This is not up to the mark in today's world. Other issues are the low cost, emissions, fossil fuel requirement and manpower needed. Moreover, IoT-assisted garbage collection provides a service that protects public safety, public health, and environmental quality.

In this model, the frequency of labour-intensive activities is expected to be reduced. In addition, the proposed system generates an instant alert for the garbage bin load. A dynamic system that responds based on the data collected on site will be established. This will change the scheduled collection service, reduce the need for more manpower and drastically reduce the service cost. In this model, the system is equipped with LoRaWAN, which is a low power wide area network (LPWAN) protocol. Low power wide area network is more efficient than global system for mobile communications (GSM)-based solutions in many ways, such as deployment cost and licence. Based on the statistical expectation as shown in Figure 1, the number of LPWAN connections by the technology worldwide will increase dramatically from 2017 to 2023. This is another indicator that LPWAN technologies will gain traction.

In many IoT projects, regardless of the type of connectivity, power consumption is always the main issue. The power consumption of an IoT product is a primary indicator that shows whether it is suitable or not. The following Table 2 [2] shows that LoRaWan is 30 times more efficient in terms of idle power consumption.

This paper starts with an introduction and general explanations, then continues with a literature review, and then, in order to identify the problem, the status of greenhouse gas emissions in Turkey, environmental pollution, the population growth and frequency of fossil fuel use, and dependence on foreign countries for the supply of these fossil fuels are expressed in figures and the study aims to design a smart waste management system and make it available to the public sector. By providing information about the IoT and wireless technologies, the study flow goes through the hypothesis, research section and results. Notations within this study listed in the Table 1.

TABLE 1 Notations used for this study

MHz	Megahertz
TTN	The Things Network
LoRaWan	Long range wide area network
ISM	Industrial, scientific, and medical fields
LPWA	Low power wide area
IoT	Internet of things
CO_2	Carbon dioxide
NO_2	Nitrogen dioxide
CH_4	Methane
EU	European Union
ICT	Information and communications technology
ITU	International Telecommunication Union
GSM	The global system for mobile communications
M2M	Machine to machine
RFID	Radio frequency identification
UN	United Nations
ISO	The International Organisation for Standardisation
NB-IoT	Narrow band IoT
5G	The fifth generation of wireless communications
RF	Radio frequency
dBm	Decibel-milli watts
www	World Wide Web
dB	Decibel
V	Volt
Kbps	Kilo bit per second
PA	Power amplifier
mA	Milli ampere
RX	Receive
nA	Nano ampere
Hz	Hertz
FSK	Frequency shift keying
GFSK	Gaussian frequency shift keying
MSK	Minimum-shift keying
GMSK	Gaussian minimum-shift keying
OOK	On-off keying
LTE	Long-term evolution
3G	The third generation of wireless communications
4G	The fourth generation of wireless communications
LAN	Local area network
GUI	Graphical user interface
SSH	Secure shell
DC	Direct current
TTL	Time to live

2 | LITERATURE SURVEY

In Reference [3], the data was monitored only through LCD. It was not moved to a central structure. Therefore, it remains quite weak compared to our research. Only a small experimental environment was set up and no data was collected. There is no efficiency measurement and no field application. No observations have been made in the field with energy support.

In Reference [4], a different Arduino circuit was used to send the data, and the relay module rytlr896 was used instead

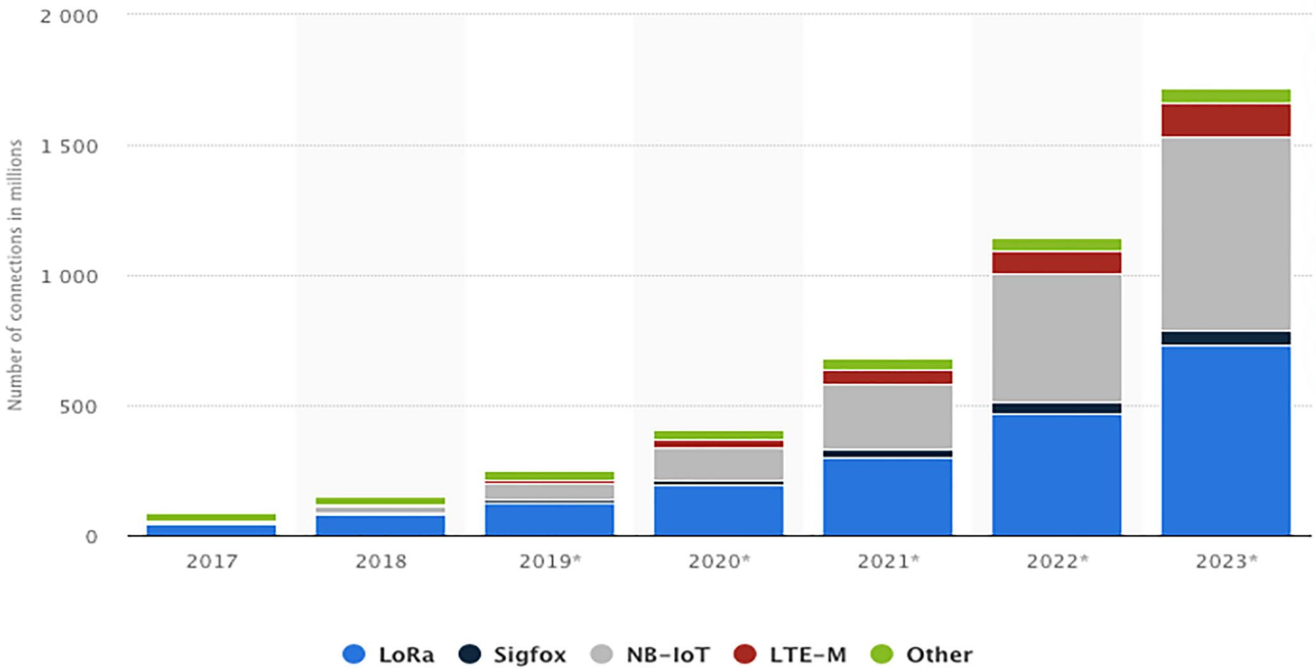


FIGURE 1 Low power wide area network connections by technology worldwide from 2017 to 2023 [1]. LoRa, long range; NB-IoT, narrow band Internet of Things; LTE, long-term evolution

of the sx1276 used in our research. A different gateway design was created instead of the LG01-P IoT that we use as a gateway. The study was designed to measure values such as gas, humidity, and temperature in homes and factories etc. This study, called a smart automation system, was never included in the IoT infrastructure. No field implementation has been introduced, and no smart waste management system has been introduced. In practice, there is no collaboration with public will. There is no solution to energy needs. A theoretical approach has been shown.

In Reference [5], unlike our research, a 433 MHz bandwidth was studied. No field research was conducted in collaboration with others, and it was accepted to provide theoretical information. On the other hand, sensor nodes are not used in an industrial format.

3 | ESSENTIAL PROBLEMS SHOULD BE ADDRESSED FOR TURKEY: SUSTAINABILITY, GREENHOUSE GAS EMISSION AND THE ENERGY DEPENDENCY RATE

Year after year people move to the cities to find better living conditions [6]. The United Nations projects that by 2050, 68% of the population will live in urban areas, which means that the population in urban areas will increase from 55% to 68%. The United Nations' expectation for 2050 also shows that 2.5 billion people will be added to the population in urban areas, and a significant part of this increase will be in Asia and Africa [7].

TABLE 2 Power consumption

	LoRaWAN	NB-IoT
TX current	24–44 mA	74–220 mA
RX current	12 mA	46 mA
Idle current	1.4 mA	6 mA
Sleep current	1.1 μA	3 μA

Abbreviations: LoRaWAN, long range wide area network; NB-IoT, narrow band Internet of Things.

It should also be considered that people can find jobs more easily in urban areas than in rural areas. In addition, many jobs require people to sit at a desk all day. In contrast, people in rural areas have to perform much more muscular activities at work. It is not just the greater supply of jobs that makes cities more attractive. People can access high-speed Internet, shopping malls, more public transportation, and food in cities [6]. These are the main factors that favour the increasing trend of living in cities and the growing population.

Turkey is facing environmental pressures due to population growth, industrialisation, and rapid urbanisation. Table 3 shows the number of people living in rural and urban areas by year. It is not difficult to see that both the population and the number of people living in urban areas have increased dramatically. Table 3 shows the number of people living in urban and rural areas in Turkey [8].

The number in the table shows that millions of people live in huge cities and it creates many chaotic problems. Air pollution, management of cities, and the use of natural resources are some of them. Table 4 [9] shows how much fossil

TABLE 3 Number of people living in urban and rural areas in Turkey [8]

Year	Total population	Urban population	Rural population	Urban population	Rural population
1927	13,648,270	3,305,879	10,342,391	24.2	75.8
2017	80,810,525	74,761,132	6,049,923	92.5	7.5

TABLE 4 Total number of petrol import by years in Turkey

Years	Metric	Total
2009	Ton	14,219,427
2019	Ton	25,820,442

energy Turkey has consumed last year. The numbers in the table illustrate some realities. As people moved from rural areas to cities and Turkey's development increased year by year, the energy demand also increased in recent years. This lead to economic and environmental problems. Table 4 shows the Turkish Statistical Institution's petrol import report [9].

Another energy resource is electricity, which is mainly generated by using fossil fuels, coal, and natural gas. In this case, more waste heat is generated, so power generation from fossil fuels is not efficient. Besides this efficiency problem, fossil fuels also release a lot more pollutants into the air, which causes health problems for people.

In today's world, it is widely accepted that economic and social development depends on protecting the environment and reducing the human impact. Urbanisation has brought some problems to people's lives and raised some new problems. An inventory of greenhouse gas emissions is available for Turkey since 1990. This inventory of greenhouse gas emissions is quite new when compared with that of other countries. The fossil energy demand has increased due to industrialisation and urbanisation. In 2016, greenhouse gas emission is 135.4% higher than in 1990. In 1990, there were about 210 million tons of greenhouse gas emissions, today there are almost 495 million tons. It is expected that the rate of greenhouse gas emissions in 1990 will increase dramatically to 467% and by 2030, the total emissions will reach up to 1175 million tons [10]. Figure 2 shows the greenhouse gas emission rate from 1990 to 2018.

CO_2 emissions are not the only major cause of air pollution. NO_2 emissions, CH_4 emissions, rice cultivation, natural gas and oil production are the other causes of the problem. Another pollution is plastic waste. According to some measurements and data, one person in the EU produces 10–40 kg of plastic waste per year, with an average of 31 kg per person. According to some studies, plastic waste has become a serious problem for the human food chain. Whether air pollution or plastic waste, sustainability needs to be increasingly considered and more technologies should be used to support a sustainable environment [12]. New technologies and the speed of network connectivity in information and communications technologies (ICTs) have created extraordinary opportunities for both people and businesses. They have become the most important factors for sustainable cities and urbanisation [13].

4 | SMART CITIES AND SUSTAINABILITY

Literally, sustainability means that we should meet our needs without irreversibly compromising the needs of future generations. Moreover, we should consider not only natural resources but also economic and social sustainability. There are some important components of sustainability. Three of them are listed and briefly explained below [14].

- Environmental sustainability: there must be a balance between natural resources and human needs. If humans consume and damage the environment, it is not a sustainable approach.
- Economic sustainability: economic sustainability is another important aspect of sustainability when it comes to living a secure life that meets the needs for both food and independence.
- Social sustainability: human rights are important for all people in the world. All people have the right to access resources without compromising economic prosperity or land.

The expectation in UN World Urbanization Prospects is regularly renewed, and an estimated 70% of the world's population will live in urban areas. The increasing population and effective resource management make smart city concept a must for cities [15]. An evolving solution to address this scenario is the convergence of information and communication technologies by implementing the concept of smart cities. The concept of smart cities is the breakthrough solution for a higher standard of living. To achieve this higher standard of living, the reach of information and communication technologies must be extended to every point of a city [16].

From a historical perspective, there are some different indicators of when the concept of smart city was first used. In the late 1990s, the main components of the smart city concept, the city and ICT, were discussed in the scientific literature. In 1997, more than 2000 cities had websites (www), and this is now considered as the first example of the smart city concept [17]. The concept of smart city has emerged from the development of ICT [18]. Some other best practices are milestones for the smart city concept, such as Amsterdam, Copenhagen, Seoul, and New York City [19].

Global Data Thematic Research published a study and listed the major milestones of the smart city concept [20]. According to the study, the first proof of the smart city concept was the Big Data project for Los Angeles in 1974.

The development of the smart city concept requires some other developments in areas such as ICT, IoT and sensor networks. When all these parts are connected, the ideal system

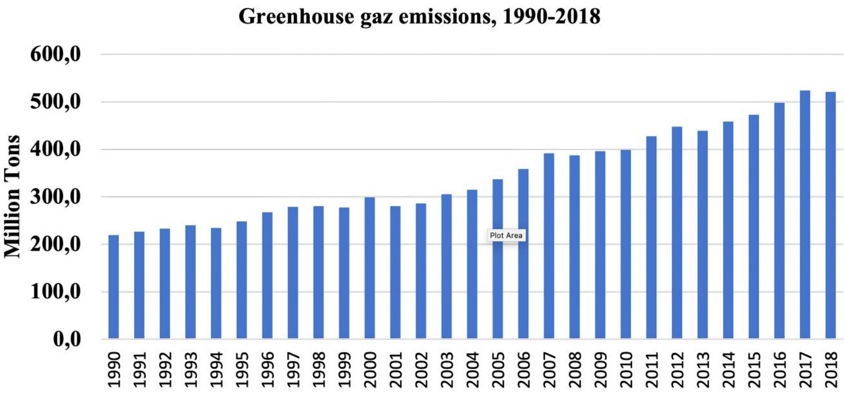


FIGURE 2 Greenhouse gas emission in Turkey [11]

would be at the service of people. This comprehensive system can be described as a cluster of hardware and software. This cluster works hard to understand the needs of people and respond in time. This cluster supports not only the people or residents of a city, but also the industry, the city administration, and the government. [21].

International Standardization Organization (ISO) has published a new standard in 2018 (ISO 37120:2018 Sustainable Cities and Communities–Indicators for Urban Services and Quality of Life). This guiding standard will guide future smart city projects and support the decision-making process. In short, the standard proposes that cities need indicators to measure their performance. The indicators and test methods mentioned in this standard are intended to support the city management in this process:

- Measure the performance of the city services and the quality of life.
- Compare measurements and create a value based on those measurements.
- Provide more data to help the decision makers make better decisions.

The indicators included in ISO37120 are listed in this standard [22].

5 | INTERNET OF THINGS

Kevin Ashton, a technology pioneer, first named the term IoT in 1999 and described a system where the devices (objects) in that system are connected via the Internet [23]. Sensors and devices (things) connected through the Internet mean the IoT. Internet of Things applications have been increasingly used in recent decades, such as home automation (smart home), industrial process control, Supervisory Control and Data Acquisition systems, waste management, and measurement devices [24]. There are two fundamental aspects of IoT. These include the remote connectivity itself and the benefits of digitised products and services for businesses. The IoT is an important topic, and the demand for it is increasing dramatically. Opportunities such as controlling devices offer a variety of solutions for people and businesses [25]. Today, people are living in times of the coronavirus pandemic and are looking for new devices to remotely touch infected patients and control the devices that support intensive care patients. This pandemic is teaching people, businesses, and governments to take an interest in medical technologies as well. IoT applications will improve the economy and the quality of life. The IoT will change the way people live and work.

The IoT has many applications and benefits for different fields. In healthcare, doctors can remotely monitor the patient's condition and take necessary actions. In the manufacturing industry, IoT applications increase productivity. The IoT enables accurate tracking of the product manufacturing chain. It is also easy to measure carbon emissions from a plant. This can help to take action to reduce these emissions when regulations are breached. [26]. In most applications, the IoT infrastructure is divided into a few stages. These tiers are briefly listed: Application Layer, Network Layer and Edge Layer. These three-layer infrastructures are an accepted model commonly found on the Edge Layer where data is collected through sensors and devices. The network layer is the communication part necessary to send data to the endpoint (edge layer). The application layer is the last part and provides services and many applications to the users [27]. In the next section, the 'network layer (for wireless communication)' of the IoT is studied and some technologies, such as Lora, are examined. In the following Figure 3, the high-level layers of the IoT infrastructure are shown.

6 | WIRELESS TRANSMISSION FOR IoT

Internet of Things systems require a transmission layer dedicated to wireless communication. Some alternative communication technologies are in stock for IoT systems. Some of them are LoRaWan, SigFox, narrow band-IoT, 5G, wi-fi, and ZigBee. One of them is LoRaWan which offers many features for low cost and long range communication. Most of the IoT projects are using LoRaWan in their network [24]. In this study, a solution based on LoRaWan is proposed.

LoRa Alliance is an open, non-profit association that has grown to more than 500 members since its inception in March

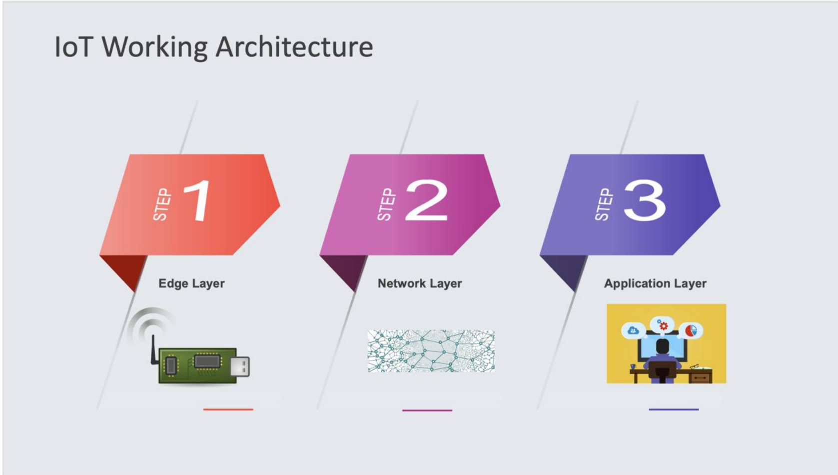


FIGURE 3 The high-level layers of the Internet of Things (IOT) infrastructure

2015, making it the most significant and fastest growing alliance in the technology sector. Its members work closely together and share experiences to promote and advance the success of the LoRaWAN protocol as the leading open global standard for secure carrier-grade IoT LPWAN connectivity. According to the LoRa Alliance definition, 'The LoRaWAN specification is a LPWA networking protocol designed to wirelessly connect battery-powered "things" to the Internet in regional, national, or global networks, and targets key IoT requirements such as bidirectional communications, end-to-end security, mobility, and localisation services' [28].

The long range and low power requirements make LPWA a preferred network communication method for IoT infrastructures. Low power wide area offers several advantages over other alternative network technologies. Low power wide area provides efficient signal propagation in indoor environments where the cellular system does not work properly. When the customised base indoor system is equipped with antennas and gateways, it provides more convenient communication than that of the cellular system. LPWA uses the MHz frequency band, for Europe 867–869 MHz, North America 902–928 MHz, China 470–510 MHz, Korea 920–925 MHz, Japan 920–925 MHz, and India 865–867 MHz. Low power wide area meets the requirements for long-distance communication applications. When the sensor nodes are attached to the garbage can, an urban LPWA is suitable. In such waste management applications, the data rate is not high, and the delay tolerance is acceptable, so LPWA is an ideal transmission method for this IoT system. The most important advantage of LPWAN is that it saves more energy and connects the endpoint sensor directly to the gateway through a star topology [29].

Low power; LPWA provides both mesh topology and star topology. When long range communication is planned for large areas, the mesh topology helps to extend the coverage of LPWA. Coverage of more than 10 km can be achieved using this method. A terminal device is expected to work for a long period of 10 years. Thanks to the star topology, the network stays alive without a dwindling battery. Each endpoint node is directly connected to the gateway, which brings higher efficiency in terms of energy consumption. Long Range Communication: LPWA's better signal propagation allows signals to reach indoor areas, so the range of the endpoint connection varies from a few kilometres to 10 km depending on the environment (buildings and plants block the signals and reduce the distance) Low cost: In most scenarios, LPWA uses unlicensed frequency bands. In Turkey, LPWA operates on 868 MHz in the industry, science, and medicine (ISM) band.

The frequency bands for ISM are radio frequency bands defined by ITU Radio Regulations. The ISM band refers to some spectra reserved for scientific, medical, and industrial requirements and not for communication. There is no spectrum cost, which makes LPWA more attractive [29]. Figure 4 shows the correspondence of different IoT protocols Open Systems Interconnection with the model.

7 | RESEARCH DESIGN AND METHODOLOGY

In the preceding sections, some information has been given and an attempt has been made to find an answer to the following questions,

- Why do people move from rural areas to urban areas?
- What makes urban areas more attractive?
- What is urbanisation and the consequences of urbanisation?
- What are the most important aspects for creating sustainable cities?
- What is the IoT and how does it work?
- What are the smart cities and sustainable smart cities?
- What are the alternatives for data transmission in smart cities?
- What are LPWANs and the advantages of LPWAN?

In addition, some topics, urbanisation, environmental issues such as pollution, the IoT, smart city and sustainable, and the LPWAN for IoT transmission will be explored.

In the light of the information from the previous sections, this section presents the research data and results. One of the

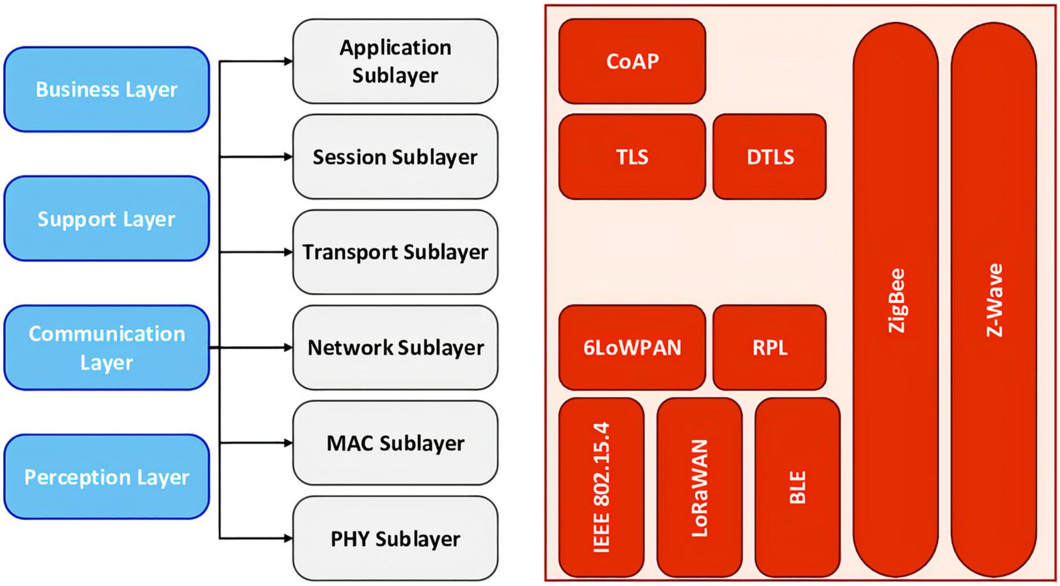


FIGURE 4 The correspondence of different Internet of Things protocols Open Systems Interconnection with the model [30]. LoRaWAN, long range wide area network. BLE, based on GATT; CoAP, Constrained Application Protocol; DTLS, Datagram Transport Layer Security; LoWPAN, The Low-Power Wireless Personal Area Networks; RPL, Routing Protocol for Low-Power and Lossy Networks; TLS, Transport Layer Security

most important issues facing local governments is effective solid waste management. At this point, the following issues are highlighted in this research;

- The traditional waste collection method is no longer suitable. It is unable to cope with the current problems due to the operating costs and environmental problems such as air pollution, waste disposal on the street and quality of service.
- Operating costs are expected to decrease dramatically due to the new approach that reduces the need for manpower and operating equipment (rails).
- No need for data subscriptions or licencing costs for the transmission of data.
- The population of Istanbul, the largest city in Turkey, is larger than that of 131 countries in the world, according to the United Nations Population Fund [31]. A survey applied to Istanbul will be an informative delivery for future applications and research.
- At the time of the on-site survey, there was no significant 868 MHz LoRaWan application in Istanbul or Turkey. The research results will show us that Lora devices can operate at 868 MHz in Turkey.
- Some computational metrics will be investigated to prove that reducing the amount of waste collection will result in less need for labour, fossil energy, and inputs, and avoid more carbon emissions.

The IoT infrastructure will be integrated with the current waste management service of the municipality to find solutions to the above problems for which conventional waste collection methods cannot find adequate and modern solutions. For field research, an official research permit was obtained from the Municipality of Beşiktaş. Beşiktaş has an exceptional historical heritage and is usually referred to as the city centre of Istanbul and is located on the European side of Istanbul. Besiktas is home to many commercial enterprises and residential buildings. Besiktas also serves as a hub for transportation in many directions in İstanbul [32] to conduct the research study. In addition, the Arnavutkoy municipality provided valuable support for some open area tests. In this research, the endpoint node is built by assembling the following hardware. General information about each hardware is provided by the manufacturer and briefly explained below.

7.1 | Components of IoT endpoint and infrastructure

- Semtech SX1276 (137–1020 MHz Long Range Low Power Transceiver): the SX1276/77/78/79 transceivers feature the LoRa® long range modem, which provides spread spectrum communication with an extremely long range and high noise immunity with minimal power consumption [33].
- LG01-P IoT gateway: the LG01-P is an open-source single channel LoRa gateway. It enables the connection of a wireless LoRa network to an IP network via Wi-Fi, Ethernet, or 3G/4G cellular via an optional LTE module. The LoRa wireless network allows users to send data and achieve extremely long ranges at low data rates. It provides spread spectrum communication with an extremely long range and high noise immunity [34].
- Arduino Uno: Arduino Uno is a microcontroller board based on ATmega328P used in various IoT projects [35].
- HC-SR04 Ultrasonic Ranging Module: The HC-SR04 ultrasonic distance measurement module is used in some IoT projects and is used for distance measurement. It can

measure distances from 2 to 400 cm with good accuracy. Both an ultrasonic receiver, and transmitter and control circuit are included in this module [36].

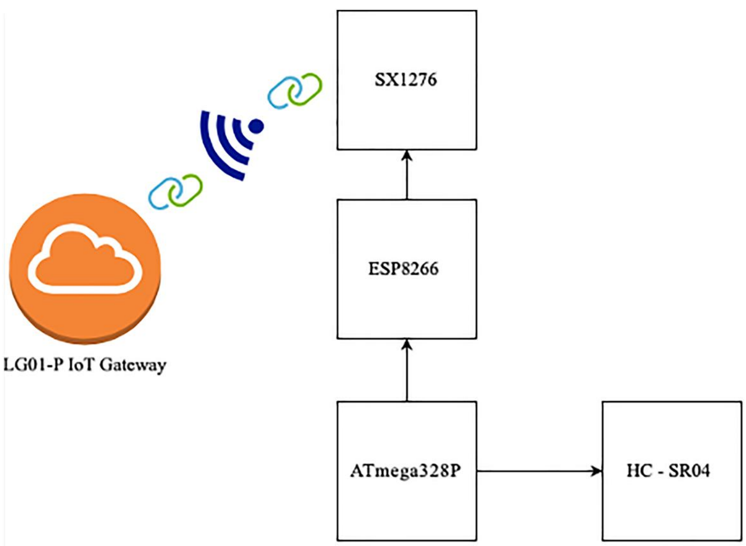
- ESP8266 Module Adapter: This module is required as an adapter for Semtech sx1276. The Sx1276 should be soldered to this module to work correctly with other peripherals.
- Other subsidiary equipment for node design: breadboard, antenna, USB cable, 9 V battery, battery connector, solid core jumper wires, jumper wires, plastic project box, solder, electric soldering iron, screwdriver (for assembly), screw (for assembly), hydraulic gas support shock absorber arm, hot silicone gun and stick (for box implementation).

The block diagram shown in Figure 5 represents the physical connections that link the components within the system.

7.2 | Software and programming

Arduino Uno Arduino software and a media access control address OSX version 1.8.9 are used for programming. The Arduino sketch uploaded to the Arduino is accessible via 'https://github.com/eaktay/LoraWan.git'. Details and essential points that should be considered for building a suitable node in this code are described in the next sections. In order to get this code working on the above hardware, a lot of testing was carried out. When the literature is examined, there was no similar design, so all circuits were tested for days and made in Turkey. The sample code was taken from the GitHub library [37], and it was configured as needed. In the following pictures, it is shown that all the parts are assembled in the final stage of the node and in the primary process of assembly. In Picture 1a, the whole development environment can be seen. Local development was successfully carried out thanks to these products. Picture 1b shows how the distance sensor is attached to the node box. The ultrasonic sensor, Lora module and Arduino board are connected as shown in Picture 1c. Connecting the Lora module to the Arduino board is not convenient without the auxiliary board shown in Picture 1d. The Lora module should be soldered to this auxiliary board in advance.

After all the necessary assembly operations are completed, all the parts of the node are installed into the box as shown in Picture 1e. After the assembly of the node was completed, it was connected to the trash can for testing. In this scenario, an



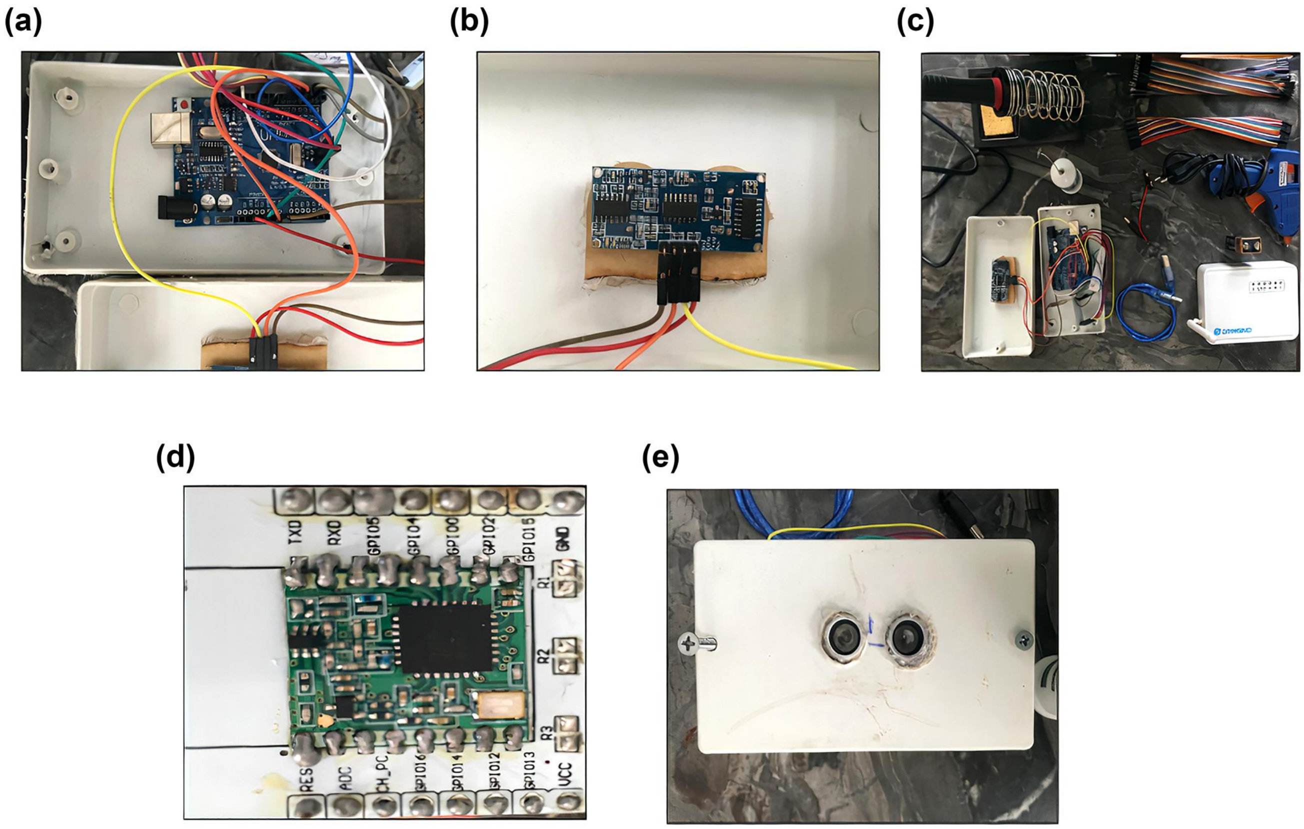
PIN CONNECTIOS

ATmega328P	HC - SR04
GND	GND
4	ECHO
6	TRIG
5V	VCC

ATmega328P	ESP8266
GND	GND
3	GPIO13
2	GPIO12
GND	TXD
5V	GPIO14
ICSP MIS02	GPIO15
ICSP MOSI2	GPIO2
ICSP SCK2	GPIO0
10	GPIO4
5	GPIO5

SX1276	ESP8266
ANT	REST
GND	ADC
DIO3	CH_PD
DIO4	GPIO16
3.3V	GPIO14
DIO0	GPIO12
DIO1	GPIO13
DIO2	VCC

FIGURE 5 Block diagram



PICTURE 1 (a) Test bed; (b) Mounting ultrasonic sensor; (c) Arduino cabling; (d) Proper pin map for Sx1276; (e) Sensor node

ordinary trash can on the street was used. It complied with the European Committee for Standardisation EN 840-2. Installation is shown in Picture 2a. The main purpose of this implementation is to keep the IoT node healthy during the opening and closing times of the flap. Another reason for this setup was to absorb the shock when closing the flap of the container. The flap weighs too much, which can accelerate the closing motion and destroy the node, as seen in Picture 2b, where the node is attached to the top of the flap.

The reason for this is to keep the node clean and increase accuracy. Picture 2c–e shows the whole stand-by container with the implementation of the node. The QR Code shown in Picture 2f has been added to provide more information on the web.

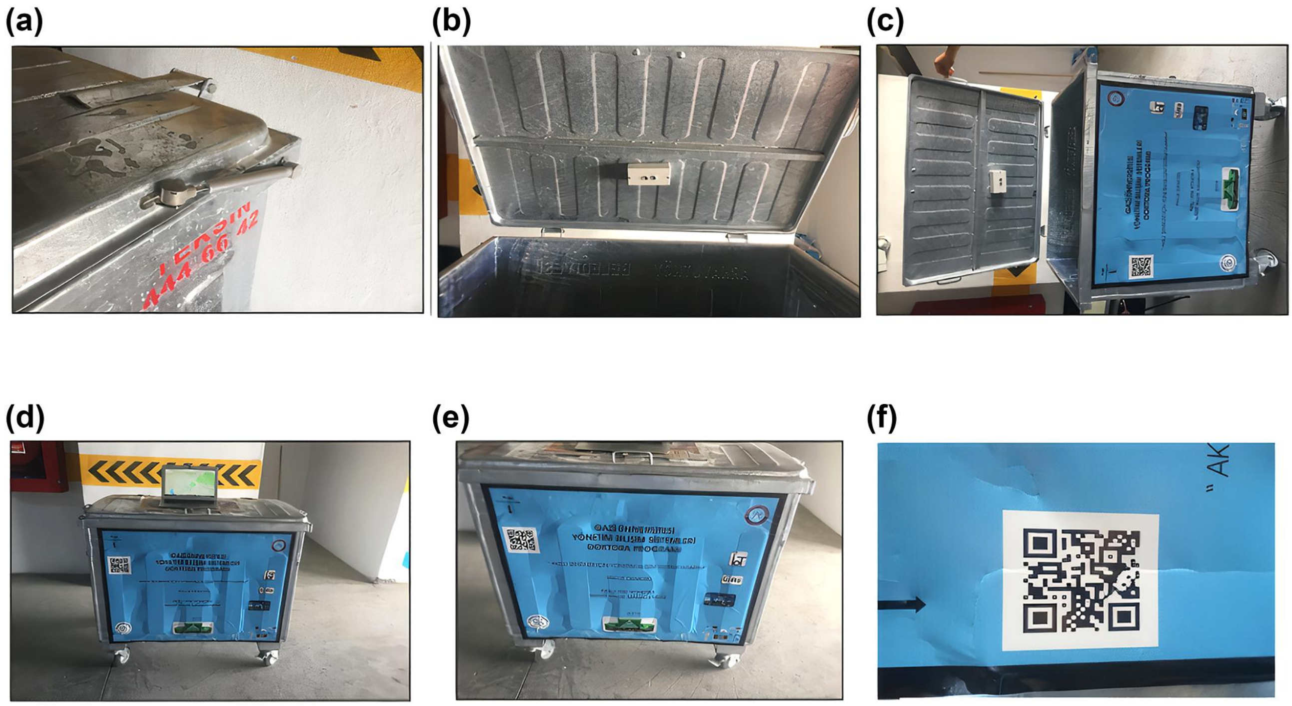
Figure 6 shows the overall network topology of the system and the data flow. In the following section, there are answers to the questions: how is the data collected from the test environment? And how is the information generated from the raw data?

7.3 | Management of the operation and hardening the system

After the node is installed in the field, the system is started, and the data is collected from the nodes. As mentioned earlier, the code is uploaded to the Arduino Uno board. In this code, many indicators and parameters are configured. First of all, the distance is 30 cm for the ultrasonic sensor data read by the node. This means that the node sends a message (data) to the central system when the city residents put solid waste in the bin and the height of this waste is approaching the top, that is less than 30 cm, and that the bin will soon be full. Technically, ultrasonic sensors send ultrasound into the bin, and when the sound wave is reflected, the ultrasonic sensor measures the distance and sends this data to the card Arduino Uno. At this point, the process can be called a boundary layer.

The next step is the transmission phase where the Arduino board sends the data to the central database. The Dragino gateway has already been introduced in the previous sections. The gateway receives the data from the node and forwards it to the next phase. In this project, The Things Network (TTN) infrastructure is used to collect, store and process data from the field. The Things Network is an open-source initiative that operates an open IoT infrastructure supported by a global ecosystem of thousands of developers, IT integrators, hardware manufacturers, universities, and governments. In order to achieve data transfer from the endpoint to the central database, all devices must be configured. It is used for the node side, and some parameters that Arduino uses to forward data are inserted.

First, the gateway is registered in the TTN. The gateway is configured through its graphical user interface and the parameters for forwarding data to the TTN are set. Once the gateway receives data from the node, it forwards all the data to the servers of the TTN. While configuring the Arduino, the



PICTURE 2 (a) Shock absorber arm; (b) Node attachment flap; (c) The whole view of the bin; (d) Receiving signal; (e) Research information stick; (f) QR code for bin details

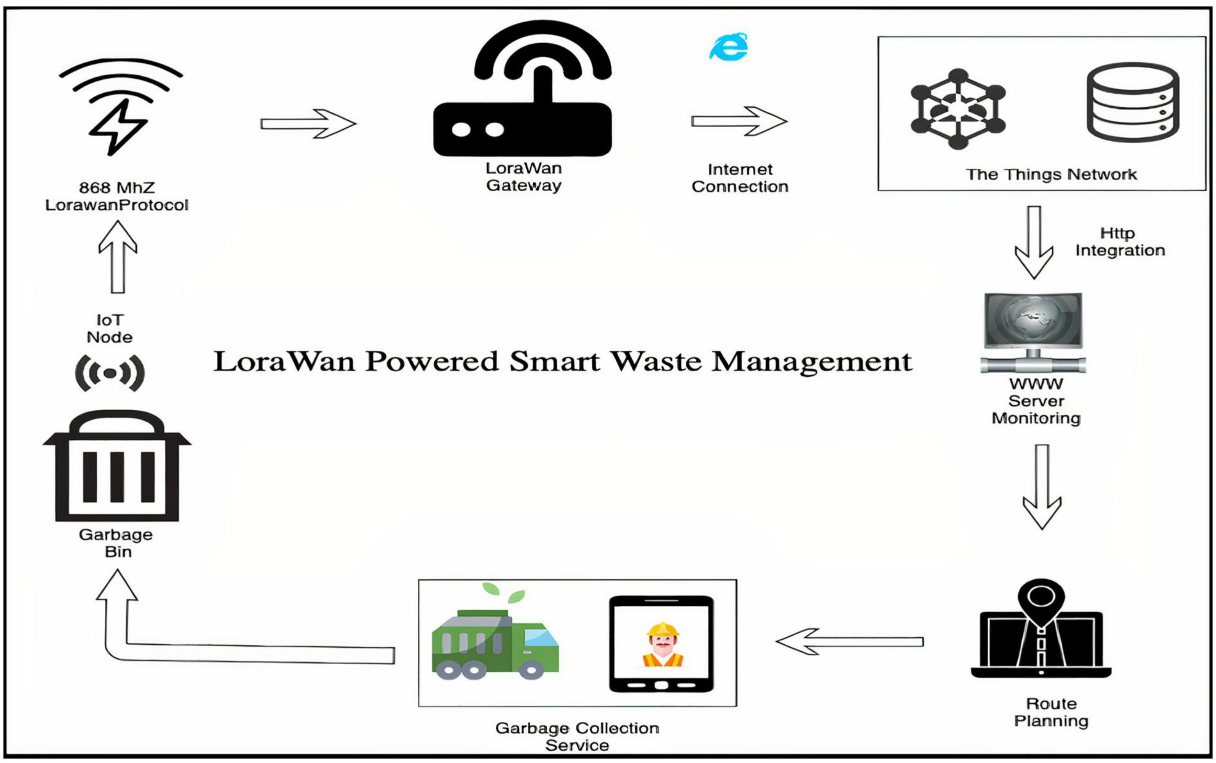


FIGURE 6 Overall processes in the infrastructure. IOT, Internet of Things; LoRaWAN, long range wide area network

keys are inserted in the Arduino code such as access key, gateway ID, gateway key APPLICATION Extended Unique Identifier (Multiple; EUIS), Activation Method, device EUI, application EUI, Device Address, Network Session Key, and App Session Key, which TTN provides. For all these settings, the following website was visited. Some of the screenshots of TNN web pages are shown: https://account.thethingsnetwork.org/users/login.

After logging into the TTN website, Picture 3 appears. On this page, a gateway must first be set up. In this scenario, the Dragino gateway is registered in the TTN. Using the maintenance interface of the gateway, it is not difficult to set up a gateway to communicate with the TTN. Once the gateway is registered in the TTN, the page shown in Picture 4 displays the details of the gateway registration.

When the gateway is registered, the infrastructure is also provided. Thanks to the communication between the gateway and the TTN, it will be possible to send the data from the endpoint node to the central database of the TTN. Picture 5 shows the data monitoring screen. When the Arduino board collects data, it sends it to the TTN and the data flow is monitored on the following screen.

The Things Network allows the developer to integrate their system with TTN systems. In this application, the integration is set up to send data to the web server to be monitored on the website. Picture 6 is the page of the HTTP integration configuration page.

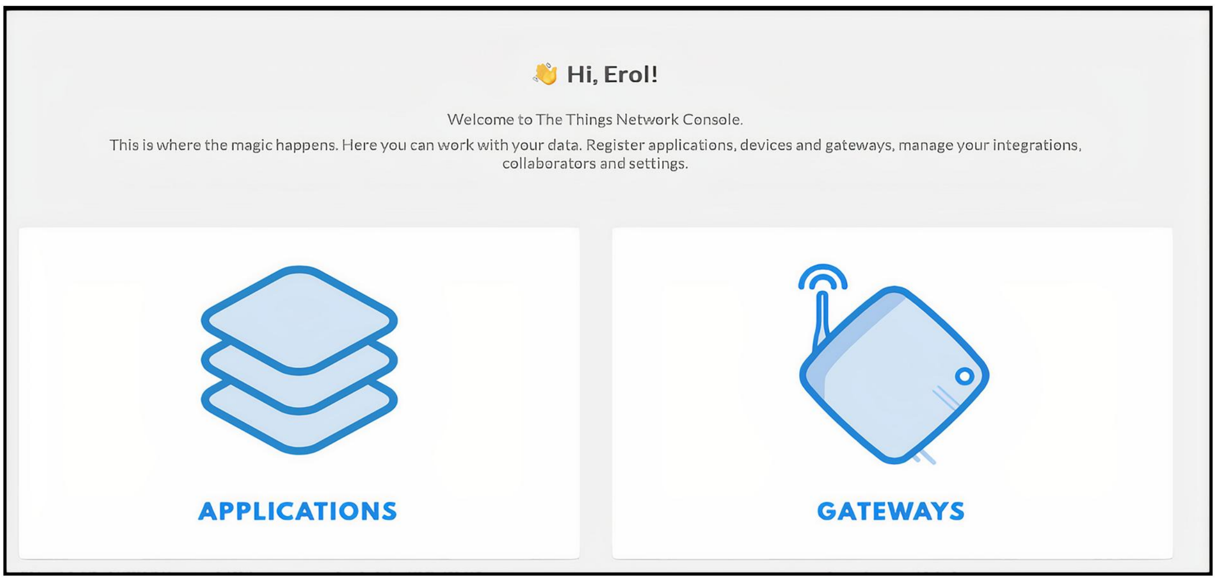
All the required information should be defined on this page. In this configuration of the node, gateway, and TTN, data is collected from the field. Data does not mean everything independently. An alarm should be set and an ideal workflow for waste collection should be designed. When the data shows up on the TTN, it is forwarded to the web server through HTTP integration. The Things Network provides such functions. On the web server, the location of the bin is stored in advance.

The best route is created for regular garbage collection and searching for empty bins is avoided. To facilitate this process, an app is being developed for the Firebase platform iPhone operating system (IOS). Firebase is an application development platform from Google that provides powerful tools for creating a mobile application. Thanks to this application, the work can be easily carried out using the map algorithm of IOS, and determining the location of the garbage can or creating the best route is no longer a headache. The sample video of using the app uploaded to the cloud IOS is available at the following link; https://www.dropbox.com/s/tjv821fra2qs53l/da5ba8fd-a392-4c47-b55b-e5178dc74bfb.mp4?dl=0.

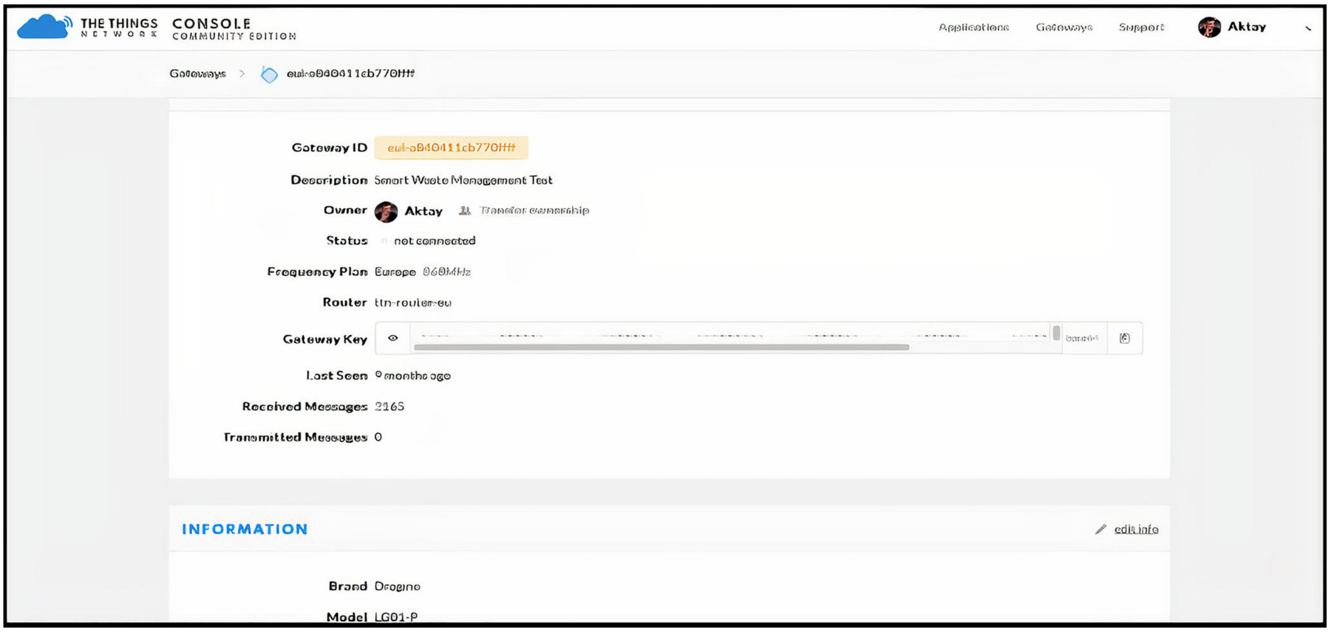
The following screenshots are examples of the progress of the application.

When the application IOS is opened, the screen in Picture 7 appears. After providing the credentials, the application searches for the location to add a new note, as shown in Picture 8. Since the infrastructure of the GPS is used, the location data is completely correct. In the following steps, meaningful information is added to determine the node, as shown in Picture 9. The node identity information is added to the code of Arduino Uno and uploaded to the node. When the node sends data to the TTN, the load is realised in the node, then the collection process is queued based on the best route. The value of distance is set to 30 cm by default. When the height of the garbage load reaches this value, the node sends data to the TTN because the node is full. More frequent reading and sending to the TTN network consumes more energy, so the frequency is four hours per day. Different districts in Besiktas and Arnavutköy were selected to provide data to the system. For this purpose, a site visit is planned with the officials of Besiktas and Arnavutköy municipalities. Thanks to this visit, it is possible to estimate how this system would efficiently manage some cost and environmental issues.

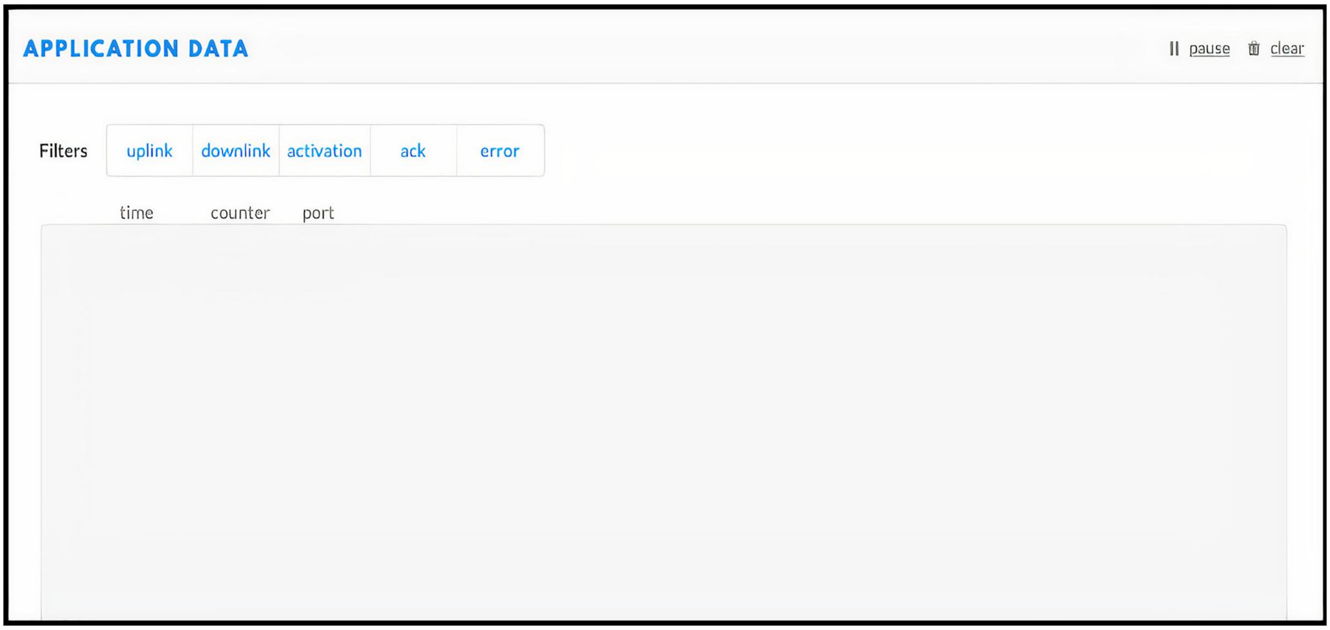
The location of the garbage bin and its load are recorded, and this data is then entered into a map (shown in Picture 10). When the IoT node is implemented on all garbage bins, these green bins would no longer need to be hit, saving money and reducing air pollution. All commercial vehicles used for garbage collection use fossil oil, which causes air pollution, as mentioned in the previous section.



PICTURE 3 The Things Network registration page



PICTURE 4 Registered gateway profile

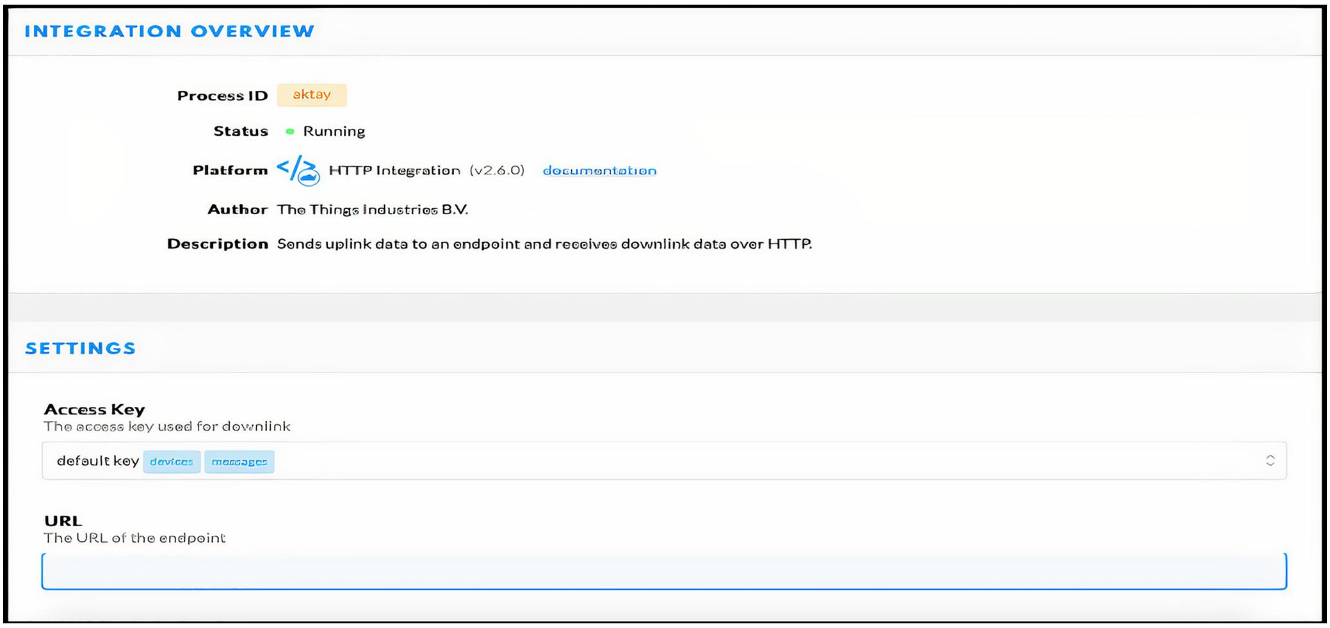


PICTURE 5 Data monitoring screen

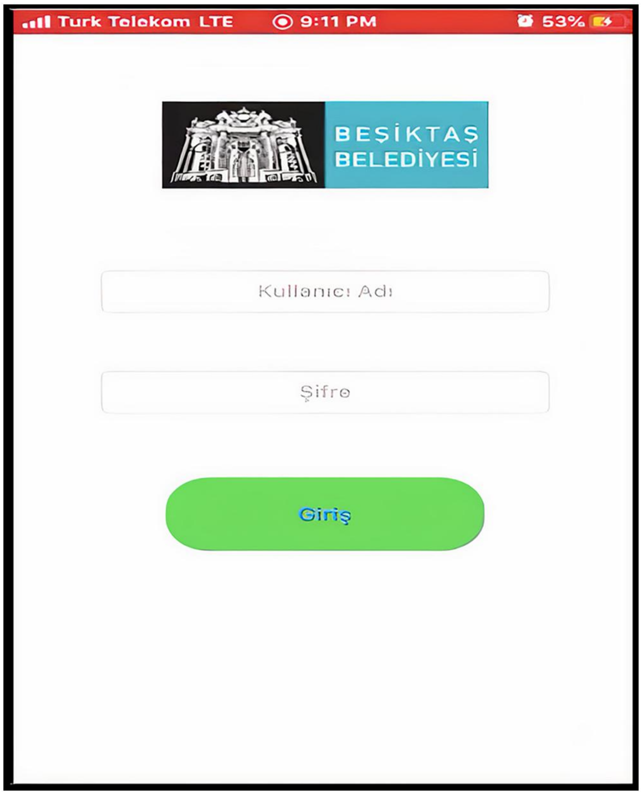
This study shows that the LoRaWan technology and protocol are applicable in Turkey. It was achieved to establish a sample node and a point-to-point LPWAN network. Collecting data from the field is possible and this supports the idea that if the same nodes are implemented in a wide area, this will reduce the expenses of the traditional garbage collection method. When all the information from the field visits, observations and the proposed IoT system are taken into account, the proposed model will definitely reduce the cost of waste disposal by at least 40%–45%. This rate is estimated based on the operational costs such as fuel, employees and trucks.

Another fact is that if this new waste collection system is used by most of the communities in Turkey, it will also lead to a cleaner environment. In addition, it is estimated that the initial savings of 40%–45% in operation will lead to less need for fossil energy. This will be an opportunity to reduce dependencies and positively impact the foreign trade deficit.

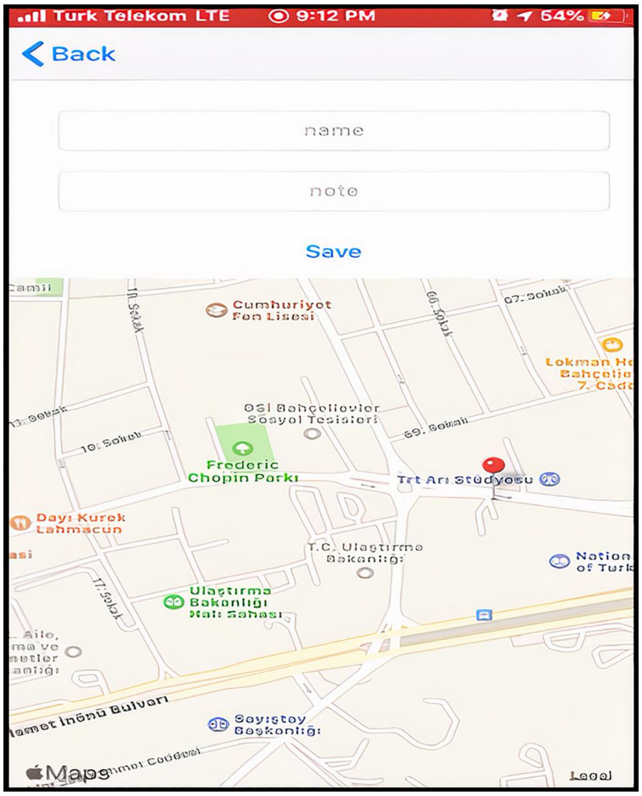
The map in Picture 11 shows the study area. This area is called Gayrettepe. The area was visited together with community officials to understand how the garbage collection system works. During this visit, it was found that some of the garbage bins were not full and should not be included in the



PICTURE 6 The Things Network HTTP integration configuration for data posting



PICTURE 7 Login screen

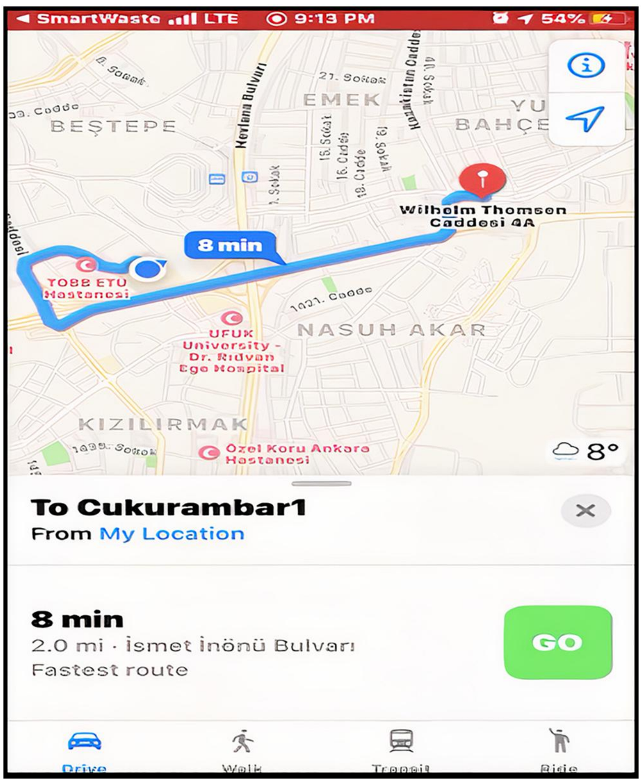


PICTURE 8 New node adding

collection queue. The number of full and empty bins provides an indication of the extent to which the proposed system creates economic and sustainable value for the environment.

One of the main purposes of the site visits is to understand the operational process of garbage collection and to identify the weaknesses of the current garbage collection system. The site visit provided valuable information on where the sensor node should be placed, which bins should not be targetted, and how to develop a well-designed garbage collection system. In some cases, the garbage collection system should be triggered due to environmental issues. That is, if some garbage bins are

PICTURE 9 Node list



PICTURE 10 Route planning

full before the regular time, these bins should be emptied to maintain a healthy and pleasant environment for the city residents.

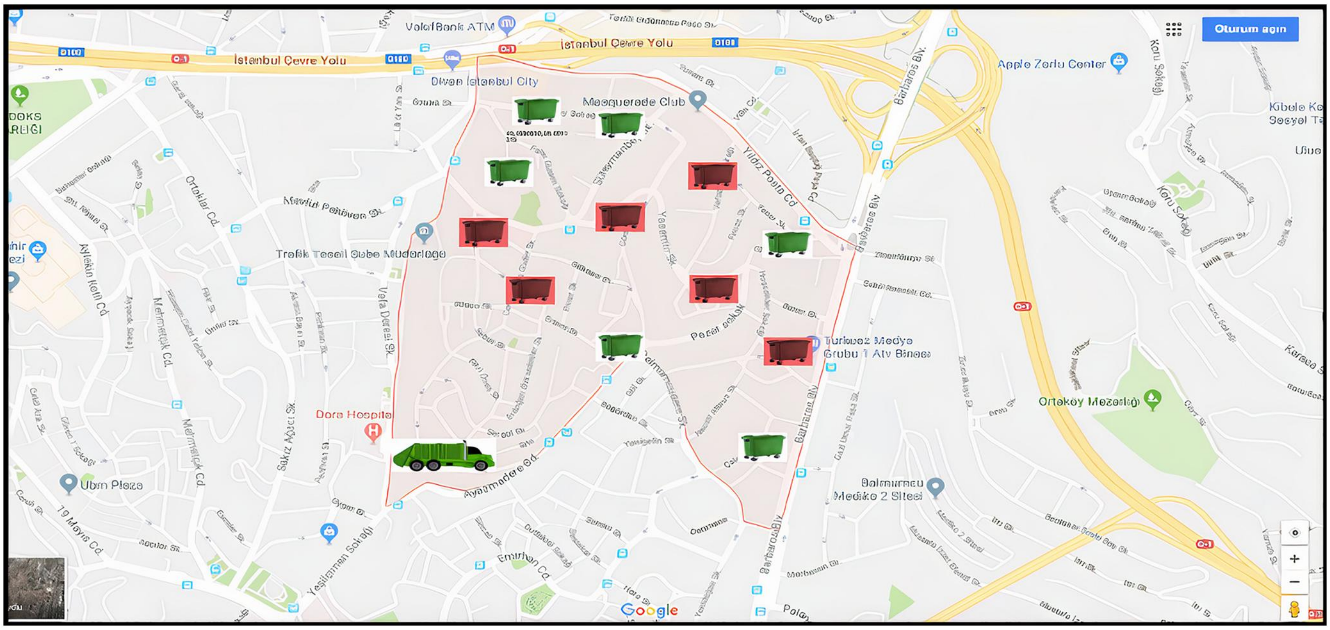
Authentication, trust, and integrity of the communication channel between IoT devices are the critical security parameters those modern solutions deal with. Although the IoT is at the cutting edge, it lacks support for powerful devices and is not compatible enough to deal with the increasingly heterogeneous entities [38]. To harden the entire IoT infrastructure, some security parameters are mandatory. To make the entire system more secure, there are several aspects that need to be considered during implementation and also during operation. Some of them include the following: Public key infrastructure/digital certificates, network security, application programming interface security, network access control, segmentation, security gateways, patch management, continuous software updates, and training and consumer education.

8 | CONCLUSIONS, IMPLICATIONS, AND FUTURE DIRECTIONS

In this study, a LoRaWan-based smart city waste management system is proposed. In this article, the problems are clearly expressed. They include environmental problems, population, lack of ICT-based systems and operational costs. Before proposing a solution, the current situation in Turkey is considered in terms of greenhouse gas emissions, fossil fuel import costs that affect the state budget, and waste collection costs for local authorities. Several important issues are examined; the proposed solution addressed all of them. Site visits and observations have shown that traditional garbage collection is no longer satisfactory. The following questions arise: why does the garbage truck go to all the garbage cans that are not full? Why do garbage trucks have to travel more miles for daily garbage collection? Why is more fossil fuel needed to operate? Why are more people hired for daily garbage collection? In order to create a sustainable environment, reduce the fossil fuel import budget and reduce the expenditure on garbage collection, a new approach is developed.

Long range wide area network wireless technology is the first application in Turkey. The design of nodes, network configuration, application-level management and operation process are well regulated. Instead of the current licenced spectrum and services, an unlicensed free ISM band is proposed. The innovative feature of this proposal is the low cost and low power consumption of the applications. Once the node is connected to the bins, there are no GSM data charges and no higher battery requirements. This is a breakthrough approach.

The major goal is this study is to find a solution for crucial issues such as the negative impact of carbon emission on the environment, increase the sustainability of the natural resource, provide a better livable city for residents of the city, decreasing the dependencies of fossil oil, exist in the cities. The solution is



PICTURE 11 Sample waste collection operation map

relay on the IoT applications maintained by the Lora and LoraWan technologies which do not require more power and are license-free. Some of the field works has been done in Besiktas and Arnavutkoy which are the districts of Istanbul. Based on the above facts, the designs and coding of all system elements in the first 868 MHz range in Turkey were specifically carried out and an end-to-end system was built. After that, the existing modules were installed in dumpsters for further testing. A case study on smart waste management was conducted, and the data was collected, processed, and prepared for the end user on site. Based on random sampling of garbage collection with direct observations (which dumpster is empty, and which is full) during field visits with the city garbage collection staff, the proposed system will be at least a 40%–45% cost effective solution if installed in all dumpsters in a large area. All the instruments of the system worked smoothly during the tests and when used in the field, it would be appropriate to install the system depending on the location, proximity to buildings and distance from the gate. By taking measurements at a specific frequency using a 9 V battery and a power switch, it was determined that the sensor node would operate for at least 5 years. For this measurement, the system was kept open for a long period of time and the battery measurement was performed regularly on a daily basis.

For future studies, all bins should be powered by other sensor nodes. This means that there is an existing infrastructure; thanks to this infrastructure, other sensors such as humidity, air quality, sound and weight could be connected to the node. In this way, the government agencies in charge of city management will gain significant power to build a fully smart city.

The establishment of sensor clusters will provide local governments with important data and information to make cities more sustainable. The main problem faced by the research is the limited resources, so only some nodes have been built to show the efficiency and working process. In future studies, there could be support from companies or policy makers to expand the scope of the study.

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CONFLICTS OF INTEREST

All authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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