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PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA  
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MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH  
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UNIVERSITY OF LAGHOUAT



FACULTY OF SCIENCES  
DEPARTMENT OF COMPUTER SCIENCE

**Field** : Mathematics and Computer Science  
**Option** : Computer Science  
**Specialization** : Networks, Distributed Systems, and Applications.

MEMOIRE SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE  
MASTER DEGREE IN COMPUTER SCIENCE

**SUBMITTED BY:** Ali Kheireddine Belboul

**THEME**

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## Real-Time Smart Home Surveillance Application using Heterogeneous Cooperative Sensors and IoT Devices

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*Jury members:*

<i>Mr</i>	Nasreddine Lagraa	Professor	(University of Laghouat)	President
<i>Ms</i>	Zohra Abdelhafidi	MC(A)	(University of Laghouat)	Examiner
<i>Mr</i>	Mohamed Bouzidi	MC(A)	(University of Laghouat)	Examiner
<i>Ms</i>	Fatima Zohra Bousbaa	MC(A)	(University of Laghouat)	Advisor

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DEPARTEMENT D'INFORMATIQUE

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**Filière** : Informatique

MÉMOIRE DE MASTER  
PRÉSENTÉ PAR : Ali Kheireddine Belboul & Ali Touaitia  
THÈME

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**Application intelligente de surveillance domestique en temps réel utilisant des capteurs coopératifs hétérogènes et appareils IoT**

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*Soutenu publiquement devant le jury composé de :*

<i>Mr</i>	Nasreddine Lagraa	Professor	(University of Laghouat)	President
<i>Mme</i>	Zohra Abdelhafidi	MC(A)	(University of Laghouat)	Examiner
<i>Mr</i>	Mohamed Bouzidi	MC(A)	(University of Laghouat)	Examiner
<i>Mme</i>	Fatima Zohra Bousbaa	MC(A)	(University of Laghouat)	Advisor

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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*Ali & Ali, June 2023*

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# *Dedications*

*I offer this humble work as a dedication to the two remarkable individuals who have consistently made sacrifices to ensure my success.*

*To my beloved mother and father, no dedication can adequately express my gratitude for the kindness, love, and unwavering support they have shown me throughout my academic journey. They are truly treasures of goodness and generosity. May God watch over them.*

*To my dear brother and sisters, all members of my family, and to all my cherished friends who have supported me throughout my studies.*

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*Belboul Ali Kheireddine*

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# *Dedications*

*I am filled with profound gratitude as I commence this heartfelt expression of appreciation to Allah for His blessings and unwavering guidance throughout this extraordinary voyage. Without His divine support, none of the achievements would have been attainable.*

*To my cherished parents, your unwavering love and unwavering support have been an unwavering wellspring of strength in my life. I am forever thankful for the sacrifices you have made and the guidance you have provided. May Allah bestow upon you His boundless mercy and protection. This humble undertaking is dedicated to you.*

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*Touaitia Ali*

## Abstract

In today's world, the safety of our homes has become a pressing concern, with issues such as gas leakage surveillance, water tank control, security, and monitoring the well-being of the elderly and children posing significant risks if not addressed effectively. Manual monitoring is impractical, necessitating the need for an automated solution. To tackle these challenges, we propose a smart home system that integrates heterogeneous sensors, [Cloud Computing \(CC\)](#), and [Internet Of Things \(IoT\)](#) devices. Through the collaboration of these sensors, we can offer a cooperative approach to enhance the efficiency, comfort, and security of home occupants. Gas leakage surveillance is of particular concern, and our system suggests the installation of gas detectors in key areas of the home to provide early warnings and alert residents to potential gas leaks. Real-time monitoring is ensured through advanced technology that continuously tracks gas levels and promptly notifies users in the event of a leak. Our solution allows to customize protection, with users being able to configure the gas detection system to suit their specific layout and requirements, providing personalized safety measures. Additionally, our mobile [Application \(App\)](#) empowers homeowners to remotely monitor gas levels and receive immediate notifications from anywhere, granting them peace of mind and a greater sense of control over their home's safety. In case of unusual events like smoke or gas leaks, our system goes beyond local alerts by notifying relevant authorities, ensuring a swift response to emergencies. With this comprehensive smart home application, individuals can effectively prevent potential risks related to gas leaks and other safety concerns, offering continuous monitoring, personalized protection, and remote access to safeguard families and property even when homeowners are away.

**Keywords:** Smart Home, Sensors, Mobile App, IoT Technology, CC.

## ملخص

في عالم اليوم، أصبحت سلامة منازلنا مصدر قلق ملح، مع قضايا مثل مراقبة تسرب الغاز، والتحكم في خزان المياه، والأمن، ومراقبة رفاهية كبار السن والأطفال التي تشكل مخاطر كبيرة إذا لم يتم التعامل معها بشكل فعال. المراقبة اليدوية غير عملية، مما يستلزم الحاجة إلى حل آلي. لمواجهة هذه التحديات، نقترح نظام المنزل الذكي الذي يدمج أجهزة الاستشعار غير المتجانسة والحوسبة السحابية (CC) وأجهزة إنترنت الأشياء (IoT). من خلال التعاون مع هذه المستشعرات، يمكننا تقديم نهج تعاوني لتعزيز الكفاءة والراحة والأمن لشاغلي المنزل. تعتبر مراقبة تسرب الغاز مصدر قلق خاص، ويقترح نظامنا تركيب أجهزة الكشف عن الغاز في المناطق الرئيسية بالمنزل لتوفير الإنذارات المبكرة وتنبيه السكان إلى تسرب الغاز المحتمل. يتم ضمان المراقبة في الوقت الفعلي من خلال التكنولوجيا المتقدمة التي تتعقب باستمرار مستويات الغاز وتبلغ المستخدمين على الفور في حالة حدوث تسرب. يسمح حلنا بالحماية القابلة للتخصيص، حيث يتمكن المستخدمون من تكوين نظام الكشف عن الغاز ليناسب التخطيط والمتطلبات الخاصة بهم، مما يوفر إجراءات أمان مخصصة. بالإضافة إلى ذلك، يمكن تطبيق الهاتف المحمول الخاص بنا أصحاب المنازل من مراقبة مستويات الغاز عن بُعد وتلقي إشعارات فورية من أي مكان، مما يمنحهم راحة البال وإحساساً أكبر بالتحكم في سلامة منازلهم. في حالة وقوع أحداث غير عادية مثل الدخان أو تسرب الغاز، يتجاوز نظامنا التنبيهات المحلية من خلال إخطار السلطات المعنية، مما يضمن الاستجابة السريعة لحالات الطوارئ. من خلال تطبيق المنزل الذكي الشامل هذا، يمكن للأفراد منع المخاطر المحتملة المتعلقة بتسرب الغاز وغيرها من مخاوف السلامة بشكل فعال، وتقديم مراقبة مستمرة وحماية شخصية والوصول عن بُعد لحماية العائلات والممتلكات حتى عندما يكون أصحاب المنازل بعيداً.

الكلمات المفتاحية: المنزل الذكي، المستشعرات، الحوسبة السحابية (CC)، أجهزة إنترنت الأشياء (IoT)، تطبيق الهاتف المحمول.

Dans le monde d'aujourd'hui, la sécurité de nos maisons est devenue une préoccupation urgente, avec des problèmes tels que la surveillance des fuites de gaz, le contrôle des réservoirs d'eau, la sécurité et la surveillance du bien-être des personnes âgées et des enfants qui posent des risques importants s'ils ne sont pas traités efficacement. La surveillance manuelle n'est pas pratique, ce qui nécessite une solution automatisée. Pour relever ces défis, nous proposons un système de maison intelligente qui intègre des capteurs hétérogènes, des dispositifs de Cloud Computing (CC) et de l'Internet des objets (IoT). Grâce à la collaboration de ces capteurs, nous pouvons proposer une approche coopérative pour améliorer l'efficacité, le confort et la sécurité des occupants de la maison. La surveillance des fuites du gaz est particulièrement préoccupante, et notre système suggère l'installation de détecteurs de gaz dans les zones clés de la maison pour fournir des avertissements précoces et alerter les résidents des fuites de gaz potentielles. La surveillance en temps réel est assurée grâce à une technologie de pointe qui suit en permanence les niveaux de gaz et avertit rapidement les utilisateurs en cas de fuite. Notre solution permet une protection personnalisable, les utilisateurs pouvant configurer le système de détection de gaz en fonction de leur disposition et de leurs exigences spécifiques, en fournissant des mesures de sécurité personnalisées. De plus, notre application mobile permet aux propriétaires de surveiller à distance les niveaux de gaz et de recevoir des notifications immédiates, leur offrant une tranquillité d'esprit et un plus grand niveau de contrôle sur la sécurité de leur maison. En cas d'événements inhabituels tels qu'une fumée ou des fuites de gaz, notre système va au-delà des alertes locales en avertissant les autorités compétentes, garantissant une réponse rapide aux urgences. Grâce à cette application complète de maison intelligente, les particuliers peuvent prévenir efficacement les risques potentiels liés aux fuites de gaz et autres problèmes de sécurité, en offrant une surveillance continue, une protection personnalisée et un accès à distance pour protéger les familles lorsque les propriétaires sont absents.

**Mots clés:** Maison intelligente, Capteurs, Application mobile, IoT technologie, CC.

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## List of Acronyms

- API** Application Programming Interface. 5, 13
- App** Application. v, 23, 24, 25, 27, 28, 40, 41, 42, 45
- BLE** Bluetooth Low Energy. 6
- BPAAS** Business Process As A Service. 12
- CAAS** Container As A Service. 12
- CC** Cloud Computing. v, i, 2, 3, 10, 12, 15, 16, 47
- CDN** Content Delivery Network. 13, 40
- DAAS** Desktop As A Service. 12
- DIY** Do It Yourself. 35, 38
- EC** Edge Computing. 13, 16
- HVAC** Heating, Ventilation and Air-Conditioning. 9
- IAAS** Infrastructure As A Service. 11
- IBM** International Business Machines. 6
- IC** Integrated Circuit. 38
- IDE** Integrated Development Environment. 34, 35, 39
- IEEE** Institute of Electrical and Electronics Engineers. 6
- IoT** Internet Of Things. v, i, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13, 15, 16, 18, 19, 33, 34, 35, 47
- ISM** Industrial, Scientific, and Medical. 6
- LDR** Light Dependent Resistor. 9

- LED** Light Emitting Diode. 39
- Li-Fi** Light Fidelity. 6
- LINDAR** Light Detection And Ranging. 8
- LR-WPAN** Low Rate Wireless Personal Area Network. 6
- MCC** Mobile Cloud Computing. iv, vi, 13, 14
- MEC** Mobile Edge Computing. iv, vi, 13, 14, 15
- MQTT** Message Queuing Telemetry Transport. 6
- NAAS** Network As A Service. 12
- NFC** Near Field Communication. 6
- PAAS** Platform As A Service. 11, 12
- QR** Quick Response. 31
- RFID** Radio Frequency Identification. 4, 5, 6
- RISC** Reduced Instruction Set Computer. 35
- RTOS** Real Time Operating System. 35
- SAAS** Software As A Service. 11, 12
- SDK** Software Development Kit. 40
- SOA** Service Oriented Architecture. iv, 4
- UI** User Interface. 24, 40
- UML** Unified Modeling Language. 17, 27, 33
- UUID** Universal Unique Identifier. 5
- VLC** Visible Light Communications. 6
- Wi-Fi** Wireless Fidelity. 5, 6, 26, 35, 41, 48
- WSN** Wireless Sensors Networks. 2, 3, 47

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## 1.1 Context

In recent years, The IoT is thought to be the next industrial and academic revolution in the technological world, the collaboration between this new technology and other devices such as, sensors may become an interesting way to offer new IoT services including agriculture surveillance, medicine applications, and smart homes surveillance [10]. More recently, smart homes have become very fashionable as occupants seek out methods to keep their places of residence more secure, productive, and convenient. One of the key components of a smart home is the ability to monitor, automate and control various aspects of the home in real-time.

## 1.2 Problem Statement and Motivation

The importance of technology in Algerian households has significantly increased, particularly in relation to the crucial task of ensuring the safety of our homes. This encompasses various concerns such as monitoring gas leakage, controlling water tanks, enhancing security, and keeping an eye on the well-being of both the elderly and children. If these issues are left unattended, they can pose considerable risks. Relying solely on manual monitoring proves impractical, highlighting the need for an automated solution. The seriousness of the situation is further highlighted by the alarming number of gas-related incidents that have resulted in 608 deaths over the past 10 years [11]. Additionally, the significant number of residential burglaries reported by the Algerian Police [12] underscores the importance of integrating technology into homes to safeguard the safety and security of families. These factors make the implementation of a smart home system a valuable investment for any household.

## 1.3 The Objectives

Our objective is to develop an advanced smart home surveillance application that harnesses the capabilities of diverse cooperative sensors and IoT devices. The primary goal is to detect and promptly respond to unusual events, including gas leaks, in order to ensure the safety and well-being of occupants. By providing real-time monitoring and alerts, we aim to offer homeowners peace of mind, ensuring they feel secure and confident about the safety of their home. Additionally, we aim to enhance security features to establish a safer living environment, providing occupants with the assurance that their property is adequately protected. Moreover, we strive to deliver convenience by enabling convenient and automated control over various aspects of the smart home.

## 1.4 Organization of the Memoire

This memoire is organized as follows :

- In **Chapter 2**, we provide an overview of Internet Of Things (IoT), Wireless Sensors Networks (WSN), Cloud Computing (CC), and Smart home.
- In **Chapter 3**, we showcase some of several works and applications concerning smart homes, highlighting their advantages and drawbacks. Furthermore, we provide an overview of our own system's design, starting with an summary of our system presentation, and subsequently exploring the modeling of our application.
- In **Chapter 4**, we present the implementation of our solution. First,provide an overview of the hardware and software tools that were deployed. Subsequently, we delve into the various stages of functionality within our system.
- Finally ,we conclude by summarizing this work and the potential avenues for future growth and expansion.

# Internet Of Things, Sensors, Cloud Computing, and Smart Homes: Background

## Contents

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## 2.1 Introduction

The concept of smart homes has revolutionized the way people live and interact with new services in their daily lives. These new services are realized thanks to the development of new technologies such as **IoT**, **WSN**, and **CC**, which played a critical role in the development and deployment of smart homes.

This chapter provides an overview of the **IoT**, **WSN**, **CC**, and Smart Home technologies.

## 2.2 Internet Of Things

The Internet of Things **IoT**, refers to a system comprising a wide variety of physical devices and objects, such as home appliances and vehicles, that are equipped with sensors, Internet connectivity, and software that links them.

In his first 1999 proposal, Kevin Ashton defined **IoT** as a network of **Radio Frequency Identification (RFID)**-enabled connected items that can be uniquely identified. However, the precise definition of **IoT** is still being developed and depends on the viewpoints used. "Dynamic global network infrastructure with self-configuring capabilities based on standards and communication protocols" was the general definition of the **IoT** [1].

**IoT** devices communicate with each other and with other computer systems, creating a vast network of interconnected devices that can be remotely monitored, controlled, and managed. The data collected from **IoT** devices can be analyzed to reveal insights, trends, and patterns, which can be used to optimize processes, make more informed decisions, and enhance the overall user experience, or can be used in a forward manner to make decisions based on the information received like notifying users in case of a breach or an event [13].

These devices are typically designed to operate with minimal human intervention and can be remotely managed and updated. The use of **IoT** can have significant benefits across a wide range of industries, such as healthcare, agriculture, home safety, transportation, and manufacturing. For example, **IoT**-enabled healthcare devices can allow for remote patient monitoring and telemedicine, while **IoT**-enabled agriculture equipment can optimize crop yields and reduce waste [14].

The ultimate aim of the **IoT** is to improve the efficiency, convenience, and quality of our lives by providing new ways of interacting with technology and the world around us.

### 2.2.1 Service-Oriented Architecture

**SOA** is a software design approach that involves breaking down complex software systems into smaller [1], independent services that communicate with each other to achieve a common goal. The **SOA** can improve the scalability, flexibility, and maintainability of software systems, while enabling the integration of legacy systems and creating new applications that can be quickly and easily deployed.

The **SOA** architecture consists of four (4) main layers as shown in 2.1.

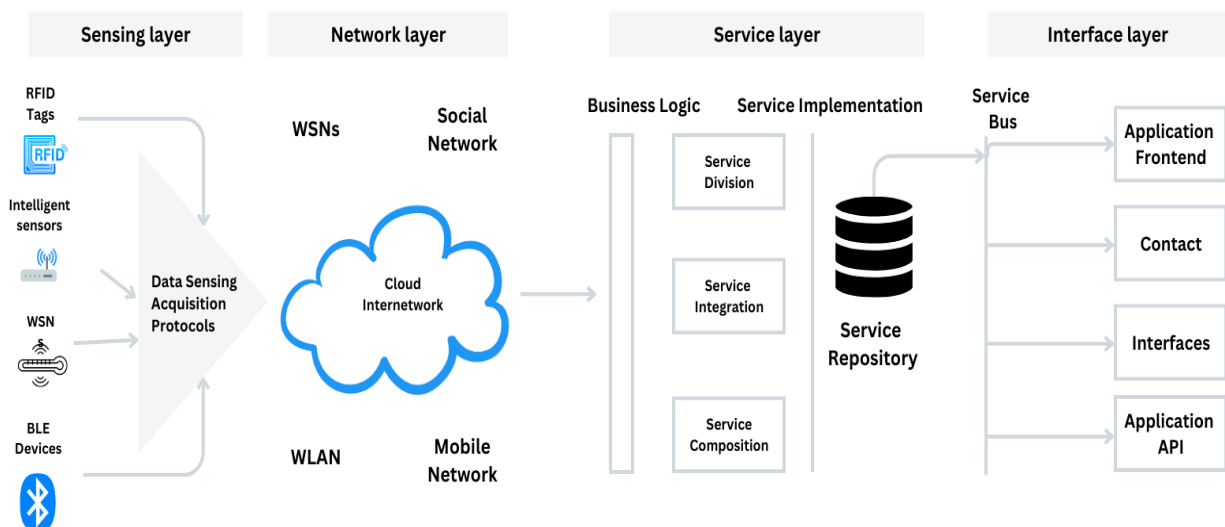


Figure 2.1: SOA Architecture [1]

1. **Sensing Layer** : In the sensing layer, smart systems integrated into tags or sensors have the ability to automatically perceive the environment and exchange data with other devices. Objects within this network can be easily distinguished and the surrounding environments can be monitored for a variety of purposes and applications. Each object in the **IoT** possesses a digital identity and can be effortlessly tracked within the digital domain. This method of assigning a unique identity to an object is known as a **Universal Unique Identifier (UUID)**, which may include names and addresses. A **UUID** is a 128-bit number that serves the purpose of uniquely identifying an object or entity on the Internet [1].
2. **Network Layer** : The **IoT** network layer connects devices and enables them to share data, which is important for intelligent event management. A strong network is essential for sharing data and providing services. Devices should be assigned roles automatically to enable collaborative task performance. The network layer must address issues such as network management, quality of service, data searching and processing, security and privacy. Confidentiality and human privacy are critical issues in **IoT** due to the potential risk of privacy breaches. While existing network security technologies can provide a basis for privacy and security, more work still needs to be done [1].
3. **Service Layer** : The service layer is an important platform in **IoT** that allows for cost-effective reuse of software and hardware. It runs services directly on the network to locate new services and retrieve data dynamically. Although various organizations have developed specifications for the service layer, a universally accepted service layer is necessary for **IoT**. The service layer consists of a minimum set of applications, **Application Programming Interface (API)**s, and protocols that support required services. All service-oriented activities are performed at the service layer, including information exchange, data management, search engines, and communication. Service discovery finds objects that provide the required service and information effectively, service composition enables interaction among connected things to enable the desired service, and service **API**s provide the interface between services required by users [1].
4. **Interface Layer** : The **IoT** involves connecting multiple devices that may belong to different individuals or groups and therefore may not conform to the same standards. It is essential to ensure compatibility between these devices for enabling interaction between them, which includes exchanging information, communicating, and processing events. An effective interface mechanism is needed to simplify the management and interconnection of these devices. The interface layer typically operates in the application front-end or through the use of an **Application Program Interface (API)** [1].

### 2.2.2 Communication methods

Apart from the typical communication methods such as Ethernet, **Wireless Fidelity (Wi-Fi)**, and Bluetooth, numerous other technologies can also be employed for communication purposes in the **IoT**.

1. **RFID and NFC** : **RFID** is a wireless technology that employs radio waves for the purpose of object identification. Objects can be affixed with **RFID** tags in order to monitor their location or gather data about them [15]. The application of **RFID** is frequently seen in inventory management, asset tracking, and access control scenarios.

Near Field Communication (NFC) shares similarities with RFID, it can be thought of as an integration of RFID technology into mobile phones [15]. It enables the exchange of data between two NFC-enabled devices or between an NFC-enabled device and a passive NFC tag.

2. **Bluetooth Low Energy (BLE) :** Bluetooth Low Energy (BLE) is a more recent addition to the Bluetooth family and is based on Bluetooth 4.0 standards. While operating in the same 2.4 GHz ISM band as classic Bluetooth, BLE uses a simpler modulation system and stays in a constant standby mode, consuming significantly less energy, except when a connection is established [16].
3. **LiFi : Light Fidelity (Li-Fi)** is a wireless optical networking technology that uses light to transmit data. It is a form of Visible Light Communications (VLC) system that uses LED or infrared light to transmit data bidirectionally, offering high-speed, fully networked wireless communication of data using light [17]. Li-Fi can transmit data at multiple gigabits, making it faster and more reliable than traditional wireless communication technologies like Wi-Fi.
4. **ZigBee :** Zigbee is a wireless mesh network standard that utilizes Institute of Electrical and Electronics Engineers (IEEE) 802.15.4-based specifications to establish personal area networks with small, low-power digital radios [18]. It operates on the 2.4 GHz Industrial, Scientific, and Medical (ISM) band, with additional bands available in specific regions like 868 MHz in Europe and 915 MHz in the Americas. The hardware for IEEE802.15.4 defines the physical and media access control layers for Low Rate Wireless Personal Area Network (LR-WPAN) and is intended for small-scale projects requiring wireless connectivity [19], such as home automation, medical device data collection, and other low-power, low-bandwidth applications.
5. **Z-Wave :** Z-Wave is a wireless communication protocol that is primarily used for home automation applications, allowing users to control and automate lighting, appliances, and other devices. It can also be employed for security purposes, enabling remote monitoring and control of one's property [20]. Z-Wave uses the ISM radio frequency band to transmit data, with frequencies of 868.42 MHz in Europe and 908.42 MHz in the United States. This frequency band is specifically designed for low-bandwidth data communication in embedded devices like home automation control panels, security sensors, and alarms [21].
6. **Message Queuing Telemetry Transport (MQTT):** Message Queuing Telemetry Transport (MQTT) is a lightweight machine-to-machine communication protocol designed by International Business Machines (IBM) for IoT devices. MQTT operates on a publisher-subscriber model, where publishers send data to a server (also known as a broker), and subscribers subscribe to the server to receive data. The MQTT broker is responsible for distributing messages and may reside somewhere in the Cloud [22, 23].

### 2.2.3 IoT applications

The IoT is a technology that enables the connection and communication of physical devices and objects with the Internet. The possibilities for IoT applications are endless and are continuously expanding. Here are some of the most common applications as shown in Figure 2.2.

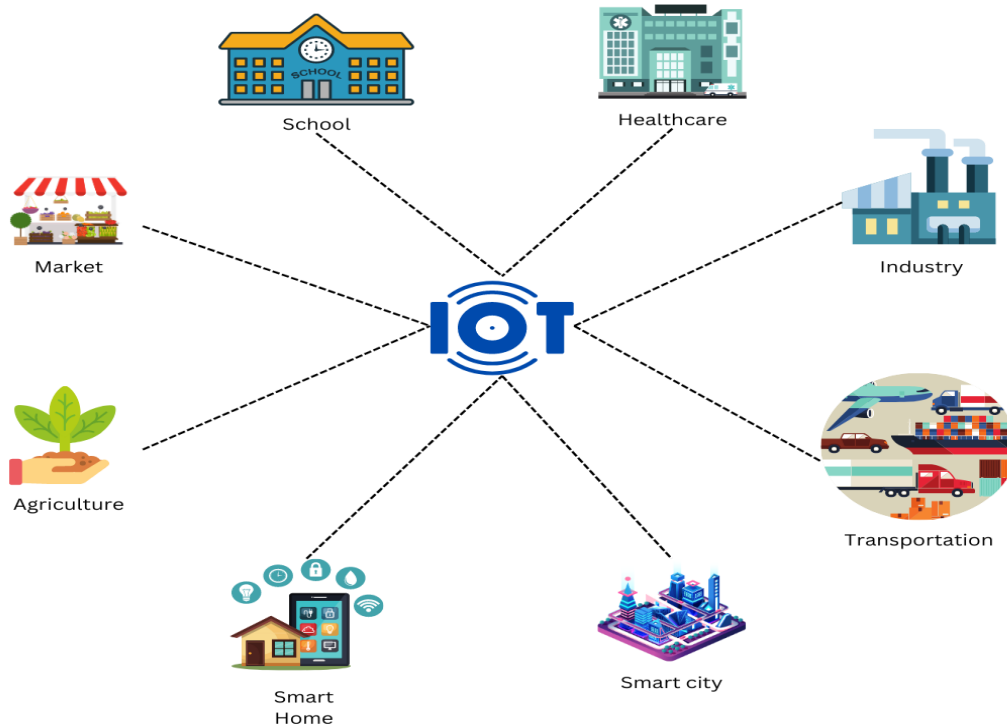


Figure 2.2: IoT's Applications

1. **Healthcare** : IoT technology is increasingly being used in the healthcare industry to monitor patients, both in hospitals and at home. By connecting various medical devices and wearables to the Internet, healthcare providers can remotely monitor a patient's vital signs and detect changes in their condition in real-time. This allows for quicker and more accurate diagnosis and treatment of medical issues, which can ultimately improve patient outcomes and reduce healthcare costs [14].

One of the key ways that IoT is being used in healthcare is through wearables such as heartbeat sensors and other medical devices. These wearables can be worn by patients to monitor their vital signs, such as heart rate, blood pressure, and oxygen levels. The data collected by these devices is transmitted to healthcare providers in real-time, allowing for quick intervention if there are any abnormalities. Additionally, wearables and medical devices can be used to remotely monitor patients at home, which can reduce the need for hospital visits and help patients to manage chronic conditions more effectively.

2. **Smart home** : IoT-enabled smart homes are becoming increasingly popular as they offer homeowners control and automation over a range of domestic functions, including lighting, security, temperature, and entertainment systems. This means that homeowners can remotely control and monitor their home's various systems and appliances through the Internet, from anywhere in the world [14].

Most frequently, a smartphone, tablet, or voice assistant like Amazon Alexa or Google Home is used to control IoT technology in smart homes. Because they are Internet-connected, homeowners may use an app or voice command to remotely manage and monitor their smart home appliances. For instance, while they are away from home, a

homeowner can use their smartphone to switch on the lights, change the thermostat, or check the security system.

3. **Agriculture** : IoT technology is increasingly being used in the agricultural sector to optimize crop management and increase farm productivity. By connecting various agricultural devices and sensors to the Internet, farmers can remotely monitor and manage their crops in real-time [14].

One of the key applications of IoT in agriculture is the collection of data on soil moisture, temperature, and humidity. By using IoT-enabled devices such as sensors, farmers can collect data on the moisture and nutrient levels of their soil, the temperature of their fields, and the humidity in the air. This data can then be analyzed to provide insights into the health of the crops, as well as to optimize irrigation, planting, and harvesting schedules.

4. **Industry** : IoT technology is used in big factories to collect data from machines and equipment to optimize operations, prevent downtime, and reduce maintenance costs, and mainly to prevent machines outbreaks and keep workers in a safe environment. Industrial IoT applications include predictive maintenance, remote monitoring, supply chain optimization, and quality control [14].
5. **Smart cities** : IoT technology is increasingly being used to optimize urban infrastructure management in what is known as a "smart city". A smart city is a city that uses IoT technology to improve the quality of life for its residents [14], enhance sustainability, and reduce costs.

## 2.3 Wireless Sensors Network

A sensor is a device that responds to physical stimulus properties [24], such as temperature, pressure, light, or motion, and converts them into electrical or digital signals. Sensors have a crucial role in automating various applications as they collect and process data to detect alterations in physical conditions. They generate a measurable response whenever there is a change in any physical condition for which the sensor is designed [24].

### 2.3.1 Types of sensors

There are numerous sensors available for IoT, and several ways to categorize them. The sensors can be divided by:

1. **Their external power supply requirements** :

- (a) **Active** : An active sensor is a sensor that relies on an external power source to detect environmental input and produce output [25]. For example, radar systems, **Light Detection And Ranging (LIDAR)** systems, ultrasonic sensors, and acoustic sensors. These sensors are widely used in various applications, such as remote sensing, navigation, surveillance, and industrial automation.
- (b) **Passive** : Unlike active sensors, which emit their own signal or radiation, a passive sensor operates by detecting environmental input without requiring an external

power source. It derives its energy from the environment itself, such as light or thermal energy [25]. Such as a temperature sensor that alters its resistance in response to temperature changes, or a camera or telescope, captures the light emitted by stars or other objects in the sky, without sending any light back.

## 2. Type of signal generated by the sensor

- (a) **Analog** : Analog sensors transform environmental inputs that are continuous and variable into analog signals as outputs [25]. For examples, [Light Dependent Resistor \(LDR\)](#), sound sensors, pressure sensors, and analog temperature sensors
- (b) **Digital** : Digital sensors transform environmental input into discrete digital signals, which are transmitted in binary format (1s and 0s) [25] before transmitting to a device. Some commonly used digital sensors are digital temperature sensors, digital pressure sensors, and digital humidity sensors.

## 3. Type of measuring device

- (a) **Chemical** : Chemical sensors are designed to identify chemical reactions, substances, or a specific set of chemicals. They can be employed to measure soil nutrient levels in agricultural fields, detect smoke or carbon monoxide in enclosed spaces, determine pH levels in water bodies, analyze alcohol levels in a person's breath, and countless other applications [24, 25].
- (b) **Motion** : A motion detector is a device that can perceive and track any movement or physical activity in a given environment, It has the capability to regulate an array of systems such as lighting, cameras, parking gates, water faucets, security systems, automatic door openers, and many other types of systems [24, 25].
- (c) **Level** : Level sensors are designed to measure the amount of a physical substance present in a given space, whether it is water, fuel, coolant, grain, fertilizer, or waste. Gas level sensors, for instance, are relied upon by drivers to avoid running out of fuel unexpectedly [25].
- (d) **Pressure** : Pressure sensors detect the magnitude of applied force and convert it into signals [24], they are widely utilized in various settings, including machinery, automobiles, aircraft, [Heating, Ventilation and Air-Conditioning \(HVAC\)](#) systems, and more, to detect and measure liquid or gas pressure [25].
- (e) **Humidity** : A humidity sensor measures both air temperature and moisture levels, providing a readout of the humidity in the surrounding environment [24, 25], These sensors are utilized in a vast array of industries and environments, spanning from agriculture and manufacturing to data centers, meteorology, and [HVAC](#) systems.
- (f) **Proximity** : Proximity sensors are designed to detect the presence of an object or measure the distance between two objects without any physical contact. They achieve this by emitting electromagnetic radiation, such as infrared, and analyzing variations in the return signal [24, 25].

### 2.3.2 Choosing an IoT Sensor: Key Considerations

In terms of sensor design for [IoT](#) networks, several factors need to be considered. Generally, the goal of a sensor and [IoT](#) device is long-term operation with minimal human interaction.

The importance of each factor and its priority for the overall design must be carefully considered. The following list of considerations can serve as a starting point for any discussion on IoT sensors.

1. **Durability** : The durability must be considered regarding the sensor's environment. The device must be as durable as necessary to function for a reasonable period without incurring unnecessary costs [26].
2. **Accuracy** : Precision is another critical factor as the sensor must be accurate enough to monitor the environment effectively, but not more precise than necessary to avoid incurring unnecessary costs [27].
3. **Versatility** : Versatility is crucial as the sensor must be able to operate in reasonable environmental variations. Therefore, sensors that can function accurately in all environmental variations are essential for IoT networks with multiple sensors in various environments [28].
4. **Energy consumption** : Depending on the situation, the needs may require low-power or even very low-power peripherals. It is necessary to decide if energy-saving functions (such as sleep mode or quick wake-up) are necessary [29].
5. **Cost** : Cost is a crucial aspect that must be examined in all aspects of sensor design. All costs, including placement, maintenance, and reliability, should be taken into account when designing sensors for IoT networks, which may involve hundreds or thousands of sensors and devices [30].

## 2.4 Cloud Computing

Cloud Computing (CC) is simply put as a general term for anything that involves delivering hosted services over the Internet [31]. However, with CC, we can access the same applications and services over the internet, without the need for any local installations, basically it provides easy access to these resources remotely through a web browser or a specialized software client, without having to install or maintain any physical hardware or software (Figure 2.3).

There are four cloud computing deployment models :

1. **Private Cloud** : A private cloud is a set of CC resources used exclusively by a company or organization. The private cloud may be located physically in the company's local data center [31]. Some companies also pay service providers to host their private cloud.
2. **Public Cloud** : A public cloud is owned and operated by a third-party cloud services provider [31], who offers computing resources such as servers and storage over the Internet. Microsoft Azure is an example of a public cloud. In a public cloud, all hardware, software, and infrastructure are owned by the cloud provider. We access these services and manage our accounts through a web browser.
3. **Hybrid Cloud** : A hybrid cloud combines public and private clouds [31], linked by a technology that enables them to share data and applications. By allowing data and applications to move between private and public clouds, a hybrid cloud offers your business

greater flexibility, more deployment options, and optimization of the existing infrastructure, security, and compliance.

4. **Community Cloud** : The community cloud is the least commonly used type of cloud, and it involves sharing a given space between several companies with the same security and privacy requirements. It is therefore similar to a shared private cloud. For example, the community cloud built in the USA by the GSA for organizations that depend on the US government [32].

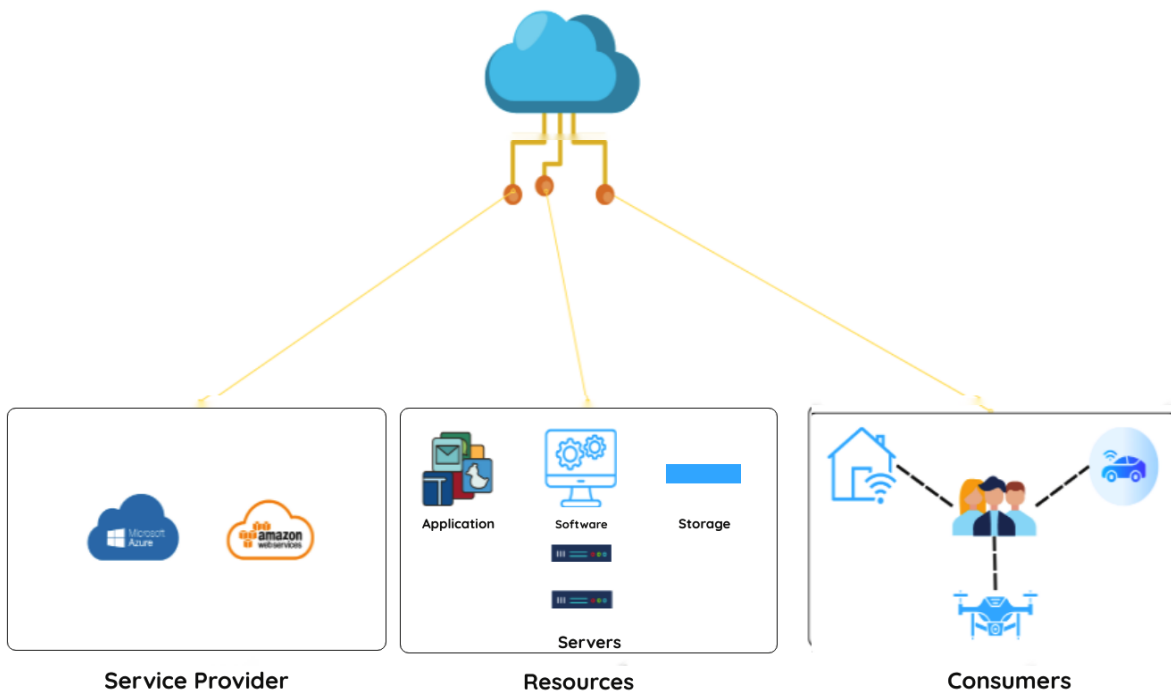


Figure 2.3: Cloud Computing

### 2.4.1 Cloud Computing Service Models

Cloud computing services are offered through three main services. **Infrastructure As A Service (IAAS)**, **Platform As A Service (PAAS)**, and **Software As A Service (SAAS)** as show Figure 2.4.

1. **Infrastructure As A Service : IAAS** refers to on-demand access to computer infrastructure housed in the cloud, including servers, storage space, and networking resources. Customers can deploy, configure, and use **IAAS** resources in a manner similar to how they would use on-premises hardware. The cloud service provider is different in that it hosts, controls, and maintains the computational and physical resources in its own data centers. **IAAS** users access the hardware over an internet connection, and they pay a subscription

or pay-as-you-go fee for doing so [33]. For example, Aws Elastic Beanstalk, Google App Engine, Microsoft Azure App, andHeroku.

2. **Platform As A Service : PAAS** offers a platform in the cloud for creating, running, and managing applications. All of the platform’s hardware and software, including servers (for development, testing, and deployment), operating system software, storage, networking, databases, middleware, runtimes, frameworks, and development tools, are hosted, managed, and maintained by the cloud services provider. They also provide related services for security, operating system and software upgrades, backups, and other things [33]. For example, Google’s AppEngine (Python, Java, Go) , Microsoft Azure App Service, and Firebase.
3. **Software As A Service : SAAS** : Cloud-hosted, ready-to-use application software is known as **SAAS** (sometimes referred to as cloud application services). To use a full program from within a web browser, desktop client, or mobile app, users must pay a monthly or annual price. The **SAAS** vendor hosts and manages the application together with all of the infrastructure needed to deliver it, including servers, storage, networking, middleware, application software, and data storage [33]. For example, BigCommerce, Google Workspace, Salesforce, Dropbox, MailChimp, etc.

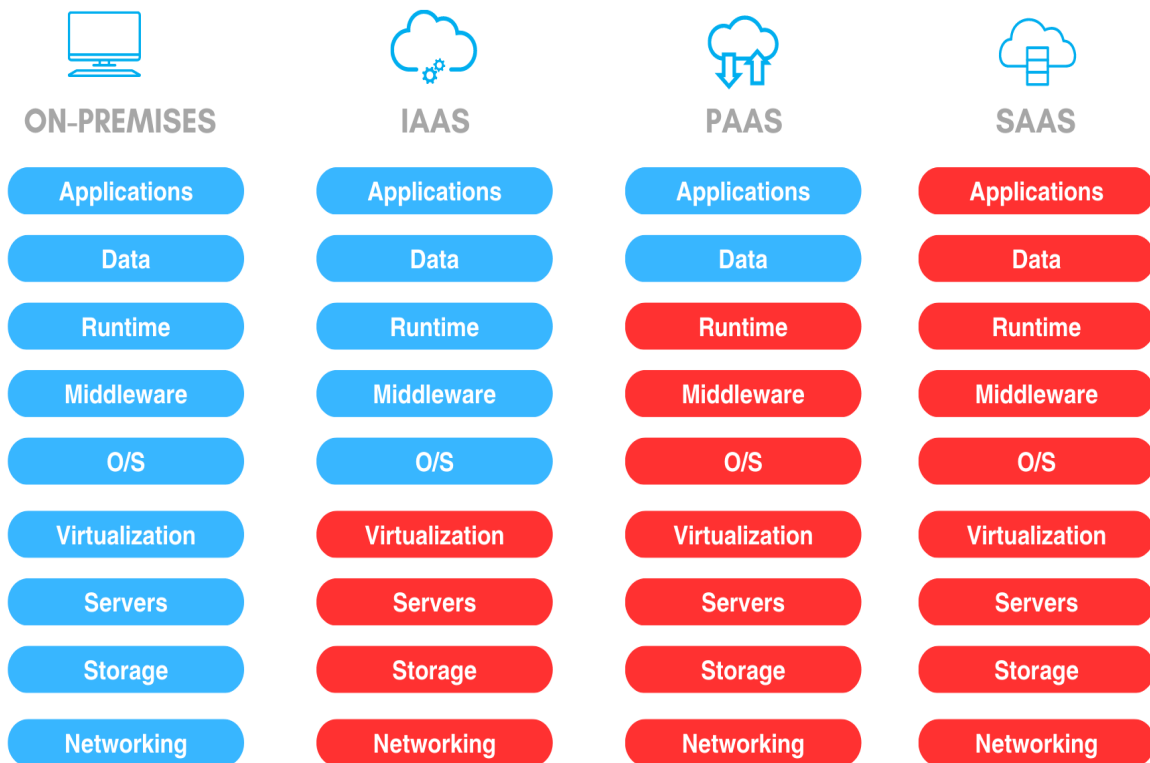


Figure 2.4: Cloud Computing Service Models

In addition, CC includes other services as well such as : Data as a service ,Business Process As A Service (BPAAS), Desktop As A Service (DAAS), Network As A Service (NAAS), Storage as a service and Container As A Service (CAAS).

## 2.4.2 Mobile Cloud Computing

MCC is a combination between cloud computing and mobile devices ,to improve the capabilities of mobile devices such as computing and storage [2]. It interacts with the cloud via web services through nearby base stations behaving like API. The architecture of MCC is presented in Figure 2.5.

## 2.4.3 Edge Computing

The concept of edge computing has evolved over the years, with its roots tracing back to 1998 when Akamai launched the **Content Delivery Network (CDN)** for storage and data marginalization [34]. Since then, related concepts such as cloudlet, MEC, fog computing, and cloud-sea computing have emerged. The term "edge computing" was first proposed in 2013, and various organizations including international standards organizations, enterprises, and academia have defined it.

**Edge Computing (EC)** is a distributed computing model that combines cloud, network and intelligence components [34]. To reduce response time and bandwidth requirements, it combines the computing power, storage, and application resources of edge nodes with distributed cloud computing technology. EC is appropriate for business scenarios such as real-time, short-period data and local decision-making, and it offers efficient capability support for edge applications such as Telematics, intelligent manufacturing, and ultra-high-definition video broadcasting. It is primarily used in IoT architectures to provide efficient and secure services to a large number of end users .

### 2.4.3.1 Mobile Edge computing

MEC is a computing architecture that tends to extend cloud capabilities to the edge of the network , meaning that it makes access to the edge more fast and reliable by making it close to the end user or devices [2]. MEC is capable of doing low latency data processing and analysis that improves mobile applications response time and reduces network latency.

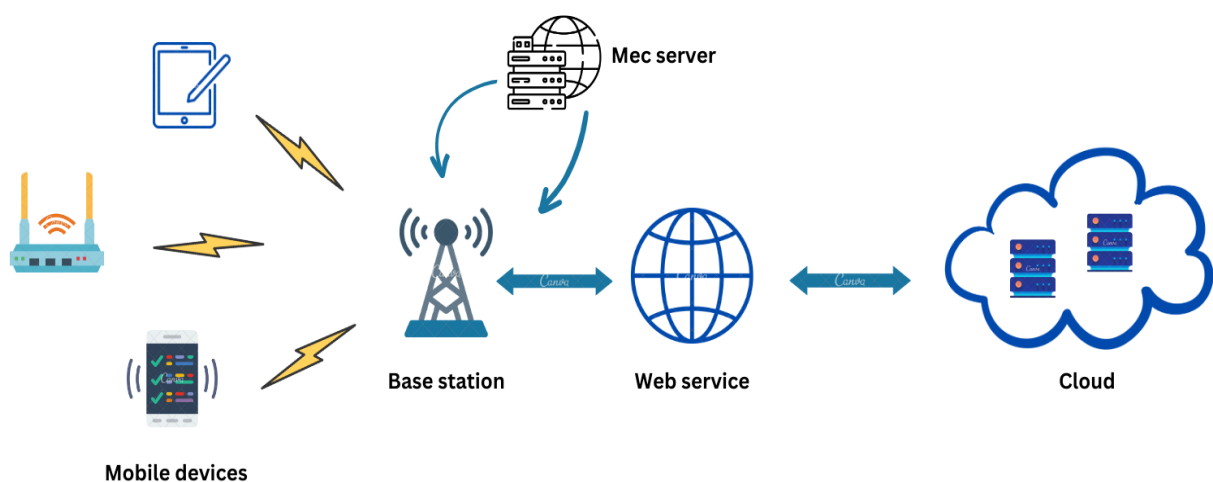


Figure 2.5: The architecture of MCC and MEC [2]

Table 2.1: Comparison of MCC &amp; MEC [2]

	Mobile Cloud Computing	Mobile Edge Computing
Physical Server	High computing and storage capabilities, located in large-scale data centers	Limited capabilities, collocated with base stations and gateways
Transmission distance	Usually far from users, from kilometers to thousands of kilometers	Quite close to users, from tens to hundreds of meters
System architecture	sophisticated configuration, highly centralized	Simple configuration, densely distributed
Application characteristics	Delay tolerant, computation intensive, e.g., Facebook, Twitter	Latency sensitive, computation intensive, e.g., autonomous driving, online gaming

### 2.4.3.2 Mobile Edge computing Architecture

The MEC architecture consists of several components, as illustrated in Figure 2.6.

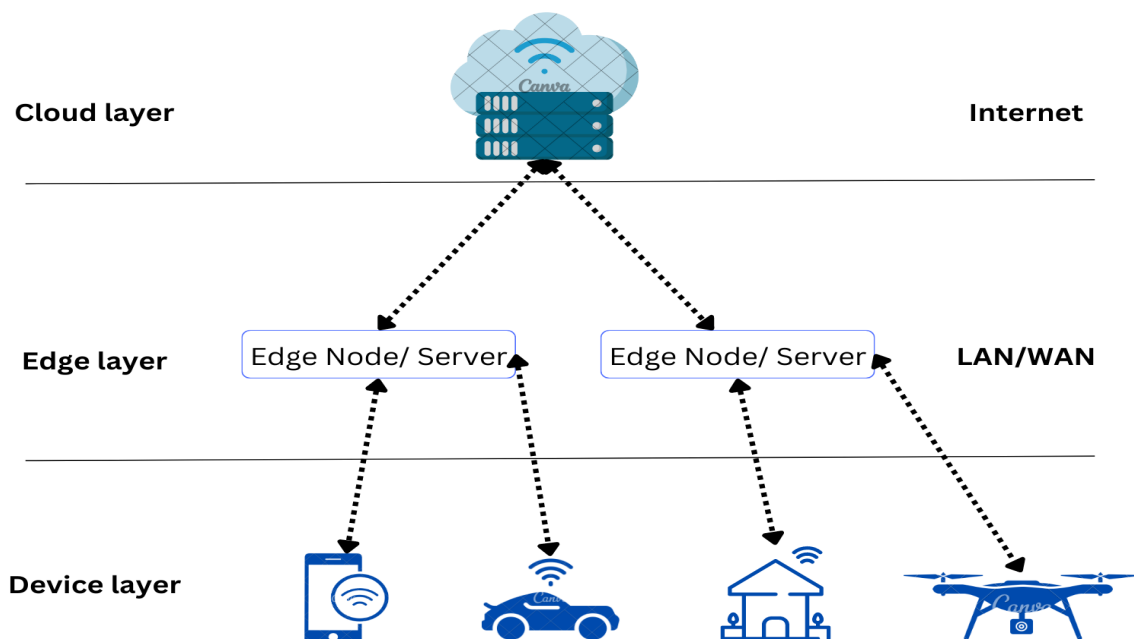


Figure 2.6: MEC Layers

The first layer that initiates the process is called Device Layer that contains mobile devices including sensors and controllers. These devices communicate with the Edge Layer via network, on the other hand the edge servers are deployed at the edge of the network, closer to the users where they will be responsible on Data processing, reduction, data caching, and buffering.

To support the MEC servers with computing resources and storage a cloud infrastructure is required.

## 2.5 Smart Home

Smart home is a living environment that uses technology to control its devices and appliances remotely or automatically [35]. These devices can be controlled through the Internet with applications or locally with an interface. The sensors used in homes connect in predefined protocols [35] using the idea of IoT.

### 2.5.1 Internet Of Things and Cloud Computing in Smart Home

The usage of IoT devices and CC has revolutionized the concept of a smart home system. While Cloud usage enables smart homes to store data and operate functions on remote servers, allowing for greater flexibility and scalability of services, the IoT technology can be used in many systems, as it enables various devices and appliances to connect and communicate with each other as shown in Figure 2.7.



Figure 2.7: Smart Home appliances

1. **Remote control** : From any location with an Internet connection, homeowners may use their smartphones, tablets, or computers to remotely control the electronics and appliances in their smart homes.
2. **Automation** : Based on predetermined conditions or timetables, smart home devices can automate normal operations like turning off lights, adjusting thermostats, or locking doors.

3. **Energy efficiency** : Smart home devices can help homeowners reduce their power costs by monitoring and modifying energy usage in real-time.
4. **Security** : By enabling homeowners to remotely monitor their houses and receive notifications in the event of any suspicious activity, smart home devices can boost security.

Overall, the usage of **IoT** devices and **CC** in smart home systems has transformed the way we interact with our homes, making them more convenient, efficient, and secure.

## 2.6 Conclusion

This chapter provides an introduction to the **IoT**, **CC**, and **EC**, and their applications in smart homes as it describes the network, service, and interface layers of the **IoT** architecture, while showing the **IoT**'s different applications. The next chapter will present and analyze the existing smart home systems and introduce our targeted **IoT** System.

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## 3.1 Introduction

The state of the art regarding smart homes is constantly evolving and expanding, with new technologies and applications being developed regularly. As smart homes become more mainstream, they have the potential to enhance the comfort, convenience, and security of households, while also reducing energy consumption and environmental impact. Along with this chapter, we start with the presentation of some works and applications made around smart homes. Then, we briefly summarise the different recent works on smart home fields. We also present the design of our system, starting with our system presentation, followed by the modeling of our application. To achieve this, we utilized three [Unified Modeling Language \(UML\)](#) diagrams: the use case diagram, the sequence diagram, and the class diagram. These UML diagrams serve as powerful tools for modeling our system, capturing its functionalities, data flow, and structural components.

## 3.2 History

Smart homes have their roots in science fiction literature where they were portrayed as theoretical and visual concepts before becoming practical in the early 20th century. The

vacuum cleaner, dryer, washing machine, iron, and toaster were all invented with the intention of making life easier. The concept of modern home automation systems can be traced back to the World's Fairs of the 1930s [36].

Although many of us will be vaguely familiar with the term “smart house”, few of us will have a very concrete understanding of what it means. It was first used in an official way as long ago as 1984 by the American Association of House Builders, though the first “wired homes” were actually built by hobbyists in the early 1960s [37]. The INTEGER Millennium House was constructed in Watford, England in 1998 with the intention of exhibiting numerous intelligent home automation technologies, such as a building management system. This system had the ability to enhance the performance of the heating system, as well as automate the garden irrigation system based on soil humidity levels. Furthermore, the management system featured a sophisticated security system, lighting that could be adjusted to one of four predetermined moods, and programmable door keys embedded with microchips [36].

Today, smart home technology continues to evolve rapidly, with new devices and systems being developed all the time. The IoT has made it possible for a wide range of devices, from smart thermostats to smart locks, to be connected to the Internet and controlled remotely. As technology advances and becomes more affordable, it's likely that smart homes will become even more common in the years to come.

### 3.3 Smart Home : Related work

We classify IoT-based smart home approaches into: (i) Non-cloud-based applications and (ii) cloud-based applications.

#### 3.3.1 Non-cloud-based applications

The architecture of local or on-premises smart home systems is designed to operate within a home without the need for an Internet connection or a connection to a cloud server. These systems are often referred to as "local" or "on-premises" smart home systems. They allow homeowners to control smart devices, such as lighting and heating, through a smart home app on their smartphone or other networked device [38]. Typically, these systems are composed of three essential elements (1) devices, (2) hub/controller, and (3) user interface, as illustrated in Figure 3.1.

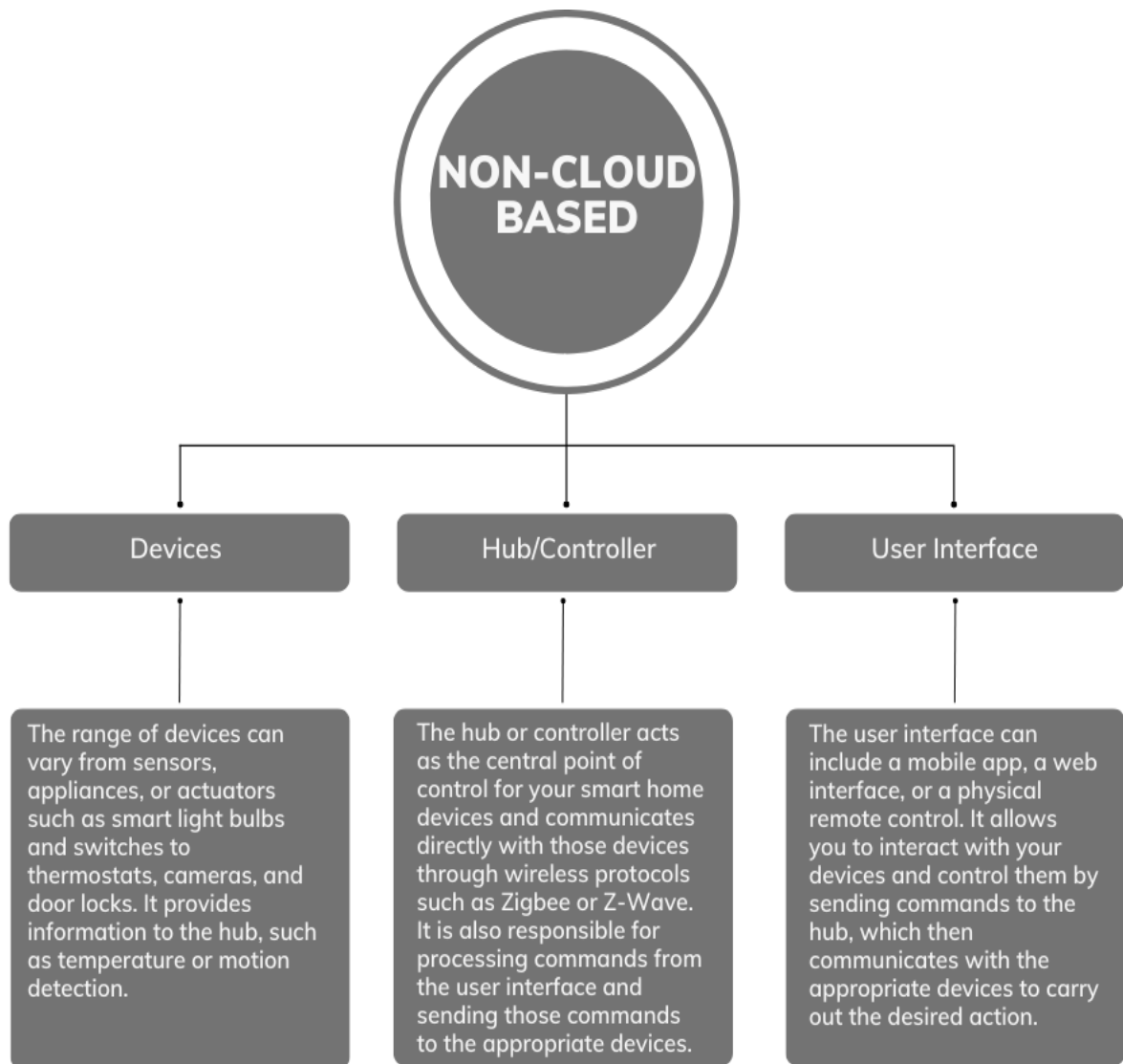


Figure 3.1: Non-Cloud Based Architecture

In the research literature, many smart home systems are presented that not need the cloud to enable remote access and control. For instance.

1. **Home Assistant :** Home Assistant is an open-source home automation system built on Python that allows users to control and monitor their smart home devices from a single interface [3, 39]. It runs on a variety of platforms, including Raspberry Pi, Docker, and cloud-based services. Home Assistant can be extended with components, each responsible for a specific domain within Home Assistant. The architecture of Home Assistant is an embedded system that provides an experience like other consumer off-the-shelf products. Home Assistant core and its integration are written in the Python programming language. The system architecture of Home Assistant is shown in Figure 3.2. Home Assistant aims to be a controller hub where users can monitor and control all the IoT devices in their home.

The system is highly customizable and extensible, allowing users to integrate a wide range of smart devices and services, such as lights, sensors, thermostats, cameras, and

more. Home Assistant uses a combination of local and cloud-based integrations to connect with these devices, and supports a variety of communication protocols including Wi-Fi, Bluetooth, Zigbee, and Z-Wave [39].

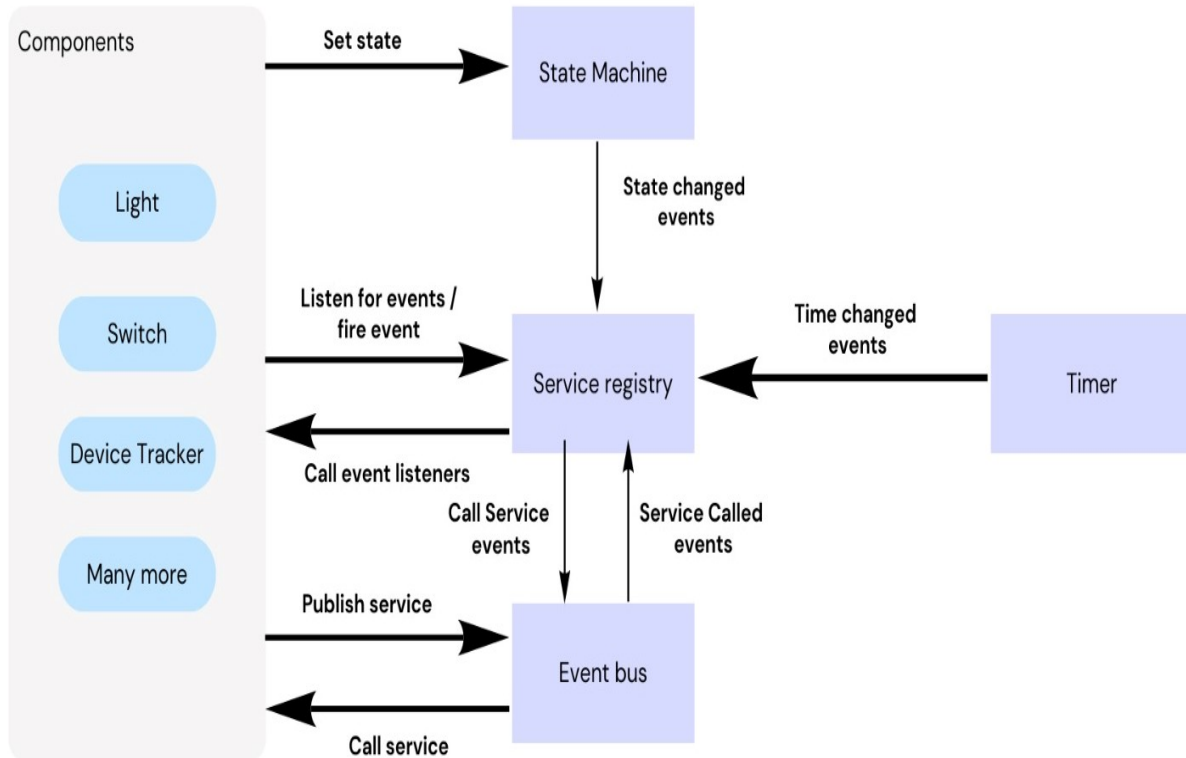


Figure 3.2: Home Assistant core system architecture [3]

Overall, Home Assistant is a flexible and powerful system that can help users simplify and streamline their smart home experience, while providing them with granular control over their devices and data.

2. **OpenHAB** : OpenHAB is an open-source home automation platform that runs locally on your network, it's based on the Eclipse SmartHome framework and developed in Java. It supports a wide range of devices and protocols, and we can control the smart home using mobile app or web interface [4, 40]. OpenHAB is customizable to interact with our smart home apps and devices as shown in Figure 3.3, allowing end-users to have greater control over their environment. OpenHAB is a free and open-source solution for the smart home that doesn't require any cloud service to work, keeps your data privately at home, and talks directly to your local devices whenever. It can be installed and configured on your personal computer by using a Raspberry Pi and the OpenHABian image, allowing you to launch a user interface dashboard. Through this dashboard, you can customize your smart home automation by installing the necessary add-ons to provide additional

functionality. The dashboard also allows you to configure your smart home automation according to your preferences.

OpenHAB supports a wide range of protocols and technologies, including Z-Wave, ZigBee, KNX, Modbus, MQTT, and more. This allows users to integrate devices from different vendors and technologies into a single system. OpenHAB also provides a range of plugins and add-ons to extend its functionality and enable users to integrate with popular services like IFTTT, weather services, and more [40].

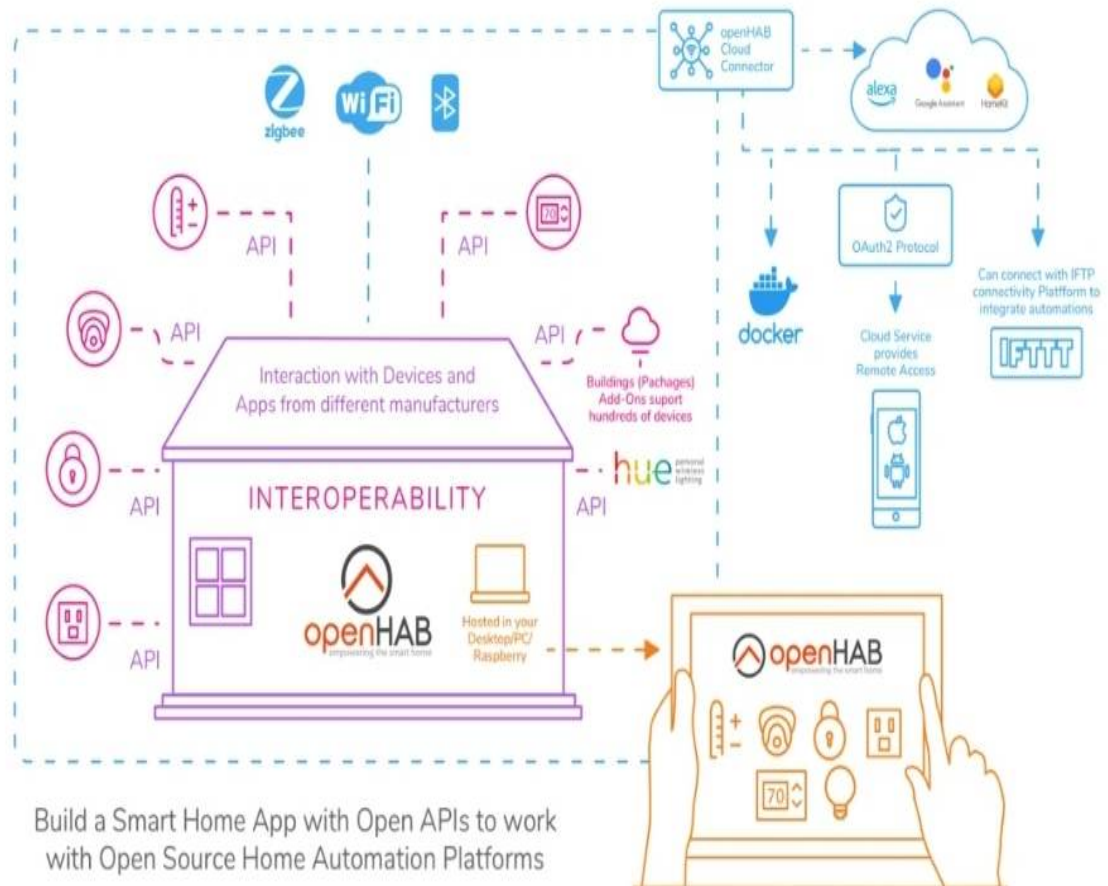


Figure 3.3: OpenHAB's interoperability [4]

Overall, OpenHAB is a powerful and flexible smart home system that provides users with the ability to control and automate various devices and systems within their homes through a single, customizable interface.

3. **Traditional gas sensors (Local)** : The government of Algeria has announced a plan to equip most homes in the country with gas detectors, in collaboration with the Sonelgaz company. Traditional gas detectors, depicted in Figure 3.4, are designed to identify specific types of gases and activate audible or visual alarms upon detection. They are commonly utilized in residential and commercial buildings to provide timely alerts for potential gas leaks or hazardous conditions. However, these detectors have limitations that impact their effectiveness, such as the need for regular maintenance and calibration,

which can be time-consuming and costly. Additionally, they exhibit a delayed response time, which increases the risk of accidents or damage.



Figure 3.4: Gas sensor [5]

- **Advantages :**

- **No Dependence on the Internet:** Local smart home systems do not require an Internet connection to function, which means that even if there is an outage, the system will still operate normally.
- **Increased privacy and better security:** Since local smart home systems are not connected to the internet, the data collected by these systems remains within the home and a data is not shared with any third-party services.
- **The software architecture of local smart home systems is often open-source,** meaning that users can modify and customize the code to suit their needs. This allows for a greater degree of flexibility and control over your smart home system, as well as the ability to integrate with other systems and services.

- **Drawbacks :**

- **Limited Functionality:** Local smart home systems are typically limited in terms of functionality and do not offer the same range of features as their Internet-connected counterparts.
- **Lack of Remote Control:** Due to the absence of internet connectivity, local smart home systems generally do not offer remote control capabilities. As a result, when you are away from home, you won't be able to remotely control your smart home devices.

### 3.3.2 Cloud-based applications

Smart home systems that utilise the cloud require Internet-based servers and services to effectively manage and control connected devices within the household. The architecture of such systems is specifically designed to enable remote access and control of smart devices from anywhere” “ with an Internet connection [41]. Generally, these systems comprise of three primary components: (1) smart device, (2) cloud infrastructure, and (3) use interface as shown in Figure 3.5.

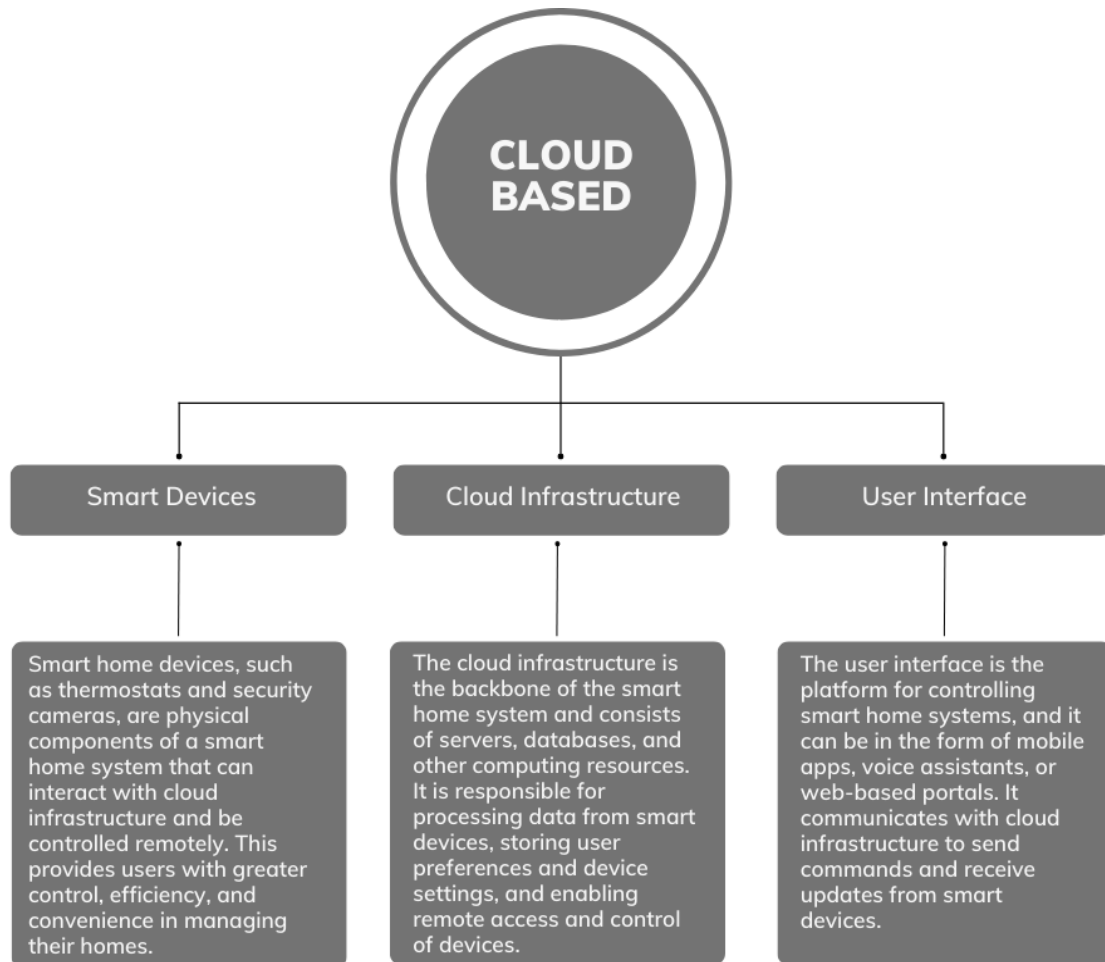


Figure 3.5: Cloud Based Architecture

Overall, the architecture of a cloud-based smart home system is designed to be flexible, scalable, and highly available. It can support a wide range of smart devices from different manufacturers and allows users to add and remove devices as needed. Additionally, the cloud infrastructure is designed to be resilient, ensuring that users can always access and control their smart devices, even in the event of a hardware failure or network outage [41].

There are many smart home systems that use the cloud to enable remote access and control. For instance.

1. **Samsung SmartThings** : Samsung SmartThings is a popular smart home system that incorporates cloud-based technology in its [App](#). The SmartThings [App](#) acts as a central

hub for users to control and monitor their smart home devices, regardless of the brand or manufacturer. The [App](#) utilises cloud technology to enable remote access and control of smart home devices from anywhere with an Internet connection [42].

The architecture of the SmartThings [App](#) is built on a cloud-based platform that uses a combination of software and hardware components to provide advanced smart home functionality. Here are the main components of the architecture.

- (a) **SmartThings Hub** : This is the physical device that connects to the Internet and communicates with smart home devices using a variety of wireless protocols, such as Wi-Fi, Zigbee, and Z-Wave [42].
- (b) **Cloud infrastructure** : The SmartThings cloud infrastructure consists of servers, databases, and other computing resources that receive and process data from the SmartThings Hub and connected devices. The cloud infrastructure is responsible for storing user preferences and device settings, enabling remote access and control of the devices, and providing data analytics and machine learning capabilities [42].
- (c) **The User Interface** : The SmartThings [App](#) is the [User Interface \(UI\)](#) that allows users to control and monitor their smart home devices. The [App](#) is available on both iOS and Android devices and provides an easy-to-use interface for managing devices, creating custom routines and automations, and receiving notifications [42].
- (d) **Smart home Devices** : These are the physical devices that make up the smart home system and are designed to be connected to the SmartThings Hub. Examples include smart thermostats, smart lighting, and smart security cameras [43].

The [App](#) and cloud infrastructure of SmartThings offer flexibility and scalability, enabling users to easily add or remove devices as needed. The [App](#) supports a variety of smart devices from different manufacturers, making it easy to create a personalised smart home system. The SmartThings Cloud service is an open ecosystem that works with a wide range of connected devices, not just Samsung devices [42]. The cloud infrastructure is designed to be highly available and resilient, ensuring that users can always control their smart devices, even during hardware failure or network outages. The SmartThings Cloud provides a single point of control for all gadgets, making it more convenient for users. Samsung has announced that SmartThings IoT platform supports edge computing, which has revolutionised the way data is generated, processed, managed, and exchanged among devices [44].

2. **Netatmo** : Netatmo is a smart home company that offers a range of cloud-based devices and applications for home automation. The Netatmo [App](#) serves as a central hub for users to control and monitor their smart home devices, and it utilises cloud technology to enable remote access and control of smart home devices from anywhere with an Internet connection [45].

The architecture of the Netatmo [App](#) is built on a cloud-based platform that uses a combination of software and hardware components to provide advanced smart home functionality. Here are the main components of the architecture :

- (a) **Netatmo Hub** : This is the central device that connects to the Internet and communicates with smart home devices using various wireless protocols such as Wi-Fi and Bluetooth [45].

- (b) **Cloud infrastructure** : The Netatmo cloud infrastructure consists of servers, databases, and other computing resources that receive and process data from the Netatmo Hub and connected devices. The cloud infrastructure is responsible for storing user preferences and device settings, enabling remote access and control of the devices, and providing data analytics and machine learning capabilities [45].
- (c) **The User Interface** : The Netatmo [App](#) is the user interface that allows users to control and monitor their smart home devices. The app is available on both iOS and Android devices and provides an easy-to-use interface for managing devices, creating custom routines and automations, and receiving notifications [45].
- (d) **Smart Home Devices** : These are the physical devices that make up the smart home system and are designed to be connected to the Netatmo Hub. Examples include smart thermostats, smart lighting, and smart security cameras [43].

The Netatmo [App](#) and cloud infrastructure are designed to be flexible and scalable, allowing users to add and remove devices as needed. The app supports a wide range of smart devices from different manufacturers, making it easy to build a customised smart home system. The cloud infrastructure is also designed to be highly available and resilient, ensuring that users can always access and control their smart devices, even in the event of a hardware failure or network outage [45].

- **Advantages** :

- Remote Access: Smart home systems based on cloud computing allow users to access and control their devices from anywhere in the world. This is because the devices are connected to the cloud, which allows users to remotely control them using a mobile app or web portal.
- Scalability: Cloud-based smart home systems can be easily scaled up or down to accommodate changes in the number of devices and users. This means that as a homeowner adds more devices to their smart home.

- **Drawbacks** :

- Dependence on Internet: Cloud-based smart home systems rely heavily on the internet. If the internet connection is lost or unstable, the devices may not work properly or may not work at all.
- Privacy and security Concerns: Smart home devices that rely on cloud computing may raise privacy concerns because they collect and store personal data in the cloud. This data may be vulnerable to hacking or other types of cyber-attacks, which can compromise the privacy of homeowners.
- Latency: The response time of cloud-based smart home devices may be slower due to the latency caused by the communication between the device and the cloud server. This delay can be noticeable, especially when controlling devices in real-time.

## 3.4 Comparison and summary

In summary, the chapter discusses the different approaches to implementing IoT in smart homes, focusing on two main architectures: local or on-premises systems without the cloud and

cloud-based systems. Local or on-premises systems provide homeowners with more control, privacy, and independence from the internet, while cloud-based systems offer remote access, scalability, and a wider range of features and device compatibility. The choice between these architectures depends on individual preferences regarding functionality, privacy, and convenience.

## 3.5 Conception of our targeted IoT System

### 3.5.1 System Presentation

Introducing **MobiGaz** a cutting-edge gas leak detection system, which is a revolutionary solution designed to ensure the safety and well-being of individuals and their surroundings.

Our system offers a wide range of advanced features that ensure the utmost safety and convenience for users. Firstly, it offers real-time monitoring of gas levels, providing continuous and up-to-date information about the environment's safety. This allows users to stay well-informed and take immediate action if necessary. In the event of a gas leak, the system activates immediate alerts through various channels, guaranteeing prompt notification and enabling swift response. The user-friendly interface simplifies the monitoring and control of the system, ensuring effortless navigation and ease of use.

### 3.5.2 A global view of the main architecture

Our system architecture, as illustrated in Figure 3.6, is designed to enable seamless communication between heterogeneous sensors within each home, all connected to the **Wi-Fi** network. Each home is assigned a dedicated session on Cloud, where a single document is created to store the user's data and a comprehensive list of devices associated with that particular home.

In the event of a gas leak detection, the responsible sensor captures the alert data and sends it to the cloud, specifically to the corresponding house document. This ensures that the relevant information is centralized and readily accessible.

Once received, the cloud triggers an immediate notification or alert, which is then sent to the user's smartphone through our mobile app. This allows the user to promptly take action, either by intervening directly or by contacting the local authorities for assistance.

By leveraging this architecture, we ensure efficient data management, real-time alerts, and seamless communication between the sensors, cloud, and user devices. This robust system empowers users to swiftly respond to gas leak incidents, enhancing safety measures and mitigating potential risks in their homes.



Figure 3.6: The main architecture

### 3.5.3 Conception

We chose three [UML](#) diagrams to model our system:

- **Use case diagram.**
- **Sequence diagram.**
- **Class diagram.**

#### 3.5.3.1 Use Case Diagram

It illustrates the essential functionalities (use cases) required by the users. A use case diagram can be formulated for the entire system or for individual sections of the system [46].

- **Actors of our system:** The system involves five main actors, User, Administrator, Sensor, Cloud server, and Mobile App. Each actor has specific roles and responsibilities within the system. .
- **Description of use case diagram of our system:** Users can request installation or authenticate themselves to access the system and can check gas percentages, add devices, and

receive notifications. Administrator manage users, handle system installation requests, and view statistics. Sensors detect gas leaks, trigger buzzers, and store data in the cloud server. The cloud server reads sensor events and sends data to the mobile App, while the App notifies users about events.

Following diagram (Figure 3.7) illustrates overall use case of our system.

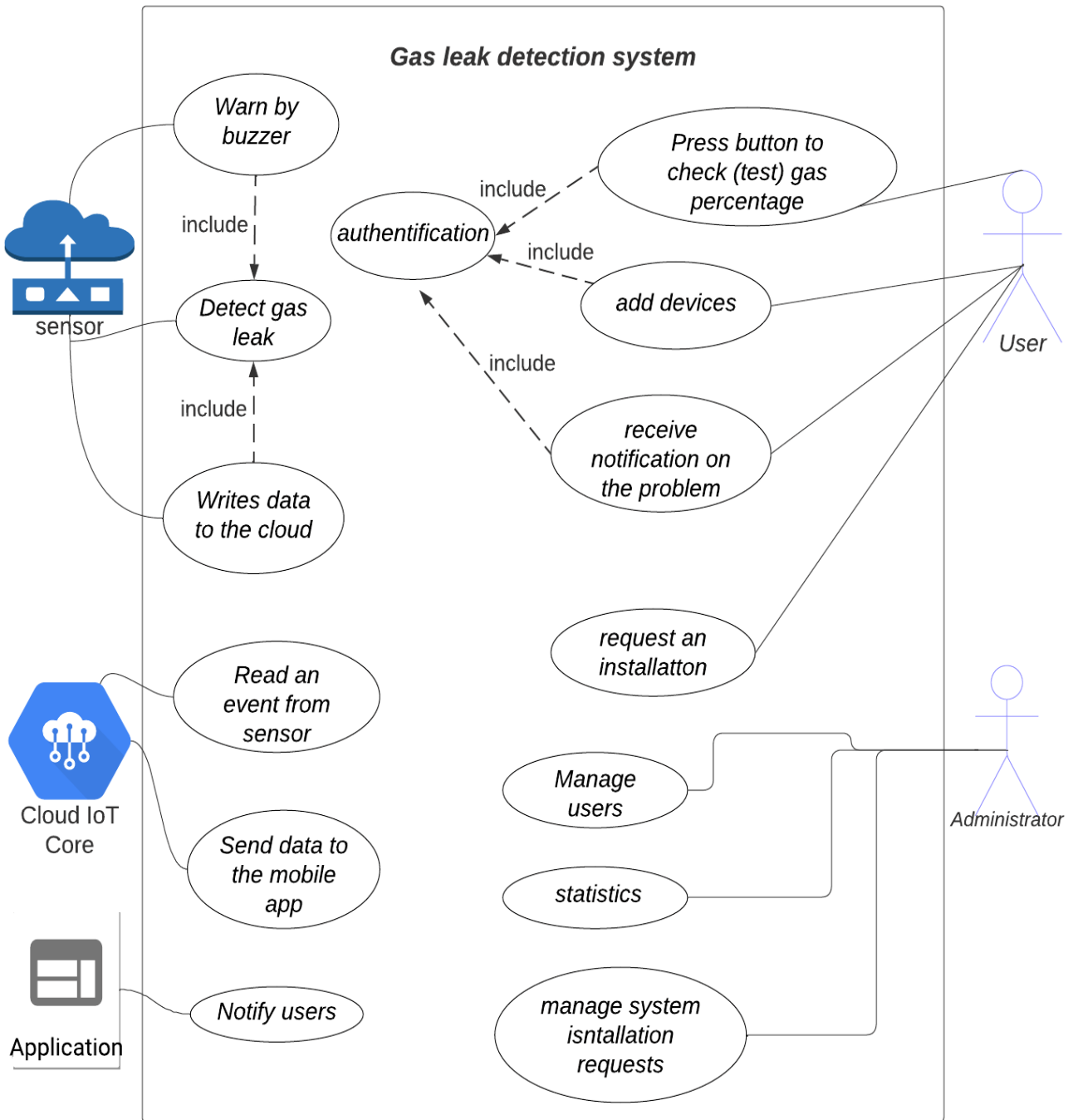


Figure 3.7: Use case diagram

### 3.5.3.2 Sequence Diagram

Sequence diagrams serve as a method to document the possible scenarios linked to each use case described within the system [46]. Figures 3.8 ~ 3.11 show the sequence diagrams of our application.

- Scenario "Installation request"

If the user does not possess an account and intends to access the installation request page. The application requests the user to input the necessary fields. Subsequently, the user enters the essential information. The application then validates the provided details. In the absence of any errors, the request process is deemed successful, and the user's information is securely stored in the database. Otherwise, an error message is displayed.

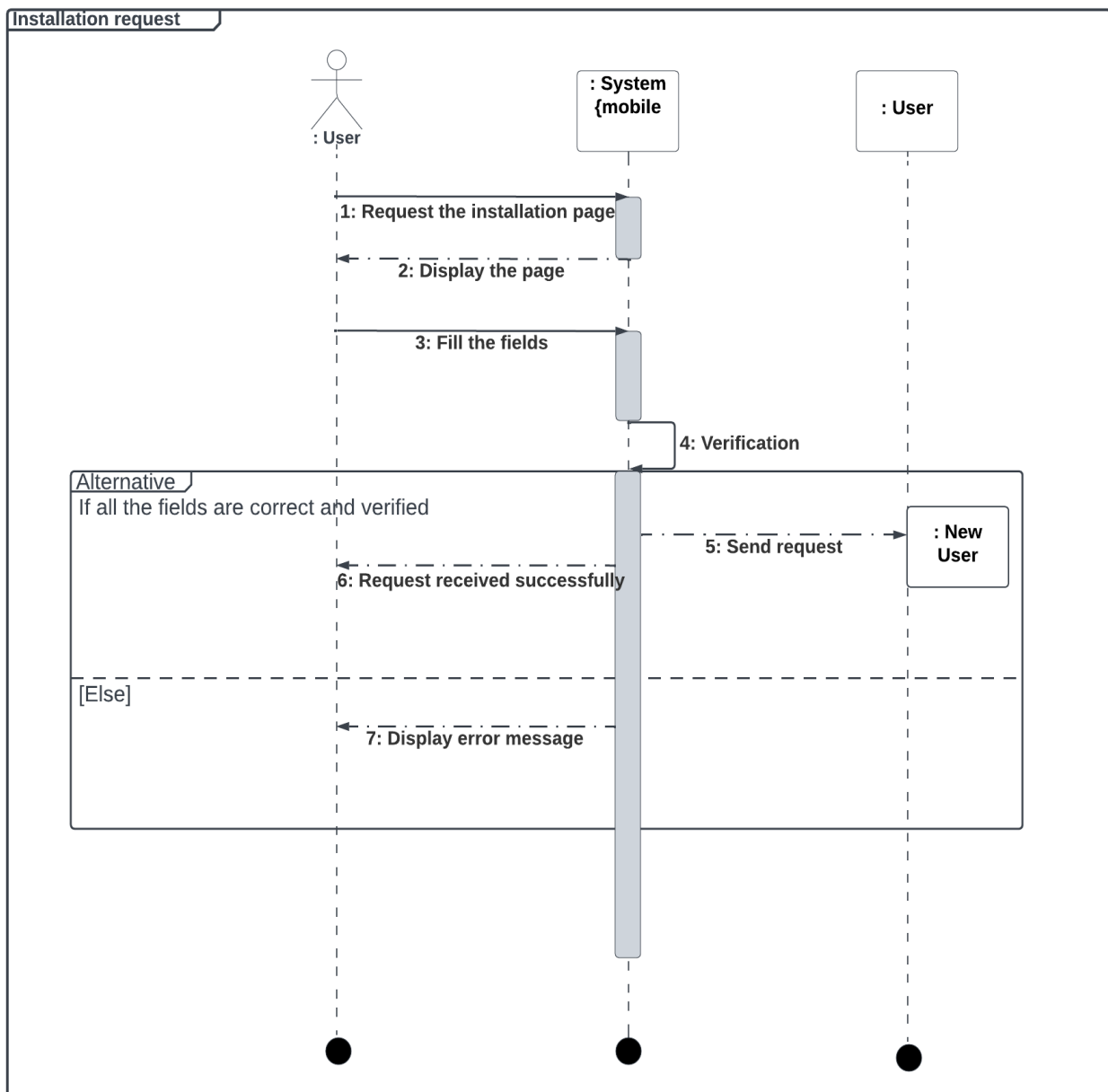


Figure 3.8: Sequence diagram "Installation request"

- Scenario "User authentication" :

The user desires to access the application. The application initiates an authentication request to the user. The user provides the necessary information. Subsequently, the application validates the entered information. If no errors are detected, the user will be granted access. However, if any errors are identified, an error message will be shown.

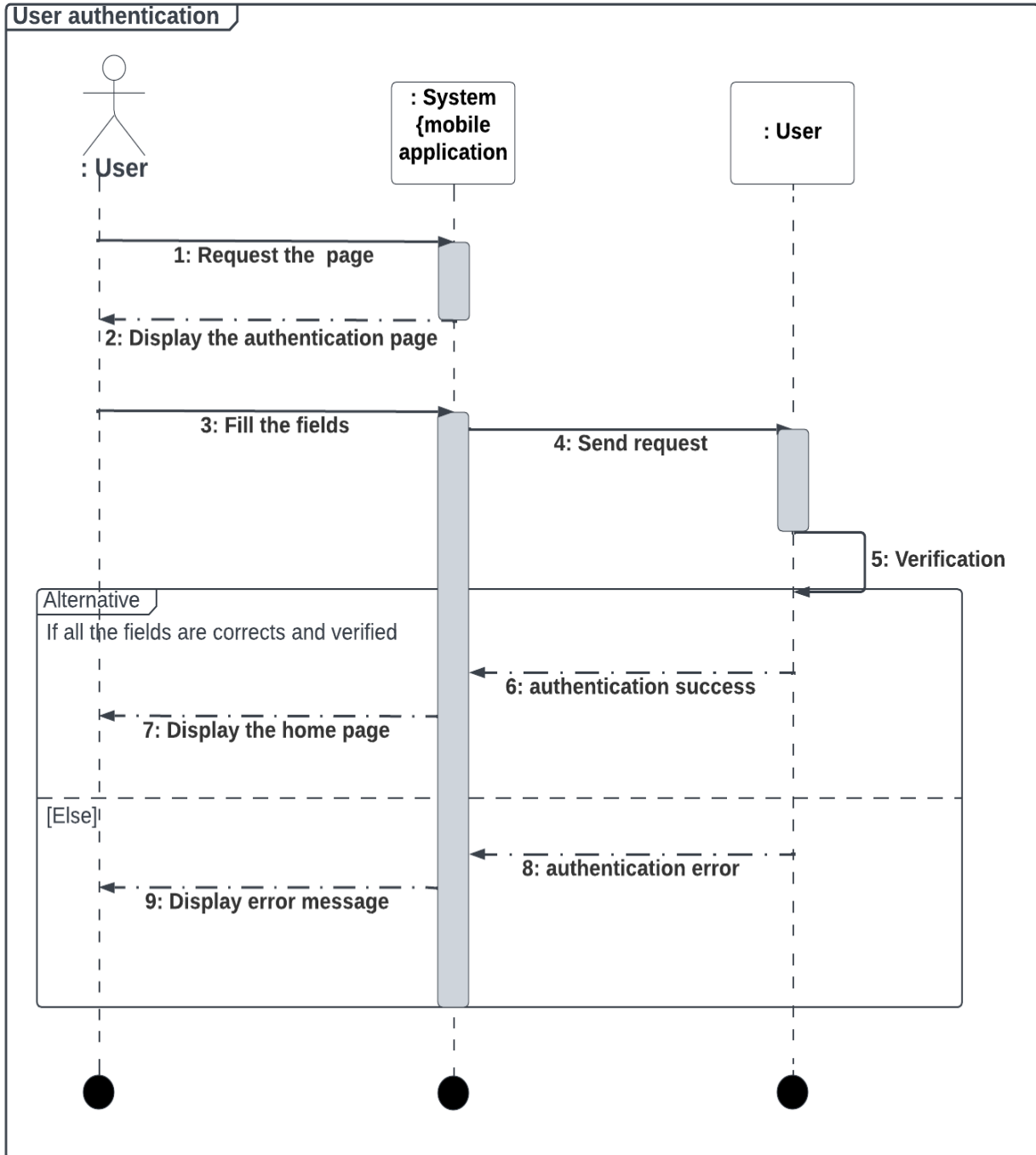


Figure 3.9: Sequence diagram "User authentication"

• Scenario "Add device"

After the user successfully completes the authentication process, they gain access to the device addition page. Upon initiation, the user proceeds to scan the Quick Response (QR) code of the device. The application then verifies the scanned code. If no errors are detected, the new device is successfully added and stored in the database. However, if any errors occur, an error message is promptly displayed.

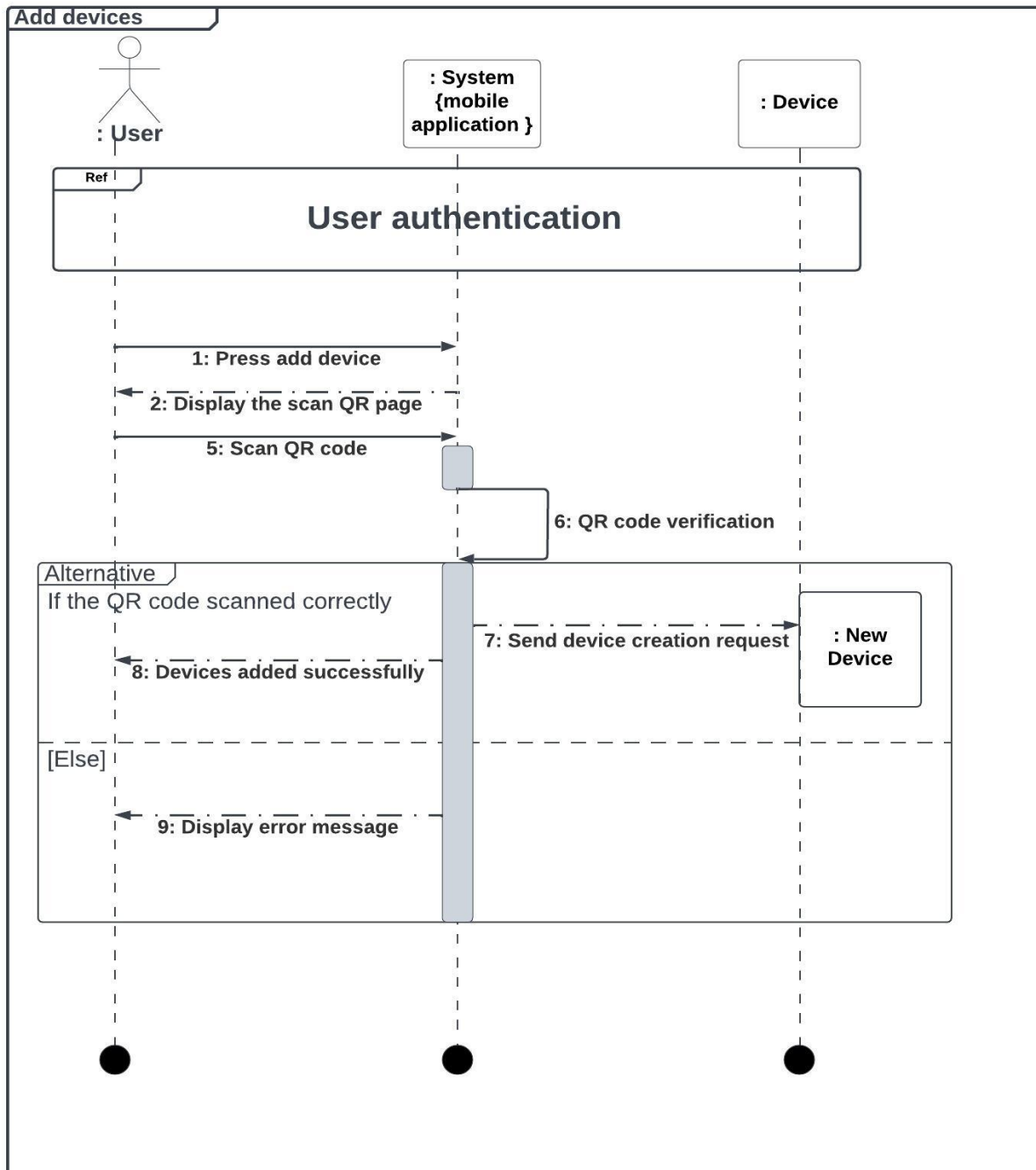


Figure 3.10: Sequence diagram "Add device"

- Scenario "Gas detection"

In the event that a gas leak is detected by one of the sensors, it transmits the data to the server to update the device status, which in turn notifies the mobile application. This allows the user to promptly become aware of the incident and take immediate action in real-time.

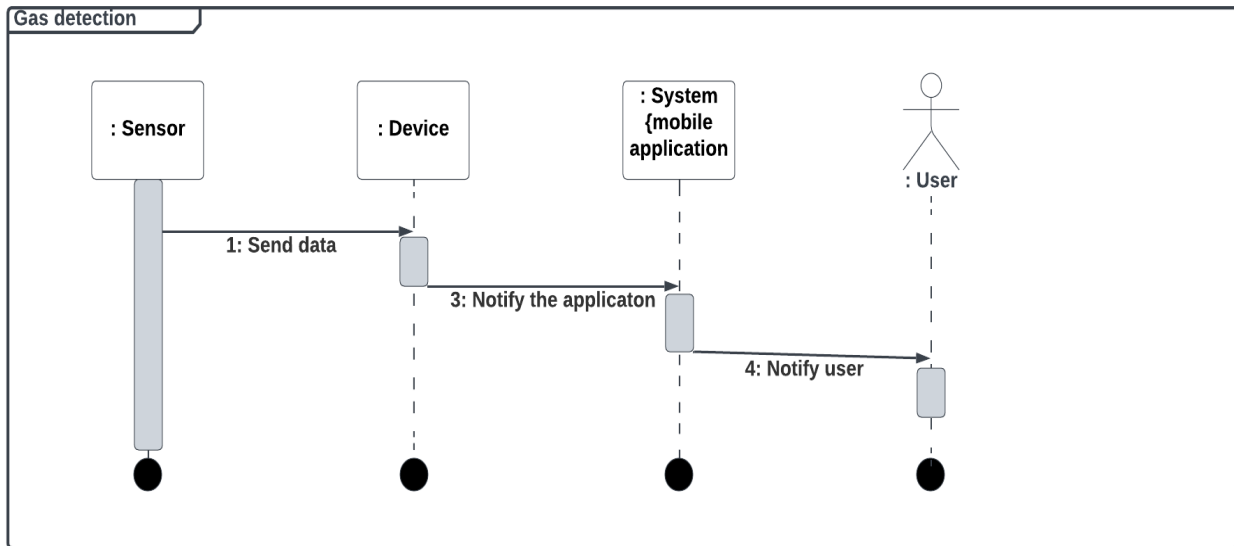


Figure 3.11: Sequence diagram "Gas detection"

### 3.5.3.3 Class diagram

In the analysis phase, this diagram depicts the entities (information objects) that users manipulate. In the design phase, it represents the object structure of an object-oriented development [46].

The Smart Gas Detection System has three main classes: User, Device, and Administrator.

- The Administrator class represents an administrator of the system. He possesses certain attributes such as a username, email, and password. They have the ability to add, remove, and update users, as well as manage installation requests.
- The User class symbolizes a customer with attributes such as username, email, password, and phone number. It provides methods for authentication, device management, registration, status checking, and installation requests.
- The Device class stands for a device with attributes such as ID, name, location, and device status. It provides methods for adding, deleting, updating the device, sending alerts, and retrieving or setting device values

The relationships between the different classes of the application are showing in Figure 3.12.

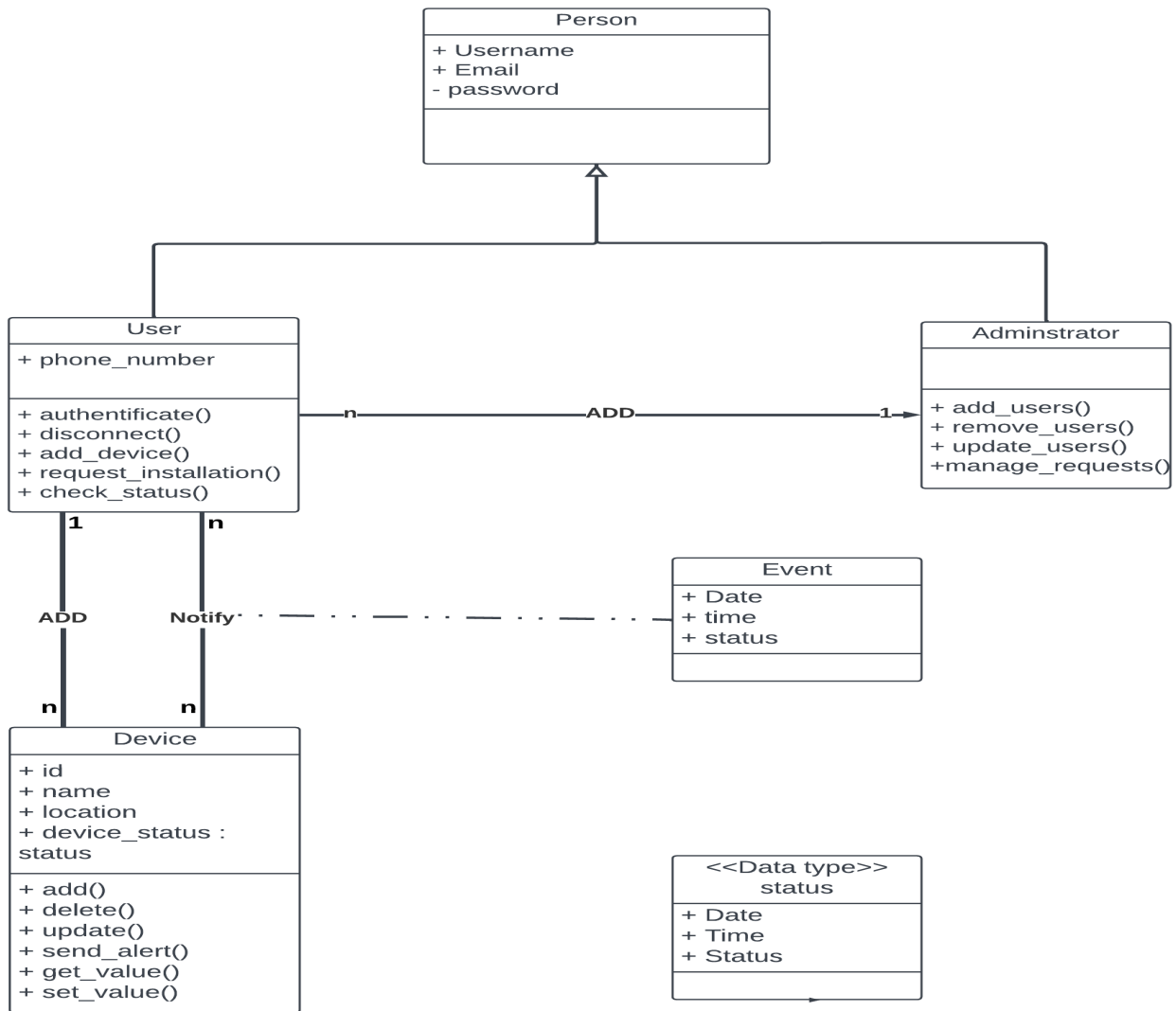


Figure 3.12: Class diagram

### 3.6 Conclusion

In this chapter, we presented some systems made around smart homes and we employed various diagrams, including use case diagrams, sequence diagrams, and class diagrams, utilizing UML to simplify and facilitate the implementation phase. These diagrams have allowed us to effectively illustrate the structure and behavior of our system, aiding in the development process. Moving forward, we will proceed to the implementation phase, utilizing the insights gained from this chapter. By adhering to the design principles outlined here, we are confident in our ability to create a robust and efficient IoT system that fulfills the requirements of a smart home system.

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## 4.1 Introduction

To ensure the successful execution of an IoT system, it is crucial to choose technologies that streamline its implementation. To accomplish this, once the conceptual study has been completed in the preceding chapter, we will now proceed to the implementation phase. Our initial step involves illustrating the deployed hardware and software tools, which provides us with an array of implementation tools. Subsequently, we will outline the different stages of functionality within our system.

## 4.2 Used tools

To implement our system, we require a set of hardware and software tools. We have selected specific modules, sensors, a programming language, and an [Integrated Development Environment \(IDE\)](#) for this purpose.

### 4.2.1 Hardware

#### 1. IoT nodes

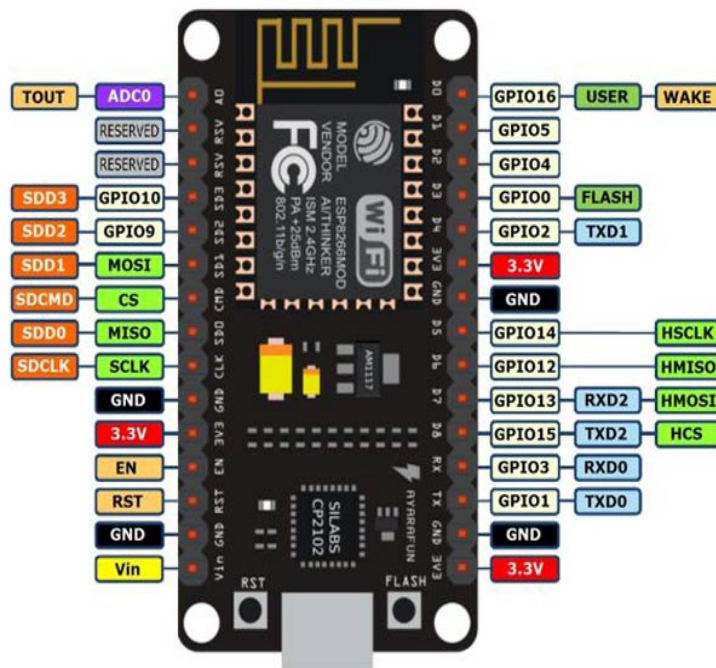
- **ESP8266 NodeMcu :**

The NodeMCU ESP8266 is a development board and firmware created with a specific focus on IoT applications. It functions on an open-source platform, granting users

the ability to access and customize its firmware [6]. This development board presents an economical choice for Do It Yourself (DIY) IoT and home automation projects by merging Wi-Fi capabilities with input/output control, making it one of the most affordable options available [47].

Here are some important features and specifications of the NodeMCU ESP8266:

- **Hardware** : The NodeMCU ESP8266 is built around the ESP-12 module, which houses the ESP8266 chip. This chip utilizes the Tensilica Xtensa 32-bit LX106 **Reduced Instruction Set Computer (RISC)** microprocessor. The microprocessor supports **Real Time Operating System (RTOS)** and can operate at an adjustable clock frequency ranging from 80MHz to 160MHz. The NodeMCU also includes 128 KB of RAM and 4MB of Flash memory [6, 48].
- **Peripherals** : The NodeMCU ESP8266 supports a variety of peripherals including I/O as shown in Figure 4.1, SPI, I2C, I2S, SPI, UART, and ADC. These peripherals allow for seamless integration with other devices and components [6].
- **Programming** : The NodeMCU ESP8266 can be programmed using the popular **Arduino IDE** programming environment. This familiar programming interface simplifies the development process for users who are already familiar with the Arduino ecosystem [6].
- **Applications** : The NodeMCU ESP8266 is well-suited for **IoT** applications, home automation projects, and various **DIY** endeavors. Its versatility makes it suitable for a wide range of projects and its affordability makes it an attractive choice for hobbyists and enthusiasts [6].



While our sense of smell is limited in identifying specific types and quantities of gas, specialized gas sensors play a vital role in detecting gas leaks. These sensors, such as the MQ gas sensor series, are capable of identifying and classifying different gas types including alcohol, smoke, methane, LPG, hydrogen, NH<sub>3</sub>, benzene, and propane. These sensors rely on estimating gas concentrations and identifying explosive or dangerous gases [49].

The MQ sensor family includes various gas sensors with specific functions:

- **MQ-2** : This sensor is sensitive to gases such as LPG, propane, hydrogen, and methane. It is commonly used for detecting flammable gases [49].
- **MQ-3** : This sensor is designed to detect alcohol vapors, making it useful in applications such as breathalyzer devices or alcohol detection systems [49].
- **MQ-4** : This sensor is used to detect methane gas. It is commonly employed in gas leak detection systems or for monitoring methane levels in industrial settings [49].
- **MQ-5** : This sensor is sensitive to natural gas (LPG) and is commonly used in gas leakage detectors or domestic gas alarms [49].
- **MQ-6** : This sensor is used to detect flammable gases such as liquefied petroleum gas (LPG), butane, and propane. It is widely employed in gas leakage detection systems for household and industrial safety [49].
- **MQ-7** : This sensor is designed to detect carbon monoxide (CO) gas, which is a highly toxic and dangerous gas commonly found in combustion processes or faulty heating systems [49].
- **MQ-8** : This sensor is sensitive to hydrogen gas and is commonly used in applications where the detection of hydrogen leaks is critical, such as hydrogen fuel cell systems or industrial processes involving hydrogen [49].
- **MQ-9** : This sensor is used to detect multiple gases, including flammable gases like methane and propane, as well as carbon monoxide (CO). It is commonly used in gas detection and safety systems [49].
- **MQ-135** : This sensor is used to detect dangerous gases and smoke, including ammonia( NH<sub>3</sub>), sulphur( S), benzene( C<sub>6</sub>H<sub>6</sub>), and CO<sub>2</sub> [49].

For our product, we selected the following sensors :

- **MQ-4, sensor module (METHANE, CNG GAS)** : The MQ-4 Gas Sensor is a reliable and efficient sensor designed for detecting natural gas. It exhibits excellent sensitivity to gases like propane and butane, along with high sensitivity to natural gas and methane. This cost-effective and durable sensor is commonly utilized for gas leak detection purposes.

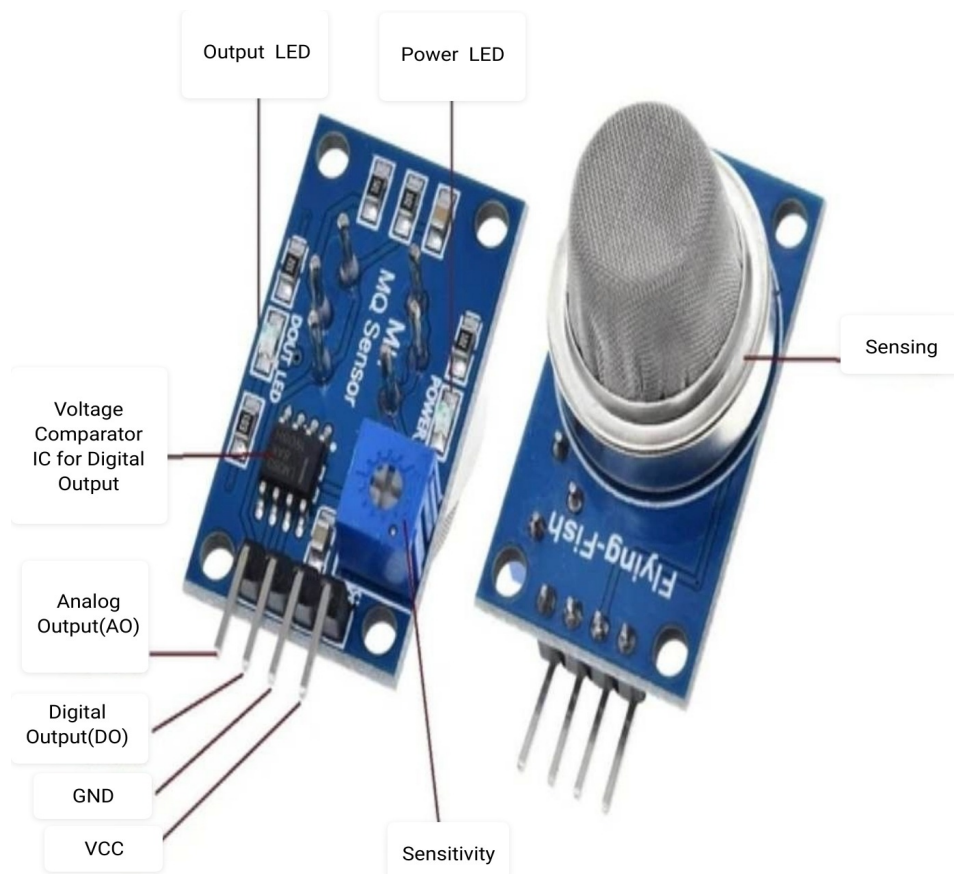


Figure 4.2: MQ-4 description [7]

- **MQ- 135, air quality(CO, AMMONIA, BENZENE, ALCOHOL, SMOKE)** : The MQ-135 Gas Sensor is capable of detecting hazardous gases and smoke, including ammonia ( $\text{NH}_3$ ), sulphur (S), benzene ( $\text{C}_6\text{H}_6$ ), and  $\text{CO}_2$ . Like other sensors in the MQ series, this sensor features both digital and analog output pins. The digital pin goes high when the concentration of these gases in the air exceeds a predefined threshold. The threshold value can be adjusted using the onboard potentiometer. The analog output pin generates a voltage that can be used to estimate the concentration of different gases present in the atmosphere.

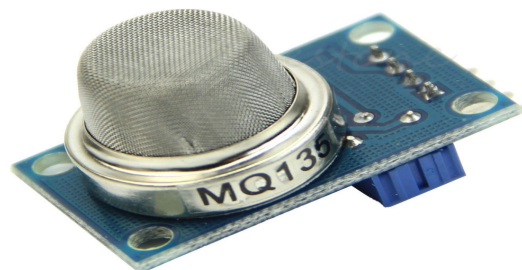


Figure 4.3: MQ-135

- **Power supply** : Regarding the power supply, our choice is as follows:
  - **TP4056 Lithium Ion Battery Charger** :  
The TP4056 Lithium Ion Battery Charger, illustrated in Figure 4.4, is a dedicated **Integrated Circuit (IC)** used for charging single-cell lithium-ion batteries. It offers reliable and efficient constant-current/constant-voltage charging and safeguards against overcharging and undercharging. This charger is commonly used in power banks, portable speakers, and **DIY** projects. It provides two status outputs for easy monitoring and can be conveniently connected to a micro USB female connector for charging using a mobile phone charger [8, 50, 51].

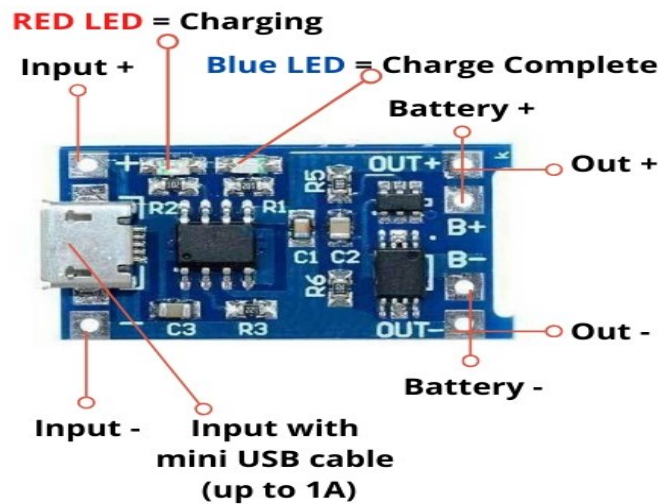


Figure 4.4: TP4056 Pinout [8]

- **18650 Lithium Ion Battery** : The 18650 battery, shown in Figure 4.5, is a rechargeable lithium-ion battery commonly used in electronic devices such as laptops, flashlights, and electric vehicles. It is known for its compact size (18mm diameter, 65mm length), high energy density, long lifespan, and low self-discharge rate, providing excellent performance [52].



Figure 4.5: Samsung 18650 Li-on Battery

- **Suitable case** : The case is compact, portable, and easy to transport. It can be deployed in different locations for gas detection and monitoring. The design

prioritizes user convenience, providing easy access to components like the MQ sensor and battery. Made with durable materials, the case is resistant to impact, dust, and other external factors, ensuring longevity and robustness.

2. **The architecture :** In this configuration as depicted in Figure 4.6, we have established a connection between the Analog Pin A0 of the MQ4 sensor and the A0 pin of the ESP8266. The VCC and GND of the sensor are connected to the 3.3 Volt and GND pins of the ESP8266, respectively. Additionally, we connected a [Light Emitting Diode \(LED\)](#), where the anode pin is connected to the D5 pin and the cathode pin is connected to the ground. Lastly, the positive pin of the buzzer is connected to the D6 pin of the NodeMCU, while the negative pin is connected to the Ground pin.

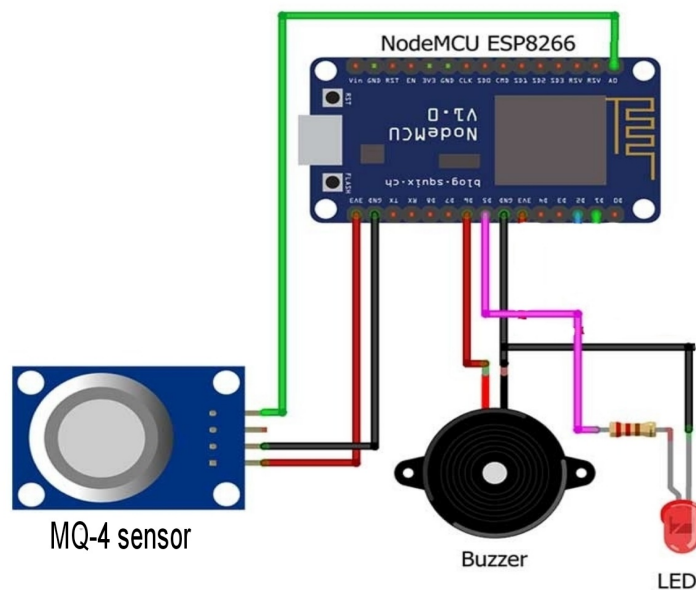


Figure 4.6: Circuit Diagram

## 4.2.2 Software

- **Arduino IDE :**

The [Arduino IDE](#) is an open-source software for programming Arduino boards. It includes a text editor, console, and toolbar as illustrated in Figure 4.7. It supports multiple languages, has a user-friendly interface, and offers tutorials for beginners. Programs are saved as .ino files [53, 9].

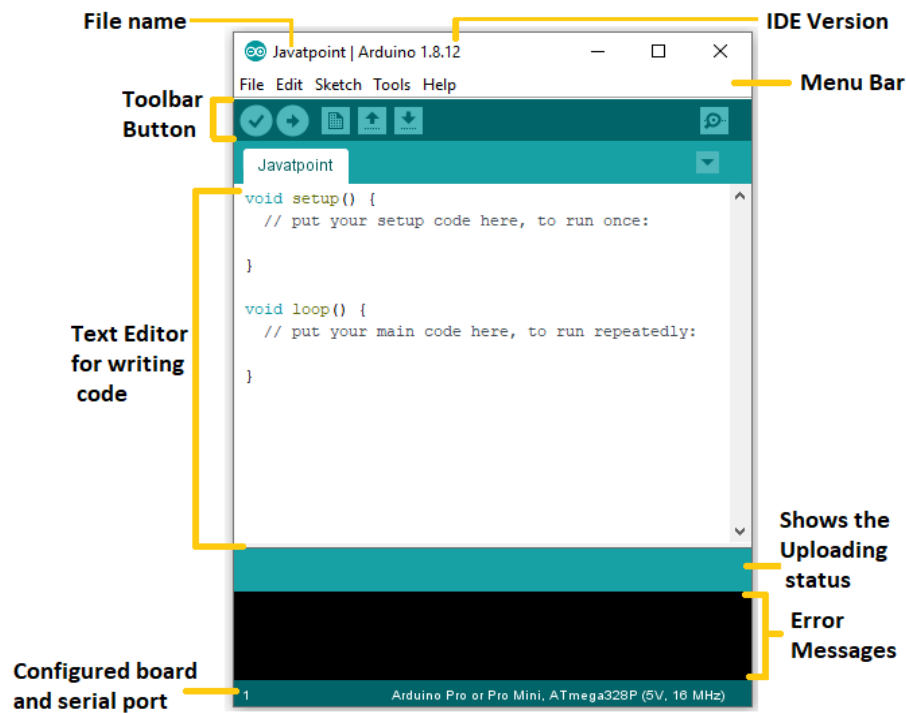


Figure 4.7: Arduino IDE [9]

- **Flutter** : Flutter is a free and open-source [UI](#) toolkit developed by Google. It allows developers to create impressive applications for mobile, web, and desktop platforms using a single codebase. Flutter's key advantage is its ability to build native apps for both iOS and Android. It consists of an [Software Development Kit \(SDK\)](#) with development tools and a [UI](#) framework based on customizable widgets [54].
- **Firebase** : Firebase, developed by Google, is a platform for building and scaling web and mobile apps. It offers cloud-based services including authentication, real-time database, cloud storage, and hosting. The real-time database enables synchronized data storage across multiple clients. Firebase also provides user authentication, cloud storage for user-generated content, and features like messaging, analytics, and remote configuration. Firebase Hosting allows secure deployment of web apps using a global [CDN](#) [55, 56].

In our [App](#) we went with : **Cloud Firestore**

- **Cloud Firestore** : Firebase Cloud Firestore is a versatile and scalable NoSQL document database that is suitable for building mobile, web, and server applications. It provides several noteworthy features that cater to modern application development requirements [56]:
  - \* **Real-time synchronization** : Cloud Firestore ensures that your data is synchronized in real-time across all clients, guaranteeing that users always have access to the most up-to-date information [56].
  - \* **Offline support** : With Cloud Firestore, your application can seamlessly function offline, allowing users to continue using the app even without an internet connection. Once the connection is restored, the data updates are automatically synchronized [56].

- \* **Robust security** : Cloud Firestore prioritizes the security of your data and incorporates multiple protective measures. It offers fine-grained access control, allowing you to define specific rules for data access. Additionally, it provides encryption at rest and in transit to safeguard sensitive information [56].
- \* **Scalability** : Cloud Firestore is designed to effortlessly handle the scaling demands of even the most resource-intensive applications. It can effectively accommodate a growing user base and increasing data requirements without sacrificing performance [56].

Overall, Cloud Firestore is a powerful tool that presents an excellent option for developers seeking a versatile and reliable NoSQL database solution. It accelerates application development thanks to its scalability, security features, real-time synchronization, offline support, and seamless integration with other Firebase services. [55, 56].

### 4.3 System description

Our product is a smart gas leak detection system that provides real-time monitoring of gas levels and immediate alerts in the event of a leak. The system consists of two integral parts: a gas sensor and a mobile application.

- **Gas sensor** : The gas sensor is responsible for detecting the presence and concentration of gas in the environment. It is designed to continuously monitor the gas levels and provide accurate readings. The sensor is typically installed in the area where gas leakage is a concern, such as near gas pipes, appliances, or storage areas. The sensor can trigger local alerts through buzzers and also send notifications to a mobile application.

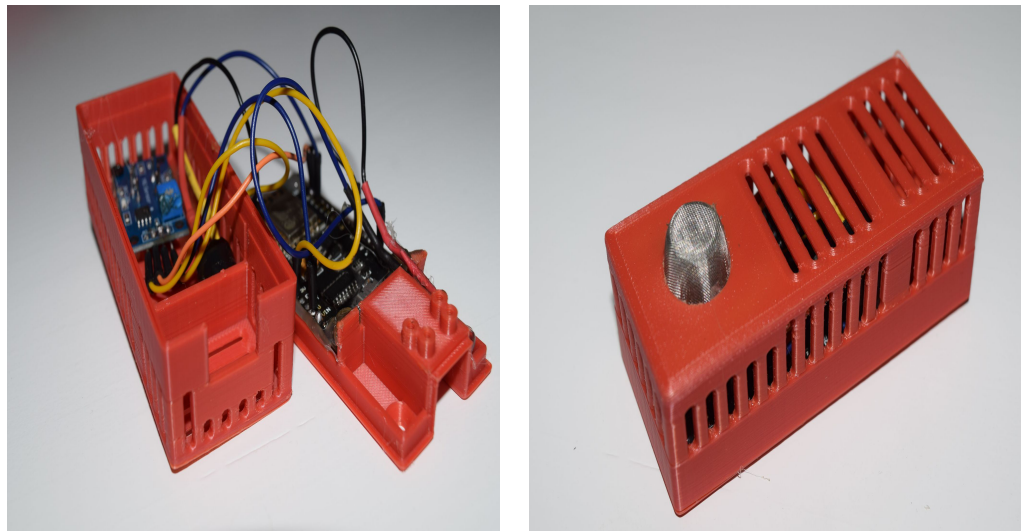


Figure 4.8: Sensor pictures

To ensure the connectivity between the sensor and the mobile [App](#), we need To establish the connection between the sensor and the [Wi-Fi](#) as illustrated in [Figure 4.9](#).

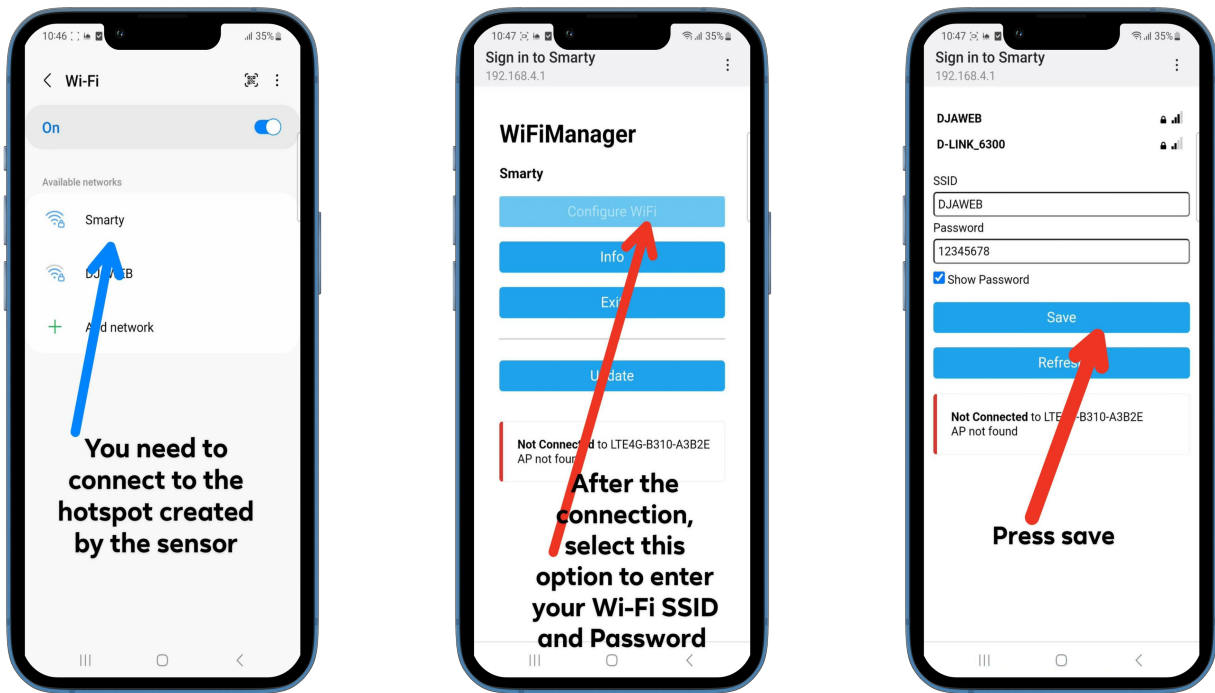


Figure 4.9: Wi-Fi Sensor Connection Process

- **Mobile application :** The mobile application serves as the user interface and control center for the gas leak detection system. It allows users to remotely monitor the gas levels in real-time and receive immediate alerts in case of a gas leak. The alerts can be transmitted through notifications sent to the user's mobile device.

The main features of our mobile application include:

- **Installation request :** The installation request feature in Mobigaz simplifies the process of installing gas sensors in homes or businesses. Users can submit a request through the mobile [App](#) (Figure 4.10).



(a) Wel- come page

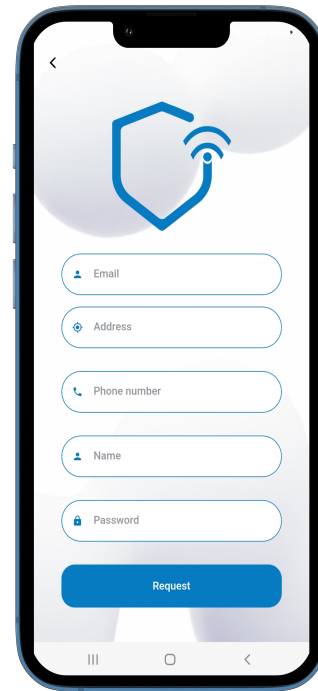
(b) Installation re-  
quest page

Figure 4.10: Installation request

- **User Authentication and Device Management :** The app provides a secure user authentication system, allowing users to sign in and manage their devices conveniently (Figure 4.11).

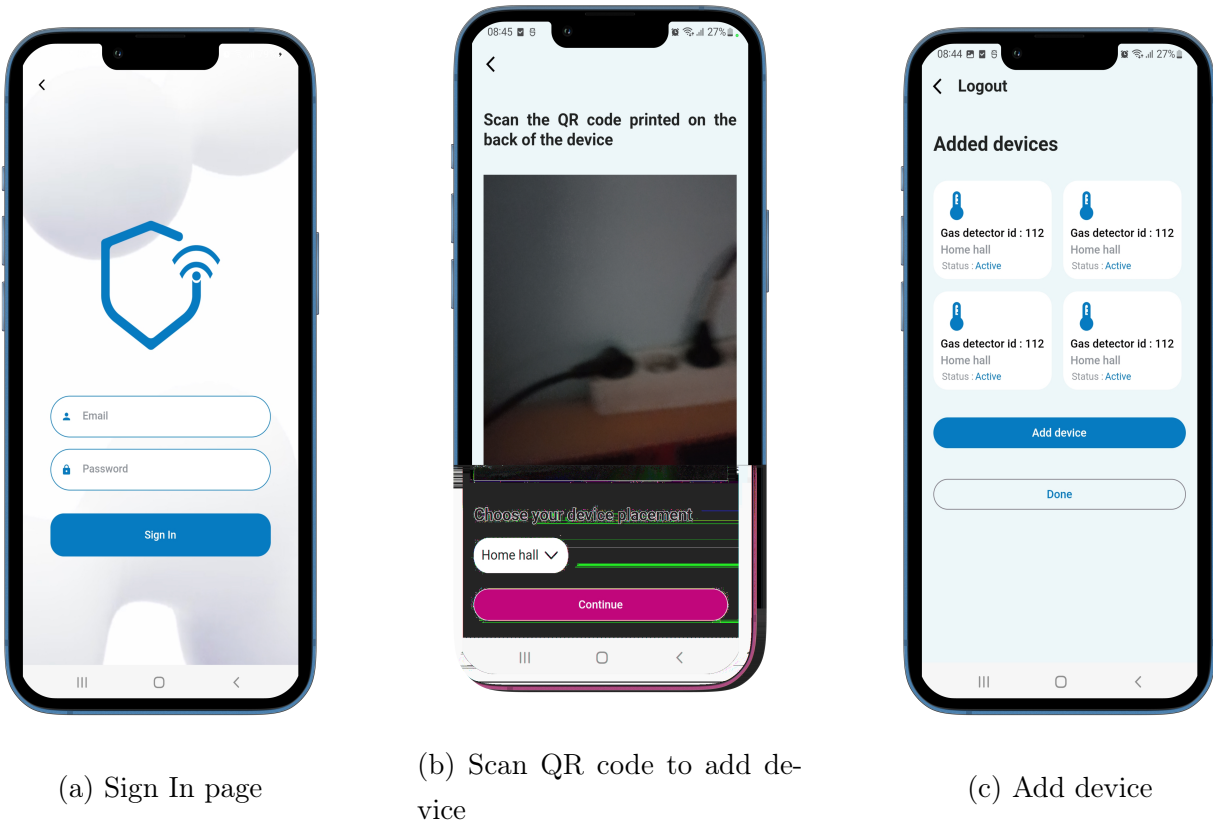
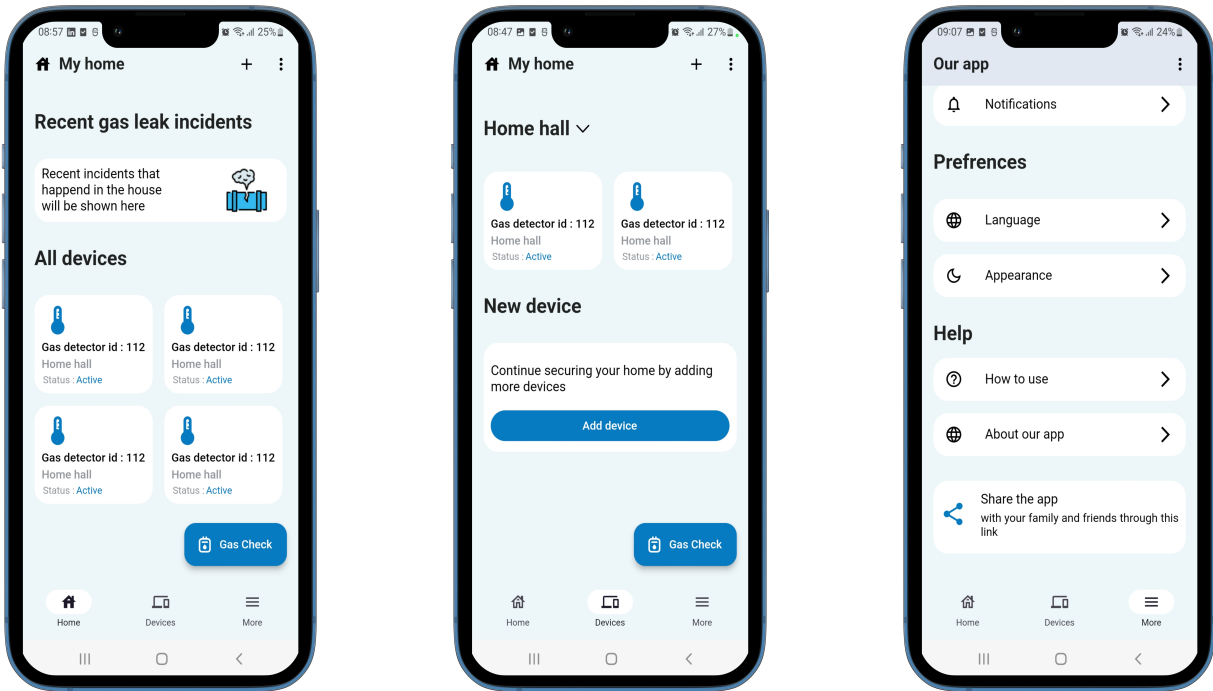


Figure 4.11: User Authentication and Device Management

- **Real-Time Gas Level Monitoring and Device Health:** Through seamless integration with our gas detection system, the app offers real-time monitoring of gas levels in the user’s home. This allows Users to conveniently check the health status of their devices, ensuring optimal performance and reliability (Figure 4.12).



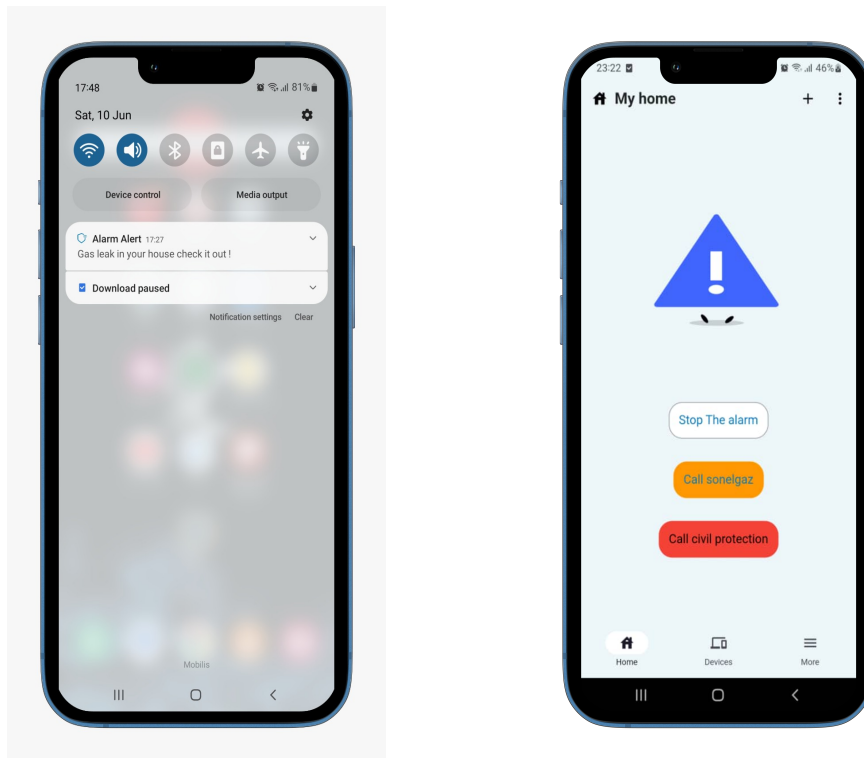
(a) Home page

(b) Devices page

(c) Settings page

Figure 4.12: Real-Time Gas Level Monitoring and Device Health

- **Push Notifications** : The App utilizes push notifications to deliver timely alerts to users in the event of a gas leak or any significant changes in gas levels. Users can receive instant notifications on their mobile devices, ensuring quick response and enhanced safety (Figure 4.13).



(a) Notifications outside the app

(b) Notifications inside the app

Figure 4.13: Push Notifications

By combining the robustness of the flutter framework and the versatility of Firebase's backend services, our mobile application provides users with a seamless and efficient experience. The use of cloud firestore enables us to utilize streams for real-time data updates and to store relevant documents securely. These features ensure that users can actively monitor their gas levels, manage their devices, and receive immediate notifications, ultimately enhancing the safety and peace of mind of our valued customers.

## 4.4 Conclusion

This chapter provided a detailed overview of the hardware and software tools used for the implementation of the system. The chosen components and technologies were described, emphasizing their features and suitability for the intended purpose. On the other hand, we have introduced our system by explaining all its functionalities.

## Conclusion and future perspectives

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### 5.1 Summary of our work

The IoT has attracted significant research interest to its advantages and widespread applications in industries such as manufacturing, healthcare, smart homes, agriculture, and transportation. It enables device interconnection, improving operational services and efficiency across sectors. IoT offers benefits like decreased latency, increased reliability, rapid data processing, and meeting throughput requirements. This enhances services such as real-time traffic monitoring, continuous sensing, search and rescue, wildfire management, and agriculture. IoT has the potential to transform industries and improve quality of life by optimizing processes and enabling data-driven decision-making. In this work, we focused on developing a Real-Time Smart Home Surveillance Application utilizing Heterogeneous Cooperative Sensors and IoT Devices. Our study involved several steps to ensure a comprehensive analysis and implementation. In the first step, we provided an overview of three key technologies: the Internet of Things (IoT), Wireless Sensor Networks (WSN) and Cloud Computing (CC). This introduction aimed to familiarize readers with the fundamental concepts and principles underlying these technologies. Additionally, we highlighted the significance of these technologies in the context of Smart Home. As a second step, we illustrated some related methods of Smart home systems with a brief showing to their advantages and drawbacks and with a synthesis and comparison of the discussed methods. In the third and final step, we introduced our own smart gas leak detection system. We provided a detailed description of its functionality and workings, along with thorough explanations to ensure clarity. This section aimed to showcase the specific contributions of our work and the novel features of our system.

## 5.2 Future perspectives

As part of our future programs, we have prioritized the advancement of our gas detection system to deliver superior performance and stability. This involves upgrading key components of our sensor, such as the ESP8266 NodeMcu and MQ detectors, to leverage the latest technological developments. These enhancements will result in improved **Wi-Fi** connectivity and a larger detection radius for gases, facilitating seamless communication between the sensor and connected devices, and ensuring highly accurate detection.

In addition to gas detection, we recognize the growing need for extensive smart home solutions. We are therefore growing our product range to meet a range of needs in smart homes. Monitoring water use, with a particular emphasis on water tanks, is one area of focus. By integrating modern sensors and information analytics, we aim to provide true period insights into water usage, empowering homeowners to make informed decisions and encourage water conservation. Furthermore alongside gas detection and water consumption monitoring, we understand the importance of home security and the well-being of elderly individuals in smart homes. To address these needs, we are expanding our product to include innovative solutions that enhance home security and provide assistance to the elderly. In order to integrate our gas detection system with different smart home gadgets and technologies, we are also actively looking into partnerships and collaborations. This collaborative approach may enable us to create interconnected options that enhance the overall efficiency and convenience of smart homes. By broadening our item portfolio and catering to different market needs, we strive to become an extensive provider of wise home solutions.

Finally, through ongoing research and development efforts and engagement with industry experts, we are committed to staying at the forefront of technological advancements. Our focus is on delivering products that meet the evolving needs of homeowners while prioritizing safety, effectiveness, and ease of use. Our future strategies exemplify our dedication to technology as we strive to create smarter and safer homes for our valued customers.

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